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PILOTLESS AIRPLANES

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PILOTLESS AIRPLANES

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ABSTRACT

This book provides a concise introduction to a special kind of aircraft, pilotless airplanes, using every-day, easy-to-understand language and clearly drawn illustrations. The structural characteristics of pilotless airplanes are discussed, and a history of their development is provided. Special emphasis is given to the problem of how control systems guide pilotless airplanes in carrying out a variety of tasks. Examples of the uses of pilotless airplanes are given, and projections are made concerning their future prospects.

This is a book written at a popular level for a broad audience of young people and aviation enthusiasts.

PUBLISHER'S FOREWORD

To satisfy the broad needs of soldiers drawn from the industrial and agricultural classes, as well as of our youth, in understanding science and technology, to serve the cause of Socialism still better, to serve the building of our national defense, and to make new contributions for the rapid realization of our country's "four modernizations," we have, along with the expert aviation editorial department, edited and published our "Little Series of Books on Aviation and Aerospace Technology."

This "Little Series" aims at a lively and vigorous presentation and plain and simple language. We make every effort to explain difficult concepts in easily understood terms, striving for excellence both in the written and graphic presentation. This approach is well-suited to the broad ranks of worker/farmer soldiers and young people.

Because our level is limited, it is inevitable that defects and errors will appear. We respectfully request comments and suggestions from our readers, in order to accomplish better the work of spreading knowledge of aviation science and technology.

AUTHORS' PREFACE

We have written this popular science book in order to disseminate understanding of aviation science and to satisfy the needs of aviation enthusiasts among the broad masses of farmer/worker soldiers and young people. Our object was to provide a general, all-inclusive introduction to the field of pilotless airplanes, and in words and pictures to provide our reader a fairly systematic understanding of the structural characteristics, principles of flight, and major applications of pilotless airplanes. This book was compiled by Comrades Yang Guozhu, Hu Zheyan, and Yin Yüchun; Comrade Chen Zhaohe made the illustrations. Our expertise in this field is not great, and it is inevitable that defects and errors in the content and presentation will occur. We respectfully request corrections and comments from our readers.

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

CHAPTER I

INTRODUCTION TO PILOTLESS AIRPLANES

In the last few years, many countries throughout the world have been developing pilotless airplanes. Because no crew is on board, there is no possibility of casualties to fighting men when the aircraft are used as weapons to attack the enemy. At the moment, because of developments in electronics, telemetry, remote and automatic control, and other technical and scientific fields, a foundation has been laid for the development of pilotless airplanes.

The constant development and study of pilotless airplanes have brought about an increasing breadth in their use. The military, in addition to using them as target drones, reconnaissance planes, and radio interference planes, also regards them as planes that can be used in aerial warfare.

1.1 WHAT ARE PILOTLESS AIRPLANES?

What we mean by "pilotless airplanes" are aircraft that operate without the presence of a pilot. Broadly speaking, aerodynamic missiles may be considered a type of pilotless airplane. With their on-board guidance system, automatic control system, and remote control and telemetry system, they are in principle the same as the airplanes. The main subject of this booklet, however, is airplanes without pilots.

Because of current rapid developments in science and technology, the uses for pilotless airplanes are increasing day by day. According to use, they can be generally classified into the following categories:

1) Target drones.
2) Pilotless reconnaissance planes.
3) Electronics opposition planes.
4) Pilotless combat planes.

5) Planes to collect radioactive specimens from atomic explosions.

6) Unmanned investigation and experimentation planes.

7) Geological prospecting planes.

8) Aerodynamic missiles--the embryonic form of pilotless aircraft in the early period, and the cruise missiles now under development.

Pilotless airplanes can also be classified according to their performance:

1) On the basis of speed, they can be divided into subsonic, high-range subsonic, and supersonic pilotless airplanes.

2) On the basis of flight altitude, they can be classified into high, middle and low altitude types.

3) On the basis of range, there are long, medium and short range pilotless airplanes.

Pilotless airplanes can also be classified according to the style of control:

1) Radio remote control: Controlled by control commands issued by the operator in a surface or airborne remote control station.

2) Program control: Independent flight controlled automatically by the pilotless airplane's on-board navigation guidance system according to a pre-set flight program. Airplanes controlled in this manner are able to avoid enemy interference.

3) Radio remote/program control: The majority use the radio remote mode during the process of take-off and landing, and the program control mode for independent navigation during the performance of their mission. The reasons for choosing this style of control are first, that if the mission involves a long-range flight, radio remote control is difficult to achieve; and second, that it prevents enemy interference.

4) Television remote control: This style employs on-board television which, by means of a television transmission system, sends on-the-spot information to a surface station; it implements real-time remote control according to commands sent from the surface station to the pilotless airplane. This style obviously must be used in conjunction with radio remote control.

In addition, in order to expand the range of action without the possibility of interference, program control must also be employed at times. Under normal conditions, a remote control/telemetry system and television transmission system are included in the control system of television remote control pilotless airplanes; a program-controlled independent flight-guidance system may also be included.

As can be seen from this survey, the uses of modern pilotless airplanes are very broad. Because of the range of uses, however, and the individual advantages of the different control systems, the equipment installed on pilotless aircraft, as well as its performance, varies greatly.

1.2. A SURVEY OF THE DEVELOPMENT OF PILOTLESS AIRCRAFT

The earliest pilotless airplanes used radio remote control. Early in the present century, investigations began concerning the possibilities of the use of radio in controlling air navigation. The first example of radio remote control was used merely for a model airplane; only afterwards, when automatic pilot instruments appeared, could development of a true pilotless airplane begin.

The earliest aerial targets were towed targets--small flags or cloth bags. Only in the 1930's, after relatively advanced pilotless airplanes had come into existence, did pilotless airplanes begin to be used as target drones. Most target drones of this period were pilot-controlled planes that had been refitted, like England's "Queen Bee" drone, the Soviet Union's PO-2, and the United States' OQ-19 and PQ-8.

Afterwards, in the early 1940's, during the Second World War, the United States developed a pilotless bomber. These were mainly a few existing bombers, like the B-17 and B-24, that had been re-equipped; the work involved installing a few necessary automatic control systems, and removing a few redundant defensive weapons (the aircraft guns, for example) and equipment (like the oxygen system). When undertaking long-range bombing, the plane was first operated for a period by the pilot; before reaching the enemy target, the pilot parachuted out. Hereupon the airplane was controlled by accompanying aircraft in making the bombing attack.

These early pilotless airplanes, when carrying out their missions, were difficult to use because of the limited level of technological development in radio, navigation guidance equipment and automatic control. For this reason, they were of minimal use.

Toward the end of the Second World War, the Germans had been secretly developing pilotless bombers. In June 1944, they made their first V-1 guided missile air attack on London. Within five weeks, about 3,000 V-1 missiles were launched against London. They were fired from installations in Belgium, Holland, and France, which were under German control at that time. A total of about 8,000 missiles of this kind were sent against London. Because the navigation guidance equipment was not of high quality, however, and because the missiles were shot down in mid-flight owing to their slow flying speed, only 29% landed within the city of London.

In external appearance, the V-1 was similar to an ordinary airplane (Fig. 1-1). It had mid-unit wings and a tail section composed of horizontal and upright elements. A pulse-jet engine with a thrust of 390 kg was installed on the vertical member of the tail. Its speed was 640 km/hr. The speed of fighter planes at that time had already reached 750 km/hr, so the flying speed of the V-1's was not spectacular; fighters could easily overtake them and shoot them down.

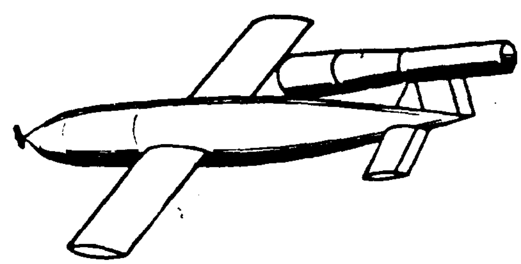

Fig. 1-1. V-1 guided missile.

The altitude of the V-1's flight was ordinarily between 900 and 920 meters, maintained by means of an altitude control device. Control of the V-1 was achieved through a navigation control calculator with a program installation, and an automatic pilot. The navigation control calculator of that era's V-1 was not able to make accurate corrections for wind speed and wind direction. When flight altitudes of less than 1000 meters, at which the effect of wind is very great, were selected, the percentage of hits was not high. But the structure of the V-1 was very simple, making it easy to manufacture; each missile required only 900 worker-hours for assembly. Furthermore, by the current standards, the unit oil consumption rate was relatively low.

Considering the V-1 as a weapon of war, although from the point of view of percentage of hits it was not a success, nevertheless it has an important place in the development of pilotless airplanes. It is the first pilotless aircraft entirely under the automatic direction of a control system for the entire course of its flight.

Shortly afterwards, Germany launched the V-2 guided missile. The V-2 is a controlled trajectory guided missile. It was able to fly higher and farther than the V-1.

Before and during the Second World War, the most important countries developing pilotless airplanes were the United States, England, the Soviet Union and Germany. Before the conclusion of the war, the United States had obtained a V-1 guided missile from England. Once the war against Germany had ended, the United States at once made use of German technical material, and furthermore recruited many German specialists, to begin the study of guided missiles. England, France, and the Soviet Union also used German information and specialists, to a lesser degree, to develop a guided missile industry. The V-1 and V-2 guided missiles used by Germany in the latter stages of the war without a doubt hastened the development and production of pilotless airplanes in the United States, England, the Soviet Union and France.

During the decades of the 1950's and 1960's, development of pilotless airplanes made great progress. In addition to refitting a few kinds of pilot-operated aircraft as pilotless models, several pilotless target drones, reconnaissance planes, and investigation planes were built. At the same time, reconnaissance planes, and investigation planes were built. At the same time, aerodynamic missiles (having wings, and flying within the atmosphere) were successfully developed. This progress was chiefly because of the advances in navigation guidance systems, including Doppler systems, astronavigation, and inertial navigation systems. Technological development in the fields of electronics, automatic control, and electronic computers also spurred advances in the field of pilotless airplanes.

During this period the turbine jet engine underwent a very strong development. The performance of aircraft using the turbine jet engine improved greatly. Because the thrust of this kind of engine is quite strong, it improves flying speed and power, and so is suitable for use in high-speed aviation. Pilotless airplanes equipped with turbojet engines may have a relatively large carrying capacity (or loading capacity), speed, range, and endurance. The performance of pilotless airplanes climbed steadily, and the use of pilotless airplanes expanded accordingly. In fact, the development of pilotless airplanes is a process of uninterrupted enhancement of capabilities and of expanding applications. For example, the speed of target drones during this period increased from subsonic to supersonic; the range of altitude of pilotless reconnaissance airplanes developed towards its upper and lower limits. Because of the lowering of the oil consumption rate, the range and endurance of pilotless reconnaissance planes were greatly improved. Pilotless airplanes were developed specifically to study problems of high altitude and high speed. To accommodate the capabilities of different weapons in target practice, target drones with a variety of performance capabilities, entering the target range according to different schemes, made their appearance. To fulfill a range of reconnaissance mission requirements, pilotless reconnaissance planes using many reconnaissance techniques (like photographic reconnaissance, infrared reconnaissance, electronics opposition) were developed. In order to develop the technology, pilotless combat aircraft using television real-time remote control for use in scientific studies have also appeared.

television real-time remote control pilotless airplanes are the signs of this period's achievements.

Cruise missiles are pilotless flying devices that use a turbojet engine for their motive power. They are an improved kind of aerodynamic missile. They are able to undertake long-duration, long-range flights at cruising altitude and cruising speed; on approach to their target, they are able to fly at an extremely low altitude to break through the enemy's defenses. Cruise missiles use small, high-performance turbojets; highly accurate, small-scale, light-weight guidance systems; and, within the guidance system, high-capacity, high-speed microcomputers with real-time processing capabilities. These features have greatly enhanced the cruise missile's accuracy in finding its target. The cruise missile, in a word, is the result of achievements in many fields of modern science and technology.

Television remote control pilotless airplanes are currently still in the developmental stage. Programs are being proposed for consideration, and there already exist pilotless airplanes for experimentation, demonstration and study. Because they are highly mobile, and because they do not require a pilot, the television remote control pilotless airplane has exceptionally attractive long-term prospects.

1.3. A SIMPLE DESCRIPTION OF A PILOTLESS AIRPLANE

To advance your understanding of pilotless airplanes, a concrete example is described briefly below.

1.3.1. The Essentials of a Pilotless Reconnaissance Plane

This is a high-altitude pilotless reconnaissance plane. Its total weight is about one and a half tons. The total length of the aircraft's fuselage and wingspan are both about 8 meters. It has one turbojet engine. It is able to fly at an altitude of 18,000 meters at a speed of about 800 km/hr. It has a range of up to 3000 km (or four hours of continuous flying time). This particular plane has a high-altitude camera installed in the camera compartment in its nose end. For its external appearance and for side, front, and top views of it, see Fig. 1-2 and Fig. 1-3.

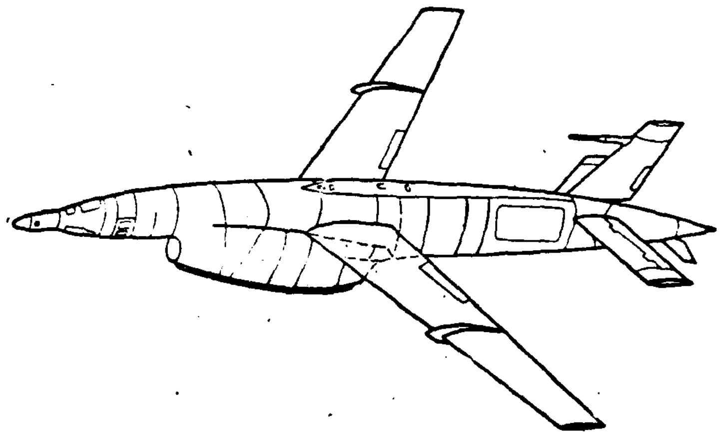

Fig. 1-2. External appearance of a pilotless reconnaissance plane.

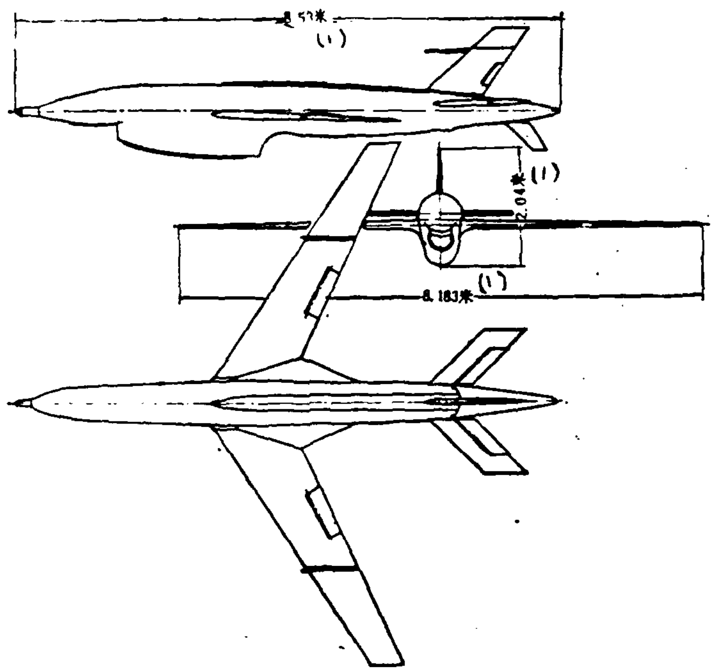

Fig. 1-3. Three views of a pilotless reconnaissance plane.
Key: (1) meter.

1.3.?. Aerodynamic Layout of the Pilotless Reconnaissance Plane

The aerodynamic layout of the plane corresponds to its characteristics as a high-end subsonic-speed, high-altitude, mid-range turbojet pilotless reconnaissance plane.

To increase the range and raise the ceiling, the composition of the entire plane was designed with a view to reducing resistance to a minimum. Since there is no pilot on board, it was possible to eliminate the pilot compartment; the fuselage of the plane could be designed as a smooth, spindle-shaped, streamlined form without any additional external protuberances or projections. For the location of the wings, the mid-unit arrangement was chosen; this arrangement produces less wind resistance than locating the wings at the top or the bottom of the unit. To reduce the interference and resistance of the fuselage and the wings still further, carefully designed air-flow adjustment casings are located at the junctures between wing and fuselage. The engine is dropped down from the belly of the plane, an arrangement which allows for the minimum length of the air intake and the exhaust nozzle, and so greatly reduces the internal resistance of the engine. In this way, the cross-section of this part of the airplane assumes a gourd-like shape.

For the wings, a refined layer-flow wing shape was chosen in order to reduce resistance to a minimum when the plane is flying at its intended cruising speed (0.85 Mach). To increase the plane's flight ceiling and range, and to reduce as much as possible the leading resistance, wings with a spread to chord ratio of 9 and a taper ratio of 2.5 were chosen. To improve the plane's flight at speeds bordering on the Mach number, the frequently used swept-back wing style was chosen, with a sweep angle of 33° measured at a position 25% along the chord line. To guarantee the serviceability of the tail wings, the horizontal tail wings and the vertical tail wing have a 45° sweep angle; to further increase the tail wing effect, an additional downward vertical tail wing has been designed.

To control the downward glide angle, a flow-interrupt plate on the upper surface of the right and left wings, which is able to increase the angle of descent.

1.3.3. General Design of the Pilotless Reconnaissance Plane

Because there is no pilot on board a pilotless airplane, a great amount of electronic apparatus must be installed in the plane for the purpose of control. It is important to have a relatively centralized electronics compartment for the necessary equipment. Below, we describe the layout of the different compartments for this plane (see Fig. 1-4).

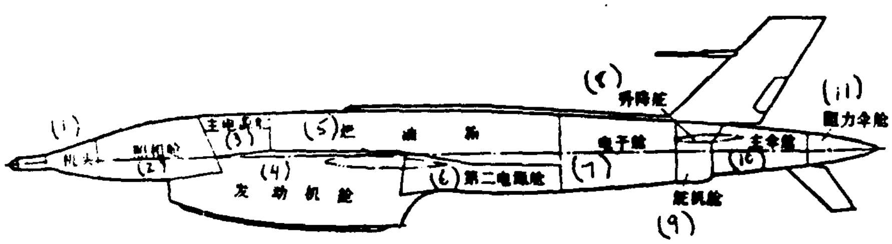

Fig. 1-4. Arrangement of compartments in the pilotless reconnaissance plane. Key: (1) Nose; (2) Camera compartment; (3) Main electrical power supply compartment; (4) Engine compartment; (5) Fuel tank; (6) Secondary electrical power supply compartment; (7) Electronics compartment; (8) Elevator; (9) Steering mechanism compartment; (10) Main parachute compartment; (11) Resistance parachute compartment.

The compartments within the fuselage of the airplane can be classified into ten groups according to their function:

1) Nose: A sensor for the angle of assault is installed in the front-most portion of the nose. To the rear of the sensor are the receiver, transmitter, and antenna installation of the Doppler guidance instrument. This compartment is tightly sealed and packed with foam plastic.

2) Camera compartment: The camera and the camera control accessories are installed here. This compartment is also sealed and contains a heat-maintenance device.

3) Main electrical power supply compartment: This contains an electrical storage battery and the main electrical power control box.

4) Engine compartment: One turbojet engine and its accessories are installed here.

5) Fuel tank: Contains a low-pressure fuel pump and reservoir.

6) Secondary electrical power supply compartment: Contains the aileron rudder mechanism, Doppler high-pressure power source, converter, and vacuum pump.

7) Electronics compartment: Contains the Doppler radar frequency tracking device; alternator and flight-guidance computer; the flight control box; the remote control receiver; the telemetry transmitter; the radar beacon; and other electronics equipment. The electronics compartment is water-tight.

8) Elevator steering mechanism compartment: The elevator steering mechanism is installed here.

9) Main parachute compartment: One recoverable main parachute for the descent is installed here.

10) Resistance parachute compartment: One parachute for providing resistance is installed here.

1.3.4. The Flight of the Pilotless Reconnaissance Plane

In this section, we provide a concise description of the flight process of the pilotless reconnaissance plane.

This particular pilotless reconnaissance plane is carried by a "mother craft" to a specified altitude, and then released. After the pilotless plane has completed its mission, it flies back to a position over its base and parachutes to the surface, to be prepared for another mission.

The pilotless plane flight, from take-off to landing, can be divided into four phases:

1) Transportation by the mother craft: During this phase, the mother craft undertakes testing of the equipment on board the pilotless plane.

Before the pilotless plane is released, the electrical power source on the mother craft activates the turbojet engine of the pilotless plane in preparation for its flight. When the mother craft has reached the predetermined airspace at the required altitude and speed, it releases the pilotless plane. At this time, the engine is placed in its rated power mode.

Figure 1-5 shows the pilotless reconnaissance plane being carried by the mother craft at the time of mid-air release.

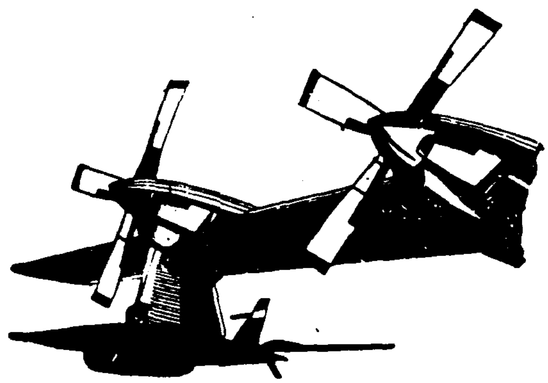

Fig. 1-5. Release of pilotless reconnaissance plane from mother craft.

2) Initial flight phase: After release, the pilotless reconnaissance plane immediately passes under program control and begins its independently controlled flight. When required, the surface remote control station (or the remote control station in the mother craft) is able to control the thrust (throttle) of the plane's engine, make changes in its flight pattern, and direct the plane to fly to the airspace over the predetermined goal. Under normal circumstances, this kind of remote control may not be implemented.

3) Reconnaissance flight phase: When the pilotless reconnaissance plane has flown to its predetermined location, the on-board program control equipment automatically causes the on-board remote control and telemetry apparatus to shut down, in order to prevent enemy radio interference. After this, the pilotless plane can no longer be controlled by the surface remote

control station, but uses the Doppler guidance instrument to control its course. The plane enters its reconnaissance flight phase at this time, having been placed entirely in independent flight mode under its own automatic control.

During the entire reconnaissance flight phase, the pilotless plane executes according to its program all prescribed actions, including change of direction, level powered flight, and opening and closing the camera.

4) Recovery phase: When the pilotless reconnaissance plane has completed its reconnaissance according to its program and returned to its base, it enters the remote control recovery phase.

The surface remote control station first determines whether the plane has deviated from its predetermined course. It makes any necessary adjustments in the plane's course, and guides it into its correct position; then it issues remote control commands to implement the plane's parachute drop recovery. Figure 1-6 illustrates the entire recovery process.

When the surface remote control station issues its recovery command, the on-board recovery system causes the engine to stall, dump the remaining fuel, and cuts off the power supply for the electrical equipment that is no longer needed. At the same time, it causes the resistance parachute to open, and reduces rapidly the plane's flying altitude and speed. Nine seconds after the resistance parachute has opened, and when the altitude has decreased to 1800 meters, the main parachute opens automatically. At this time, the plane, suspended in a horizontal position from the main parachute, slowly descends to earth. After the plane lands, a ground-contact switch on the plane's underside is activated, causing the parachute to separate from the plane; this prevents the parachute from dragging the plane under windy conditions.

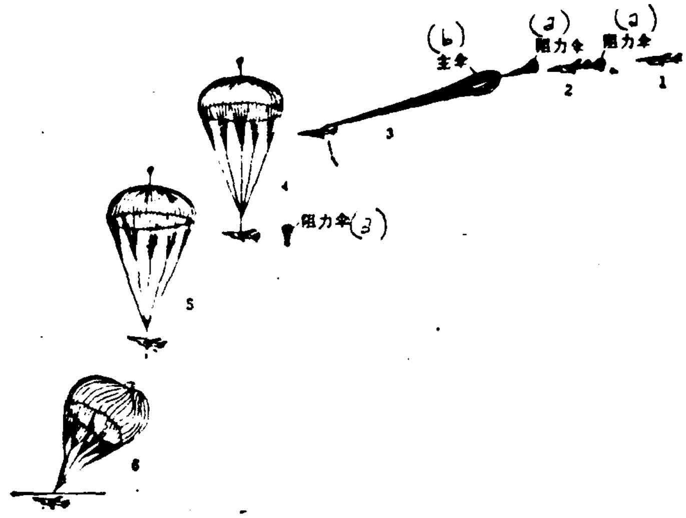

Fig. 1-6. Parachute recovery.
1) Remote command "X": Engine slows down and air speed decreases.
2) Remote command "Y": Electrical detonation bolt in resistance parachute compartment goes off, resistance parachute opens, engine stops. Plane loses speed, electrical power supply switches to storage battery, at the same time cutting off power supply to large and small converters, navigation control box, telemetry control system, the program structure, gyroscope, etc.
3) When altitude ≤ 1800 meters, electrical detonation bolt in main parachute compartment goes off. Resistance parachute pulls main parachute straight; main parachute stretches out straight. Plane continues to lose speed; fuel tank executes emergency fuel release. Time elapsed between step 2) and step 3) ≥ 9 seconds.
4) When time elapsed after step 3) = 4 seconds, tension cord to resistance parachute is cut, and main parachute expands fully and fills with air.
5) When time elapsed after step 3) = 20 seconds, an electrical charge in the wings sets off a canister explosion; wing extremities are shed.
6) Plane lands, electrical contact charge explodes, releasing main parachute and closing fuel-release valve.
Key: (a) resistance parachute; (b) main parachute.

1.4 TAKE-OFF AND RECOVERY: A SPECIAL PROBLEM FOR PILOTLESS AIRPLANES

The above introductory discussion of a typical pilotless reconnaissance plane has provided a broad understanding of one modern pilotless airplane. It can be seen that its design is compact, and the whole plane is relatively small in scale and light in weight. It belongs to the category of light-weight aircraft.

Currently, in order to increase the effective load of pilotless airplanes, no landing gear is installed. Omitting the landing gear allows simplicity of structure, and reduces unnecessary structural weight during flight. Pilotless aircraft consequently require special installations for take-off and recovery.

1.4.1. Take-off

To achieve their take-off from the ground, some pilotless airplanes make use of a surface launcher or small taxiing vehicle; some are carried by a mother craft and launched from mid-air. Launching from a mother craft was discussed in the previous section; here we shall consider the methods for launching from the earth's surface.

Figure 1-7 shows a pilotless airplane as it would be launched from a surface launcher.

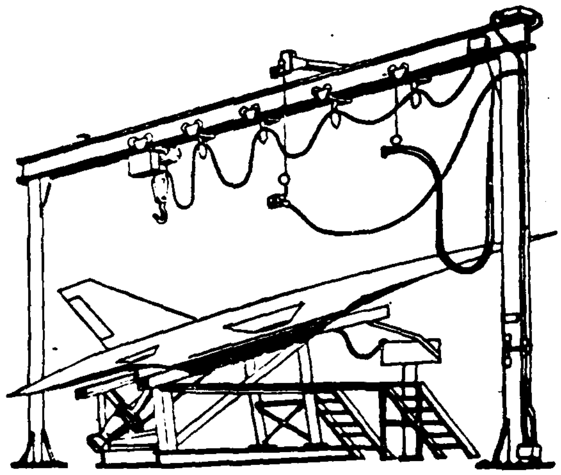

Fig. 1-7. Surface launcher installation at time of launch.

A short-track launcher is illustrated here. It forms a 15° angle with the horizontal, and is solidly set into a concrete base. The control tower must be able to see all the equipment on the launcher, and also be able to take cover safely. The rear guidance installation on the rear of the fuselage link up with the rear end of the launching track; a solid propellant booster rocket is seated at the rear of the plane. For safety, only after all systems on the pilotless airplane have been checked out is the booster rocket ignition device installed. The airplane engine is now activated, the surface electrical power supply is unplugged, the booster rocket is ignited, and the plane takes off. When the work of the booster is completed, it drops off automatically. The upright frame in the illustration supports the horizontal sliding track of a suspended gantry crane, which is used to set the surface equipment in place and to hoist the pilotless airplane onto it. Figure 1-8 shows the pilotless plane taking off with the rocket booster from the surface launcher.

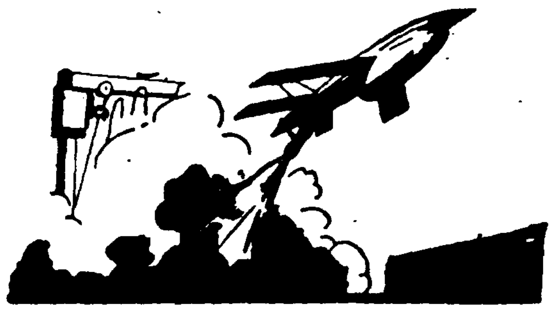

Fig. 1-8. Booster-assisted surface launch.

We shall now discuss the launching of a pilotless airplane using a small taxiing vehicle (Fig. 1-9).

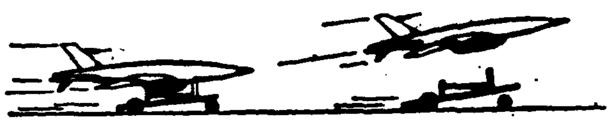

Fig. 1-9. Surface launch using taxiing vehicle.

At the time of launching, the pilotless airplane is put in place on a small surface taxiing vehicle. After the engine of the airplane is activated, the plane can be taxied down the runway using surface remote control. When the plane reaches take-off speed, a command issued by the surface control station causes the plane to separate automatically from the taxiing vehicle; at this time, the pilotless airplane is able to take off automatically from the surface.

1.4.2. Recovery

All pilotless airplanes use the parachute method for recovery. Because conditions at different bases are not the same, however, the recovery is sometimes made at land and sometimes made on water; at times, for reasons of security, helicopters are used for a mid-air recovery.

The procedures for a parachute recovery and a helicopter mid-air recovery are as follows:

The process of parachute recovery has already been discussed briefly above; refer to Fig. 1-6 for an illustration. We shall now carry the discussion a step further.

This recovery system uses two classes of parachutes. The first type, with a two-meter diameter when opened, is the resistance parachute; the second, with a 25-meter diameter, is the main parachute. After the recovery system begins to operate, the resistance parachute first opens, exerting a braking force on the pilotless airplane. After the resistance parachute has opened, after a nine-second delay (or a drop in altitude to 1800 meters), the detonation bolt of the main parachute chamber goes off. The resistance parachute pulls straight the main parachute and the leading parachute, and then separates automatically. The main parachute, as it opens, makes use of a tension cord installation, which first causes the main parachute to open only partially. A delayed-time separator then severs the tension cord and allows the main parachute to open completely. This method allows the main parachute to expand fully with two separate blasts of air, reducing the impact on the main parachute when it first opens. After the main parachute is fully open, the pilotless plane, hanging in a horizontal position below the parachute, slowly descends to earth. When the plane lands, a ground-contact switch in the fuselage is activated. and causes the main parachute to separate from the plane; this keeps the parachute from dragging the plane and causing damage when conditions are windy.

The process for recovery on water is entirely comparable to that for recovery on land. After the plane hits the water, the action of the water activates the switch, causing the parachute to be sloughed off. After the plan has landed safely on the water, it is transported back to the base by a surface naval vessel or by a helicopter.

These styles of recovery can by implemented by surface remote control or by set programmed command. For safety, when accidents (like engine failure, main power source breakdown) occur in a pilotless plane, the emergency system can transmit a recovery signal, immediately setting the recovery system into operation. To reduce the weight of the plane at the time of recovery, it is necessary that the recovery program dispose of the remaining fuel before the main parachute opens. These are effective recovery methods; they can be controlled quite precisely, and bring the pilotless airplane to a predetermined landing location.

Because the pilotless airplane has a certain rate of descent when using the main parachute, these methods, particularly the method for recovery on land, involve the possibility of damage to components of the airplane.

To eliminate this problem, the method of mid-air recovery by helicopter is used (Fig. 1-10, 1-11).

In this method, the process of opening the parachutes is identical with the previously discussed methods; the difference is that after the main parachute opens, the stabilizing parachute is changed into a hook-suspension parachute. The hook parachute also includes a set of hanging cables and a swivel detachment mechanism. When the suspended hooks on the helicopter latch onto the hook-suspension parachute, the main parachute immediately drops off automatically. The cables below the hook-suspension parachute keep the main parachute oriented in a forward direction; and a flag for indicating wind direction is attached to the cables, to aid the helicopter in making judgements and in hooking the airplane. In this way, after the helicopter has hooked the cables, the main parachute can be dropped automatically and not become entangled with the cables. When the helicopter is hooking the descending airplane, it must proceed against the wind. When it has hooked the airplane, it can transport it to the designated landing position.

This recovery method protects the pilotless airplane from damage, and is relatively safe. The level of technical skill required of the helicopter pilot, however, is quite high, both during the hooking process and afterwards in transporting the plane.

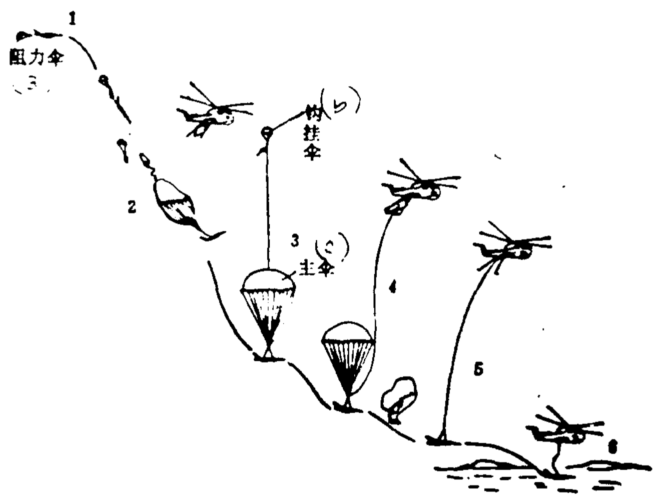

Fig. 1-10. Typical parachute opening procedure during mid-air recovery.
1) Navigation control system lowers plane's speed to subsonic range, resistance parachute opens.
2) Hook-suspension and main parachutes open, resistance parachute pulls away from main parachute compartment, tension cord puts main parachute in gathered-in state.
3) After 13 seconds tension cord is cut, and the main parachute expands fully.
4) Helicopter hooks hook-suspension parachute and cables.
5) Main and hook-suspension parachutes drop away, and suspension cable is wound in by capstan on board helicopter.
6) Helicopter lowers plane to ground, and suspension cable is released from plane.
Key: (a) Resistance parachute; (b) Hook-suspension parachute; (c) Main parachute.

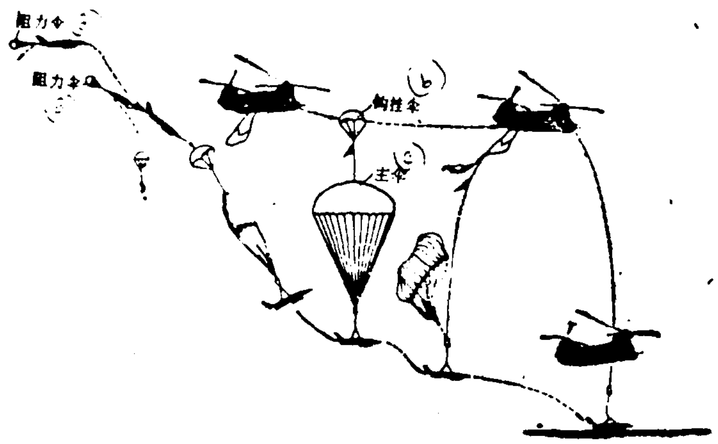

Fig. 1-11. Helicopter hooking the suspension cable during mid-air recovery.
Key: (a) Resistance parachute; (b) Hook-suspension parachute; (c) Main parachute.

CHAPTER II

THE ESSENTIALS OF PILOTLESS AIRPLANE CONTROL SYSTEMS

How is it that pilotless airplanes are able to navigate automatically? The main reason is that they are equipped with an automatic pilot instrument that operates the plane in place of a human pilot, as well as with navigation and program control, remote control, telemetry, and other instruments and equipment. These devices compose the control system of the pilotless airplane, and can make the plane perform according to plan, as determined in advance by human operators: The plane can take off and climb, then fly along a preset flight pattern to a preset destination, and finally descend for recovery. During the flight, the airplane is able to undertake a variety of actions, which may be either set in advance or commanded by remote control from the surface as need arises. At the same time, the surface operators are able to know, in detail and at any time over the course of its flight, the circumstances of the pilotless airplane. This chapter is an introduction to several important instruments and pieces of equipment from the control system of pilotless airplanes; we hope it gives you a basic idea of how pilotless airplanes are able to navigate automatically.

2.1. THE AUTOMATIC PILOT

2.1.1. The Origins of the Automatic Pilot

The automatic pilot is a very important piece of equipment in a pilotless airplane. It is installed in almost all currently existing pilotless airplanes. But at the beginning, the automatic pilot did not make its appearance for the sake of pilotless airplanes, but because during long flights in piloted airplanes, the pilot was unable to take his hand and feet from the controls, or his eyes from the instruments. He had to be sure at all times that the plane did not deviate from its course or lose altitude, and had to be ready constantly to make corrections. The pilot was likely to suffer fatigue. For this reason, a device was proposed that would perform certain actions for the pilot, and share a portion of his responsibilities. This device was called an "automatic pilot." This device was naturally quite simple and primitive; but in principle it is identical with today's complex automatic pilots.

2.1.2. Basic Make-Up of the Automatic Pilot

What component instruments make up the automatic pilot? Let us consider first how a human pilot operates an airplane. Suppose a plane is flying from Nanchang to Beijing (see Fig. 2-1). The predetermined direction that the plane must fly is due north. There is a compass on board the plane, whose needle points constantly to Beijing. While the plane is flying north, the plane's axis (or its nose direction) is the same as the needle on the compass. If the plane is subjected to an unexpected force that causes its nose to veer west, its axis from nose to tail is no longer lined up with the compass needle, and an angle of deviation (or "yaw") is produced. This is the angle by which the plane has deviated from its predetermined line of flight. When the pilot in the cockpit sees the angle of deviation appearing on the compass, he knows that the plane has veered off to the west. He steps on the right foot-pedal at once, bringing the directional rudder to the right. At this point, an aerodynamic force is produced at the vertical portion of the tail wing; the aerodynamic force in turn produces a controlling torque which causes the nose of the plane to return to its original orientation (Fig. 2-1). When the nose of the plane rotates back to

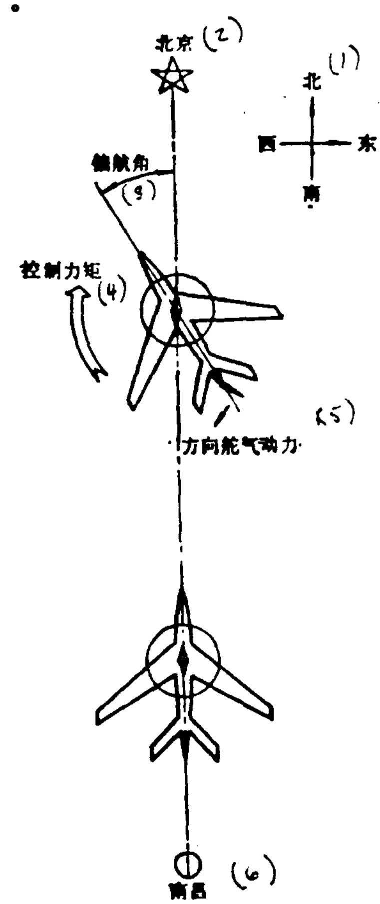

Fig. 2-1. Maintaining a course with a compass.
Key: (1) North; (2) Beijing; (3) Angle of yaw; (4) Controlling torque; (5) Aerodynamic force of rudder; (6) Nanchang.

its preset due-north direction, the pilot immediately stops pressing on the right foot-pedal. The directional rudder returns to its middle position, and the torque disappears. The plane now continues along its predetermined course. The process by which the pilot controls the plane in the above action can be shown on a diagram (Fig. 2-2). If the automatic pilot is to perform the same action as the human pilot, three kinds of instruments must be used to perform the human pilot's tasks. To replace his eyes, we must have a sensor that is able to detect changes in the plane's situation; to perform the actions of the human's mind and muscle, an amplifier/transformer must be used. To take the place of his hands or feet controlling the appropriate directional device (ordinary planes have elevators, ailerons, and rudders) or control mechanisms (like the engine's throttle control, the resistance parachute, or the flaps) an execution mechanism is required. In Fig. 2-2 the arrows show the flow of the actions. The automatic pilot is made up of just these three components.

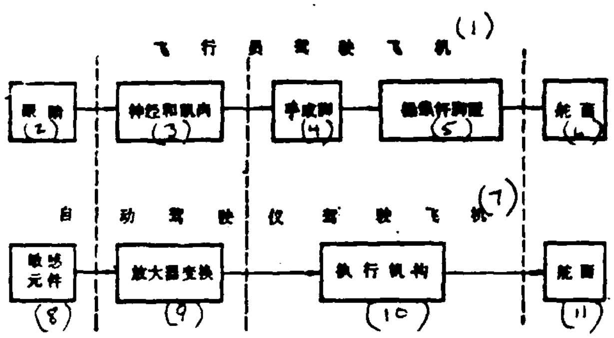

Fig. 2-2. A comparison between a human pilot and an automatic pilot operating an airplane.
Key: (1) Human pilot controlling flight; (2) Eyes; (3) Mind and muscle; (4) Hand/foot; (5) Control stick/pedal; (6) Rudder; (7) Automatic pilot in control; (8) Sensor; (9) Amplifier/transformer; (10) Execution mechanism; (11) Rudder.

2.1.3. State of Motion and Positional Angle of an Airplane in Flight

It can be seen from what we have said that the most important function of the automatic pilot's sensors is to detect and measure changes in the airplane's mid-air state of motion. To explain this, we will first analyze the state of motion of an airplane's flight.

When we look up and see a airplane flying in the sky, the airplane appears to be a small white dot. From the point of view of mechanics, it may be regarded as a particle. This "particle" can move in three dimensions, up or down, right or left, forward or backward. This type of movement is normally called the airplane's orbital movement. To determine the airplane's mid-air orbit involves measuring the airplane's altitude and its longitudinal and latitudinal location on the earth's surface, as shown in Fig. 2-3.

The airplane, however, is after all a physical object with a certain scale. In addition to having an orbital movement, it can also rotate in three directions around its center of gravity; the angles of rotation are called the "angle of pitch," the "angle of inclination," and the "angle of yaw" (see Fig. 2-4). This rotation-type movement is normally called "attitudinal angle motion," and the angle at which the airplane is turned is called its "attitudinal angle."

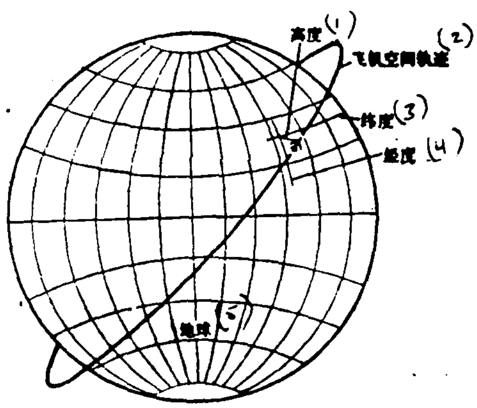

Fig. 2-3. Position of an airplane in space.
Key: (1) Altitude; (2) Orbit of airplane; (3) Latitude; (4) Longitude; (5) Earth.

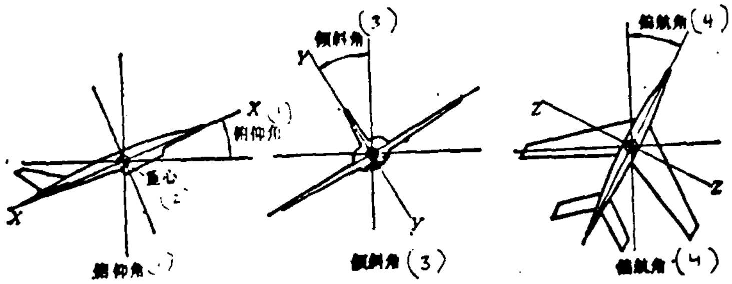

Fig. 2-4. The three attitudinal angles of an airplane.
Key: (1) Angle of pitch; (2) Center of gravity; (3) Angle of inclination; (4) Angle of yaw.

From this, we can see that the state of motion of a plane in the air is made up of three attitudinal angle motions and three orbital motions. Therefore, if we want to know what changes occur in a plane's state of motion, we need to measure these three attitudinal angles, the altitude, and the earth's latitude and longitude on which the airplane's center of gravity can be projected at a given time. In general, the plane's attitudinal angles and altitude can be measured by simple sensors, while the latitude and longitude of the plane's center of gravity must be measured with its navigation equipment.

2.1.4. The Gyroscope: For Measuring the Attitudinal Angles

The measurement of the attitudinal angles of an airplane in flight depends chiefly on the *gyroscope*. The term "gyroscope" may be unfamiliar to you, but everyone knows about its stabilizing abilities. We see children playing with tops. Once the tops are set turning, they are able to stay upright without falling over (see Fig. 2-5). If you pick up a top rotating on the ground and set it on a board as a base, and then lift up on one end

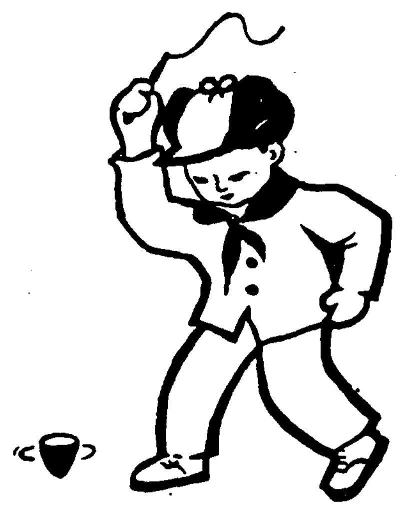

Fig. 2-5. A top remains upright while rotating.

of the board, you will find that the top maintains its original orientation (see Fig. 2-6). This characteristic is called axial stability. The axial stability of the top is not affected by changes in the position of the base. We make use of this characteristic in a gyroscope to measure the attitudinal angles of airplanes.

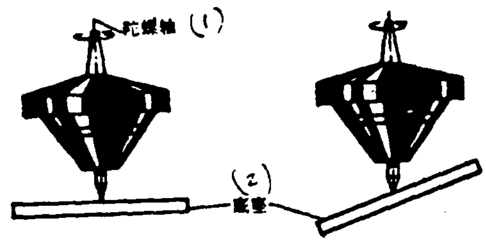

Fig. 2-6. Axial stability in a top.
Key: (1) Axis of top; (2) base.

Suppose we take a disk spinning at a high rate and mount it in an inner ring, and then mount the inner ring in an outer ring, which in turn can rotate around in its housing. The disk can rotate on the X-X, Y-Y, and Z-Z axes; for this reason it is called a "three-dimensional gyroscope" (see Fig. 2-7). Because the top has axial stability when rotating at high speed, the position of its axis in space does not change, no matter how the housing is turned. If an electrical potentiometer brush is mounted along the axis of the gyroscope disk, and the coil of the potentiometer is installed on the housing, which is fixed within the airplane, when the airplane's center of gravity rotates around the Y-Y axis, the potentiometer coil also rotates. But the electric brush of the potentiometer, because of the effect of the disk's axial stability, does not change its position, and the potentiometer will put out a signal. This signal stands in a direct ratio with the angle of the airplane's rotation around the Y-Y axis, which is to say that it is in a direct ratio with the angle of

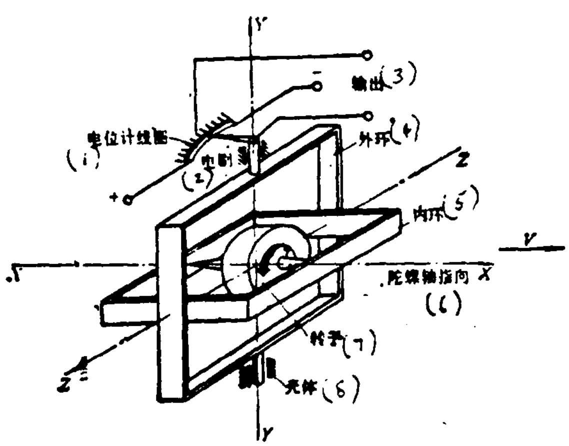

Fig. 2-7. The principle of the navigational gyroscope.
Key: (1) Potentiometer coil; (2) Electrical brush; (3) Output; (4) Outer ring; (5) Inner ring; (6) Direction of disk's axis; (7) Gyroscope disk; (8) Housing.

deviation from the airplane's course. Because the potentiometer uses a neutral tap, positive or negative voltage exists on the two sides. In this way, it is able to determine whether the airplane has veered to the right or to the left. And this, basically, is the operating principle of the navigational gyroscope. Figure 2-7 shows how it works. Using the same principle, it is possible to make gyroscopes that measure the angle of pitch and the angle of inclination. With these gyroscopes, we can measure the three angle-motion parameters of an airplane.

From this description, you can see that the three dimensional gyroscope is a gyroscope disk rotating at high speed, and installed in a three-axis support which can turn independently in any direction. It is able, by using a sensor (here, a potentiometer), to measure and report changes in the angle between the direction of the rotating gyroscope wheel and the gyroscope mount (which is in a fixed position in the airplane corresponding the direction of the plane's nose). A gyroscope like the one shown in Fig. 2-7 which can measure the airplane's angle of yaw is called a navigational gyroscope. Using the same principle, but installing the gyroscope's wheel so that its axis is perpendicular to the earth's surface, it is possible to measure the angle of pitch or the angle of inclination. This kind of three dimensional gyroscope is often called a vertical gyroscope.

Not only can a gyroscope directly measure all attitudinal changes in an airplane's movement, but other of its characteristics can be used to measure the angular velocity and angular velocity acceleration of the airplane's attitudinal angles. The signals for angular velocity and angular velocity acceleration, which improve the airplane's flight, are also sent to the automatic pilot; but we cannot pursue this topic further at this time.

2.1.5. Using Air Pressure and Radio Waves to Measure Altitude

Of the sensors for measuring altitude, the ones most frequently used are the air-pressure sensor and the radio sensor.

We know that when mountaineers scale high peaks, the higher they climb the harder it is to breathe. On high mountains, water quickly comes to a boil, but the temperature of the boiling water is far below 100° C. These phenomena can be explained by the fact that the atmosphere becomes thinner and thinner as altitude increases, and the air pressure becomes lower and lower. For this reason, it is hard to breath and the boiling point of water (which is 100° C at sea level) decreases. With this natural law in mind, people have developed the air-pressure altitude sensor, or altimeter. The air-pressure altimeter uses a vacuum membrane box (made up of two thin corrugated phosphorized bronze plates soldered together, in the cavity between which is a vacuum) to detect changes in the external pressure and produce an altitude signal. Because the higher the altitude, the lower the air pressure, the effect of the pressure on the membrane box is also lessened, and the membrane box gradually swells, causing the connecting rod to move upward, and making the electric brush of the potentiometer rotate slightly (see Fig. 2-8). This puts out a signal in direct proportion with the altitude.

Air-pressure altimeters are simple in construction and convenient to use. Their shortcoming is that they can only measure the altitude of the airplane above sea level, and not the actual distance of the airplane from the surface of the earth in any given location. For example, an airplane is flying over the Qinghai-Tibet Plateau. An air-pressure altimeter will report its altitude as 10,000 meters, but the Plateau itself is 5,000 meters above sea level. The actual altitude of the airplane above the ground is only 5,000 meters. During flight, this actual altitude (or "relative" altitude) is very important, especially for low-altitude flying. Currently, radio altimeters are available to take care of this problem.

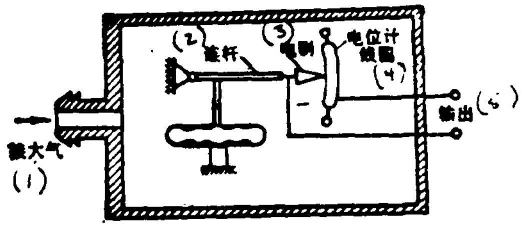

Fig. 2-8. The principle of the air-pressure altimeter.
Key: (1) Atmospheric pressure; (2) Connecting rod; (3) Electric brush; (4) Potentiometer coil; (5) Output.

Radio altimeters are also based on a very simple principle. A radio wave transmitter and a radio wave receiver are installed on the airplane. A high-energy ultra-high frequency pulse is sent out from the transmitter. This pulse is actually a radio wave with a speed of 300,000 km/sec. When the wave hits the surface of the earth, it is immediately reflected back. The receiver on the plane receives it. Because the speed of the wave does not change, it is only necessary to measure the time elapsed from the moment the wave is broadcast to the moment the reflected wave is received in order to calculate the relative altitude of the airplane above the surface of the earth.

You can see from Fig. 2-9 that, if the interval between the two pulses is 200 microseconds (1 microsecond = 0.000001 second), calculation shows the relative altitude is 3,000 meters. Naturally, the time difference can be transformed into an electrical signal; this signal is the relative altitude signal.

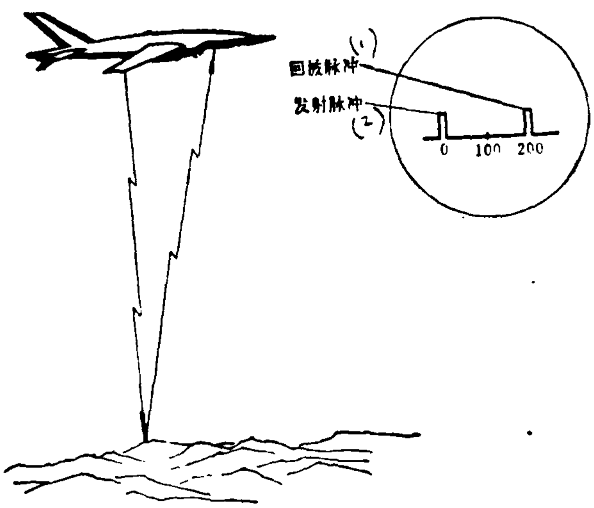

Fig. 2-9. Principle of the radio altimeter.
Key: (1) Returning pulse; (2) Broadcast pulse.

2.1.6 The Function and Characteristics of the Automatic Pilot's Amplifier/Transformer

Generally speaking, sensors are very sensitive to any change in the airplane's navigational attitude; but the signals that are output are quite small, and cannot operate the airplane's rudder directly. For this reason, they must pass through an amplifier/transformer, and then move on to drive the execution mechanism, which ultimately operates the plane's rudder.

The amplifier/transformer is mainly used to enlarge the signals from the sensors, and then to transform them into the kind of signals that the execution mechanism needs. Because the large majority of sensors currently use an electrical signal as their output, and because the signals that the execution mechanism needs are also electrical, the amplifier/transformer can be any ordinary signal amplifier.

Amplifiers frequently used in aviation for electrical signals include electronic amplifiers, magnetic amplifiers, and relay amplifiers. Early electronic amplifiers had an electron tube as their most important component, and so were called "electron tube amplifiers." In the 1960's, transistors were used in place of electron tubes, so these amplifiers were called "transistor amplifiers." Currently, integrated circuits, large-scale integrated circuits, and other new components are used, so the electronic amplifier is small, light, and reliable.

Everyone has some familiarity with the electronic amplifier. When announcements are made at large meetings, we know that the sound coming out of the loudspeaker has passed through an audio amplifier. What actually happens is that a person speaks facing the microphone; the microphone is like the sensor, taking the sound waves and transforming them into electrical signals. The signals then enter the audio amplifier, which enlarges, or amplifies, the electrical signals. Finally, the signals cause the loudspeaker to produce sound. The audio amplifier here is a just simple electronic amplifier.

Many kinds of electronic amplifiers are used in air navigation, but there are two main kinds that are used as equipment for automatic pilots. One kind is the direct current electronic amplifier, the other kind is the alternating current/direct current electronic amplifier. Both kinds need certain capabilities for use in automatic pilots: First, an amplifier must be able to synthesize various kinds of electric signals, because the signals received by an automatic pilot amplifier, in most cases, are not all of the same type. For this reason, the amplifier uses one specialized circuit to synthesize all kinds of electric signals; this component circuit by itself is called the "synthesizer circuit." The synthesized signal is then sent to the amplifier to be enlarged. Second, the automatic pilot amplifier must be able to filter out interference in the signal. For example, in an alternating current amplifier, it mainly eliminates the useless component that is 90° out of sync with the main signal; only in this way can the amplifier operate normally. Third, the amplifier must have an adequate amplifying capacity. Generally, in order to make the automatic pilot work quickly and accurately, the amplifier should be rather powerful. Fourth, the amplifier must be able to distinguish between positive and negative signals, because the operation of the airplane's rudder depends on polarity.

2.1.7. The Operation and Varieties of Automatic Pilot Execution Mechanisms

The execution mechanism in automatic pilots is mainly used to operate all rudders, ailerons, and elevators. For this reason, the execution mechanism is normally called the "steering mechanism." The most important work of the steering mechanism is to take the command signals which have been synthesized and amplified and convert them into force or torque. This is the way the steering mechanism takes the place of the human foot or hand in operating the rudders, etc. In addition to being light in weight and small in volume, the rudders used in air navigation must also have adequate power and be able to move quickly; in other words, the movement must take place over a short time, and there must be only a small delay in initiating it. Various kinds of power sources are in use; the most important are electrically operated steering mechanisms, hydraulic steering mechanisms, and pneumatic steering mechanisms. The structural components and working principles are different for each kind. Here, we will only discuss the principles behind the electrically operated steering mechanism.

2.1.8. Working Principles of Electrically-Moved Steering Mechanisms

Figure 2-10 illustrates the principle behind the electrically-moved steering mechanisms. You can see that when the steering mechanism is in operation, the electric motor rotates the whole time in one direction. The electric motor causes gear (1) to rotate in a clockwise direction, which in turn causes gear (2) to rotate in a counterclockwise direction. Gear (2) makes gear (3) rotate; this time, the direction is again clockwise. When there is no control signal, the rudder does not move. When there is a positive control signal, the signal enters clutch windings (I), magnetizing the iron core of the clutch and produce an attractive force which attracts and holds the armature plate, thereby causing the plate to rotate. Gear (4) is linked firmly with the armature plate, so gear (4) also turns in a clockwise [sic] direction, setting gear (5) into motion. This causes the cylinder to rotate in a counterclockwise direction, and causes the rudder to turn downwards. When the control signal is negative, it passes through the other clutch, and ultimately causes the rudder to turn upward. From this you can see that as long a control signal is output, it causes the rudder to turn a certain degree. The force or torque that the rudder needs to turn is provided by the electric motor. For this reason, the size of the force or torque that the electric steering mechanism provides is mainly determined by the power of the motor.

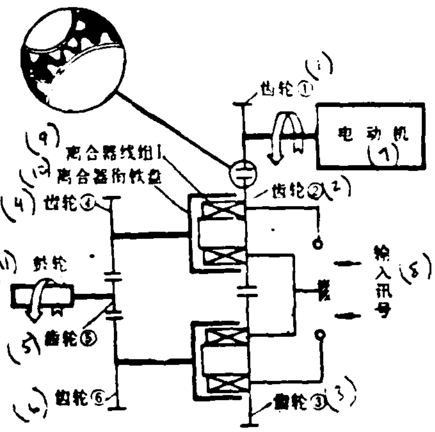

Fig. 2-10. Principle of the electrical steering mechanism.
Key: (1) Gear 1; (2) Gear 2; (3) Gear 3; (4) Gear 4; (5) Gear 5; (6) Gear 6; (7) Electric motor; (8) Input signal; (9) Clutch windings I; (10) Clutch armature plate; (11) Cylinder.

2.1.9. One of the Uses of an Automatic Pilot -- Flight Stabilization

Now that you have a certain understanding of the main components of an automatic pilot, you can see how it takes the place of a human pilot in doing its work. We will now look at the functions of the automatic pilot, starting from the most basic, one of which is flight stabilization.

Recall how the human pilot maintains the course of the airplane. Suppose an automatic pilot with a directional gyroscope, amplifier/transformer, and steering mechanism is installed in an airplane. Suppose it has been

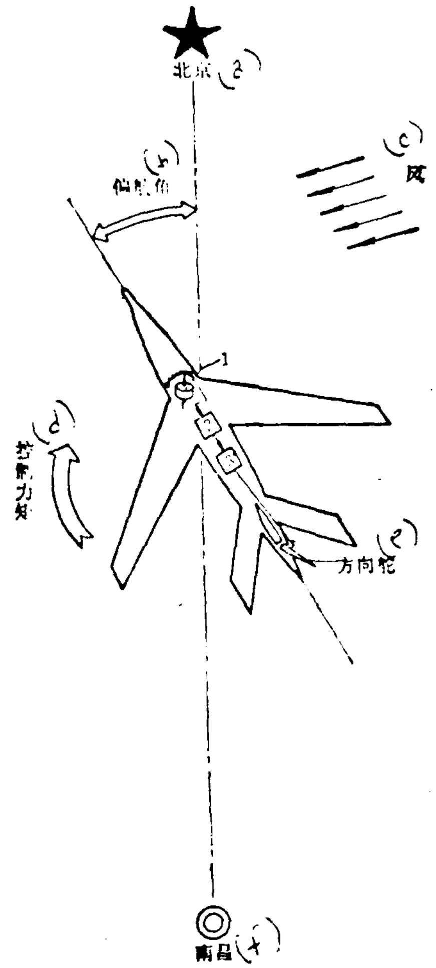

Fig. 2-11. The stabilizing action of an automatic pilot. 1. Gyroscope; 2. Amplifier; 3. Steering mechanism.
Key: (a) Beijing; (b) Angle of yaw; (c) Wind; (d) Controlling torque; (e) Directional rudder; (f) Nanchang.

determined in advance that the directional gyroscope's wheel should be alined with due north (as the airplane's preset course). When the plane is flying due north, the gyroscope's potentiometer has no signal output. When the airplane is subjected to an unanticipated force, like a sudden gust of wind, that makes the plane's nose veer west by a certain angle, the gyroscope's potentiometer outputs a signal that is in direct proportion to the angle of yaw. This signal, when it has been amplified, operates the steering mechanism, which in turn operates the plane's directional rudder, turning it to the right. This produces a controlling torque, causing the plane's nose to veer eastward (see Fig. 2-11). Only when the nose of the plane returns to its preset due-north course does the signal of the directional gyroscope potentiometer return to zero. When the amplifier no longer outputs a signal, the steering mechanism returns to zero, and the rudder also goes back at once to its zero position. At this time, the airplane has returned to its original due-north course. This entire process was automatically performed by the directional system of the automatic pilot, exactly as a human pilot would have performed it, only with greater speed, greater accuracy, and greater reliability. This is because the sensors are even more sensitive than human organs of sense. The amplifier/transformer is both sensitive and fast, and basically operates without any delay. The reaction of the steering mechanism is much swifter than that of a human, and its power output greatly exceeds human capacity.

The automatic pilot not only can take the place of a human in stabilizing the direction of flight, but can also stabilize the angles of pitch and inclination. For this, we must also install a vertical gyroscope, two amplifier/ transformers, and two steering mechanisms, to form the pitch system and the inclination system. These two systems control respectively the elevators and the ailerons of the plane. These two systems, as well as the directional system, are found in almost all automatic pilots. For this reason, the automatic pilot is able to stabilize the plane's three attitudinal angles. In addition, the automatic pilot can stabilize altitude and speed; this requires altitude and speed sensors, whose signals are used to control the plane's rudders and throttle. For example, in the case of altitude, the signal to change altitude is sent to the pitch system; when it is amplified, it operates the plane's elevators, causing the plane to go up or down, maintaining the preset altitude. The signal to change speed ordinarily requires an additional system, using another amplifier/transformer to operate the electric motor controlling the engine's throttle. This electric motor is like a steering mechanism, controlling the amount the throttle is open, which in turn directly effects the thrust of the airplane's engine. This is a frequently used method for controlling a plane's speed.

Advanced automatic pilots contain very many parts and assemblies and can perform an increasing number of functions; but all automatic pilots are able to maintain the stability of the plane. As regards pilotless airplanes, this one function is absolutely necessary.

2.1.10. A Second Function of an Automatic Pilot -- Executing Control Commands

An automatic pilot, in addition to being able to stabilize an airplane's attitudinal angles, altitude and speed, has another important function. This is executing a variety of commands to make the plane perform a variety of actions, and ultimately to change the plane's flying attitude. This is just as when a human pilot flies a plane: He is able to make it perform according to his own intentions and make it change its attitude continuously. For example, if while a plane is flying from Nanchang to Beijing malfunctions appear, the pilot makes an immediate decision to turn the plane eastward and fly to Shanghai. If an automatic pilot is installed in the plane, the human pilot can use it to help him turn. The pilot only needs to turn the potentiometer coil of the directional gyroscope toward the left by a certain amount. This is equivalent to changing the position of the directional gyroscope in the plane by that same amount. That amount is the same as the angle between the plane's nose when directed due north and the plane's nose when directed toward Shanghai. This angle produces an electrical voltage signal on the potentiometer, which is the control command to turn the plane. Passing through the directional rudder system, this signal controls the directional rudder, causing it to turn toward the right, and producing a controlling torque that makes the airplane veer right, as Fig. 2-12 shows. When the plane veers to the right, it of course also carries the potentiometer coil along in rotation to the right until the potentiometer's neutral position and the gyroscope wheel's direction (which is the same as the direction of the potentiometer brush) are in agreement. At this point the voltage signal put out by the directional gyroscope is zero, which causes the steering mechanism to stop doing work, and the directional rudder returns to its central position. By this time, the plane's nose has already turned by an angle equal to that which the pilot set at the beginning. The plane now

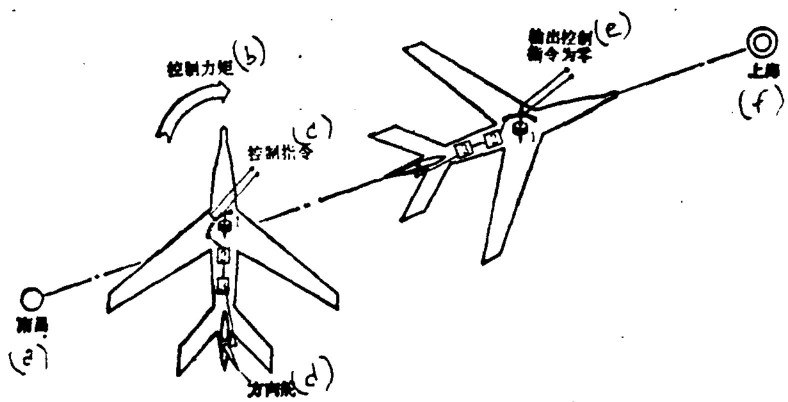

Fig. 2-12. Control function of the automatic pilot. 1. Gyroscope; 2. Amplifier; 3. Steering mechanism. Key: (a) Nanchang; (b) Controlling torque; (c) Control command; (d) Directional rudder; (e) Output control command = 0; (f) Shanghai.

continues on in the direction of Shanghai. This is a simple example of the use of an automatic pilot in controlling the airplane's flight attitude.

The coil of the potentiometer that controls turns in the plane's course issues what amounts to a control command. If you want to cause a plane to change direction continuously according to a previously determined course, or, in other words, if you want to issue a continuous series of control commands, how can you create and issue these commands? Normally, you would use navigational equipment to solve this problem. From this, you can see that the navigational equipment, for an automatic pilot, is very important indeed.

When the control commands for changing the plane's direction are input to the automatic pilot's directional system, it is the directional rudder that ultimately changes the course. In actual flying, it is not really so simple. An experienced pilot, in addition to operating the directional rudder to turn the plane, also has to make the plane to incline slightly, causing the plane's lift on the horizontal to produce a component of force to offset the centrifugal forced produced during the turn. At this time, the plane's lift may be a little smaller, and for this reason the plane may lose altitude. The pilot, in order to maintain his original altitude, must also operate the elevators to increase the lift. In a word, the pilot is very busy at this time. He must not only operate the directional rudder, he must also operate the ailerons and the lifts in coordination. Perhaps he must also adjust the throttle. If an automatic pilot is installed on the plane, he only has to press an electric button and at once all the control commands are issued automatically to the directional system, the pitch system and the inclination system. The distribution of the commands is put through repeated calculations and tests, so the use of the control commands to operate a plane is as accurate and error-free as if you had the most experienced pilot.

To sum it up, an automatic pilot can accept a variety of control commands and make an airplane perform a variety of actions in accordance with human intentions. There is of course a one-to-one correspondence between the actions and the commands, and these are all determined in advance by human beings. For this reason, although there is no human pilot on board, all the plane's actions are predetermined by people. From this, you can see that a true "pilotless" airplane is an impossibility.

2.2. NAVIGATION EQUIPMENT OF A PILOTLESS AIRPLANE

2.2.1. The Question of "Navigation" in Daily Life

We often meet with problems in our daily life that are similar to the problems of navigation. For instance, we set out from the Beijing Station toward Tiananmen Square. At this time, there are at least two ways to walk: One route is to go directly north after leaving the station, and to make a 90° turn to the west when we reach East Changan Street; we then pass Dongdan and the south end of Wangfujing Street, and reach Tiananmen Square. Another route is to go west after leaving the station, pass through Chongwen Gate and Taijichang to Qian Gate, then turn 90° to the north and continue on to the Square. No matter which route we select, during walking we still must constantly determine our bearings (are we going west? north?) and consider road signs (Dongdan, Chongwen Gate, Taijichang). On the basis of bearings and road signs (which taken together are often called navigational information), control commands are formed in our brain, which cause us to make the right turns and maintain the correct forward direction, finally taking us to Tiananmen Square.

2.2.2. The Main Function of Navigational Equipment

It is not so easy to determine the position of an airplane in mid-air as it is to determine the position of a man on the ground, especially when the plan is flying at high altitudes with boundless blue skies overhead and a sea of clouds below. There is not a single road sign. At this time, we need help from the navigational equipment to determine the plane's location in the air. The altitude can normally be determined by an altimeter. The plane's position relative to the earth can be shown using the earth's lines of longitude and latitude; for this reason, the navigational equipment's main function is to establish the plane's position in relation to the earth, and to issue the appropriate control commands.

2.2.3. Basic Working Principles of Non-Independent Navigational Equipment

There are many kinds of navigational equipment. There are two categories, based on the source of the navigational information obtained. The first category is the non-independent navigational equipment. This kind of equipment undertakes navigation using surface radio equipment, external to the plane. The method normally used is to set up several navigation stations on the surface; these stations in fact are radio stations, just like the broadcasting stations that we receive on our own radios. They constantly emit radio waves at a set frequency. At the same time, a radio directional compass is installed on the plane. This directional compass is in fact a radio receiver that is able to determine bearings. It can automatically point out the position of the navigation stations. If we look at the navigation stations as a kind of "mid-air road sign," the plane can use its directional compass to determine its bearings relative to the "road sign." Because the location of the navigation stations on the earth is known, if the plane is able to determine its position relative to two or three stations, it is possible to determine with great precision its latitude and longitude. Taking this information along with the plane's altitude as read from the altimeter, the plane's position in space is established.

The aim of navigation is to guide a plane to a predetermined goal. Generally speaking, the position of the goal and the position of the starting point are known in advance. The course that the plane will fly from take-off to its objective is also considered and set in advance, and drawn on a map. This map is a "navigational map" or a "course map." For pilotless aircraft, this is even more important; navigation routes are all set in advance. In this way, when the plane is under way, the navigational equipment is used continuously to read the position of the plane and to undertake a comparison between the actual position and the predetermined course. If the plane deviates from its course, the navigational equipment is able to produce a control command and transmit the command to the automatic pilot, which operates any of the rudders or control mechanisms to make the plane return to its original course. In this way, it succeeds in making the plane fly along its predetermined course to its predetermined goal.

2.2.4. An Example of Independent Navigational Equipment: Navigational Equipment Time-Programmed for Angle of Yaw

The second category of navigational equipment is independent navigational equipment. The characteristic of this type is that all the equipment is installed within the airplane, and does not rely on any external equipment like the surface navigation stations.

One of the simpler representatives of this category of navigational equipment is "navigation equipment time-programmed for angle yaw." The principle it works on is very simple. Because the predetermined course is known in advance, if we suppose the plane flies at a uniform speed, we will be able to find a time corresponding to each section of the trip (equal to the distance flown) along the predetermined route. We put together a program on the basis of the time period and the angle of yaw for each section of the trip along the predetermined route. After the plane has flown a certain time period (or a certain distance), the program outputs a control command for the angle. If the plane deviates from its course, the control function of the automatic pilot makes the plane fly according to the predetermined angle. In this way, the plane repeatedly changes its flight direction on the basis of the commands issued by the program, and flies along its predetermined course. This kind of independent navigation is accurate only under conditions of constant speed, because it issues its commands on the basis of the time elapsed. In fact, however, flying speed is always changing; there are many interference factors in flight. Because of this, this kind of navigation method has an inferior rate of accuracy. It is most frequently used in flights where the requirements are not high, as an example of this kind of control.

2.2.5. Another Kind of Independent Navigation Equipment -- Doppler Navigation Equipment

To improve the accuracy of navigation, Doppler navigation equipment is now widely used. Doppler navigation equipment is ordinarily made of components including Doppler radar and a navigational computer.

Doppler radar is a special kind of radar that makes use of the principle of the "Doppler effect." The Doppler effect is a physical phenomenon possessed by waves of all kinds. We often meet with the Doppler effect in our daily lives. When an automobile drives toward us honking its horn, the tone of the horn becomes more and more piercing; but when the automobile races away, the tone again becomes deep, as shown in Fig. 2-13. And what is more, as the automobile accelerates, this change in tone becomes more pronounced.

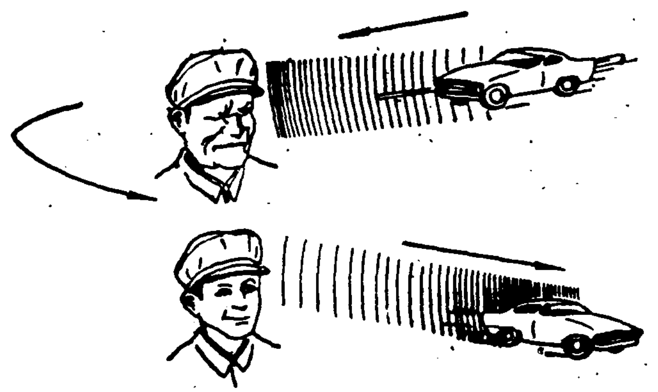

Fig. 2-13. The Doppler effect. An example is your perception as an automobile comes and goes. When the automobile is driving toward you, the sound waves seems to be condensed, compressed. When the automobile drives away, the sound waves seem dispersed, as if they were unfolding.

This phenomenon shows that a change in the frequency of sound waves ("frequency" is the number of vibrations per second) is connected with the speed of physical movement. Generally speaking, the greater the speed, the greater the change in frequency. This is the case not only for sound waves, but also for radio waves. For this reason, we can use this principle to create Doppler radar. When Doppler radar is installed in an airplane, it continuously sends out, forward and downward, two beams of radio waves of identical frequency, as shown in Fig. 2-14.

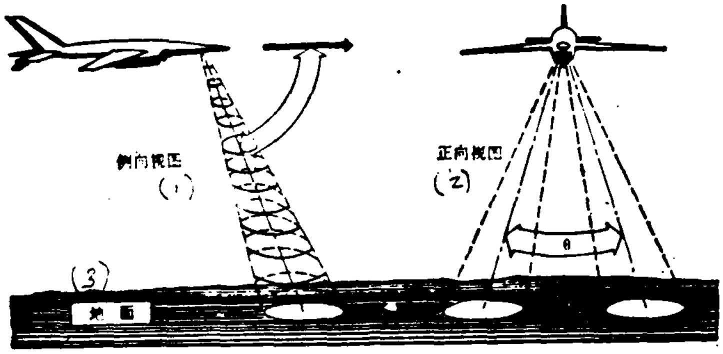

Fig. 2-14. Doppler radar wave beams.
Key: (1) Side view; (2) Front view; (3) Ground surface.

Doppler radar uses the difference between the frequency of the radio waves it sends out and of the radio waves it receives back (the Doppler frequency effect) to establish the airplane's "ground speed" and "side-flow angle."

What is "ground speed"? It indicates the speed of movement of the airplane in relation with the ground. "Air speed" indicates the speed of the plane's movement in relation with the atmosphere. When the atmosphere and the earth have no movement in relation with each other, or in other words when there is no wind, the ground speed of an airplane flying horizontally is the same as its air speed. Under actual conditions, however, there always is a wind; at this time the ground speed is a composite of the air speed and the horizontal wind speed. It is very important to know the ground speed, because navigational courses are always reckoned in relation with the earth, and range always indicates the surface distance. For this reason, the range of a flight is accurate only when calculated using ground speed.

What is "side-flow angle" It is the angle between the direction of the plane's nose and the direction of the ground speed. When the direction of the plane's nose and the air speed direction are the same, the side-flow angle is the angle between the air speed direction and the ground speed direction; see Fig. 2-15.

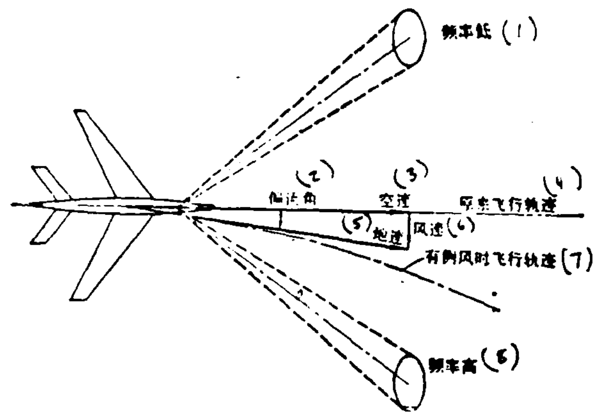

Fig. 2-15. Doppler radar measuring ground speed and side-flow angle.
Key: (1) Frequency low; (2) Side-flow angle; (3) Air speed; (4) Original course; (5) Ground speed; (6) Wind speed; (7) Course as affected by side wind; (8) Frequency high.

You can see from Fig. 2-15 that when there is no wind, the air speed is the same as the ground speed. For this reason, the side-flow angle is zero. But when there is a wind blowing horizontally from the left, the ground speed deviates to one side. At this time, a side-flow angle appears, and the plane's course also changes, veering off to the right.

Doppler radar sends out toward the earth two beams of radio waves, and receives two beams back. When there is no wind, the frequency of the waves that are sent out and the waves that are received are equal; this is explained by the fact that the air speed equals the ground speed, and the side-flow angle is zero. When there is wind, there is a change in the beams corresponding with the ground speed, and the frequency of the waves that are sent out and the waves that are received back is no longer equal. As shown in Fig. 2-15, the frequency of the waves received on the right is high, while that of the waves received on the left is low. For this reason, the difference in frequency between them can be used to calculate the size and direction of the wind speed, which amounts to establishing the size and direction of the ground speed and the side-flow angle. Because Doppler radar works continuously, it supplies a steady stream of information on changes in ground speed and side-flow angle.

The navigational computer is a comprehensive computer installation. There are ordinarily two types: One is the digital type of computer, like a small electronic computer; the other is the analog type, composed of an analog calculation installation, like a small analog computer. Their most important function is to convert the information provided by the Doppler radar on changes in ground speed and side-flow angle into control commands for the navigation system. Ordinarily Doppler navigation uses flight path deviation angle and range program control. For this reason the navigation computer must be able to calculate the flight path deviation angle and the flight range. To calculate the range, it is only necessary to perform integration on the ground speed. For the flight path deviation angle, the side-flow angle and the angle of yaw as measured by the directional gyroscope are used together. The flight path deviation angle is the angle between the airplane's ground speed direction and the preset course, as in Fig. 2-16. Comparing this with the angle of yaw in Fig. 2-4, you can see that the wind factor is considered for the flight path deviation angle. Under windless conditions, the flight path deviation angle is the same as the angle of yaw. Doppler navigation equipment uses the signals for the range and the flight path deviation angle to synthesize control commands for navigation. Because the flight path deviation angle includes the wind factor, using it in navigation it is

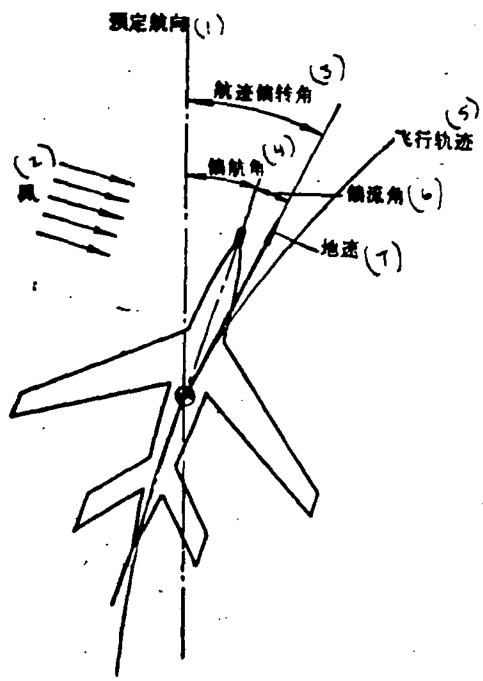

Fig. 2-16. Flight path deviation angle and angle of yaw.
Key: (1) Predetermined direction; (2) Wind; (3) Flight path deviation angle; (4) Angle of yaw; (5) Navigational orbit; (6) Cross-flow angle; (7) Ground speed.

much more accurate than using the control commands created by the signal for the angle of yaw alone.

2.2.6. Working Principles of the Program Control Installation

A program control installation in an automatic pilot is a very important piece of equipment; when the automatic pilot is to fly independently, this equipment is even more necessary. "Program control" is making the airplane perform movements following control commands that are issued in accordance with a predetermined pattern. The program and the control commands within the installation can of course be adjusted in advance according to human intentions.

The simplest program control installation is composed a cam mechanism that is moved by an electric motor. The cam puts out control commands according to a time program. Rather more advanced is an installation using a dedicated electronic computer; it is able to store a set program in advance in its memory, and when at work continuously selects and performs operations which are turned into control commands. Installations using a relatively broad program control are electro-mechanical in their structure; this type of program control installation is composed of a step relay, program mechanism, and other components. The step relay is set into operation by a standard pulse. When used together with the Doppler navigational equipment, the standard pulse is produced by a course unit. For example, it can be determined that after flying every ten kilometers one standard pulse is produced. This standard pulse causes the step relay to jump forward one step. In the structure of the program connected with the step relay there are control commands which are set up in advance according to the course of the flight. For this reason, because the step relay is advancing constantly, the program mechanism constantly puts out predetermined control commands, which when transmitted to the automatic pilot, operate the rudders of the airplane and make the plane, on the basis of its course, constantly change the angle of yaw of its flight as it flies, or, in other words, to fly according to a predetermined course. Some control commands can be directly sent to execution mechanisms, like the mechanism that controls the throttle's electric motor. The command can open or close the throttle, and so change the airplane's speed.

The time program navigational equipment for the angle of yaw is actually also a time program control installation. It can also be electro-mechanical in structure, with its standard pulse a time period. A time-period standard pulse can be output by a timer motor or a clock-like mechanism, which causes a step mechanism to advance a step, after which a control command is issued by the program mechanism. If the plane's speed changes, this mechanism may introduce an error with every step it jumps, the more steps, the greater the error.

2.2.7. A Third Kind of Independent Navigational Equipment -- Inertial Guidance Equipment

Doppler navigational equipment is able to take the wind factor into account, but often has no way to handle other interfering motions. In actual flight, there are many kinds of interfering motions, so the accuracy of navigation cannot be very high. To improve navigational accuracy, and to manage the influence of all kinds of interference, the "inertial navigation" method is currently being used.

Inertial guidance equipment is made up mainly of a straight-line accelerometer, an inertia platform, and its own dedicated computer.

The straight-line accelerometer is a kind of sensor that measures the acceleration of a physical object. Acceleration and inertia stand in a direct relation with each other. You can see this in everyday life. Everyone has ridden a bus: Ordinarily, when the bus first starts, we may feel pressure on the back of the seat. As the bus picks up speed, the pressure continues; but once the bus reaches an even rate of speed, this pressure disappears at once. The explanation for this is that as long as physical objects are undergoing acceleration, they have inertial force; when moving forward at an even speed, or when they are at rest, there is no inertial force. This concept is what is called "Newton's Second Law" in physics. The straight-line accelerometer is designed on the basis of this principle. Figure 2-17 shows the principle and structure of the straight-line accelerometer. It uses a solid object to detect axial straight-line acceleration. When the axial direction experiences straight-line acceleration, inertial force is produced on the axis. Under the effect of this inertial force, the brushes of the potentiometer produce a displacement, which corresponds to an electrical voltage signal. The signal produced on the potentiometer stands in direct relationship to the straight-line acceleration.

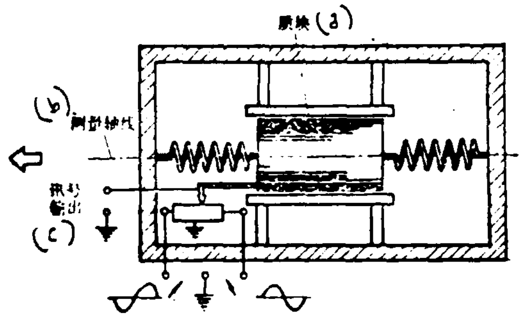

Fig. 2-17. Principle and structure of a straight-line accelerometer.
Key: (a) Solid object; (b) Axial line of measurement; (c) Signal output.

A straight-line accelerometer can only measure straight-line acceleration in one direction (namely, the axial line of measurement shown in Fig. 2-17). But orbital motion has three directions. Therefore, it is necessary to install three straight-line accelerometers. In addition, we cannot install a straight-line accelerometer directly in the body of the plane, because when the plane is flying there is not only the three-directional orbital motion, but also the three-directional rotational movement around the plane's center of gravity. Accelerometers installed on the body of the plane would not only sense orbital motion, but also rotational movement. To eliminate the influence of the plane's rotational movement, it is necessary to install the straight-line accelerometer on an "inertia platform." Because the inertia platform constantly stays parallel with the earth's surface, a straight-line accelerometer installed on an inertia platform is only able to sense acceleration in the plane's orbital motion; additional acceleration caused by rotation is eliminated.

Why does the inertia platform constantly remain parallel to the earth's surface It uses the gyroscope's characteristic of maintaining unchanged its spatial orientation. Using a gyroscope as a sensor and three high-speed directional supporting servo mechanisms (like the systems in an automatic pilot), it operates three frames that are able to follow movement, and keep the inertia platform stable in its orientation, and parallel to the earth's surface. Figure 2-18 shows the principle behind it.

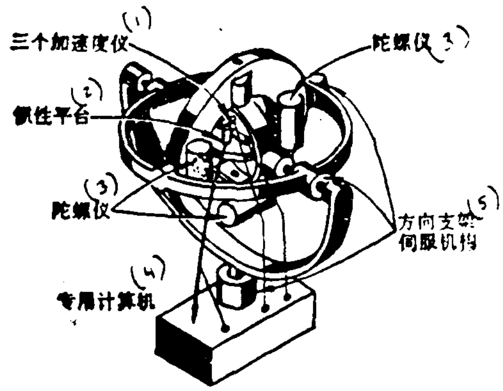

Fig. 2-18. Principle of inertial guidance.
Key: (1) Three accelerometers; (2) Inertia platform; (3) Gyroscope; (4) Dedicated computer; (5) Directional supporting servo mechanism.

The dedicated computers in inertial guidance equipment almost all use digital electronics, and really are just a small, single-purpose computer. On the basis of the acceleration in the three orbital directions measured by the straight-line accelerometers, and the known spatial position of the starting point for the flight (zero position on the coordinates), the computer is quickly able to calculate the altitude and distance relative to the starting point, or, in other words, information regarding the plane's position in space (see Fig. 2-19). In addition, information on the predetermined flight line pattern is also stored in this computer, and for this reason it can make

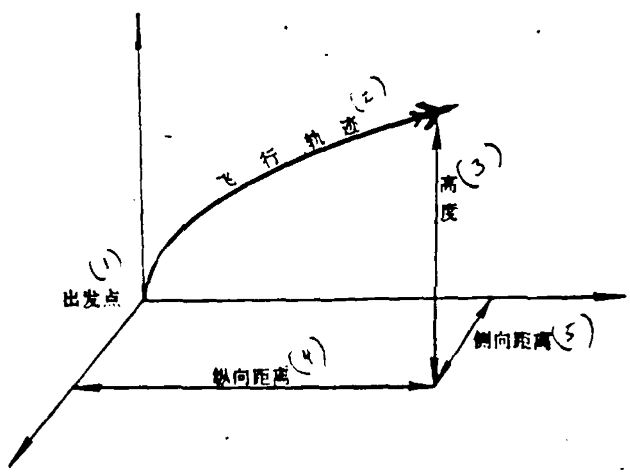

Fig. 2-19. Computed altitude and position relative to starting point.
Key: (1) Starting point; (2) Flight orbit; (3) Altitude; (4) Lengthwise distance; (5) Crosswise distance.

comparisons between the calculated position and the predetermined flight line pattern, and then convert the results into control commands. These control commands are output to the automatic pilot or to the operating mechanisms, to fly the plane according to its predetermined line of flight. You can see that this kind of dedicated computer is used not only for calculation, but also performs the function of a program control installation; this kind of computer is at times called a control device.

With the use of inertial guidance, navigational accuracy is far higher than with Doppler navigation, but errors still persist. The most important of these errors are a result of the low accuracy of the navigational equipment; others are related to the duration of the flight, with longer durations allowing the accumulation of more errors. For this reason, to improve accuracy still further, a composite type of navigation is currently being used which combines inertial guidance with a "topographical matching installation." On long-distance flights, inertial guidance is used for far the greatest share of the time, but the topographical matching installation is used after a certain interval to correct the spatial position; then control is again turned over to inertial guidance. This pattern is repeated over and over during the flight. It results in the accumulated error over a long flight being relatively small, with a great improvement in navigational accuracy. The demands on the accuracy of the inertial guidance equipment itself, however, decrease, and the capacity and scale of the dedicated computer in the topography matching installation can also be reduced (because it only has to store information on a small number of regions and to calculate comparisons). It has a final result of reducing the size, weight, and price of the whole navigational installation, as well as providing a great improvement in accuracy.

The topography matching installation is also a kind of navigational equipment. It is composed mainly of a remote sensor, a high-accuracy altimeter, a transformer, and a dedicate computer. It makes a matching comparison between topographical information gathered by the remote sensor and the altimeter and the pertinent topographical information previously obtained from man-made satellites or other aerial mechanisms. The dedicated computer performs real-time operations and comparisons, and finally converts these into control commands. The commands are sent to the automatic pilot or control mechanisms, and ultimately cause the plane to make adjustments within the adjustment region (also called the matching region) according to the predetermined line of flight. At the same time the inertial guidance standard pulse information is regulated, effecting the greatest possible reduction in the inertial guidance equipment's error.

This navigational style is currently in use in pilotless bombers and cruise missiles.

2.3. TELEMETRY AND REMOTE CONTROL IN PILOTLESS AIRPLANES

2.3.1. Working Principles and Functions of the Radar and Telemetry Systems

The word for "radar" in Chinese is borrowed from the English term that implies the meaning of "radio detection and ranging." It is able to detect the movement objects moving in the sky and determine the position of the moving object.

The basic principle behind radar is quite simple. It makes use of the physical phenomenon that all objects reflect radio waves. The interval between the time that the waves are sent out and the time that they return is calculated using electrical pulses. This is the same as the altimeter using radio waves to measure altitude, as discussed above. But the angles of elevation and direction of radar wave beams are determined by the position of the radar antenna. For this reason, radar is able to determine three motion parameters of a moving object: The oblique distance, the angle of elevation, and the azimuth, as shown in Fig. 2-20. Using a simple conversion, we can determine the spatial position of the object. This means we can use radar to track an airplane, and determine its position in space at any time.

To understand the situation of an airplane in the air, we have to know not only its location, but at the same time we have to understand its attitudinal angles, the position of its throttle and the fuel level, as well as the changing condition of other parameters. These parameters cannot be measured by radar; a telemetric system must ordinarily be used to determine them.

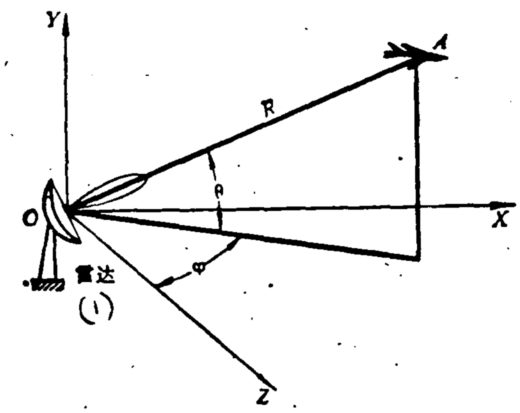

Fig. 2-20. Radar determination of a mid-air object's position. R. Oblique distance; θ. Angle of elevation; φ. Azimuth.
Key: (1) Radar.

The telemetric system is composed of an on-board and a ground component. The component on the airplane consists mainly of sensors, a transformer and a transmitter. The ground component consists of a receiver, a transformer, and a display device, as shown in Fig. 2-21.

The sensors used for telemetry are sensitive elements which detect the parameters that are to be measured. For example, to detect the angles of pitch and inclination, we can use a vertical gyroscope sensor; to detect changes in the fuel level we use a fuel sensor. There are many parameters to be measured, of course, so the kinds of sensors are also of a great variety. The output of the sensors is normally

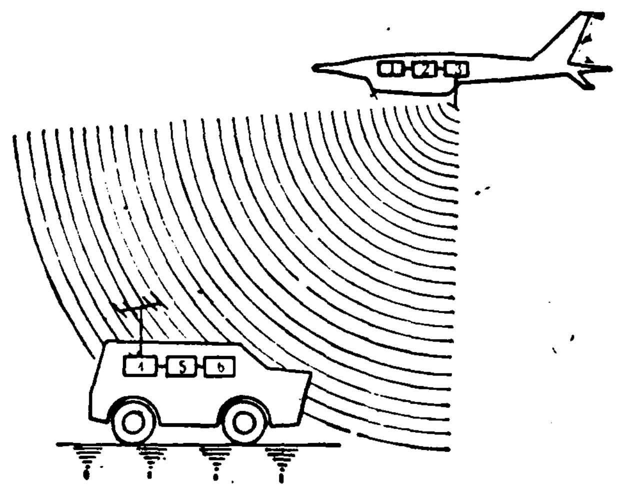

Fig. 2-21. Principle of the telemetric system. 1. Sensor; 2. Transformer; 3. Transmitter; 4. Receiver; 5. Transformer; 6. Display device.

electrical signals, but there are also mechanical signals for reading displacement, volume of flow, etc. All these signals must undergo a conversion to radio wave signals, and are then sent out by the transmitter. Currently the telemetric system normally found in pilotless airplanes uses an ultra-high frequency transmitter whose transmission wave length ordinarily uses the metric wave wave bands, because their scope is relatively broad, they are relatively unaffected by static (the effect on radio waves of air masses in the atmosphere, rain, fog, etc.), and they are good for straight-line broadcasting. The ground equipment uses a metric wave receiver to receive the broadcast signals. These signals pass through the transformer and the parameters that have been measured can be displayed on the display device. Normally, the display device is a fluorescent screen, though instruments ar- occasionally used. At the same time, the results of the telemetric parameters can be fed into a recorder, typewriter, or other equipment. In this ways the results can be directly shown in written or graphic form for immediate inspection, and can also be automatically recorded for reference.

2.3.2. Principles and Functions of the Remote Control System

During the flight of a pilotless airplane, there are times when a change in conditions occurs, or unanticipated circumstances require a change the originally determined course, or some flexible maneuvers must be performed on the spur of the moment. The remote control system can manage all these eventualities.

Early pilotless airplanes used the direct radio remote control method. This method is still widely used to control model airplanes. Remote control systems for controlling models are of course rather simple, the distance over which the control is exercised is not great, and the systems can only make the models perform a few simple predetermined movements. Still, the model remote control system is, in principle, similar to those used for pilotless airplanes.

Remote control systems now in use on pilotless airplanes still make heavy use of radio wave command control. There are in general two types of commands: The first is "continuous command"; the second is "occasional command." When an occasional command is given, it indicates the presence of absence of a control command, and makes no distinction in degree. For this reason, this type of command is often used to order the performance of a single movement or the change from one orientation to another -- for example, shutdown engine, open parachute, fly horizontally, descend, and similar actions. A typical model plane uses this style of command. For the continuous style of command, the degree of the action varies with the length of time the command continues; this style is mainly used to control the plane's motion and orientation. For example, continuous command is normally used when rectifying a deviation in the flight path: The ground station transmits two continuous commands, one to the automatic pilot's aileron system and one to its directional rudder system, which ultimately operate the ailerons and the rudder to correct the deviation.

In a radio remote control system, the remote commands are normally made up of a digital pulse code. Say that "1" is used to represent the presence of a pulse, and "0" is used to represent the absence of a pulse. If within a certain time period, at set intervals, a set of pulse codes is transmitted, this set of pulse codes can be used to represent a meaning, or, in other words, a command. For example, the pulse code set "1 1 1 1 1" could order engine shutdown. "1 0 0 0 1" could represent the command to open the parachute. This example uses a five-digit group, because five-digit binary numbers can be used to represent 31 commands (not 32: the number "0 0 0 0 0" is not a command). The commands represented by these 31 codes are occasional commands. If the codes are to be used to represent continuous commands, it is possible to add three additional pulses, called an "identification code," in front of each code. The identification code tells what parameter is to be affected; the five-digit code that follows indicates the degree to which the parameter is to be affected. Because there are 32 possible five-digit codes, the command parameter can be subdivided into 32 degrees. You can see that dividing the parameter more finely would allow you to raise the accuracy of the control parameter. Increasing the number of pulses would lengthen the whole pulse code and increase the amount of time needed to issue a command; this would influence the frequency (that is, the frequency of remote control commands transmitted per second) used by the remote control system, so that many factors must be taken into consideration when a pulse code is selected.

The remote control system, like the telemetry system, is also composed of a surface and an on-board component. The component on the plane is composed mainly of a receiver, a decoder, and relays. The component on the ground is mainly composed of an operating station (or dedicated computer), a coding device, and a transmitter. For the principle behind it, see Fig. 2-22.

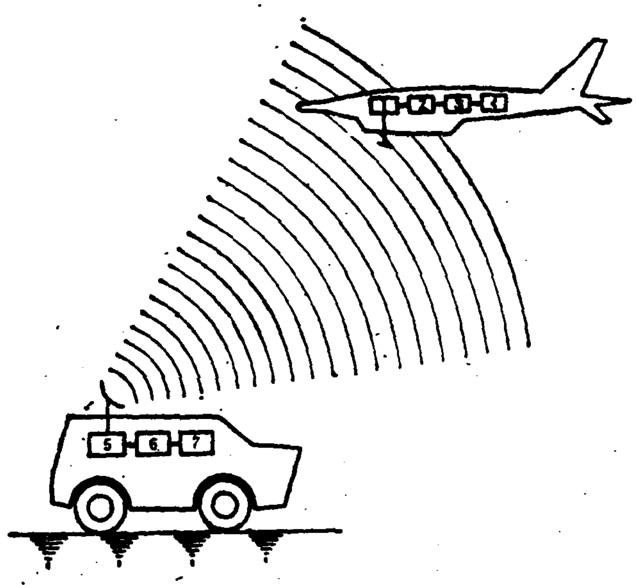

Fig. 2-22. Principle of the remote control system. 1. Receiver; 2. Decoder; 3. Relay; 4. Execution mechanism or automatic pilot; 5. Transmitter; 6. Coding device; 7. Operating station or computer.

You can see from Fig. 2-22 that when remote control is undertaken for a pilotless airplane, remote control commands are transmitted from the control station on the basis of observations made at the time or on the basis of evaluation of the telemetry system output. (A computer designed for the task can be used instead of a human being.) The coder quickly codes the commands into the chosen pulse code format, and transmits them group by group. When the receiver in the plane receives the pulse code groups, the decoder "translates" their meaning. The meaning of each pulse code group has been determined in advance, so no confusion or mistakes are possible. Afterwards, the command operates the corresponding relay and control circuit, causing the relay contact point to put through a control signal, or the control circuit directly to put out the control signal. This signal goes into the automatic pilot or the execution mechanism, and makes the plane change its motion or orientation or perform maneuvers as desired.

Because remote control and telemetry both require a transmitter and receiver, some systems combine both functions together. In this way, one transmitter and one receiver are used, and so the number of components and the room they need are reduced; on the other hand the number and accuracy of control commands and telemetry parameters is subjected to certain limitations.

The radio waves used for remote control and telemetry have a certain effective range. If the distance is too great, there are operating difficulties. Especially when the pilotless airplane is flying over enemy territory, the distance is normally rather great, and because radio waves are difficult to conceal, it is easy to interfere with them. For this reason, for long flights, pilotless planes use independent program control combined with remote control.

The amount of equipment in pilotless planes is very great. For example, a pilotless reconnaissance plane ordinarily must have an optical camera apparatus or an electronic reconnaissance device. A target drone normally has a "missed target" indicator, a target simulator, and so on. So the equipment and instruments required for a particular pilotless plane are determined by the function of the plane. This cannot be discussed further at this point.

One final remark: The equipment and instruments used by pilotless planes are not used only in pilotless planes, but are also widely used also in planes flown by human pilots, spacecraft, and guided missiles. The principles of all the equipment and instruments, no matter where used, are the same; only their performance standards have their own different emphasis.

CHAPTER III

THE USES AND DEVELOPMENTAL TRENDS OF PILOTLESS AIRPLANES

Now that you have a broad understanding of the structural characteristics and navigational control systems of pilotless airplanes, you are in a position to consider the question of what tasks pilotless airplanes are able to perform. We know that attempts to construct pilotless airplanes were made in the early period of the development of pilot-operated airplanes. Because they did not require pilots, the military value of pilotless planes was immediately apparent. The development of pilotless airplanes is closely related to the development of pilot-operated airplanes, automatic control technology, and radio technology. The development has now reached a relatively mature stage. Especially in recent years, inexpensive remote-control planes have been used in great numbers, and the scope of the tasks to which they are put has continued to broaden. We would like to discuss the most important uses at the present time of pilotless airplanes.

3.1. PILOTLESS AIRPLANES AS TARGET DRONES

In order to train fighter pilots, antiaircraft artillery, radar operators, and guided missile operators, and to appraise the performance of guided missiles, it is necessary to have target drones that can achieve a variety of simulations. The earliest available aerial targets were target flags or socks towed by a pilot-operated aircraft for training or range practice. But to guarantee the pilot's safety, it was usually necessary to use a tow-rope several thousand meters in length. Furthermore, the towing performance was not ideal. As guided weaponry began to appear, the performance requirements for aerial targets also increased. Tracer bullets fired by antiaircraft artillery were also used, as well as parachutes released from regular airplanes; with the parachute method, incendiary bombs or radar reflectors were suspended from the descending parachute, as targets for infrared guidance or radar guidance weapons. But they were not able to simulate enemy targets under actual war conditions, and did not satisfy the requirements of training for actual fighting.

The pilotless target drones that are currently in wide-spread use are able to simulate advanced enemy aircraft (see Fig. 3-1). As radio technology has developed, target-miss indicators, radar reflected-wave intensifiers, and other special equipment have been installed on the drones. Most drones are now designed to be recoverable and reusable. There are currently very many kinds of target drones under production and in service world wide. In addition to newly designed models, there are also obsolescent pilot-operated planes that have been refitted as target drones. The United States' F-102A interceptors have in the past few years been converted into PQM-102A drones to test the performance of the F-15 fighter's air-to-air guided missile system. The F-4B fighter-bomber has been reequipped as the supersonic QF-4B target drone for the navy.

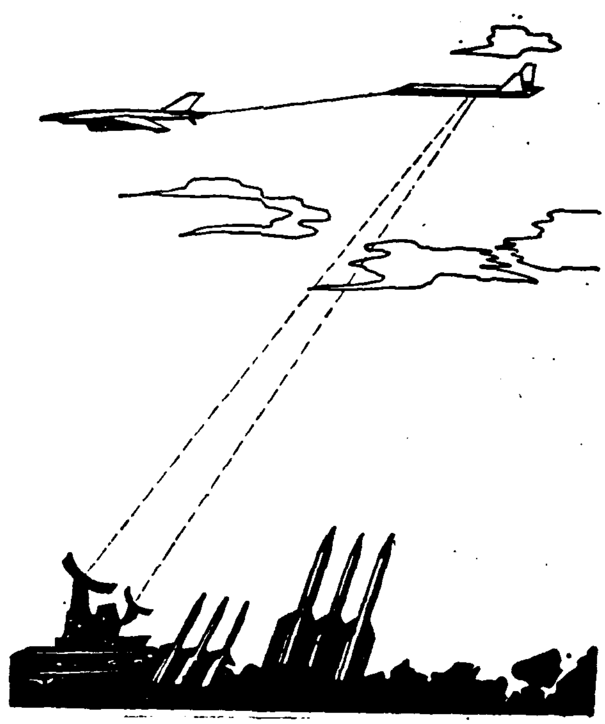

Fig. 3-1. Pilotless airplane towing a target.

Because target drones are inexpensive to construct, are light in weight, and during flight are not subject to the limitations of human physiology, their performance in flight can be excellent. Some existing supersonic models can reach altitudes above 35,000 meters and fly at speeds over 3,500 km/hr. These models can simulate the most advanced long-range bombers and even guided missiles. At the same time, models able to simulate extremely low-altitude aircraft have appeared one after the other. For example, a radar altimeter control system has been installed on the BQM-34A "fire bee" drone, allowing it to make accurate low-altitude flights. Over land, its altitude may be as low as 30 meters, while over water it may be as low as 15 meters. If mobility enhancement equipment is also installed, the craft is capable of high-mobility flight. A overload of from 7-12 g to 30 g ("g" is the acceleration of gravity) has been attained in automated flight.

On the basis of incomplete data, we can say that world-wide there currently are over 50 models of target drones that have been developed, or are under development. If modified versions of these are counted, the number may reach nearly 100.

3.2. PILOTLESS RECONNAISSANCE PLANES

In order to be able to make accurate battle plans during war, reconnaissance to obtain reliable information on the enemy situation cannot be given short shrift. Before flying devices had appeared, the goals of reconnaissance were attained by surface methods, including "going deep into the tiger's lair" and long-range observation. The balloon, however, was used for war-time purposes very quickly after its first appearance. In France, for instance, during the great bourgeois revolution of the 1780's, the revolutionary government used balloons to undertake reconnaissance against the enemy army. By the end of the nineteenth century, as aircraft began to come out, cameras were moved into the cabins. During the First World War, there were several thousand reconnaissance photos taken from airplanes. By the Second World War, the number of reconnaissance photos taken daily reached 10,000 and more.

Aerial reconnaissance is undertaken mainly against the opponent's airfields, military harbors, armaments factories, military installations of all kinds, and army concentrations, deployments and transportation.

After the Second World War, antiaircraft measures were steadily improved; especially important were the appearance of antiaircraft missiles and the great increase in surface-to-air firepower. In addition, the development of high-performance fighter planes and air-to-air guided missiles and the great increase in the search range of surface warning radar spurred on the development of high-performance pilotless reconnaissance planes. The use of pilotless airplanes as reconnaissance planes has several advantages: First, in comparison with pilot-operated planes, they are smaller, lighter, and faster; and are also able to perform low-altitude flight, so that they can easily avoid enemy radar and surface firepower. Also, they are simple in structure and inexpensive, and are easy to use and maintain. During reconnaissance, even being hit hardly influences their reconnaissance mission, and there is no danger of a pilot being captured and revealing confidential information. The shortcomings of pilotless reconnaissance planes are also apparent: They can only fly mechanically, in accordance with a predetermined scheme: their mobility and flexibility are far lower than that of a pilot-operated reconnaissance plane; and, once discovered by the enemy, they are easy to shoot down.

The major means of reconnaissance of a pilotless reconnaissance plane are: Aerial optical or infrared cameras, television imaging equipment, motion picture cameras, meteorological instruments and several kinds of sensors used in detection. In general, different equipment is installed for different tasks. Some pilotless planes are also equipped with flares for photography, allowing reconnaissance activities to go on at night. Photographic reconnaissance is able to cover a very large area. For example, the optical aerial camera used in a high-altitude reconnaissance plane built by the United States has a vacillating-style lens (Fig. 3-2). It is able to take photographs from five windows in the camera compartment. The size of the

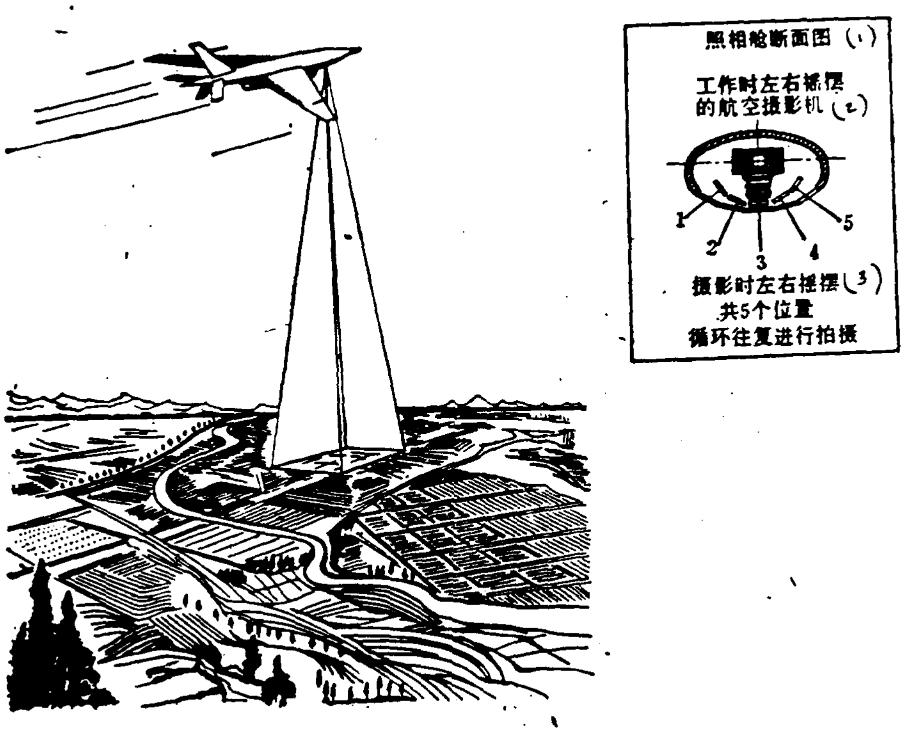

Fig. 3-2. Photographic reconnaissance.
Key: (1) Section of camera compartment; (2) Aerial camera that vacillates right and left; (3) Five positions available for photography. Photography undertaken as camera moves.

negative of the camera is 9 x 9 inches; 400 meters of film can be loaded at one time, giving the camera the capability of making nearly two thousand exposures. If the camera is installed in a plane flying at an altitude of 18 kilometers, the breadth of the area that can be photographed is over 45 kilometers, while the length is about 1400 kilometers. From the photographs taken in this way it is possible to locate clearly mountain chains, water courses, factories, communications, transportation, and military facilities of all kinds.

In addition, there are even more kinds pilotless reconnaissance planes used for battlefield reconnaissance and observation. The basic requirements for these planes are that they be small and compact, simple in structure, inexpensive, and easily operated. They must be able to be manufactured with model-construction techniques, use a simple control system, and be equipped with ordinary television cameras and laser indicators. In this way, they can be used over front line battle fields where the high level of danger prohibits the use of pilot-operated aircraft. They can be controlled using real-time television remote control, and can work in cooperation with surface units to indicate targets for laser-guided weapons and adjust the aiming for conventional artillery.

Currently, in addition to their serious efforts to develop pilotless reconnaissance planes, many countries use artificial reconnaissance satellites to undertake a variety of reconnaissance activity, stealing by hook or crook military and other intelligence from other countries (Fig. 3-3). Over the years, about one-fourth of the several thousand flying devices launched by the United States and the Soviet Union have been used for photographic reconnaissance.

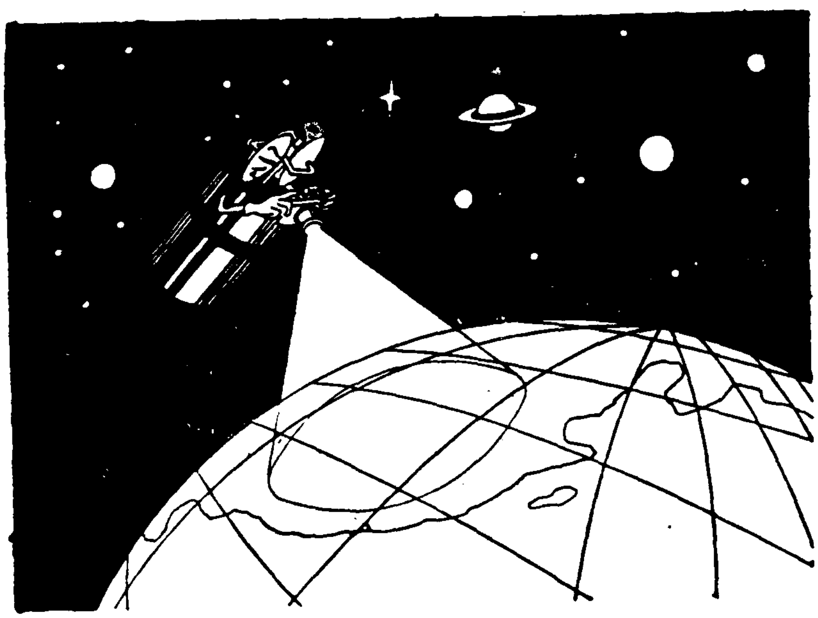

Fig. 3-3. An artificial satellite.

The most important means of reconnaissance on board the photographic reconnaissance satellites are optical cameras, used to photograph the portion of the earth's surface lying below the satellites' orbits. This optical photographic system has by now developed to the point that it can distinguish objects on the earth's surface of 0.3 meters in size. This means that it can not only distinguish the exact position of buried ICBM silos, but that it can also determine differences in size between silos. A 0.3 meter resolution is enough to allow distinction between the models of airplanes, naval vessels, tanks and automobiles on photographs; even individual persons can be distinguished. The development of infrared thermal imaging techniques, in particular, exempts satellite reconnaissance photography from the limitations of darkness, reveals the movement of troops and the navigation of fleets, and allows the detection of nuclear submarines cruising under water. Photographic reconnaissance satellites have a very important military value.

3.3. PILOTLESS AIRPLANES AS ELECTRONIC OPPOSITION DEVICES

In modern warfare, electronic opposition is a very important means of combat. Electronic opposition is one part of electronic warfare. We know that for everything from radio communications to remote control of pilotless airplanes and guidance of missiles, it is necessary to send out electro-magnetic waves into the air. These waves can not only be received by one's own side, but can be intercepted by the enemy's side as well, through the use of special electronic means of reconnaissance, or can be disturbed through the use of electronic interference devices that send out corresponding electro-magnetic waves. In these cases it is necessary to choose the appropriate anti-reconnaissance or anti-interference measures, to deprive the enemy's reconnaissance or interference of its effectiveness. Means for effectively weakening or destroying the enemy's electro-magnetic capacity in this way, while maintaining the full performance of one's own electronic equipment, are as a class called "electronic opposition" or "electronic warfare." This is a secret war carried out on an invisible battle line.

Electronic opposition, then, includes electronic reconnaissance (just like getting a prisoner to talk during surface reconnaissance) and electronic interference. Pilotless electronic reconnaissance planes and pilotless electronic interference planes have thus been developed. At times, however, these two types cannot be held completely distinct. The same kind of plane, while implementing reconnaissance, can also carry out interference. Pilotless airplanes generally are all used as electronic opposition planes, and are classified as follows:

3.3.1. Pilotless Electronic Reconnaissance Planes

In order to be able to make accurate judgements concerning the enemy situation, it is necessary to have complete information at any given time concerning enemy developments and activities; electronic reconnaissance is a good means for obtaining this information. Electronic reconnaissance mainly includes the gathering and analysis of the characteristics of enemy electro-magnetic transmissions and of the position of the transmission source. Reconnaissance concerning radar involves the investigation of the radar position, capabilities, and operation methods. The mission of tactical electronic reconnaissance planes is mainly to reconnoitre the enemy radar distribution in a given locality, in order to undertake interference against the enemy during a tactical attack, and to be able to take the necessary protective measures. Whenever the enemy radar begins operation, it always broadcasts electro-magnetic waves outward; for this reason, from the intercepted radar information, it is possible to analyze the radar's working frequency, beam width, antenna scanning style, and other characteristics, and to deduce information concerning the deployment and use of the radar. To complete this task the radar equipment that is provided includes: a reconnaissance receiver of high sensitivity to intercept and analyze the broad wave band of the electromagnetic waves broadcast by the enemy electronic equipment, a pulse analyzer to analyze the characteristics of the radar's pulse, a storage device to record video frequency signals on magnetic tape, and an automatic directional installation to determine the direction of the broadcast source.

Because reconnaissance activities are carried out in air space deep within enemy territory, it is necessary for the plane to fly fast and to be difficult to detect. At the same time, it must be equipped with electronic interference equipment and electronic warning equipment. The United States has often used the AQM-34R and AQM-34Q mid-altitude range pilotless reconnaissance planes in Southeast Asia and in Europe to gather enemy radar intelligence; on these is installed listening equipment, which gathers electronic information from eavesdropping sensors that have been let down. This kind of pilotless plane is currently being developed so as to increase its continuous flying time, to raise its working altitude, and to add reconnaissance devices. When the working altitude is high, the range of vision is broad; this allows a plane, while flying within its own borders, to monitor military activities in the adjacent enemy territory without the risk of being shot down. When the continuous flying time is long, it is possible to carry on extended monitoring and gather a relatively large amount of intelligence.

After our defensive counterattack on 17 February 1979 along the Chinese-Vietnamese border, the Soviet Union dispatched its TU-95 "Bear" electronic reconnaissance plane (Fig. 3-4) numerous times to make incursions into the Chinese-Vietnamese border air space for espionage activity. The range of the TU-95 "Bear" is about 12,000-14,000 kilometers. Its wing span is 50 meters, and its length is 45 meters. Its maximum takeoff weight is about 180 tons, and maximum speed is 880 km/hr. It ordinarily flies at an altitude of 9,000-10,000 meters, but can fly at a maximum of 15,000 meters. This kind of reconnaissance plane is a re-equipped version of the TU-95 long-range bomber. Its bomb bay was converted into a compartment for electronic equipment so that

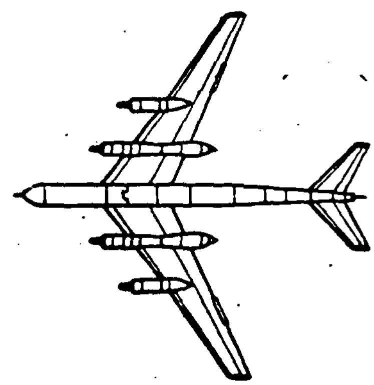

Fig. 3-4. "Bear" electronics reconnaissance plane.

it can undertake electronic and photographic reconnaissance. In some instances television reconnaissance equipment is also installed, providing surface television images which are transmitted to headquarters using radio waves.

3.3.2. Pilotless Electronic Interference Planes

In modern warfare, electronic opposition is very important, but it is not a decisive element. As long as we are able to recognize and understand it, we will be able to control and use it, because all equipment that emits electro-magnetic waves is subject to interference. The technology for electronic opposition had its origin during World War II. Most German antiaircraft bases were equipped with aiming radar; for this reason, English and French bomber losses were very serious. Later, in response to the German aiming radar, the English and French undertook interference, and managed to reduce the effectiveness of the German antiaircraft artillery by three-quarters. Even now, the most important use of pilotless interference planes is still to interfere with enemy radio and radar equipment.

For radar interference, two kinds of interference, active and passive, are used:

3.3.2.1. Passive Interference

Passive interference uses material that creates interference without emitting electro-magnetic waves, or material that attracts electro-magnetic waves. It can thus reflect or attract the electro-magnetic waves of radar transmissions, to change the characteristics of the reflected radar wave. Currently, the commonly used, and still effective, means are the metallic interference materials used thirty years ago. The most often used types have a variety of shapes; they may be thin strips of metal foil (like lead or tin), or glass fibre or plastic coated with metal. The latter can be diffused easily and is light in weight. For radar with different operating frequencies, foil strips of different lengths must be used for interference.

For S wave-band frequencies used by altitude-measuring radar with relatively high accuracy requirements and fire-control radar (approximately 3,000 kilohertz), the length of the metal foil strips should be equal to half the wave length of the radar that is to be interfered with; only then will it be effective. Pilotless interference planes fly along the enemy radar cover range forward position; the total weight of the interference matter that they disperse may be as much as several dozen tons, in order to make a "mid-air corridor" to prepare a way for attack planes (Fig. 3-5).

There are many instances in actual war of the use of passive interference. In August 1986, when the Soviet Union made its surprise attack on Czechoslovakia, it first dispatched airplanes to spread a great amount of metal filings to float suspended in the air as a measure to counter the effectiveness of Western radar. As a result, the monitoring system organized by NATO suffered interference, and was unable to gather accurate intelligence on the Soviets' large-scale airlift of troops into Prague and other Czechoslovakian cities. Again, in October 1973, in the fourth Middle East War, Israel planned to use electronic interference to break the enemy's guided missile defense, in order to establish control of the air. These tactics did not succeed; over two hundred Israeli planes were shot down. There was no alternative but for Israel to make an emergency request for assistance from the United States; a great amount of metal foil strips were sent for spreading, to provide a large-scale protective screen for the aircraft.

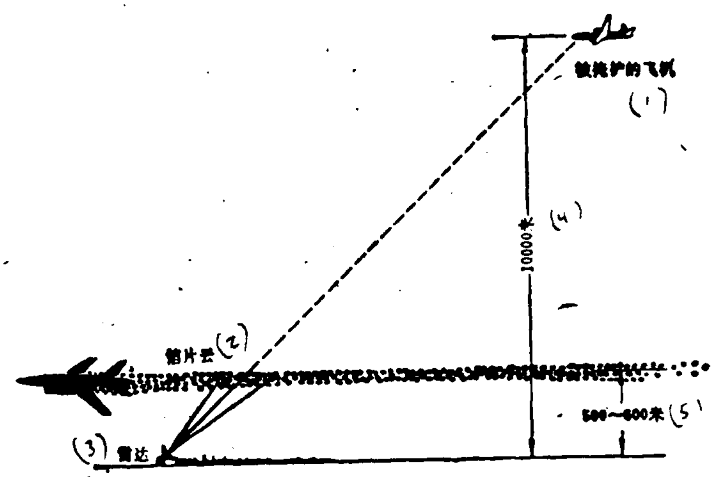

Fig. 3-5. Using a pilotless plane to disperse metal foil strips.
Key: (1) Protected airplane; (2) Cloud of foil strips; (3) Radar; (4) 10,000 meters; (5) 500-600 meters.

In addition to the passive interference discussed above, the target characteristic simulation bait carried on board large bombers is also a kind of passive interference installation. In 1958, the United States began to develop a tactical false target plane with the designation GMA-72. Its reflected radar wave was comparable to that of the B-52 bomber. This plane was carried in the bomb bay of the B-52 bomber, and when the B-52 approached the enemy target, to avoid attack by enemy fighters or guided missiles, it released the false target plane from its bomb compartment, offering it as "bait." The false target plane carried a self-destruction installation; if it had not been shot down by the enemy, it could self-destruct after accomplishing its purpose on a command from the mother ship; secrecy could thus be maintained.

3.3.2.2. Active Interference

Active interference indicates the intentional broadcast or transmission of certain kinds of electro-magnetic waves in order to disrupt enemy radar, making it difficult or impossible to operate, or to deceive it (Fig. 3-6).

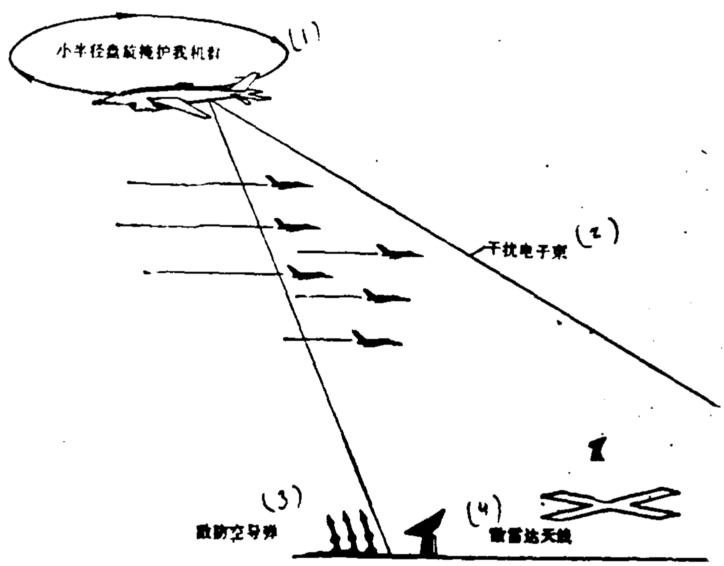

Fig. 3-6. Pilotless airplane as electronic interference plane.
Key: (1) Small-radius circular flight to cover friendly squadrons of planes. (2) Electronic interference beam; (3) Enemy antiaircraft missiles; (4) Enemy radar antenna.

Active interference equipment includes all kinds of mixed wave interference planes used to break down the working of enemy radar, non-reusable interference planes, and interference equipment that after receiving enemy radar signals transmits a variety of deceptions. On an electronic opposition plane, there are ordinarily ten or more kinds of electronic interference equipment, and at times the total can reach forty or fifty.

In recent years remote-control planes have been used for electronic interference or as bait, to simulate actual targets and mix the false with the genuine, with the intent of confusing the enemy radar.

In fact, when electronic warfare is carried on on both sides, it includes reconnaissance, anti-reconnaissance, anti-anti-reconnaissance; interference, anti-interference, and anti-anti-interference. If there is a means of attack, there is a means of defense. Since there is electronic reconnaissance, there must be electronic anti-reconnaissance. In a word, there are many means of electronic warfare under many guises; the style actually implemented should be adjusted and used flexibly to fit the actual situation.

3.4. PILOTLESS AIRPLANES AS WARPLANES

Pilotless airplanes can also undertake a portion of the tasks of fighter planes. Everyone is aware that aerodynamic missiles ought to be counted as a branch of pilotless airplanes. They belong to the class of non-recoverable, one-use pilotless airplanes. The type of pilotless warplanes we wish to discuss here are those that can be operated by remote control (those that during the entire course of their flight can be guided at any time by remote control), and which can be recovered. This type includes pilotless fighters, pilotless attack planes, and multi-use fighter planes. These pilotless planes are able to perform aerial combat, mid-air firing of guided missiles, aerial bombing (Fig. 3-7), and torpedo launching, among other combat tasks. Further, the operator can sit in a control tower far from the battle zone or in a "mother craft" to control the aerial combat. For example the BGM-34A pilotless attack plane can carry and fire "hundred-tongue bird" or "young stock" guided missiles. The QH-50C pilotless anti-submarine helicopter can carry two torpedoes and after firing by remote control can return to the mother ship.

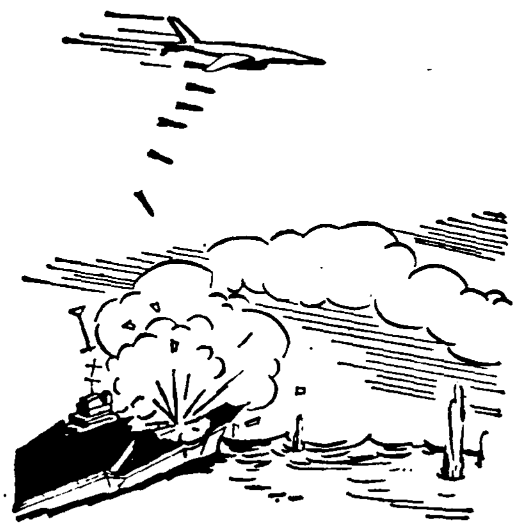

Fig. 3-7. Pilotless airplane used as a weapon.

In conjunction with the uninterrupted progress in electronics and remote control technology, many countries are currently in the process of developing fighters and interceptors for use in aerial combat. In aerial combat of the future, the scope of substitutes for manned airplanes to carry out the battles will become broader and broader, though perhaps not complete. The use of pilotless airplanes as warplanes has many advantages. For example, a pilotless fighter combines the strong points of a surface-to-air missile with those of a manned fighter plane, without their weaknesses. No pilot is required, but at the same time, unlike the surface-to-air missile, it can be recovered. Like the manned fighter, it can be used multiple times, and can be fitted with assault weapons like aerial machine guns or air-to-air missiles. On the current level of technology, extremely light pilotless fighters can be manufactured. Because they are not limited by human physiology, their mobility in combat can be greatly improved so that they can take control of the air. This is the reason that many countries are working hard to develop them.

3.5. PILOTLESS AIRPLANES AS SPECIMEN COLLECTORS AND OBSERVATION PLANES

We know that some scientific undertakings have dangerous effects on human health and atmospheric pollution. For example, nuclear tests and chemical warfare are of this type. The air sample collection and on-the-spot observations needed to analyze and study the results of the experiments are most appropriately carried out by pilotless airplanes.

In order to gain a complete understanding of the results of nuclear explosions, all nuclear countries place special weight on the technology for gauging a nuclear blast. Because when a nuclear device explodes in the atmosphere a temperature of several million degrees may be reached, and the substances within the device at high temperatures vaporize quickly and cause the pressure to reach several hundred thousand atmospheres, the gas expands outward rapidly and produces a shock wave. At the instant of the explosion, a great amount of energy is also released in the form of α, β and γ rays, and there is formed a huge mushroom-shaped fire ball that emits a visible glow, as well as infrared and ultraviolet radiation; all of this is ray radiation. When matter is irradiated by ray radiation, its surface absorbs light energy and scorching occurs. A human body encountering ray radiation would suffer burns. The distance at which injury or death from ray radiation can occur is much greater than the distance for other destructive factors. Nuclear radiation is also produced at the time of the explosion, and this poses life-threatening danger to human beings. If pilotless airplanes are used to penetrate the mushroom cloud and gather data on the rays that are emitted, it is possible to avoid danger to human life (Fig. 3-8). Pilotless airplanes use special devices, which hang down from the plane's wings or fuselage, for collecting specimens.

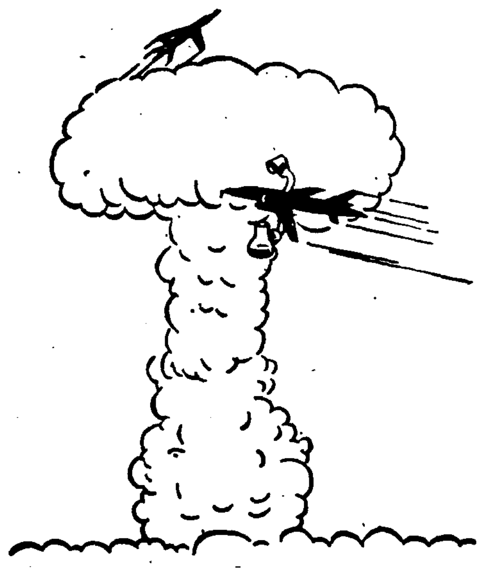

Fig. 3-8. Pilotless airplanes collecting nuclear samples.

In actual warfare, pilotless airplanes can be dispatched to the air space over the combat zone, in order to measure the effect of a nuclear attack or the use of chemical weapons. Pilot-operated planes cannot compare with pilotless planes in performing this kind of activity.

3.6. PILOTLESS AIRPLANES AS PLANES FOR SCIENTIFIC STUDIES

Pilotless airplanes used as new technological tools for performing scientific investigations have important advantages. When a new model airplane is designed, a scale model is generally produced first and placed in a wind tunnel for tests on its aerodynamics. But the data obtained from the experiment are all of a static-state nature. To determine the dynamic characteristics of the plane flying independently in the air, it is necessary to wait until the plane is built and conduct a series of test flights. However, in order to determine the plane's dynamic characteristics before the plane is constructed, it is possible to make the model plane so that it can be flown by remote control. This makes up for the deficiencies of wind tunnel testing.

In addition, the use of pilotless airplanes can supplement the test pilot's test flight. For a newly developed airplane model, it is necessary to test all phases of its performance. Generally, the test must be performed by a highly experienced test pilot. But during the test flights, because of the limitations imposed by human sense organs and other aspects of human physiology, it is rather difficult to give full play to the plane's highest level of performance; it is also quite dangerous. For this reason, in recent years, there have been continuous attempts to complete the performance of test flights with pilotless airplanes. The tiend to mechanization is especially strong in the case of tests for the new supersonic, high-altitude planes.

Recently, the so-called "pilotless flying experimental bed" has made an appearance as a device for the study of the flight of new models. This "bed" is generally small, but is capable of measuring up to a portion of the performance -- speed, altitude, and acceleration -- of newly designed airplanes and other flying devices. In this way, the motor installations, structural material, control systems and other auxiliary equipment used in the new model planes or devices can be tested individually in advance. For example, the United States developed the X-7 (M=3) and X-10 (M=4) supersonic pilotless experimental planes. The X-7 is used specifically to study pulse pressure engines and certain components of guided missiles. The X-10 is used for the development of aerodynamic missiles. The United States is currently developing a high-mobility remote-control study plane, for undertaking all experimentation involving a high degree of danger. The goal of the experimentation is to provide data for fighting planes of the 1990's. West Germany is also developing a kind of pilotless vertical take-off/landing airplane; this kind of plane is used especially to study technological problems of vertical take-off and landing planes.

3.7 PILOTLESS AIRPLANES AS GEOLOGICAL PROSPECTING PLANES

Our great socialist fatherland has a vast extent of territory, over 9,600,000 square kilometers. From the imposing grandeur of [illegible] now-covered Pamirs to the boundless azure waves of our coast, an inexhaustible number of precious deposits are hidden. This is the pride of the Chinese nation, and the inestimable material basis for our construction of a mighty socialist economy and our realization of the four modernizations.

Aerial geology is a promising kind of scientific aerial reconnaissance work that combines many technologies. It is a valuable means to study geological and mining conditions over a broad area, to direct general surface investigation, to improve the efficiency of general surveying, and to decrease the time required for these investigations. The advantages of aerial geology are striking. First, the range that can be covered from the air is vast, and is not limited by natural barriers, especially in the case of high, cold regions that are difficult to access, primitive forest, lake and swamps, deserts, and outer sea regions; it is not subject to surface physical and chemical field interference (Fig. 3-9).

Aerial geological prospecting instruments have a high degree of sensitivity. Optical photography at an altitude of 2,000 meters can reveal a line-shaped object with a width of one centimeter (for example a high-voltage power cable) or pieces of rock with a diameter of 30-50 centimeters. Owing to the recent developments in physics technology, the techniques of remote sensing and telemetry (like aerial magnetic prospecting for oil, aerial electro-magnetic searching for copper) can make the work of prospecting both faster and more accurate.

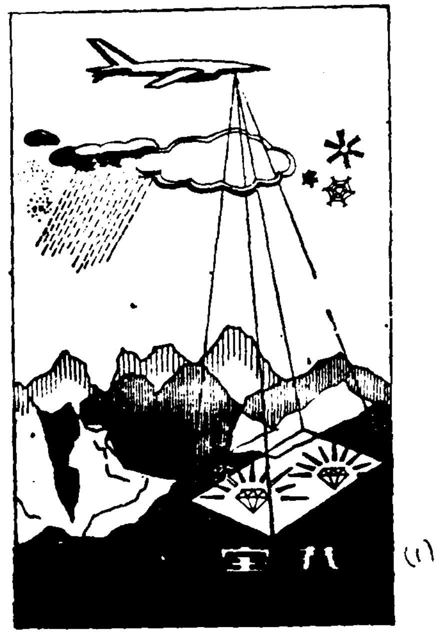

Fig. 3-9. Pilotless airplane for geological prospecting. Key: (1) mineral deposits.

These are only a few of the major uses for pilotless airplanes. In the same vein, we could mention many more examples, like the use of pilotless planes in battle zone support, to perform tactical support tasks for forward positions over a small area. It is possible to transport weapons, rations, medical supplies and equipment and propaganda materials to the battle zone (Fig. 3-10), as well as to harass the enemy positions. In a word, as scientific technology develops, the prospects for the use of pilotless airplanes are broad, both in military and non-military applications (like weather monitoring).

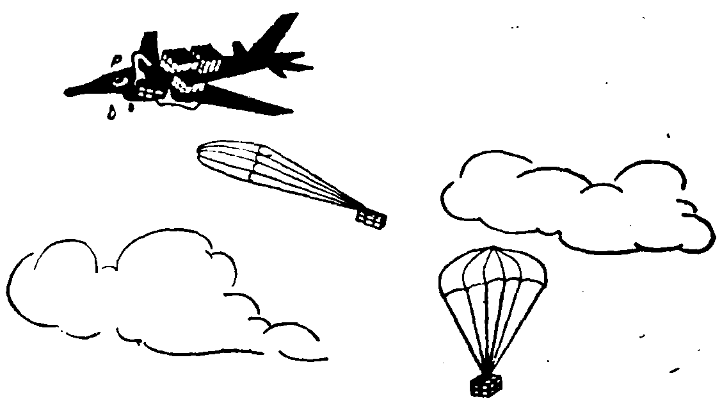

Fig. 3-10. Pilotless airplane providing aerial support.

We will close with a brief discussion of the developmental trends for pilotless airplanes.

At the present time, there are more than thirty companies in over ten countries world-wide engaged in the development of pilotless airplanes, either alone or in cooperation with other companies. Based on initial calculations, 100,000 pilotless airplanes of every model have been produced so far. From the information we have, we can see that pilotless airplane development generally proceeds along the line from target drone to pilotless reconnaissance plane to remote control combat plane. This is, of course, not to say that when development has reached a new phase the preceding phase is abandoned; every type of plane has its own particular uses. Roughly speaking, the early years of the 1970's represent the pivotal period in the development from target drones and reconnaissance planes to remote control combat planes.

Why are so many countries putting so much energy into the development of remote control combat planes The most important reason is that pilot-operated airplanes are normally rather more expensive to construct. For example, the American F-14 has a unit cost of $15,000,000, while a recoverable, remote control plane capable of making surface attacks costs only $150,000. The cost of a non-recoverable model would be as low as $25,000. In addition, it is possible to make more complete use of a pilotless combat plane's mobility (swifter climbing, tighter turning, greater acceleration). Because no one is on board the plane, violent movements are possible, producing up to 30 or 40 g (a pilot can tolerate 6 g over a short period of time). Some of the available material reports that if a pilotless airplane produces a force of 12 g during a turn, it would be able to "latch onto" a typical fighter plane's tail within 20 seconds (fighters like the F-15 require 120 seconds to take care of a plane of similar mobility). Speaking from a technological point of view, in the past few years electronics technology has undergone explosive development; the day that remote control combat planes will be a reality is not far off.

Another trend in the development of pilotless airplanes is the refitting of obsolete or currently in service pilot-operated planes as all types of pilotless planes. For example, the American Air Force has turned F-102 fighters into pilotless airplanes. As long as you are conversant with advanced electronics equipment and automatic control systems, it is possible to change the old into the new, and fulfill all the requirements for pilotless planes.

Speaking from the point of view of navigational performance, target drones and pilotless reconnaissance planes are undergoing development in the direction of increased altitude, increased speed, and increased duration of flight. At the same time, pilotless planes capable of extremely low-altitude flight are being studied. Over the last years, new models have been appearing continuously. Some of these, in order to increase their chances at survival by escaping radar detection, are constructed with non-metallic materials. Others are built as wing-shape flying devices, without fuselage or tail wings; their visual surface area and radar reflection area are very small, and if in addition non-metallic materials (like transparent plastic) are used, enemy radar will have great difficulty in catching them. For this reason, their military value is obviously greatly increased.

Technology for pilotless airplanes in the areas of take-off and mid-air recovery is also undergoing rapid development; we can do no more than mention it here.

Currently, the aerospace industry in China is still relatively backward, thanks to the interference and destruction caused by Lin Biao and the Gang of Four. Through them, our chances of catching up with international standards, which were originally quite good, have been set back again. Ever since the overthrow of the Gang of Four, Chinese science and technology has had a new lease on life. The vigor and inventiveness of scientific and technological workers has been widely brought into play, a scientific renaissance is under way, and news of successes are already pouring in. We firmly believe that, under the correct centralized leadership of the party and the unity of the people of the entire country, of one heart and one mind, pooling their wisdom and efforts, and eliminating all difficulties, our country's aerospace industry can, in the not-too-distant future, meet or surpass the advanced international standards.

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