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GLIDERS AND THE ART OF GLIDING

V.M. Zamyatin

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16. Abstract

This book discusses aerodynamics, stability, controllability and structural strength of gliders. Design and structural materials are discussed, and safety and reliability as well. Glider flight at large angles of attack and in spin are covered in detail. A history of gliders and pilot-training on gliders are discussed. The author considers that gliding is an independent field of aviation which has an important contribution to make to the field as a whole. He envisages further development of glider construction to master flights of greater distance, higher altitude and greater speed.

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Annotation

The bases of modern theory of glider flight are considered in this book--aerodynamics, stability, controllability and strength of the structure. The elements of designs used in modern glider construction are described. Special attention is given to questions of reliability and safety in glider flight. Questions of glider flight at large angles of attack and spin are considered in detail; certain questions on test flights of gliders are touched on. In the sections devoted to gliding training, brief characteristics of the development of engineless flights are given.

The book is intended for specialists who create, test fly, and operate gliders. Besides, it can be of interest to a wide circle of readers. One table, 155 illustrations, 71 bibliographical references.

Foreword

The tasks of gliding are very diverse. The optimum shapes of certain aircraft can be determined with the help of gliders; flight conditions are studied for various meterological, altitude and geographical conditions; people and cargo are transported, flying personnel are instructed and trained. Moreover, gliding is one of the most fascinating types of sport.

The principles of engineless flight like the engineless aircraft themselves are used for studying the movement of space ships in dense layers of atmosphere. Problems solved when building gliders and flying them are similar to general problems which must be solved when building any aircraft heavier than air. In the work available, engineless aircraft and their flights are looked at only in connection with the sporting aspect of gliding.

Skills in controlling the spatial movement of aircraft, the ability to orient oneself in space and by the terrain, under complex meteorological conditions (with a minimum of navigational instruments and without the help of ground radio equipment) the capability of overcoming by one's will power the emotional effect of flight which influences a pilot, the skill in the very light but adequately strong structure of a glider to embody the newest attainments of aviation engineering and science--all these basic component parts of flying and engineering mastery have a tremendous value in the development of pilots and aviation engineers and they are actually developed during flights on gliders, during their design and construction.

The characteristics of the best sporting gliders of the world and modern methods of engineless flight which correspond to actual conditions, permit perfecting non-stop flights which cover more than a thousand kilometers, ascend into the stratosphere, remain in the air continuously for tens of hours, fly on a given route at significant ground speeds for the flight regardless of wind direction.

Gliding offers tremendous possibilities for creativity both to the pilot and to the designer. Flying practice expressly brings forth demands and proposals for improvement in the design of the gliders and methods of engineless flights.

This book gives answers to many of the actual questions on engineless flying; present-day problems of gliding and methods for its further development and considered in it.

The author wishes to extend his thanks to Candidate in Engineering Sciences, I.M. Pashkovskiy, and Doctor of Engineering Sciences, G.S. Yelenevskiy, for their valuable comments made when reading the manuscript.

The author invites all of his readers to send comments to the address: Moscow, B-78, 1st Basmannyy per., 3, published by "Mashinostroeniye" Publishing House.

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GLIDERS AND THE ART OF GLIDING

V.M. Zamyatin

Chapter 1 Physical Bases of Glider Flight /5*

A glider is an engineless aircraft, heavier than air, capable of making controlled movement in space. Any motion of a material body under real consitions, wherein the environment--in the particular Earth's atmosphere--resists its motion, is determined by the forces applied to the body. The direction of the forces determines the direction of motion of the body. So that flight can be made in the Earth's atmosphere, the forces applied to a material body (in particular, to a glider) must have two basic properties.

First, it must make the glider travel horizontally and vertically in relation to the Earth's surface, usually simultaneously. Here the force results from interaction of the forces of general aerodynamic resistance of the glider and Earth's gravity, that is, its weight. A component of the total force of aerodynamic resistance, lying in the plane of symmetry of the glider and directed perpendicularly to the tangent to the flight path will be called the lift force of the glider. The component of weight tangential to the flight path of the glider,--its cruising force. If motion of the glider is in a straight line and uniform, the lift force balances the weight component perpendicular to the flight path. The cruising force balances the resistive force of the environment which exerts an opposing effect on forward motion of the glider. When there is non-uniform motion of the glider (in particular at the beginning and end of its motion or during changes in flight speed) the lift and cruising forces balance not only the components of weight and the resistance force of the environment, but also the appropriate forces of inertia. Second, so that the motion of the glider in space will be controlled (and only such motion can be considered flight) the force applied to the glider must have the capability of changing the glider's position in space. /6

Thus, the second property of this general force determines the character of travel of the glider, that is, is the means of controlling its motion.

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*Numbers in the margin indicate pagination in the foreign text.

1.1. System of Units for Measurement and Coordinate Axes

Looking at the actual conditions and the characteristics of glider flight, one inevitably encounters a certain system of values which are the calculated expression of the whole picture of glider movement. Inasmuch as the values in physics name everything that can be measured, each such value naturally must have its own unit of measure. We will use the SI international system accepted in the USSR in which the basic units are accepted as length measured in meters, mass expressed in kilograms and time expressed in seconds [6].

A reliable method of checking the correctness of calculation is an analysis of the units of measure in the results of these calculations. This is because the final unit of measurement must be obtained using the same effects which were measured when determining the numerical results of the calculation.

For geometrical measurements, also, we will use a system of units of measure which define a measurement number for a line, for a plane and in space, and also--methods of locating points, figures and bodies on a line, on a plane and in space. Many such systems exist each of which is used to provide the most convenient and simple solutions to a given problem [11]. We will use some of the generally accepted so-called "right-handed rectangular" coordinate systems. These systems are an ensemble of three mutually perpendicular axes, the origin of which is either in the center of the mass (gravity) of the glider or on the earth's surface. If the coordinate axis is strictly connected with the glider[1] (Figure 1.1) then the positive direction of the Ox_1 axis will be to the right, parallel to the axis of the fuselage or the mean aerodynamic chord, from the tail unit to the cockpit. The positive direction of the Oy_1 axis--from the landing gear to the top of the cockpit canopy in the plane of symmetry of the glider, and the Oz_1 axis--along the right wing from the fuselage to the cantilever, perpendicular to the plane of symmetry of the glider. A coupled system of coordinate axes is used when looking at relative movement of the glider and, in particular, when developing an analysis /8 to describe the parameters of movement, made by instruments mounted aboard the glider. In this case when the Ox axis is pointed along the vector of the flight path of the glider, the Oy axis--is perpendicular to the Ox axis in a vertical (relative to the earth's surface) plane and the Oz axis is to the right so that the coordinate axis forms a "right-handed" system; such a system is called semicoupled. When the Ox_c axis is pointed so that, as in the preceding case, it is along the flight path, the Oy_c

[1] In this case they are called--coupled.

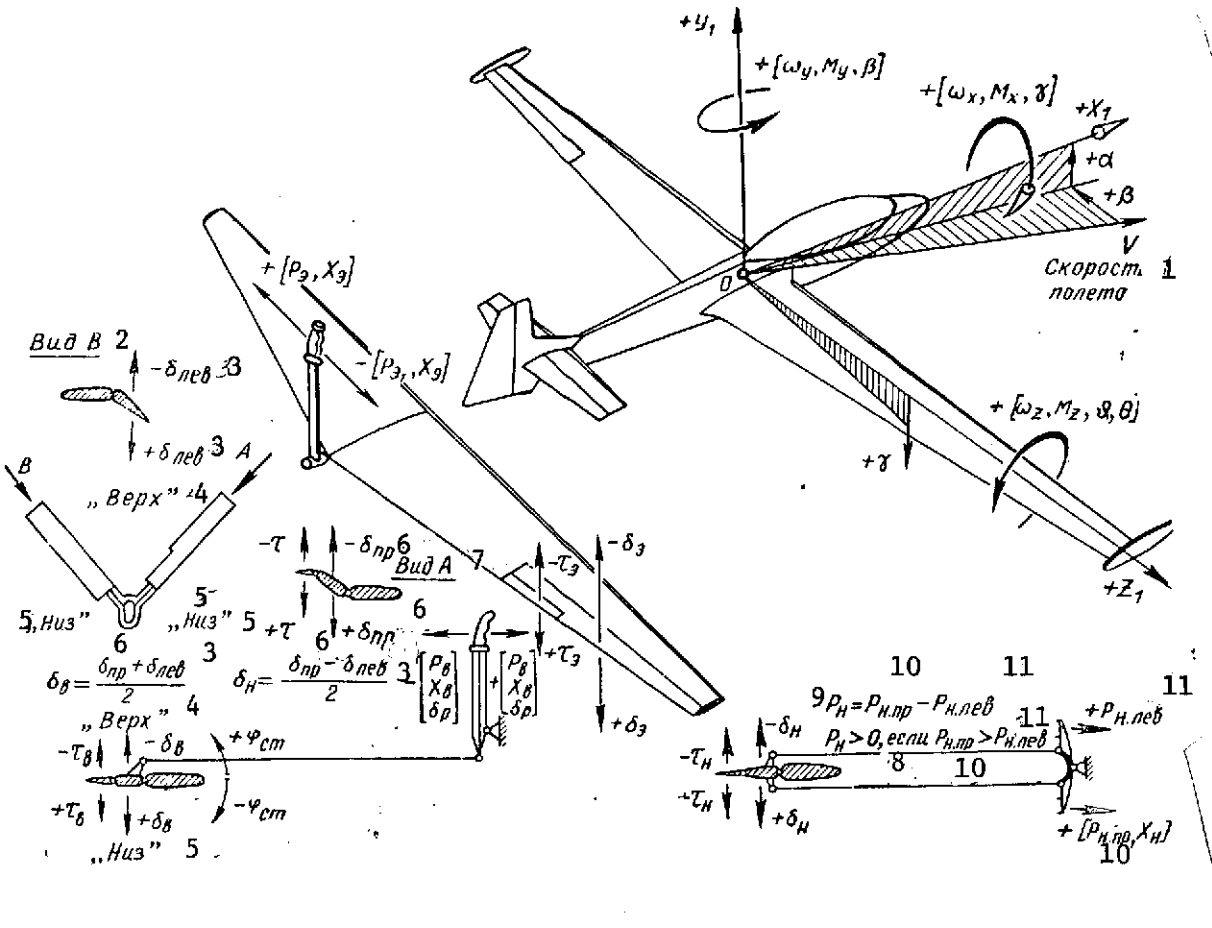

Figure 1.1. System of Coordinate Axes Coupled With the Glider
1--Flight speed; 2--View B; 3--left; 4--"Top"; 5--"Bottom"; 6--right; 7--View A; 8--if; 9--P_r; 10--P_r rt.; P_r lft.;

axis is perpendicular to it but in the plane of symmetry of the glider, and the Oz_c axis is perpendicular to the plane of symmetry of the glider along the right wing; the system is called continuous or velocity. Semicoupled and velocity systems are used, in particular, when studying translatory movement of a glider.

Finally, a system with an origin located on the earth's surface and the Ox_3 axis pointed along the meridian to the south pole, the Oy_3 axis perpendicular to the earth's surface at the origin of the coordinate and directed upward, and the Oz_3 axis directed along the earth's surface to the east, is a so-called earth system and is used, in particular, when studying the absolute movement of a glider, for example its flight along a course.

1.2. A Glider is One of the Types of Aircraft

When determining the principles of flight of aircraft made especially for movement in the air without power units, one must divide the two stages of its movement into: launching (Figure 1.2) and free flight (Figure 1.3). Launching is the initial forced movement of an engineless aircraft, during which it is given its initial supply of kinetic and potential energy. This supply of energy is utilized later on in so-called "free" flight.

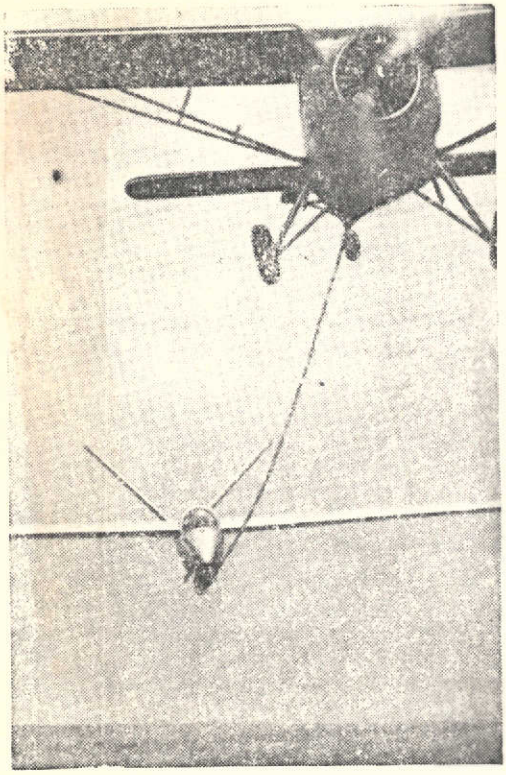

Figure 1.2. Launching a Glider Using an Airplane

Supplying the glider with a certain reserve of kinetic and potential energy before the flight begins is necessary because without it free movement of such a unit is unthinkable without an engine unit. Free flight of a glider is, as a rule, the main type of its movement in the earth's atmosphere based on the principle of interaction of two bodies--the glider and Earth (as a result of this interaction a cruising force is formed), and also--on the interaction of the glider with the air and environment (here the interaction forms a lift force and a force controlling movement of the glider.).

Thus, in free movement of a /9
glider, as a result of using the aerodynamic principle of flight, lift and control forces are formed and act solely during interaction of the glider and the flow of air going over it. The cruising force which determines the forward movement of the glider in free flight can be obtained only by utilizing its weight. Here is the basic principle of the difference of free glider flight (and naturally flight in the atmosphere of any aircraft heavier than air with inoperable engines) from the flight of other aircraft whose cruising speed is created only by using special units mounted on board, or by utilizing the energy of the wind (in the case of balloon flight). It is natural therefore that the glider itself, if it is intended for free flight, also has a number of specific differences from other aircraft whose /10
flight basically is "engine." However, from what has been said, it follows that any heavier-than-air aircraft during flight in the

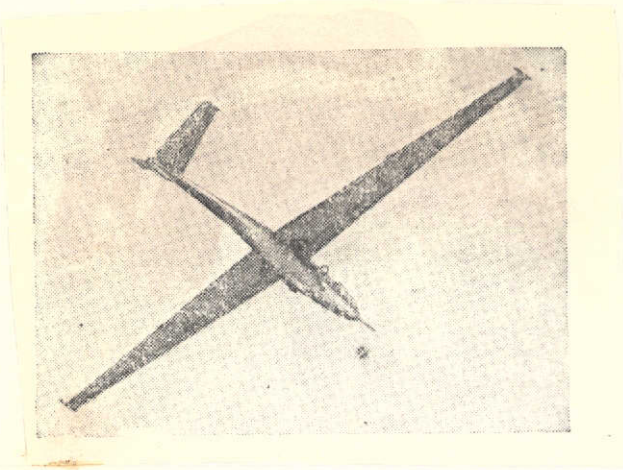

Figure 1.3. Free Fight of a Glider

atmosphere with inoperable power units becomes in principle a glider. The flying characteristics of such gliders, of course, are considerably worse than that of aircraft created especially for engineless flights.

Thus, a glider is one of the types of aircraft which has the following two principally important properties:

--the absence on board the glider of a special device which creates a cruising force causing its forward movement;

--utilization of the force of the earth's gravity (properly, the weight of the glider) as the cruising force.

It is necessary to look at glider flight as a physical phenomenon, giving attention to the following two circumstances. First, that such a flight is the result of interaction of three elements: the glider, the air medium (atmosphere) and the man who controls motion of the glider. Secondly, that glider flight is a combination of its forward and rotating motion. We will look at forces which determine the motion of the glider as a material point, that is, the motion of its center of mass. Then we will look at the motion of the glider from the point of view of forces which control its motion, that is, those forces which determine motion of the glider as a material body. In other words, we will look at its motion taking into account the change /11 of position of the glider in space. Then in all cases we will consider the interaction of the three elements mentioned above (glider, atmosphere and man) with Earth.

1.2.1. The Use of a Glider or its Operational Task[2]

Like any machine, the glider is used for solving a definite range of problems, a combination of which we will call its

[2]The expression "operational task" was coined by test pilot N.V. Adamovich [2]. This expression like a number of others previously existing are positive, useful and convenient for the study of glider flight, and will be utilized in the future with references to appropriate bibliographical sources.

"operational task." An operational task, thus, determines the use of a glider, and means its type.

In the afterglow of the growth of gliding, naturally, a single problem remains: without equipping the heavier-than-air aircraft with special devices which create a cruising force, simply to hold it in the air for a greater or lesser length of time. With the development of gliding engineering and practice this task has already begun to include such questions as: on behalf of what, that is, for the solution of which particular problems should one hold up an engineless heavier-than-air aircraft and what types of gliders and methods of accomplishing flights in them are the most acceptable and suitable for solving one or another special operational task. These particular problems must at the present time be formulated in the following way. /12

Sport task. This consists of providing those types of movement for a glider which retain the largest quantity (practically all) of possible operational procedures of engineless flight. For solving this task, a whole series of types of sporting gliders have been created in our days. With each of these as a rule, not all the sporting problems are solved, but only a certain part; these are essentially operational tasks, but are more narrow. From this point of view, modern sporting gliders can be divided into several groups: gliders intended for flight training (Figure 1.4), for training (Figure 1.5), for setting records and participating in competitions (Figure 1.6), for aerial acrobatics (Figure 1.7).

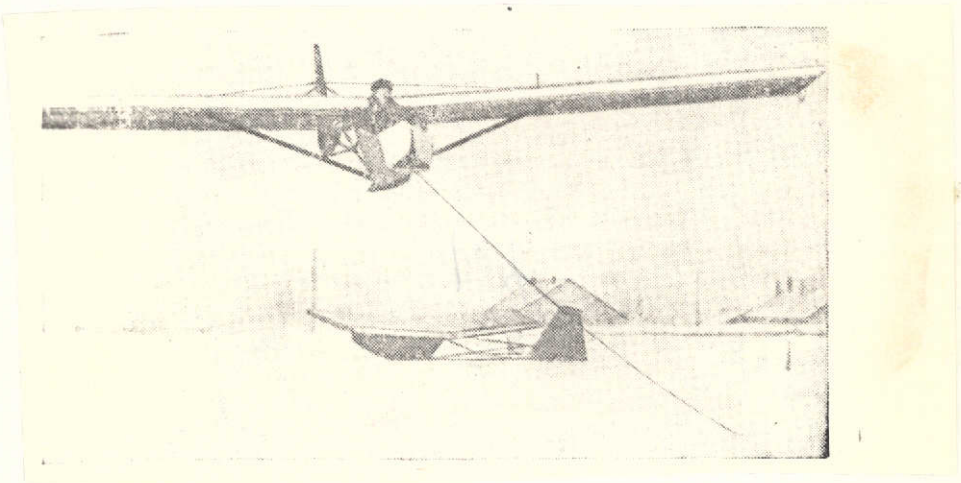

Figure 1.4. Single-place Light Glider for Basic Training

One should note that there are no sharp and inflexible boundaries between these groups of gliders. For example, a record-setting type glider must have characteristics of controllability similar to characteristics of a flight glider because in lengthy flight one

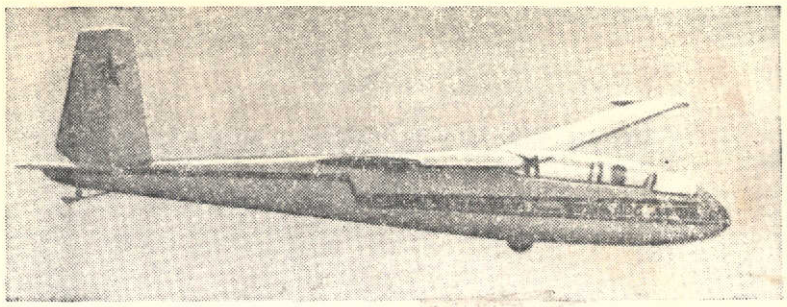

Figure 1.5. Two-place Training Sailplane

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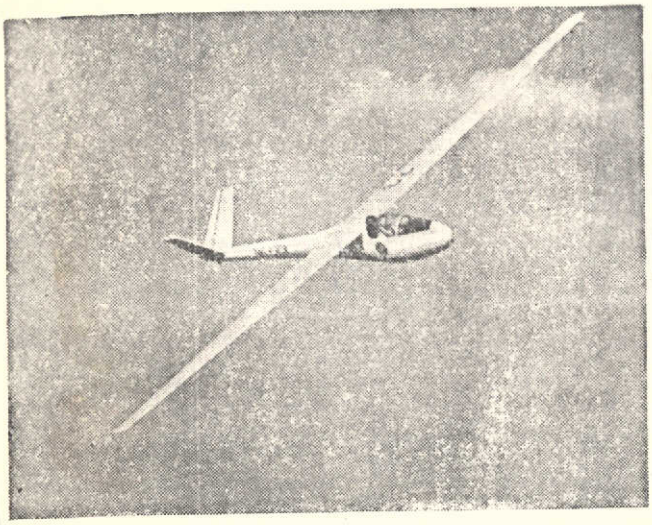

Figure 1.6. Single-place Record-setting Sailplane

Figure 1.7. Glider for Aerial Acrobatics

can encounter conditions similar to the conditions of aerobatic flight. But on the other hand, a number of qualities of the gliders in separate groups differ sharply from each other. For example, certain characteristics of training gliders, such as simplicity and cheapness, are much greater than such data for universal record-

setting and even training machines.

Aircraft whose flight involves rotating rather than fixed wings like the helicopter and autogyro are singular gliders. The flight of these units at the present time, as a rule, is limited to being towed behind some kind of moving object--automobile, motor boat and so forth. However, their free flight and even soaring flight is not completely excluded but only involves accumulating adequate experience in piloting, finding suitable localiities and atmospheric conditions and learning when designing them to /16 provide adequately low speeds for descent (Figure 1.8).

Figure 1.8. An Aircraft Without a Power Unit, With Rotating Wings Like a Helicopter

It is not a mistake to say that ski jumpers are gliders making their long gliding flight over the jumping platform, and parachutists in free-fall are gliders, but more precisely are gliding, and also when descending with an open parachute. This is true because all these types of flight are subject to the law of aerodynamics in the general sense of glider flight (Figures 1.9, 1.10, 1.11).

Another operational task which unites this group of gliders is the experimental task. The movement of gliders when solving these tasks is determined by specific flight procedures in which new structural and aerodynamic shapes of aircraft are studied, their dynamics, controllability etc. (Figures 1.12--1.17).

The task of transporting and lowering cargo and people to Earth for landings unites a special group of gliders. During landing, the movement of the glider occurs basically on a tow behind an aircraft and this and also landing conditions on unprepared fields determines the characteristics of troop-carrier and cargo type gliders (Figure 1.18).

Lowering cargo and people using parachutes or soft wings is also a field of gliding because these methods of flying are based on the same laws and principles which are used in the flight of ordinary gliders. In some of them, with a certain type of selected shape and configuration of parachutes and soft wings, these aircraft acquire the capability to develop, besides vertical motion for

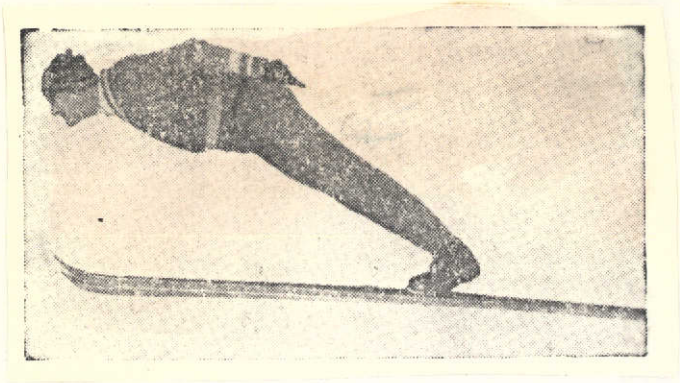

Figure 1.9. A Ski Jumper in Free Gliding Flight

Figure 1.10. A Parachutist in Free Gliding Flight

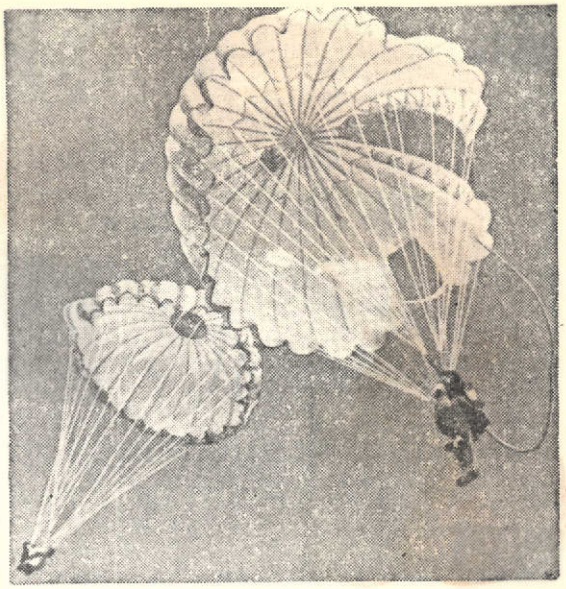

Figure 1.11. Parachutists in Free Gliding Flight with Open Parachutes

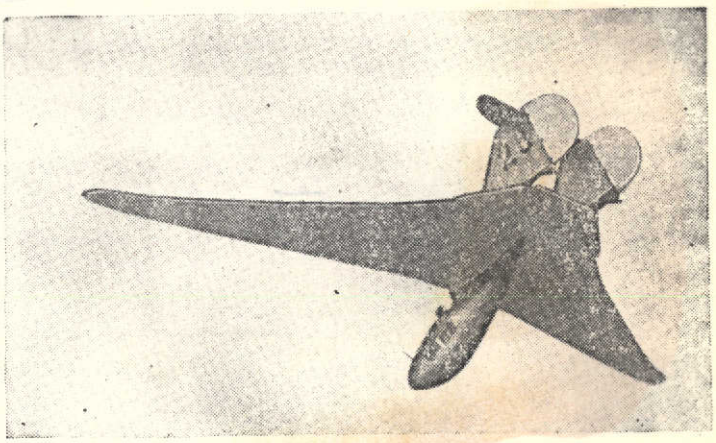

Figure 1.12. An Experimental Glider

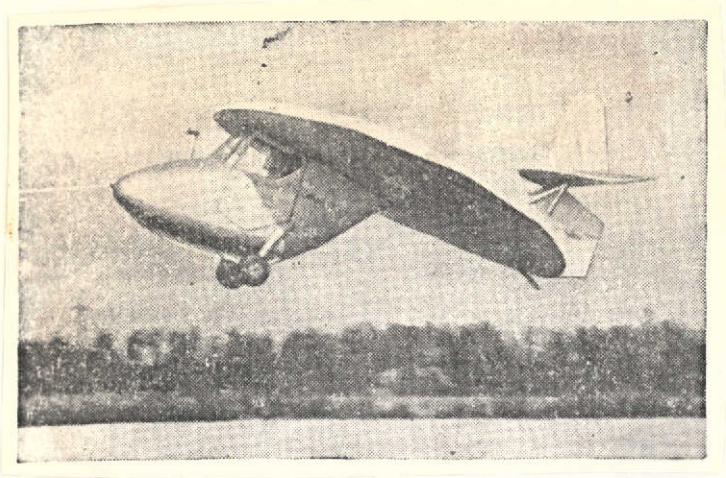

Figure 1.13. An Experimental Glider with Disk-shaped Wing

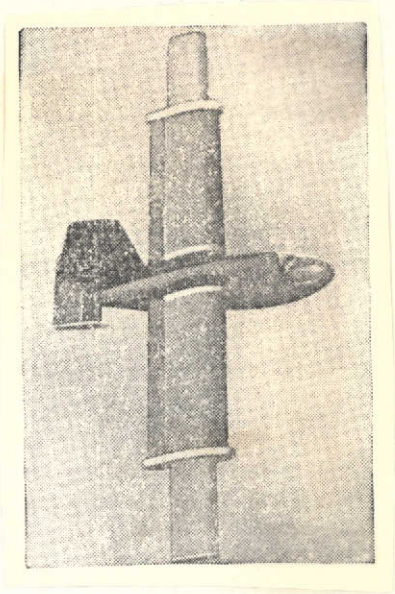

Figure 1.16. An Experimental Glider with Extensible Wing

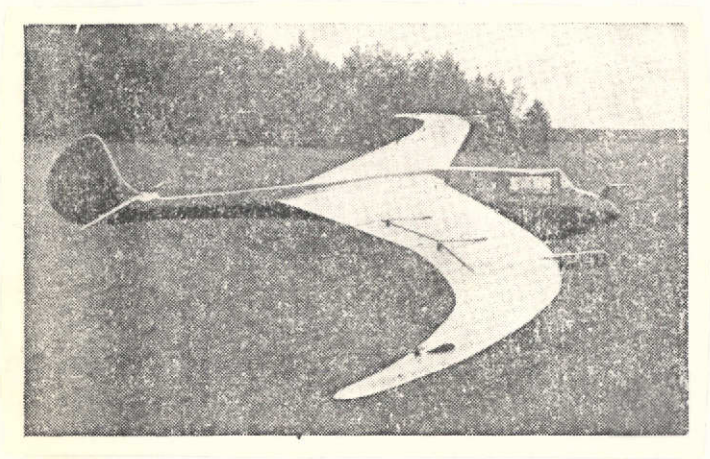

Figure 1.14. An Experimental Glider with Serpentine-shaped Wings

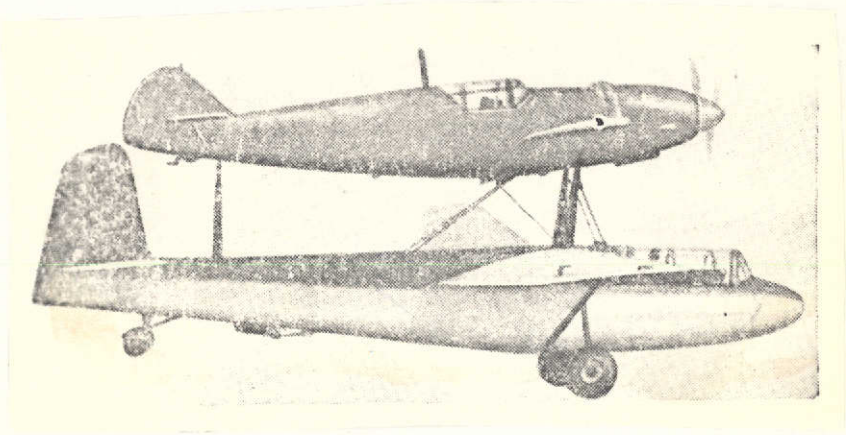

Figure 1.15. An Experimental Combination of Glider Aircraft

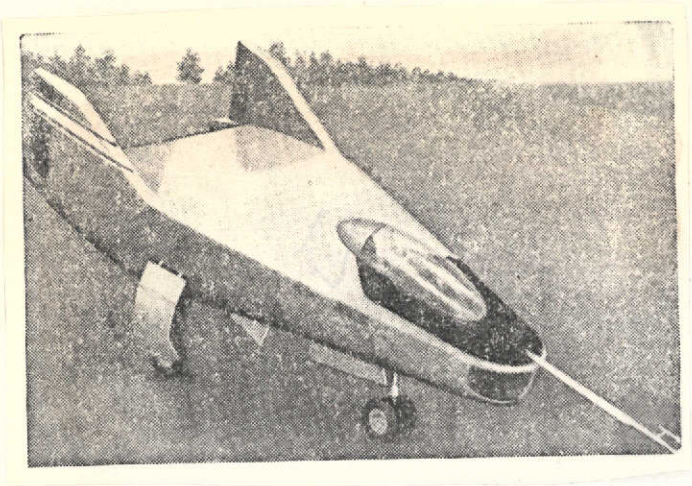

Figure 1.17. An Experimental Glider Without Wings, with Lifting Fuselage

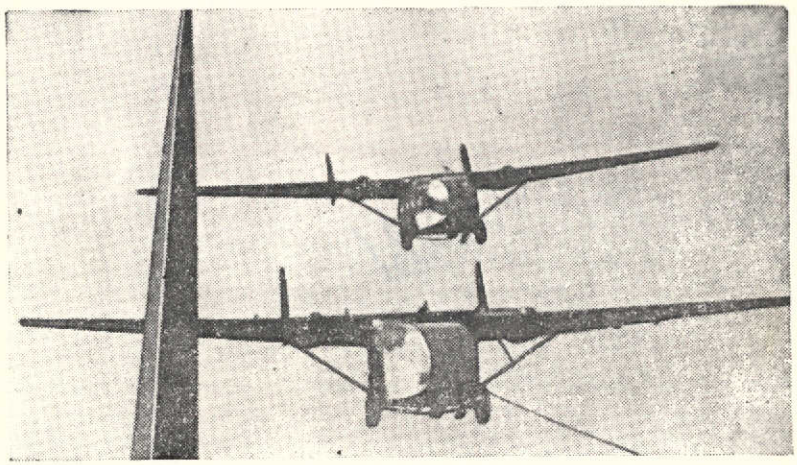

Figure 1.18. Landing Gliders in Towed Flight

descending, also a horizontal motion which makes it possible to a certain degree to control the direction of the descending apparatus (Figures 1.19, 1.20, 1.21).

The task of studying the atmosphere also joins a group of engineless aircraft. Their activity is mainly at high altitudes.

Finally, there is a group of operational tasks which unite aircraft of an intermediate type between gliders and airplanes. Machines of this group are intended for solving various questions. But principally they all are characterized by two similar properties.

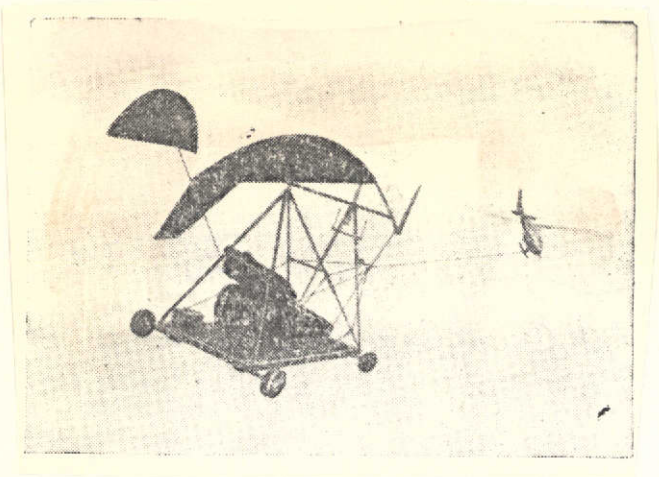

Figure 1.19. Cargo Glider with Soft Wing on a Tow Behind a Helicopter

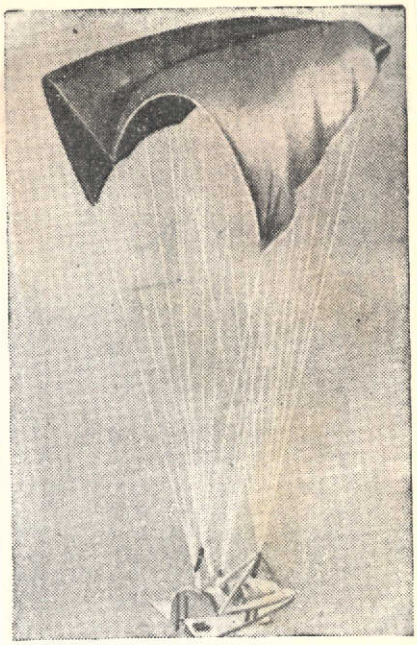

Figure 1.21. A Cargo Glider Parachute

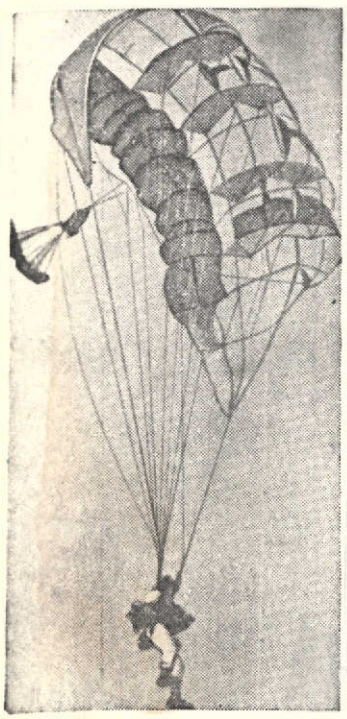

Figure 1.20. A Parachute made in the Shape of a Soft Wing with Slits and Valves Which Form a System to Give Forward Speed

On the one hand they are typical gliders in their exterior shape and in the characteristics of free flight which are their basic type of movement. On the other hand these aircraft are equipped with small (in the case of sport types) or sometimes very powerful power units (when the apparatus is used for research or other purposes) and in this sense are airplanes. The cruising force created by the power units of such "engine-assisted gliders" or "glider-planes," is used for take-off, climbing and reaching altitudes, is used when carrying out the gliding portion of the flight (Figure 1.22).

The abundance of operational tasks which are solved using gliders determines the multiplicity of structural shapes of these machines.

But the multiplicity of shapes of /18
gliders is increased even more as a result of various structural solutions for gliders as a whole, their separate

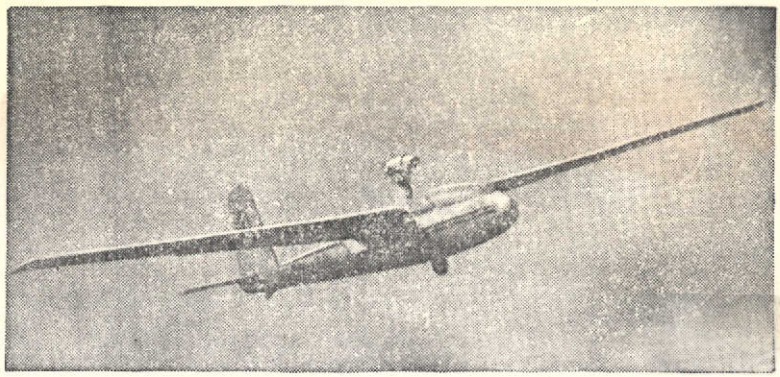

Figure 1.22. A Sport Motor-Assisted Glider with Piston Power Unit

parts and units, which are proposed when creating these aircraft even in the scope of any one sort of operational task. From the figures presented and also those which follow it is apparent that there are gliders of the so-called "normal" design (Figure 1.23), gliders in the shape of a flying wing (Figure 1.24) and in the shape of a flying fuselage (see Figure 1.17). One also encounters gliders with rectangular wings (Figure 1.25), arrow-shaped (Figure 1.26) and with tapered (see Figure 1.23) shape in plan form, with serpentine-shaped wings (see Figure 1.14) and those constructed in the shape of a disc (see Figure 1.13), wings similar to the wings of a flying mouse (see Figure 1.12). It is possible to see gliders with fuselages in the shape of a tube (Figure 1.27), with braced beam (see Figure 1.25), a boat (Figure 1.28) or truss (Figure 1.29), those having normal (see Figure 1.23), T- or V-shaped tail units (Figure 1.30, also see Figure 1.6).

Wings of gliders for varying use are variously mechanized, that is they have various devices which change their configuration in flight. This also varies the structural form of engineless aircraft.

Finally, the use of a large assortment of structural materials among which one sees metal, wood, plastic, composition materials, also to a great degree vary the family of engineless aircraft. We will familiarize ourselves in detail with the character and degree of effect of the operational task on the structural design of the glider and to do this have selected a single place sport sail- /26
plane, which is most characteristic both for the family of engineless aircraft and for the machines in the sport group itself.

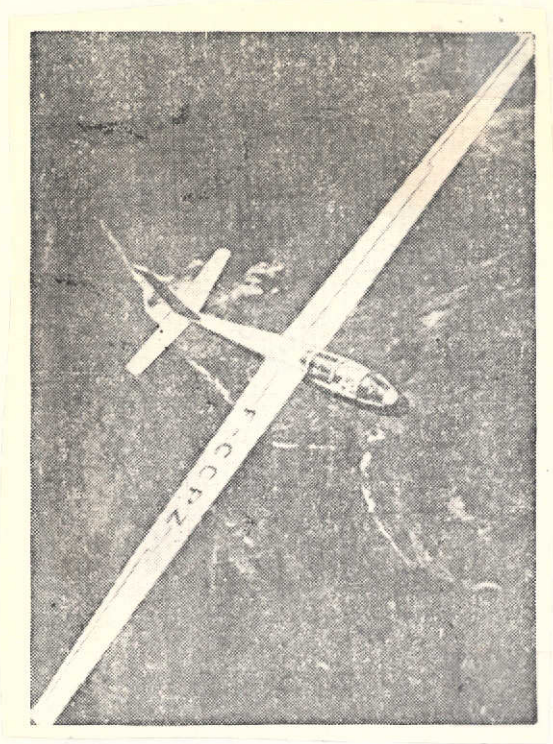

Figure 1.23. A Glider with Normal Design: the Wing is Tapered in Plan Form

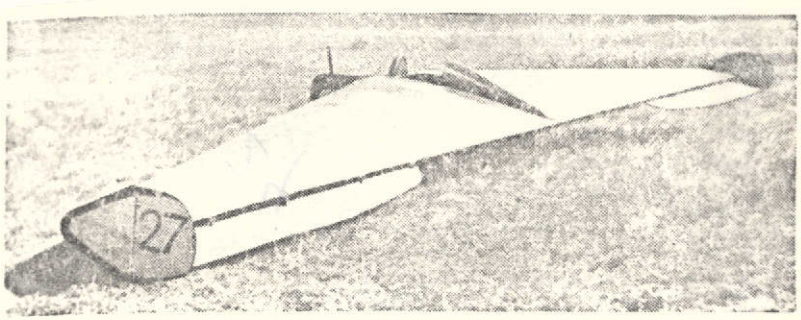

Figure 1.24. A Glider Made in the Shape of a Flying Wing

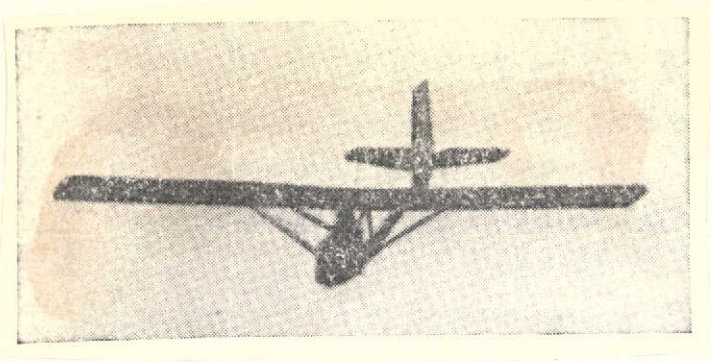

Figure 1.25. A Glider with Rectangular Wing in Plan Form and Beam Braced Fuselage

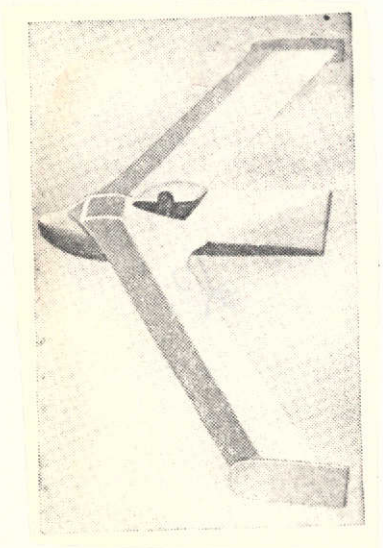

Figure 1.26. Glider Made in the Shape of a Flying Arrow-shaped Wing

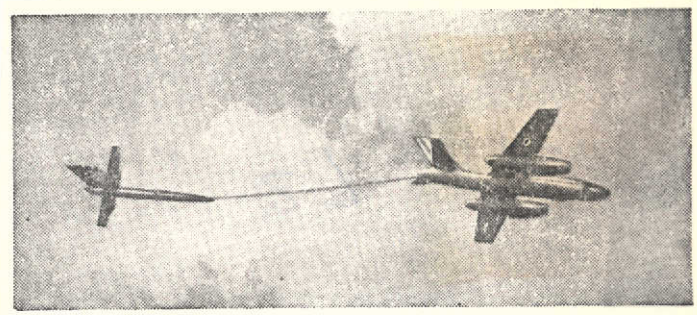

Figure 1.27. A Glider-Target. Pilotless. The Fuselage Made in the Shape of a Tube

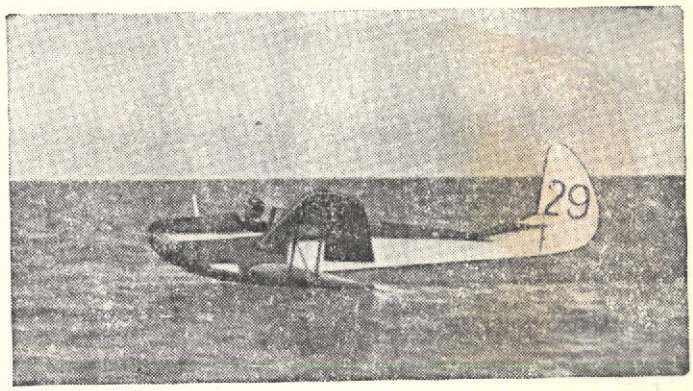

Figure 1.28. A Hydro-glider. The Fuselage made in the Shape of a Boat

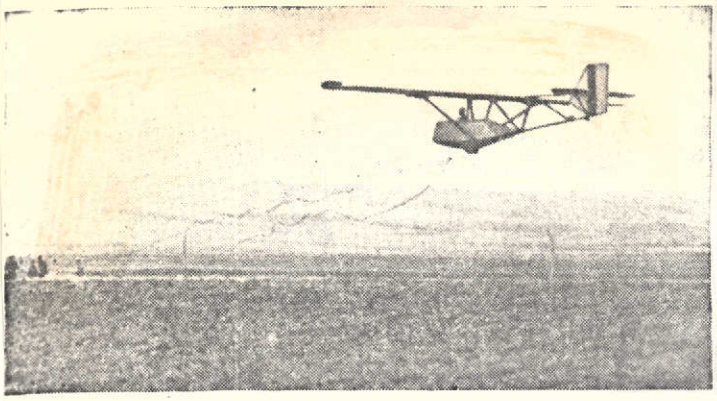

Figure 1.29. A Glider with Trussed Fuselage

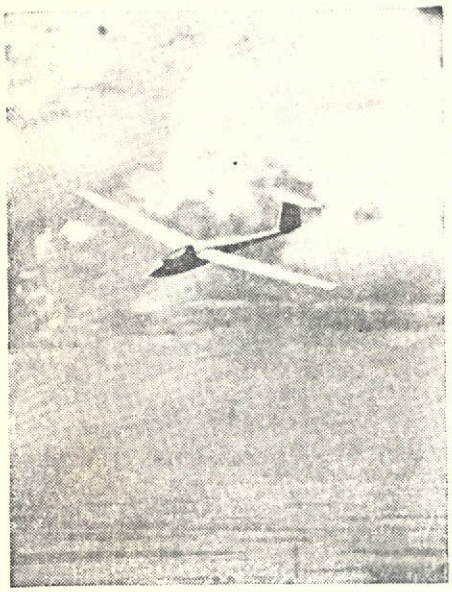

Figure 1.30. A Glider with T-shaped Tail Unit

1.2.2. Brief Information on the Structural Design and Peculiarities of Make-up of a Modern Sport Glider

A completed glider is a combination of various structural parts and units which complement each other. The interdependence of their operation is dictated by the demands of the operational task for which a given glider was built. These are the requirements of an aerodynamic, strength and operational character. The arrangement of separate parts and units which make up the entire glider are subject to certain laws of construction. By make-up we understand a single process in the course of which the requirements of aerodynamics, strength, production and operation are all interdependent and on the basis of which the optimum shape of the glider and its structural solutions are found. Make-up means the final combination of separate parts and units of the glider subject to a specific concept in which the operational task is shaped.

We will look at types of make-up of a glider which characterize various groups of laws, which must be observed when designing and building a glider. Thus, let us look at the make-up of a glider from the point of view of its construction, that is, the combination of separate structural elements of the glider which provide its operation as a mechanical system. The make-up of a glider on the whole naturally includes the arrangement of mass, that is the appropriate distribution of the mass of the structural elements, and also the appropriate placement of the pilot, cargo, equipment, ballast etc.

Another aspect of make-up of a glider is imparting certain exterior shapes to the wing, fuselage and tail unit and a certain

interdependent placement of them which will give the glider good flying qualities and good controllability. Aerodynamic make-up is involved with structural. The construction of the glider naturally is subject to aerodynamic and strength requirements set forth for the exterior shape of the glider and provides within known limits immutability or a preconceived variability of them in flight. Both immutability and preconceived changeability of exterior shape of the glider are dictated by the requirements of its operational task. The design of the glider determines ways and means of sup- /27
porting its specified exterior (aerodynamic) shapes in flight.[3]

1.2.3. The Structural Aspect of Glider Make-up

A modern sailplane is usually a cantilever wing (that is, not having struts and braces) monoplane with the main wing, tapered in plan form, placed in the center or above the fuselage (see for example, Figure 1.3).

The Wing

The shape of the wing, its strength, rigidity, mass of structure, cost and simplicity of design and operation must be as close as possible to the optimum. However, it is impossible to satisfy all of these requirements at the same time. Therefore, depending on the operational task of the glider, one selects one or another structural solution for the wing.

Before going into a description of the typical construction of a wing let's mention its basic geometric characteristics (Figure 1.31).

Let's look at a wing of a typical sailplane with tapered shape in plan form. This shape became classic because of its simplicity of construction and good aerodynamic and strength properties. Such a wing is most often made of two detachable parts called cantilevers. Sometimes the wing is made up of three parts. Then the cantilever is attached in the center section which is called the center section. Less often, in cases where the wing is not large it is made in one piece. The distance between the ends of the assembled wing are called its wing span l.

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[3]A detailed examination of the construction of gliderslies outside the framework of this book. However, besides brief observations on construction solutions of modern sailplanes, in Chapter 5 there is certain additional information on this question.

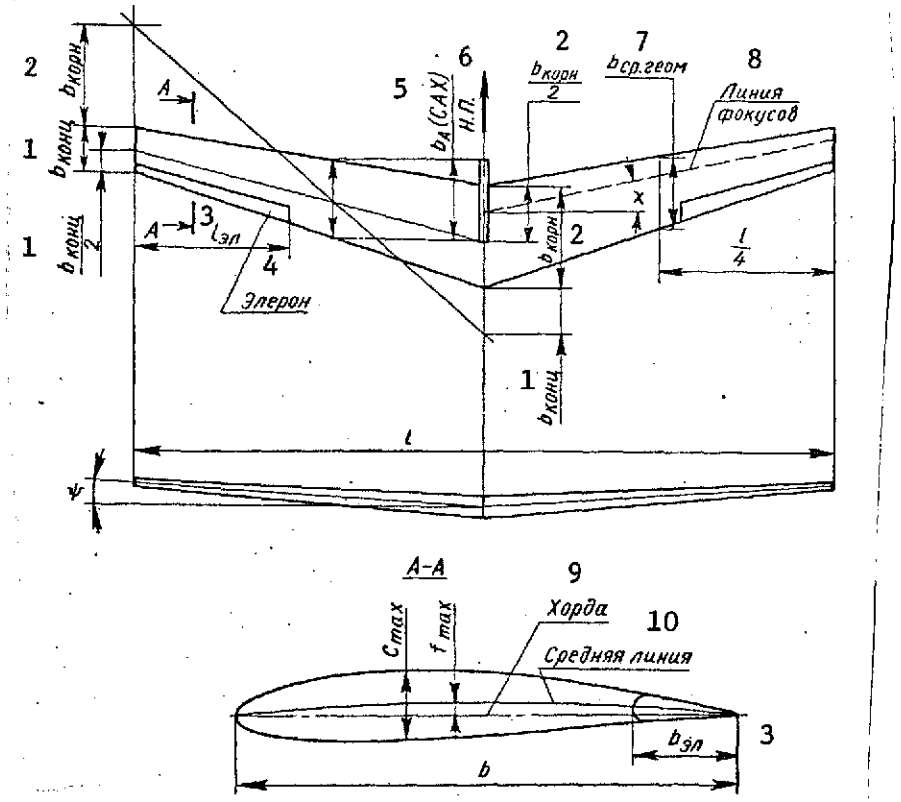

Figure 1.31. Geometric Characteristics of a Glider Wing. The negative arrow shape which is sometimes used when constructing sport gliders in this case is used to show visually the position of the M.A.C. of the glider wing. 1--Tip; 2--Root; 3--Ail.; 4--Aileron; 5--M.A.C.; 6--FD [Flight direction]; 7--Mean geom.; 8--Line of foci; 9--Chord; 10--Mean line.

The area of the wing S means the area limited by the shape of the wing projection in plan form. For a tapered wing, the area S equals the product of l and the mean geometric chord $b_{\text{mean geom}}$. The segment of a straight line which joins the leading and trailing edges of a cross section of the wing parallel to the plane of symmetry of the glider is called the chord. When looking at the geometric characteristics of the wing, bear in mind the dimensions of a series of separate chords. Among these we have already mentioned the geometric, and there are also the tip (b_{tip}) and root (b_{root}) chords.

There is still another characteristic chord of the wing which is, it is true, not a structural parameter called the mean aerodynamic b_A or M.A.C. Its size and position are defined for

a tapered wing of simple structure as conceived in Figure 1.31.[4] /28
The chord is characteristic not only of the projection of the wing in plan form, but naturally, its cross section, that is, the airfoils which have primary importance from the point of view of forming the lift force and the force of any resistance to the glider wing. Besides the chord, the airfoil is characterized by a number of other values. Among these are the coordinates of geometric location of points which form the contour of the airfoil, the thickness of the airfoil and its relative size $\bar{c} = \frac{c_{max}}{b}$,/29 the mean line of the airfoil which characterizes the camber of the airfoil and relative value of the camber $f = \frac{f_{max}}{b}$.

The angles of its arrow-shape in plan form and angles of cross section V-shape belong to the geometrical characteristics of the wing. The glider wing can have a geometric twist, that is, the angle of mounting the airfoil relative to the chord of the center wing section is non-uniform along the wing span. Sometimes instead of geometric there is an aerodynamic twist which means that when the angle of mounting the airfoil is uniform along the wing span of the wing, the airfoil itself changes.

Other geometric characteristics of the wing are its extension $\lambda = \frac{l^2}{S}$ and contraction $\eta = \frac{b_{root}}{b_{tip}}$.

The structural plans of wings at the present time are fairly varied. However, as a rule they have the following basic elements. These are spars and longitudinals joined generally by longitudinal (in relation to the wing) frame, ribs which have a lateral frame, and skin.

Let's look at some of the structural plans of glider wings which are widely used at present. The most widely used plan is a single-spar wing (Figure 1.32). It has a powerful spar which goes along the entire wing span and covers approximately 40% of

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[4]M.A.C.--is the chord of a conventional wing of rectangular shape in plan form. This wing is the same as an actual wing airfoil cross section in wing span, equal in area and in limits of streamlining gives the same momentum as an actual wing of any shape in plan form which it replaces. The position of the center of mass of the glider is determined relative to the M.A.C. The coefficient of momentum which affects the wing and the glider as a whole is related to the M.A.C.

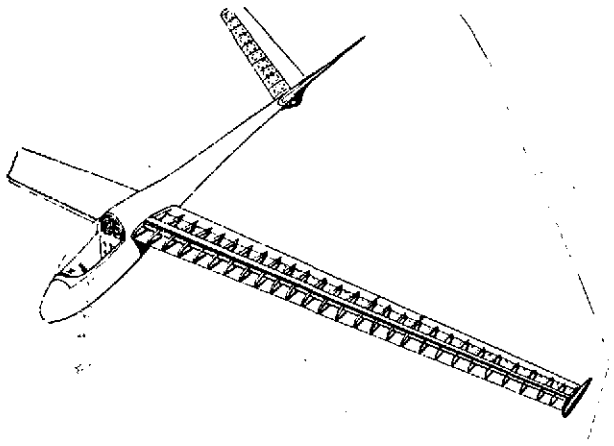


Figure 1.32. A Glider with Single-spar Wing

the chord. Thanks to this the forward part of the wing forms a closed contour which consists of skins attached by ribs and sometimes longitudinals and the spar.

The wing in cross section /30 has several shapes. An example of such a wing is given in Figure 1.33. A wing sometimes is made of two or more spars. If the skin is "stressed," that is, receives a load not only from pressure (or negative pressure) of the air (flow) washing over the wing, then such a structure differs principally from a single-spar only in the number of contours.

There are two-spar wings with non-stressed skins, that is, those which receive only pressure (static) of air (flow) washing over the wing. These wings are less suitable from the point of view of strength and mass than wings with stressed skins, but are very simple to produce and are cheap. Such wings are often used for homemade gliders. An example of a two-spar wing with non-stressed skin is given in Figure 1.34.

The constructional plan of a wing always can be changed to greater or lesser degree in its configuration by the pilot. The basic units located on the wing and intended for changing its configuration are called the lift augmentation devices. A change in configuration of the wing in flight provides aerodynamic strength and momentum required in size and direction. Inasmuch as these devices are controlled by the pilot they are one of the main links which connect the man, the glider and the environment in flight. The control conditions and the results then attained /31 mainly determine the controllability of the glider.

Lift augmentation devices which exist on all modern gliders are ailerons. They are intended for changing the cross section of the right and left cantilever of the wing variously, that is their airfoils and thus create the necessary lateral moment.

Constructionally the ailerons are made, in the overwhelming majority of cases, in the shape of independent sections of wing, which are attached to it by hinges (Figure 1.35).

This device changes the camber of the wing airfoil very roughly. However the simplicity, reliability and adequate effectiveness of ailerons have made them widespread universally. An

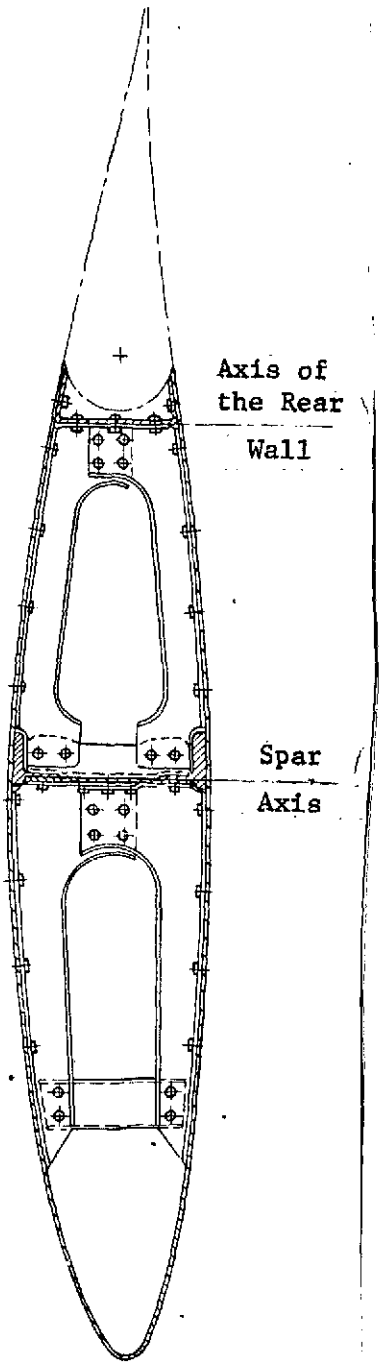


Figure 1.33. Structural Plan of a Single-spar Two-contour Glider Wing

essential requirement for the design of ailerons is providing their normal operation with large bending deformations of the wing which are frequently encountered in flight. This requirement is satisfied, as a rule, by segmenting each aileron into several sections which are connected to each other by hinges and each of which is fastened to the wing by its own hinges. This design allows one to operate normally with a system of lateral control with all permissible loads in operation on the glider wing. One should note that even the Wright brothers' glider at the beginning of the century, instead of ailerons used flexible wing tips. When deflected by the control system they smoothly changed the camber of the airfoil. This is principally the plan of ailerons but is carried out with a higher technical level and was used on the wing of one of the German sailplanes which was built in our time (Figure 1.36.)

Another wing lift augmentation device which also changes its airfoil (in distinction from ailerons--in one direction) are the flaps (Figure 1.37). Flaps are needed for changing the relationship of flight path speed to descent speed of the glider by changing the streamline flow of the wing. The change in longitudinal moment, which invariably occurs as a secondary effect, is counteracted by the other control devices. The flaps are located in the central section (along the wing span) of the wing, between ailerons. The flaps are made, as a rule, split like the ailerons, mounted to the wing on hinges (the simplest but not the most effective system). If they are made extensible they may change not only the profile of the wing but also its area. The latter solution is more suitable but is structurally complex and usually makes the structure heavier. One should keep in mind that up until recently flaps usually only deflected down because it was considered that their use was limited to requirements only of increasing the camber of the airfoil. But now it is recognized that some deflection of the flaps upward can also be valuable, for example, at high flight speeds and cases /34
where it is desirable to decrease the airfoil camber.

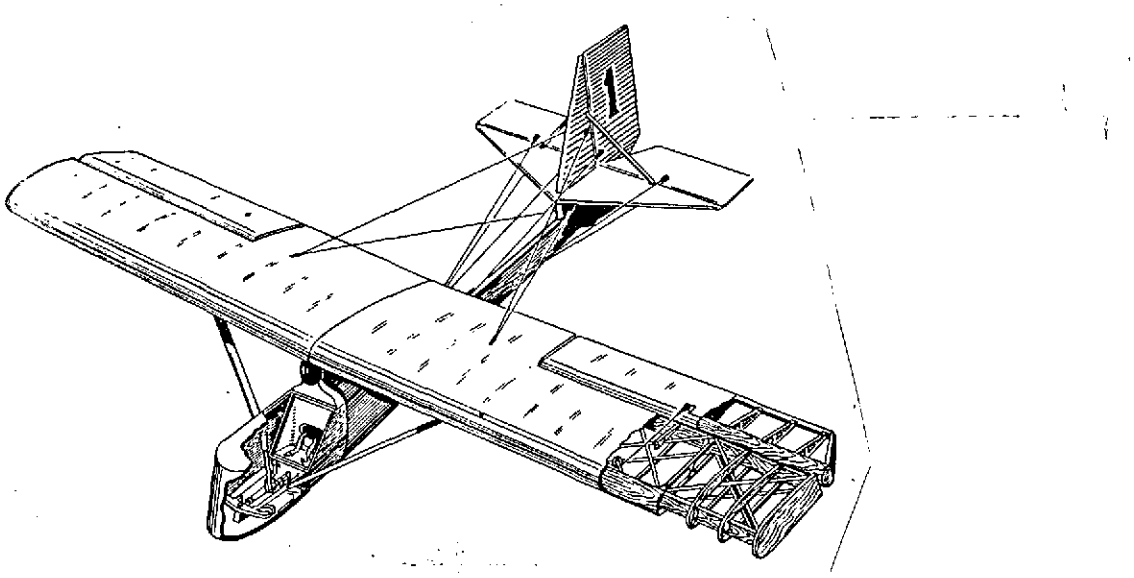


Figure 1.34. A Constructional Diagram of a Two-spar Wing with Non-stressed Skin

For increasing the efficiency of flaps their functions are sometimes taken on by ailerons which in this case can operate both controls simultaneously. Because the right and left ailerons are always deflected to opposite sides, and sections of flap located on the right and left of the wing cantilever operate symmetrically, the mechanism which joins ailerons and flaps provides the ailerons with increased angles of deflection which correspond to the angle of deflection of flaps independent of their initial deflection which is determined by the requirements of eliminating or creating banking.

Finally, there is still another lift augmentation device on the wing, the interceptors (air brakes) or as they are more often called spoilers (Figure 1.38). They worsen the character of streamline flow of the wing with the inflow of air and thus decrease its lift force with an increase in drag. The spoilers are made structurally in a shape deflecting or extending beyond the limits of the airfoil contour plates located perpendicular to the airflow on the upper and lower surfaces of the wing, approximately in the center of its cantilever. In the selected position they are described in the wing contour. In extended position the spoilers cause turbulence and break the air flow in the part of the wing where they are located. Then, thanks to the perforated design used on the larger part and the presence of slots between the lower edge of the spoiler and the surface of the wing, the change in longitudinal moment which occurs when releasing the spoilers is not large and for eliminating it, does not require /36
large operation of other control devices of the glider. The position of the spoilers along the wing chord varies to a greater degree than along the wing span. The spoilers are in the forward

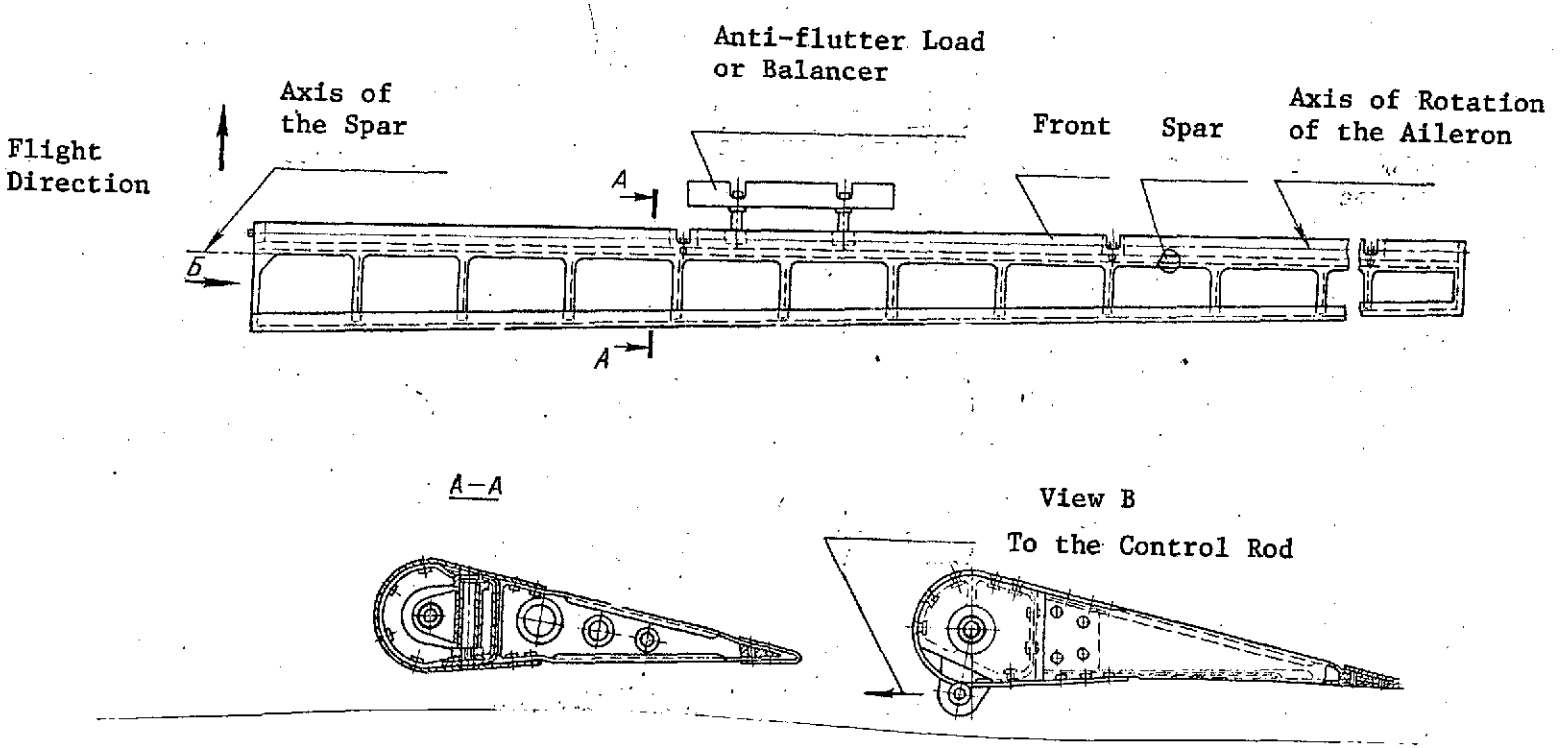


Figure 1.35. Constructional Plan of an Aileron Attached to the Wing by Four Hinges

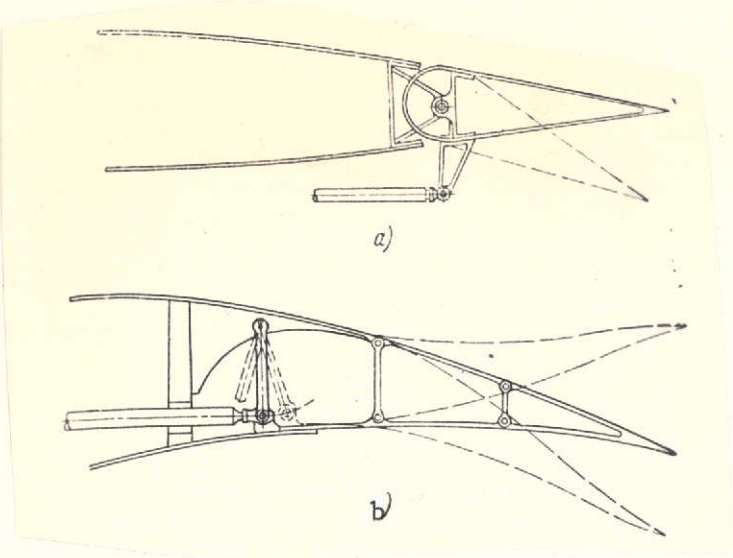


Figure 1.36. A Diagram of Ailerons Ordinarily Used (a) and Those Made in the Shape of an Elastically Bending Part of the Wing (b)

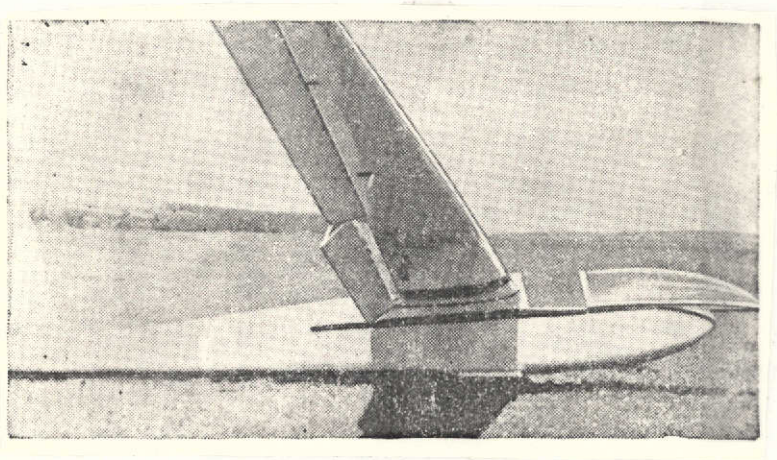


Figure 1.37. Extensible Turning Flap in Deflected Position

part of the airfoil, and in lowered position change the lift force of the wing and brake movement of the glider along the flight path. But spoilers located close to the rear edge of the wing operate mainly as air brakes. The selection of one or another position for the spoilers depends on the operational task of the glider. However, no matter which position is selected for the spoilers they always to some degree impair the surface of the wing. Therefore, in a number of cases a single- or multi-acting braking

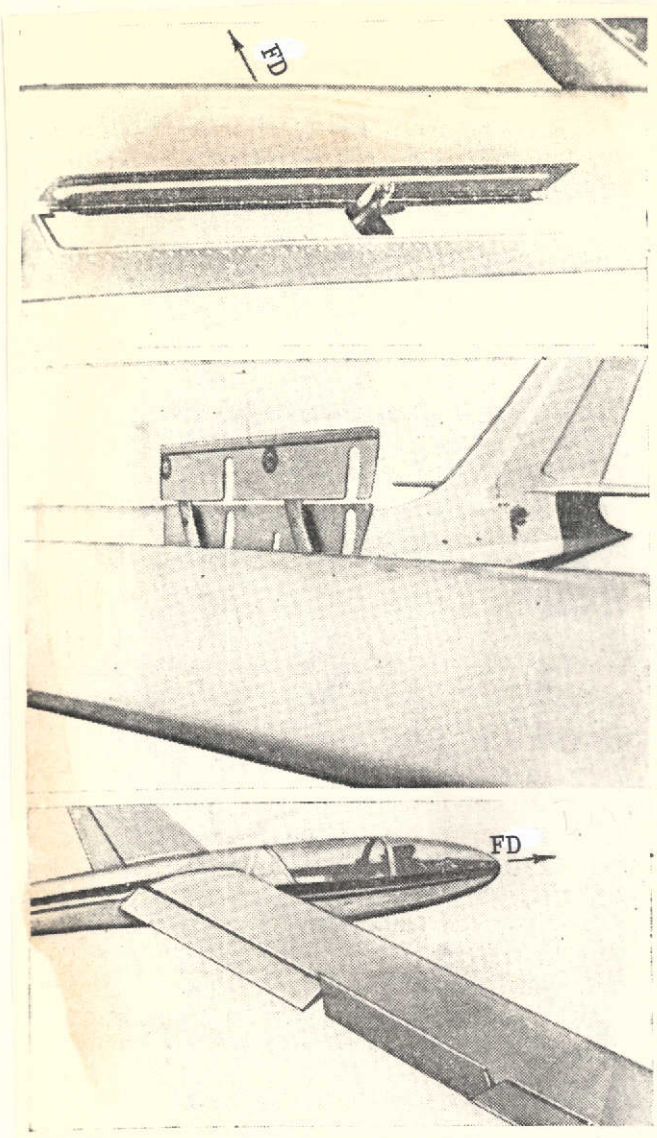


Figure 1.38. Spoilers, made in the Shape of Various Devices which Break the Smooth Streamlined Air Flow Over the Wing

parachute is utilized instead of them (Figure 1.39).

A glider wing has a number of units intended for attaching it to the fuselage and also for mounting various units and systems. Not lingering on those of minor importance let us turn our attention to the basic wing unit intended for joining the cantilever and connecting the fuselage to the wing. This unit can be either single, or made in the form of separate structures which combine the cantilever and attach the fuselage to it. The butt joint is an example of a particular problem of designers and pilots because its good condition and correct operation affect the entire glider to a significant degree.
The joint we are speaking of is made in different variations. Here one of the chief requirements for its structure, besides strength and lightness is simplicity and speed in assembly and stripping (Figure 1.40).

Sometimes the interior /37
space of the wing is used for ballast tanks with water. An increase in flight weight of the glider together with the constant possibility for pouring out the water (which the pilot can do at any time during flight) cuts down on the load on the wing and is useful for solving certain problems in soaring flight.

There are very rigid requirements for the shape of the wing and its surface finish because even a slight deviation from the prescribed shape of the airfoil or the presence of roughness can decrease the flying qualities of the glider substantially.

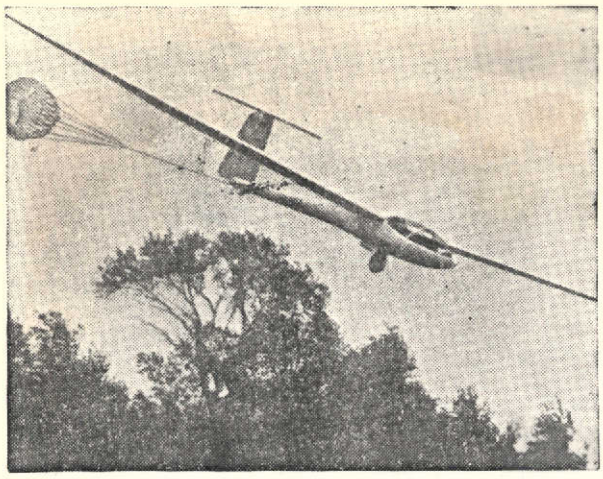


Figure 1.39. The Use of a Braking Parachute in Flight

Tail Unit

The tail unit gives longitudinal and directional stability to the glider, and also creates control moments relative to lateral and vertical axes of the glider. In constructional plan the tail is similar to the wing. But operational conditions for the tail allow one to make it more simply (Figure 1.41).

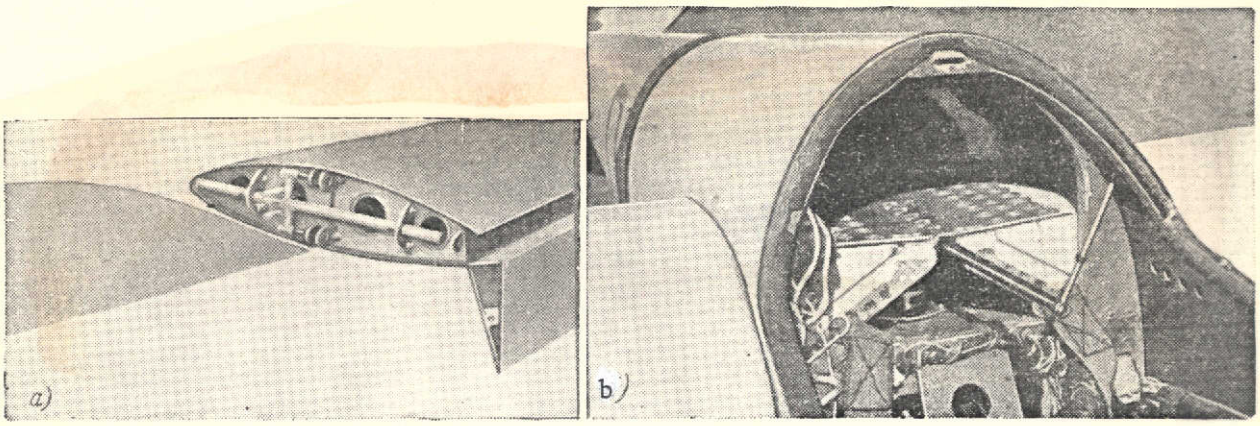
As was pointed out earlier, at present there are three basic types of tail units: the so-called normal configuration and also V- and T-shaped configurations. The selection of the tail depends on the conviction of the designer as to suitability in using one or another system when solving the operational task of a given glider. However, with all the variations of external shape of these three types of glider tails, efficiency and weight performance like the complexity of producing them are fairly similar. The geometric data on the tail is similar in character to that of the wing.

Besides geometric characteristics, like the wing, the tail has a number of specific characteristics. These include distance from hinges (that is, the axis of rotation), rudder height (of the movable part of the horizontal tail) and direction (of the movable part of the vertical tail) to the center mass of the glider.

The V-shaped tail consists of two so-called after-pieces located symmetrically relative to the $x_1 O_{y_1}$ plane with an angle to it usually in all $\pm 45°$, but sometimes somewhat larger. We note that the area of the V-shaped tail is determined not by projection on the horizontal plane (like the area of the wing) but by the actual dimensions of the after-pieces.

The glider tail, like the wing, has lift augmentation devices which deflect upward and downward, to the right and left of the rudder (altitude and direction). Moreover, in a number of cases it can be rotated, changing then its angle of attack and the forward part of the tail--the stabilizer. If the stabilizer is made rotating sometimes it prevents the use of the elevator.

Besides the devices mentioned, the tail (in the case of the normal and T-shaped configuration) has a so-called trim tab--a movable part of the rudder itself. The trim tabs on gliders are used only on the horizontal tail unit. On the vertical tail unit, as on the ailerons, the trim tabs are not mounted; but small plates are



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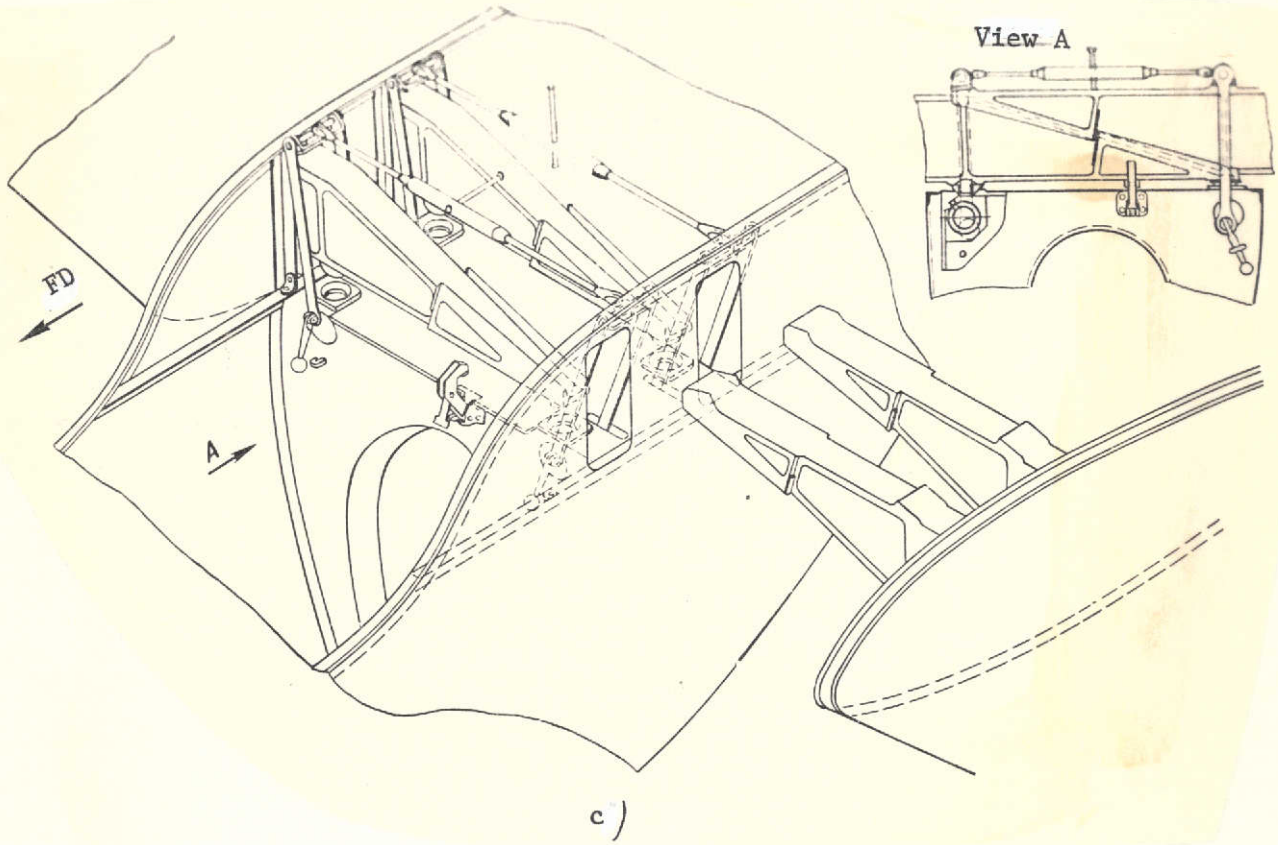

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Figure 1.40. Various Solutions for Butt Joints in a Glider: a--attaching the cantilever to the wing center section by three bolt connections; b--ramrod joining of the wing cantilever with the fuselage and each other; c--joining the cantilever spars with a tightening device

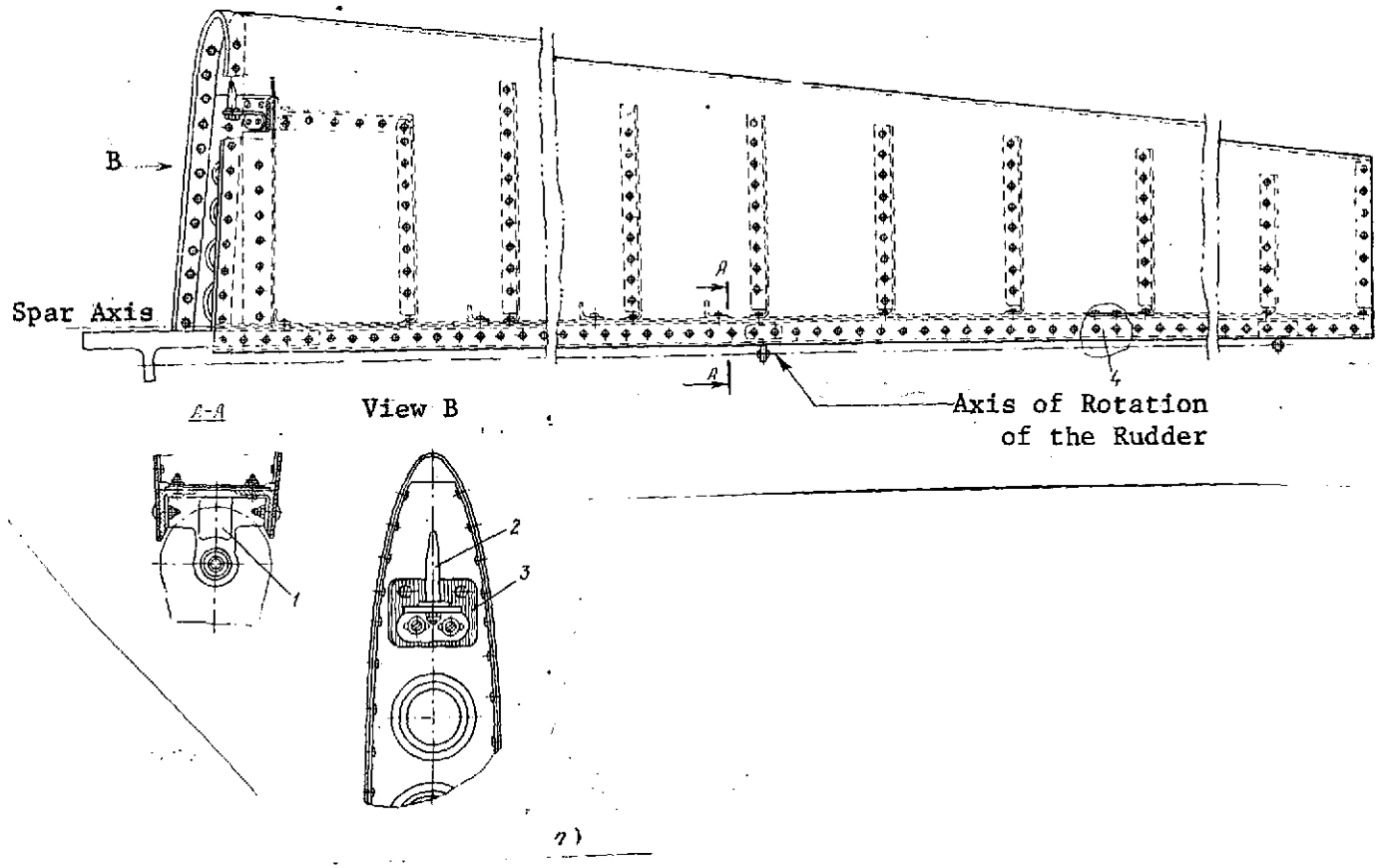

Figure 1.41. Constructional Plan of Stabilizer and Rudder of V-shaped Tail Unit of a Glider:

a--Stabilizer Diagram; 1--mounting unit; 2--forward butt joint; 3--ribbed section; 4--spar;

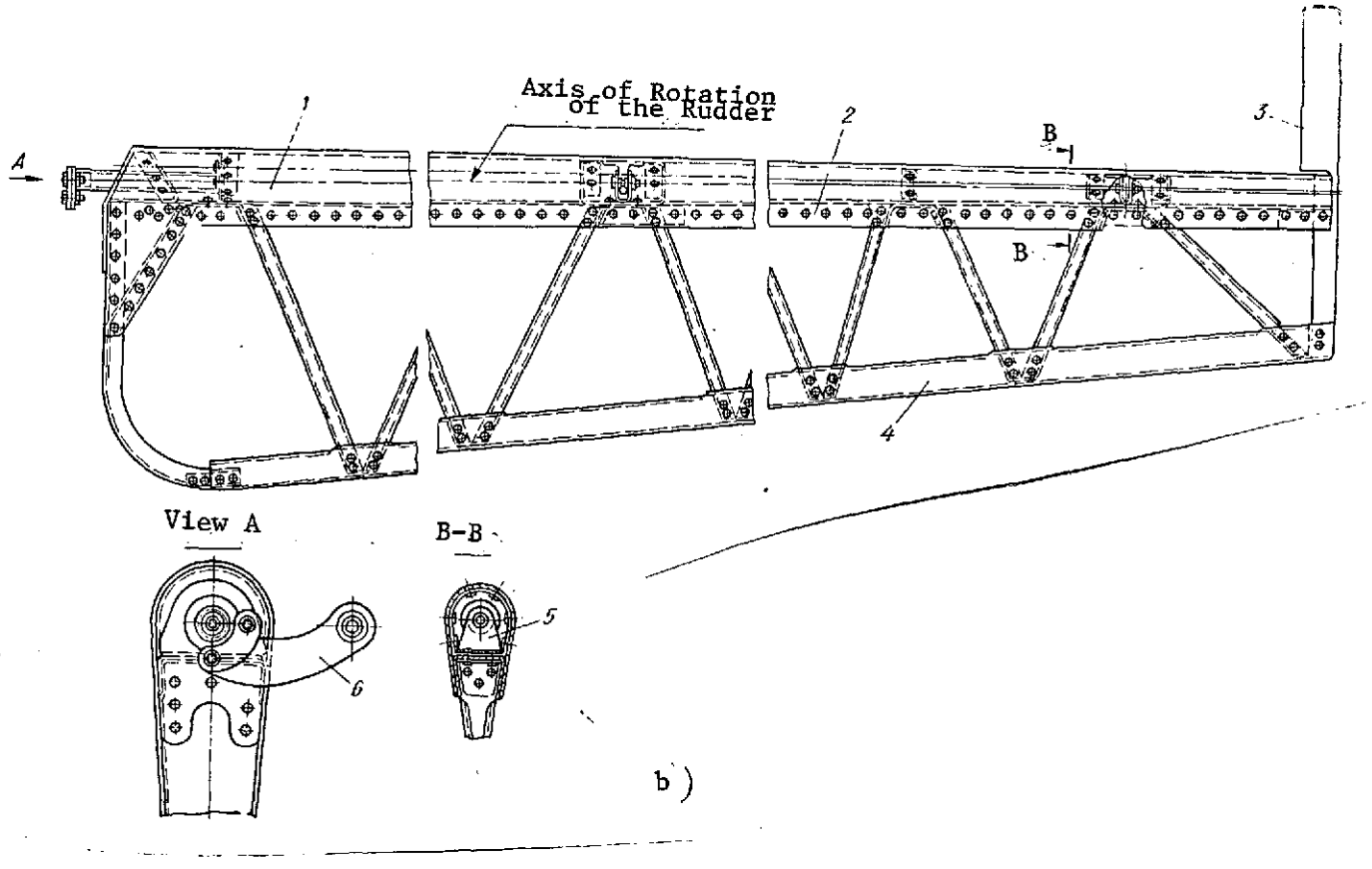

Figure 1.41. Constructional Plan of Stabilizer and Rudder of V-shaped Tail Unit of a Glider: (continued)

b--Diagram of the Rudder; 1--front; 2--spar; 3--rocker bar; 4--rear edge; 5--mounting unit for the rudder; 6--control rocker.

attached to eliminate the effect of non-symmetry of the glider in balance laterally (because of imperfections in manufacture) on the ailerons and rudder controls; they bend to the necessary side to provide lateral and directional balancing of the glider for a straight flight force without slipping.

Fuselage

The fuselage as we found earlier has girders and trusses--braced and cantilevered. The trusses, as a rule, have nonstressed skin, the cantilever girders--stressed (Figure 1.42).

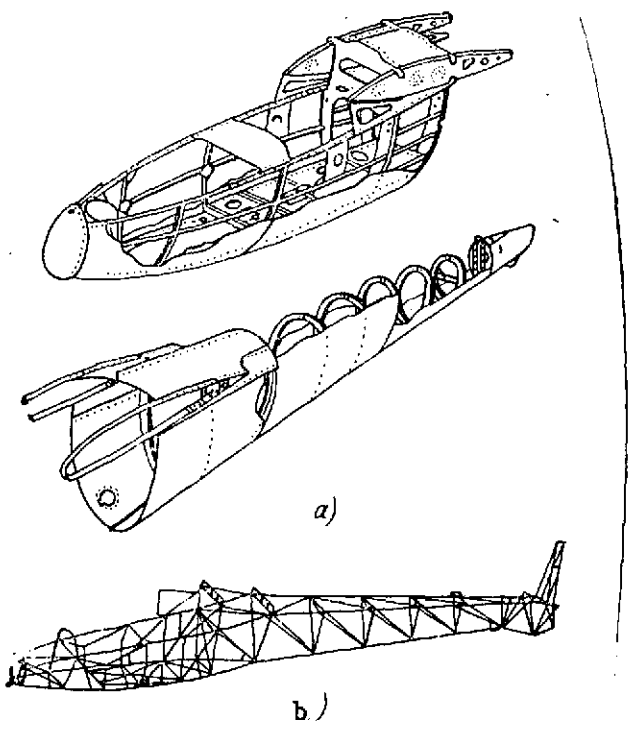

Figure 1.42. Structural Plans of Girder *a* (Cantilevered) and Trussed *b* (with Non-stressed Skin) Fuselages

The glider fuselage joins /43 the wing and the tail unit, that is, it connects the most important parts of the glider which give it lift force and forces utilized for controlling flight.

The fuselage of the glider contains the pilot, a large part of the systems used in flight for providing a given motion of the glider and safety of the crew.

Figure 1.43 shows the structural arrangement of the fuselage of one of these gliders. One should note that because of the necessity of placing the pilot in the fuselage and in this connection a large opening for the canopy of the fuselage cabin it cannot be made entirely in one perfect structural configuration. Therefore, as a rule, the forward part of the fuselage is made according to a composite spar system diagram, at the same time that the rear can be made in a more perfect monocoque configuration.

Glider Systems

A completed glider, for any kind of use made by any system is equipped with a whole series of systems necessary for solving

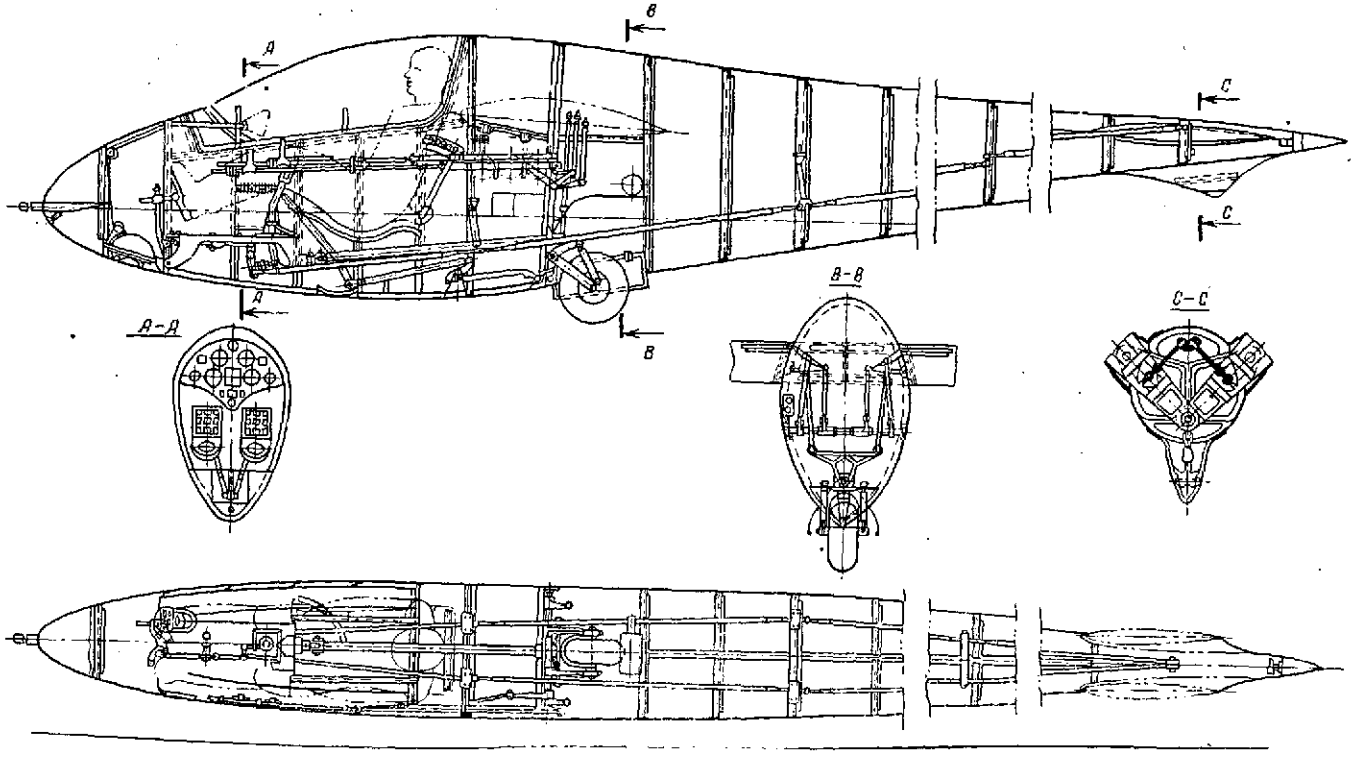

Figure 1.43. Structural Arrangement of a Glider Fuselage. The Drawing Also Shows a Diagram of Landing Gear Retractable in Flight.

/44

operational tasks.

A large part of these systems are activated by the pilot. However there are systems which operate independently of the pilot, that is, automatically. Let us look at the following systems: control system, piloting and navigational instruments system, systems to provide life support and lifesaving for the pilot, control systems for the towing lock, landing gear and water ballast, systems for radio communication, electrical supply and control-recording equipment.

The system for controlling motion of the glider is activated by the pilot on devices which change the configuration of the glider for holding a certain procedure of its motion or deliberately changing the character of its motion. This overall system consists of several systems connected to each other by their special purpose, and in a number of cases kinematically.

The system for longitudinal control or the longitudinal channel of control by rudders (Figure 1.44) starts at the control stick, goes along the entire fuselage and ends with the elevator (or stabilizer--in case there is no elevator).

If there is a V-shaped tail unit, the channel for longitudinal control ends at both afterpieces of rudder. A longitudinal shift of the stick makes the rudders deflect up and down. In the case of a V-shaped tail unit with longitudinal deflections of the control stick, the rudders also deflect up and down. But all the systems for controlling them are connected kinematically with another system--the channel for flight-path control. Figure 1.45 shows graphs of the relationship of rudder deflection, control stick and pedals.

The flight-path control system with any system of tail unit /46
(that is, normal, T- or V-shaped) also begins in the cockpit with pedals (foot levers) and ends with the rudder. With a V-shaped tail unit, the longitudinal and flight-path control systems are connected in a so-called "summarized" mechanism, after which are placed the control rods of the rudder for each of the after-pieces of the tail unit. The summarized mechanism provides deflection of each rudder with simultaneous action of the stick and pedals.

In this way, the total deflection of each rudder of the V-shaped tail unit always corresponds to the result which would have occured with sequential effect of stick and pedals on them.

The lateral control system or lateral channel system of control of the glider rudders is connected to the control stick in the pilot's cabin with the ailerons. The elements of the system of lateral control are located both in the fuselage and in the cantilevers of the glider wing. This system is not kinematically

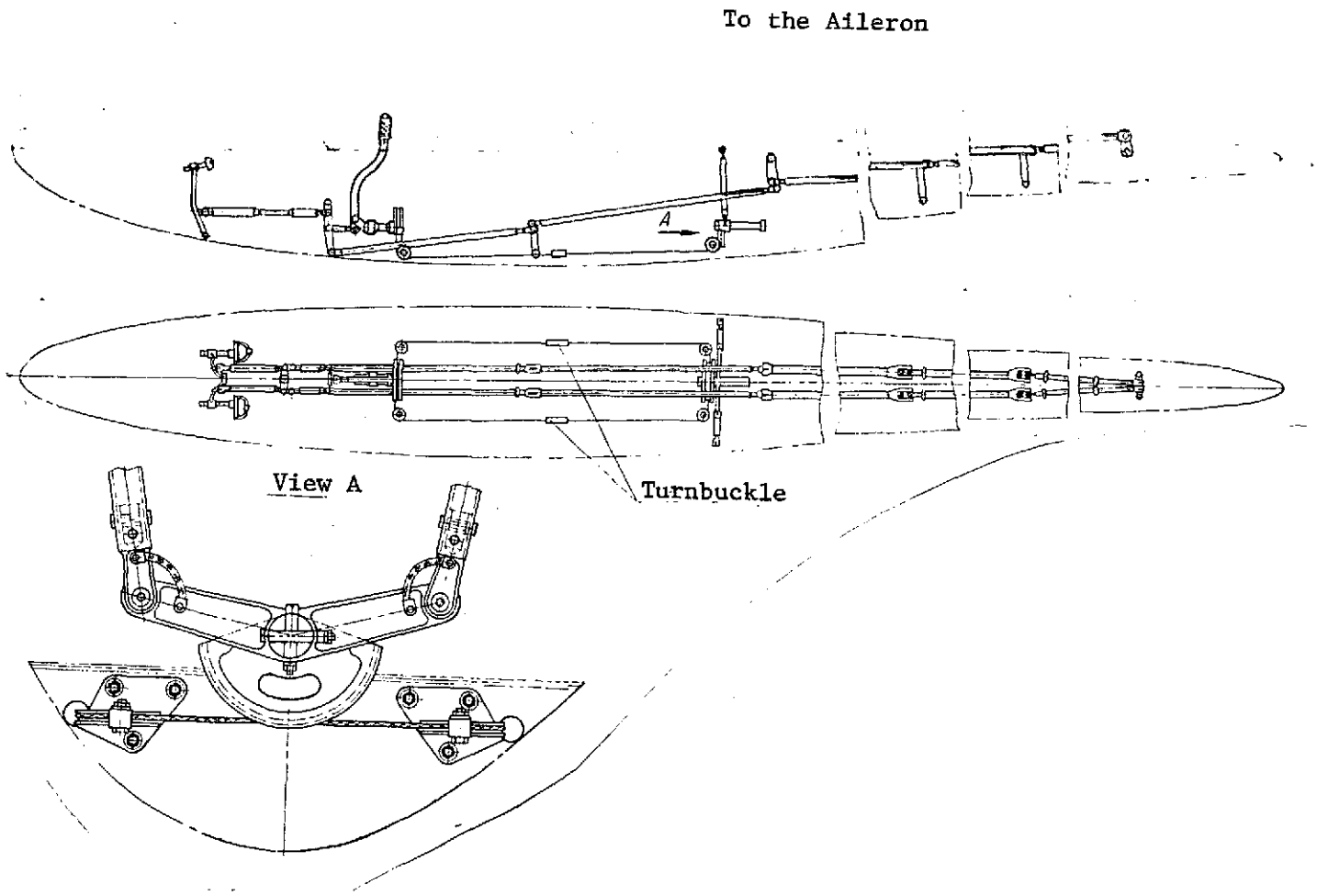

Figure 1.44. A Diagram of the Longitudinal, Directional and Part of the Lateral Control of a Glider (Lateral Control on the Drawing is Expressed Only for the Part Located in the Fuselage).

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joined to the longitudinal system although the initial element of both systems is the control stick in the pilot's cockpit (Figure 1.46).

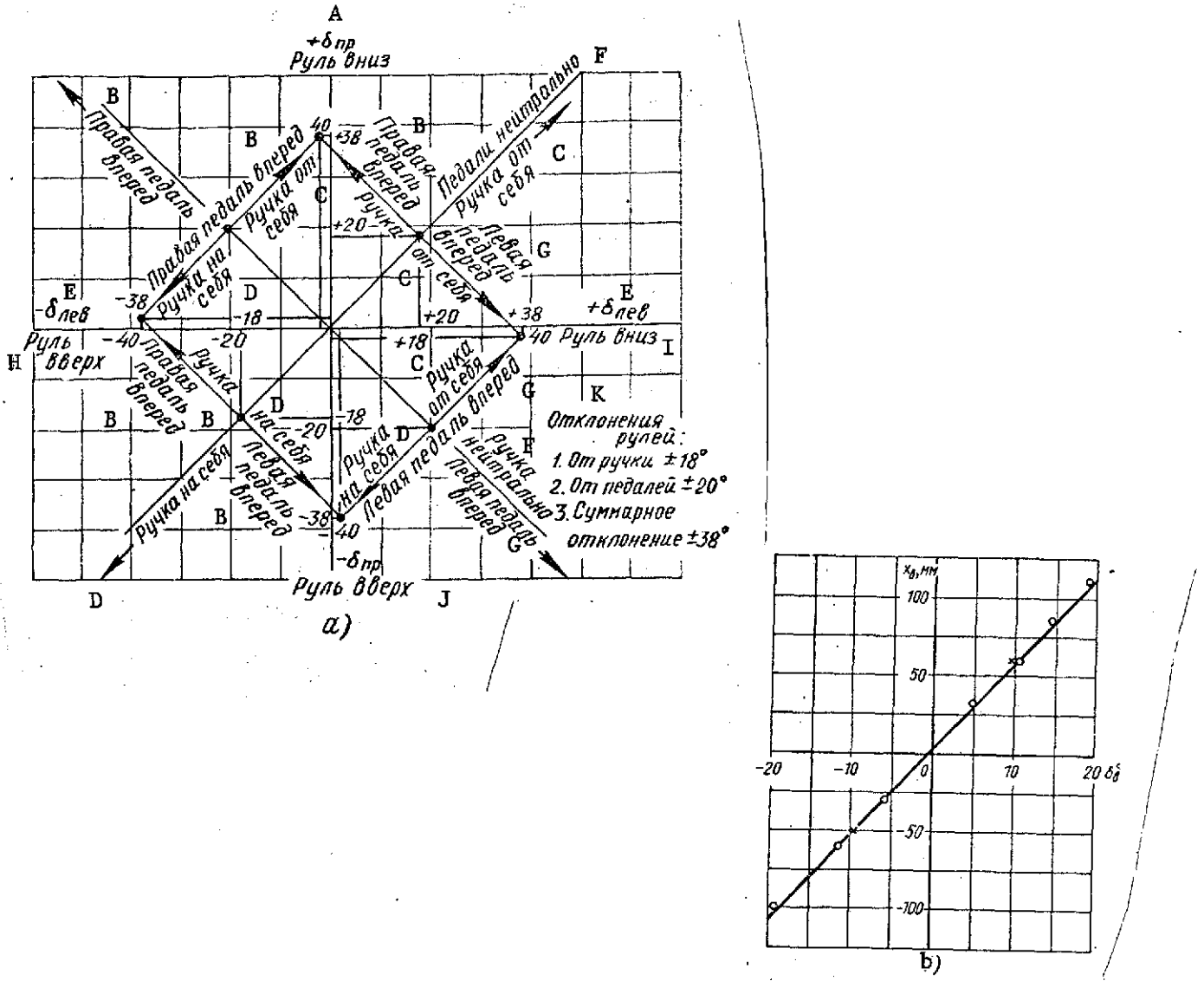

Figure 1.45. The Principle of Kinematic Joining of the Elevator with the Control Stick for Longitudinal Motion of the Glider:
a--V-shaped tail unit; b--Tail of normal system

Key: A--$+\delta_{rt}$ Rudder down; B--Right pedal forward; C--Stick forward; D--Stick back; E--$+\delta_{left}$ F--Rudder neutral; G--Left pedal forward; H--Rudder up; I--Rudder down; J--δ_{rt} Rudder up; K--Rudder deflection: 1--From stick $\pm 18°$, 2--From pedals $\pm 20°$, Total deflection $\pm 38°$

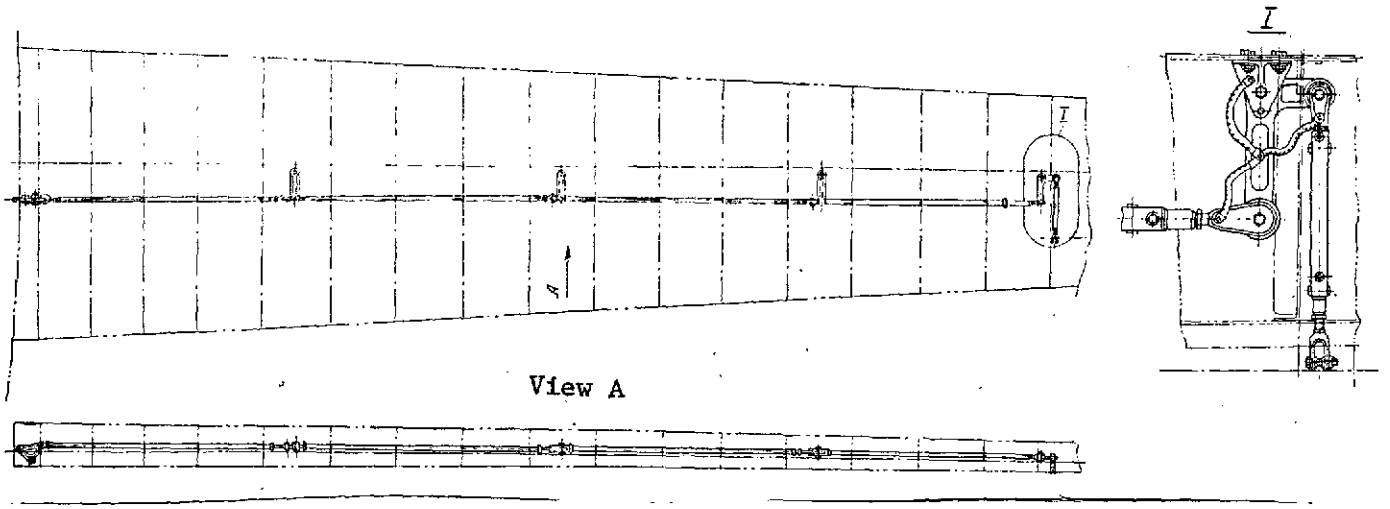

Figure 1.46. Part of the System of Lateral Control of a Glider

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When the aileron is deflected down greater resistance is created than when it is deflected at an angle upward. Therefore the system of lateral control is constructed in such a way that deflection of one aileron up is always greater than the corresponding deflection of the opposite aileron down. In this way one obtains the best equilibrium of drag increase on the right and left wings when deflecting ailerons and the absence of turning moment (yawing moment), which would occur with the ailerons deflected at equal angles (Figure 1.47).

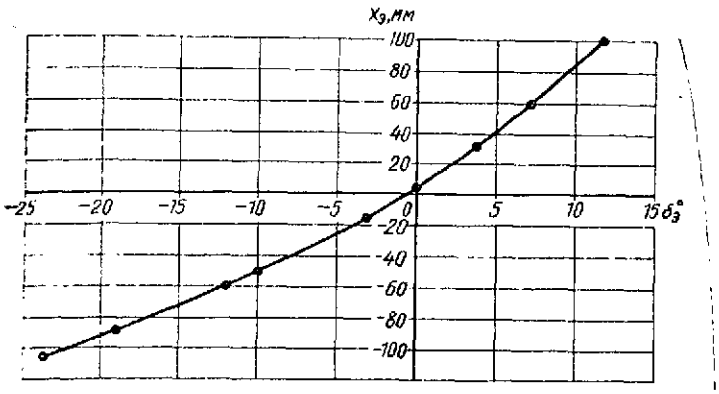

Figure 1.47. The Principle of Kinematic Connection of the Aileron (Right) with the Control Stick of Lateral (Banking) Motion of the Glider

Besides the three basic control systems enumerated which exist on all modern gliders without exception we note that there are three more systems with which many of them are equipped. We are talking about control systems for flaps, spoilers (airbrakes) and trim tabs.

As was mentioned earlier, the deflection of trim tabs changes the camber of the airfoil and sometimes its area. In those cases where operation of the flaps is joined to operation of the ailerons, there is a kinematic connection between the two systems. It is reflected in the fact that ailerons besides their own asymmetric movement have certain symmetric deflections dependent on the deflection of the flaps and corresponding to them. Such ailerons, connected to the flaps are called dependent. The flaps are controlled from the cockpit using a special lever (Figure 1.48).

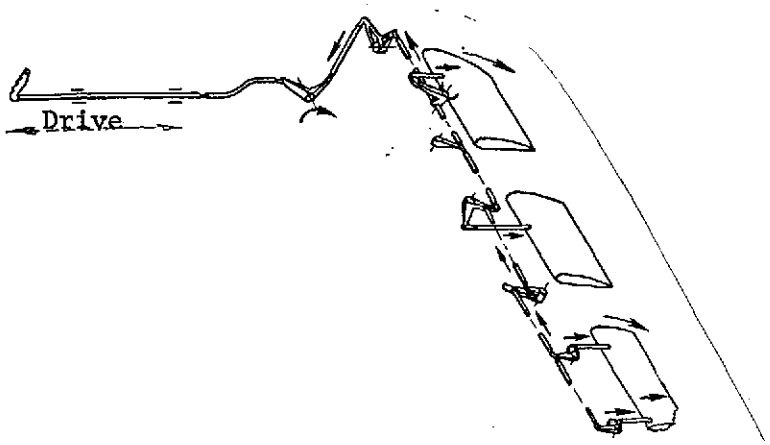

Figure 1.48. A Diagram of the Control of Flaps and Dependent Ailerons

The control system for the spoilers (airbrakes) starts with a special control stick in the pilot's cockpit and ends with the appropriate control device on the wing (Figure 1.49).

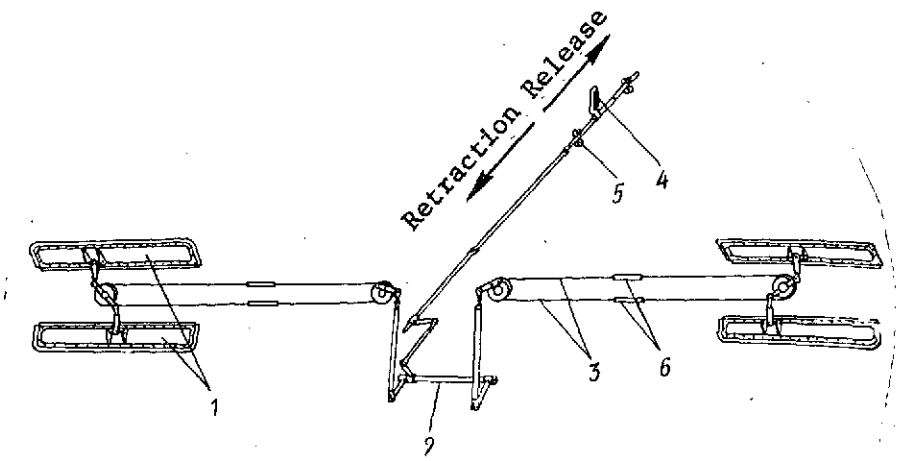

Figure 1.49. A Diagram of Control of Spoilers:
1--Split flaps of spoilers in the open position; 2--Connecting rod; 3--Cables; 4--Control lever for spoilers; 5--Glide roller; 6--Turnbuckle

Structurally this system, like other control systems consists of /49
a number of connecting rods, arms, rollers and cables which impart movement from the stick in the cockpit to the spoilers.

The control system for a braking parachute in general is similar to the control system for trim tabs, however it has a difference in that it includes a device with which the parachute can be detached from the glider.

The control system for trim tabs has the peculiarity that deflection of this device does not depend on deflection of the rudder and entirely is determined by the position of the control stick in the pilot's cockpit. However there are devices which operate in principle like the trim tab but are automatic. Then, deflection of these devices called servo-tabs or servo-rudders /50
depends on the deflection of the rudder itself and peculiarities of kinematics (Figure 1.50).

The trim tabs and servo-tabs are not mounted on the rudder of V-shaped tails of a glider because each of these rudders can operate simultaneously as an elevator and as a rudder because each one can be deflected to different sides. In this case the trim tab is replaced by a spring mechanism, whose zero position relative to the appropriate forces on the control stick can be set by the pilot. Naturally such a mechanism is easy to

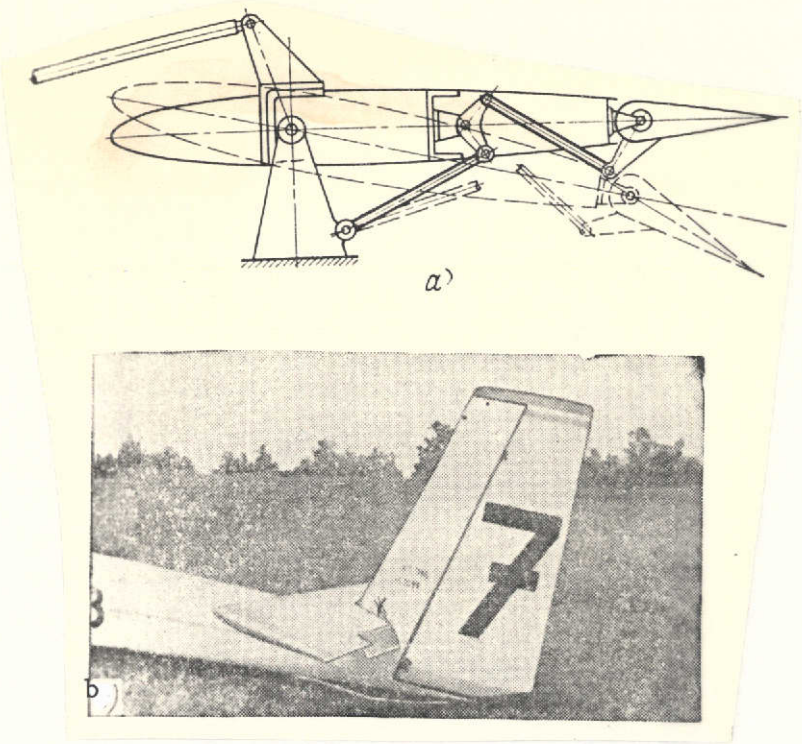

Figure 1.50. A Diagram of the Effects (a) and General View (b) of a Servo-tab Mounted on the Control Stabilizer of a Glider. In this case the servo-tab is "Backward," because it deflects on the side of the control device. This system is used in a number of cases for improving Controllability of the glider.

install in any control system, without affecting the others which is necessary especially in the case of a V-shaped tail.

Piloting and navigational instruments are installed on a glider. These systems are an arrangement of sensors (sensing elements), that is, devices which independently receive the effects of the exterior medium in which the glider flight is made, communications in the form of lines or electrical lines which connect the sensors with visual indicators, that is, with instruments which transform the effects of the exterior medium into numerical calculations of the parameters of movement of the glider; evaluating the totality of these the pilot can control the glider flight (Figure 1.51.).

The visual indicators are located on the control panel directly in front of the pilot. A number of instruments contain a sensor and indicator; as a result of this, such a system has no external /51 communications. Among the visual instruments mounted in the

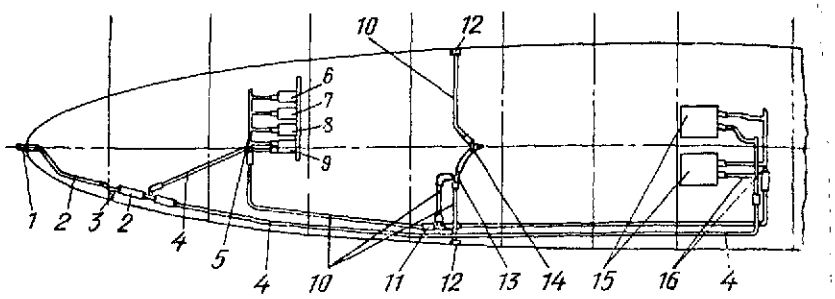

Figure 1.51. A Diagram of Communication Barometric Instruments On Board a Glider: /

1--Full pressure receiver; 2--Medical rubber hose; 3--Sump; 4--Dynamic pressure pipeline; 5--Collector; 6--VR-10 vertical speed indicator; 7--LUN-1141 vertical speed indicator; 8--VD-10 altimeter; 9--US-250 airspeed indicator; 10--Static pressure pipeline; 11--Medical rubber hose; 12--Static pressure receiver; 13--T-pipe; 14--Sump; 15--K2-715 baro-speedograph; 16--Collector

cockpit of a glider there are first the speed indicator (of instrument) of the flight path, the vertical speed indicator which shows the altitude of the vertical component of speed of flight (initial vertical speed of movement of the glider), the altimeter, the turn and slip indicator. Sometimes there are two vertical speed indicators--one which permits a rough calculation and the other which catches very small shifts of the glider vertically. In gliders intended for lengthy, long distance, high-altitude flights and flights in clouds, besides the instruments enumerated there are also installed a compass, clock and sometimes a gyrohorizon--an instrument on which one can orient the glider in space not depending on exterior reference points. Control of all the systems enumerated is limited only to switching them on and off (Figure 1.52).

On gliders there are systems intended for life support of the /52
pilot and lifesaving in case an emergency situation arises. Some of these are the following.

The oxygen supply system (Figure 1.53) is intended for life-support of the pilot during flight at high altitudes, greater than 4000 m. The system consists of a cylinder with pure (medical) oxygen compressed to very high pressure, purified of foreign substances for breathing the mixture, a reducer which reduces the gas pressure supplied to the pilot, a mask for the pilot to put on, pipelines and hose which connect the three basic elements of the system enumerated. Two visual indicators are connected to the

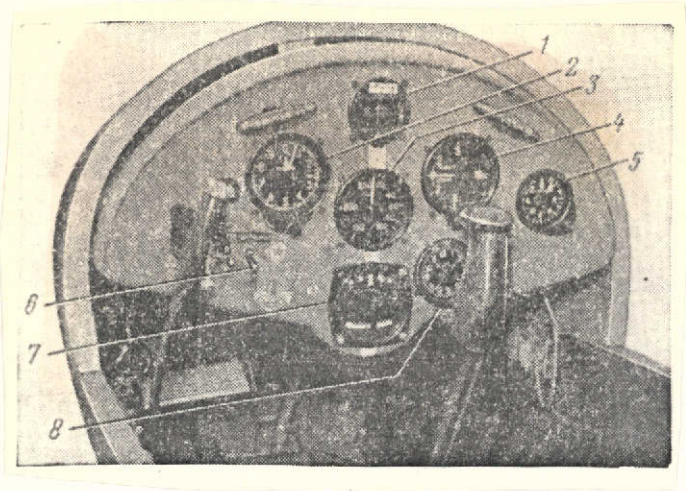

Figure 1.52. One of the Variations of Arrangement of the Instrument Panel in the Cockpit of the Glider-Soarer. The white mark on the panel is made for setting the control stick in a neutral (as to aileron deflection) position:

1--Compass; 2--Altimeter; 3--Flight speed indicator; 4--Vertical speed indicator (variometer); 5--indicator of the rate of climb; 6--Switch for life support instrument control in the system

7--Indicator of rate of turn and slip; 8--Clock; Instruments listed under 4 and 6 are mounted for test flights

system. One shows oxygen pressure in the cylinder. By its indications one can judge the quantity of gas left and consequently the amount of time for remaining at high altitude. The expenditure of oxygen depends on the altitude of the glider flight and on the construction of the oxygen reducer. Another instrument reacts to each breath of the pilot and thus shows that oxygen is being supplied normally to the mask and consequently to the breathing organs of the pilot.

A ventilating system of the cockpit (Figure 1.54) is mounted on a glider in cases where the pilot's cockpit is completely covered by a canopy. With closed cabins a constant supply of fresh air is necessary because of the small interior volume of the glider fuselage and the necessity to ventilate the cabin especially during the hot part of the day. Ventilation of the cockpit is also used for eliminating condensation on the canopy glass at low temperatures of exterior air.

By using a valve it is possible to open a special aperture through which air flows into the glider. Removing air from the cockpit usually is done through multiple slits and apertures which are in /53 the fuselage of a glider in areas where the wings, tail unit and landing gear are attached.

The lifesaving system for a glider crew is a mechanism for emergency ejection of the cockpit canopy and the rescue parachute of the pilot. The ejection mechanism permits the pilot by one or two movements of the control to eject the cockpit canopy and thus provide the pilot with an emergency exit from the glider (Figure 1.55).

Emergency parachutes with special devices provide fast

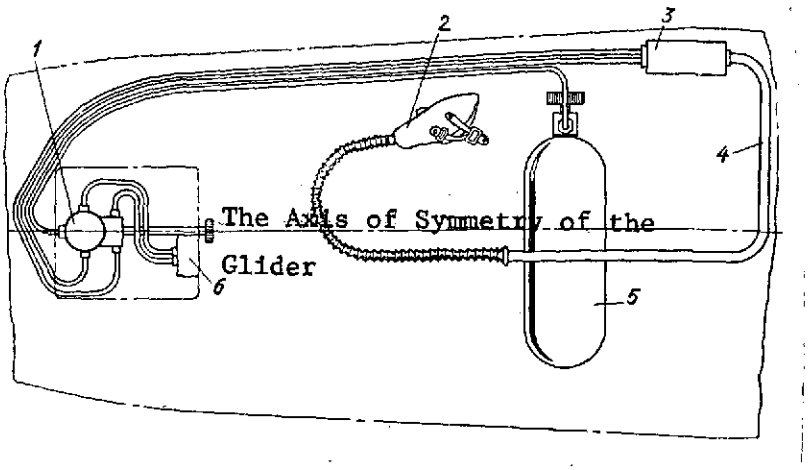

Figure 1.53. A Diagram of Oxygen Supply for the Pilot on a Glider:

1--Oxygen reducer; 2--Oxygen mask; 3--Oxygen instrument; 4--Oxygen hose; 5--Oxygen cylinder (4 ℓ); 6--Oxygen indicator. Key: A. The axis of symmetry of the glider.

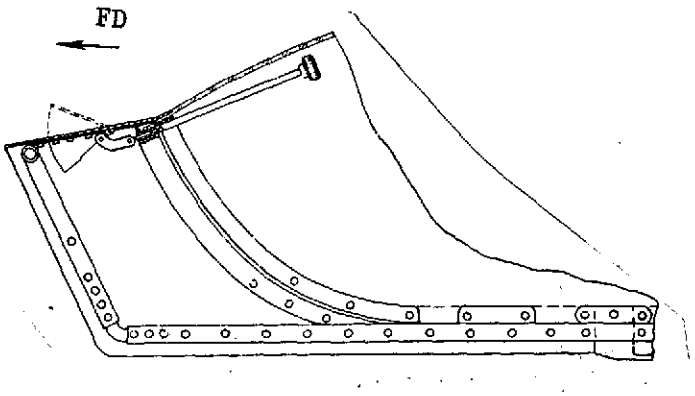

Figure 1.54. Ventilating System of a Glider Cabin

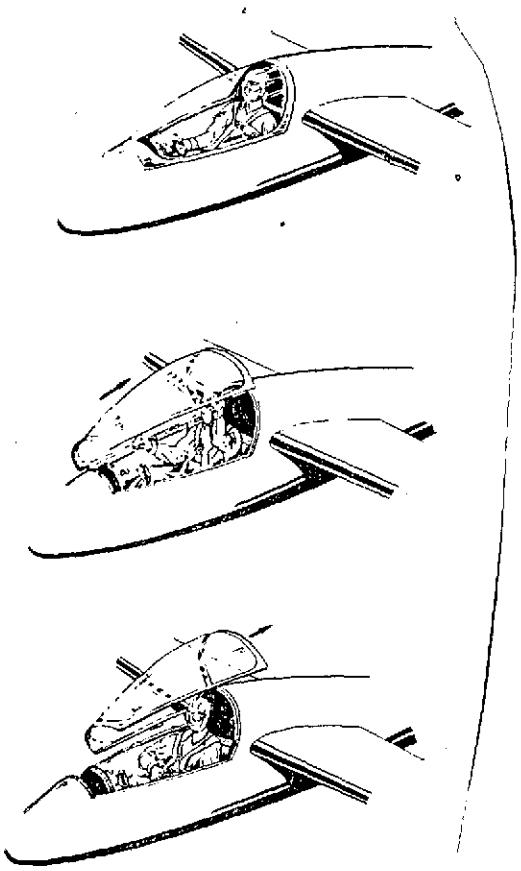

Figure 1.55. Emergency Ejection of the Cockpit Canopy of the Glider

dependable opening at a moment determined by the pilot. The emergency parachutes used for flights on gliders are as a rule "on-the-back" (Figures 1.56 and 1.57).

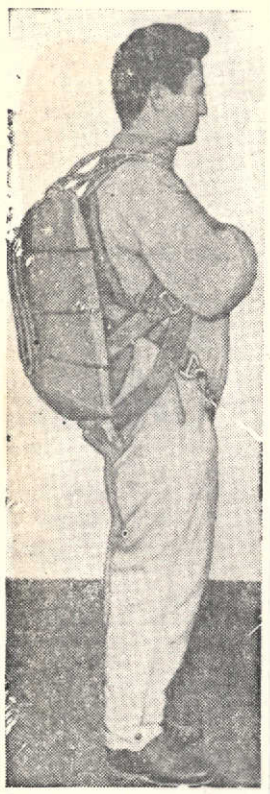

Figure 1.56 Type of Emergency Parachute Used on Gliders. The parachute pack is attached to the pilot's back to decrease the required height of the cabin.

Figure 1.57. Operation of a Lifesaving System (Training Jump)

The use of parachutes on the back is due to the fact that the structural height of the glider cabin is low and its length has comparatively free dimensions which permit placing the parachute here without increasing the length of the fuselage of the glider for this reason (Figure 1.58).

Among the systems and devices which increase the safety of flights, there is also a system of safety belts with which the pilot can strap himself securely into the cabin, which are not only

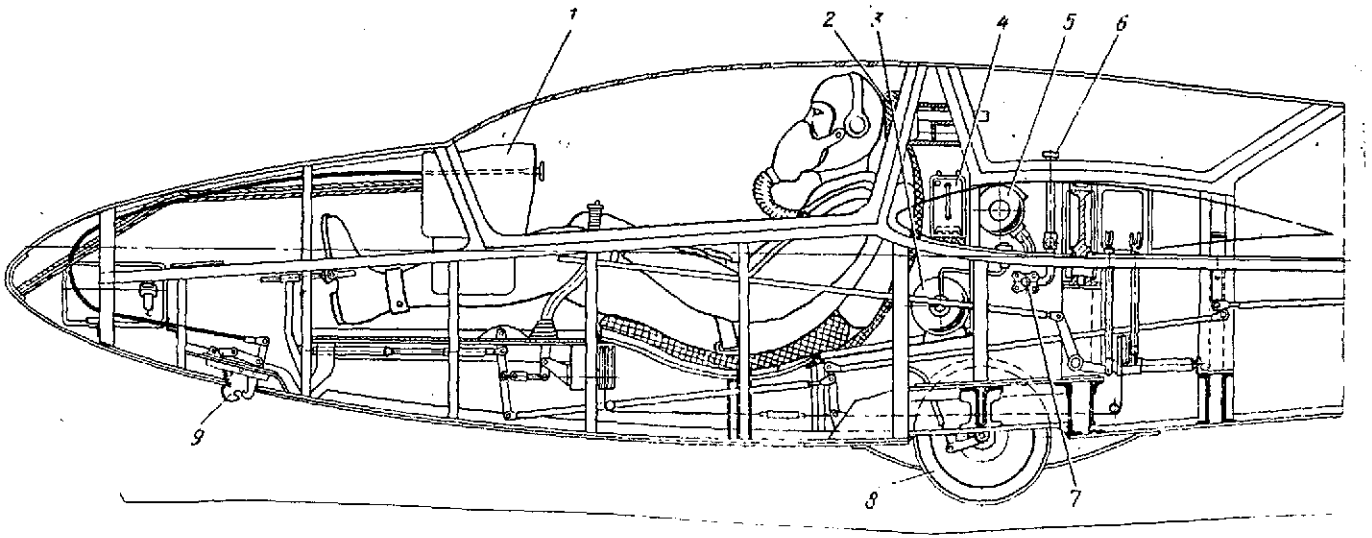

Figure 1.58. Position of the Pilot in the Cabin of a Modern Glider: 1--Instrument panel; 2--Headrest; 3--Oxygen cylinder; 4--Barograph; 5--Oxygen instrument; 6--Pouring mouth; 7--Overflow valve for water ballast; 8--Brake wheel; 9--Towing Lock.

/57

safe but from which he can quickly free himself if it is necessary /54
to escape from the glider. The safety belt system consists of the belts attached to strong elements of the fuselage and joined in one compact lock which takes the pilot a minimum of time and strength to operate (Figure 1.59).

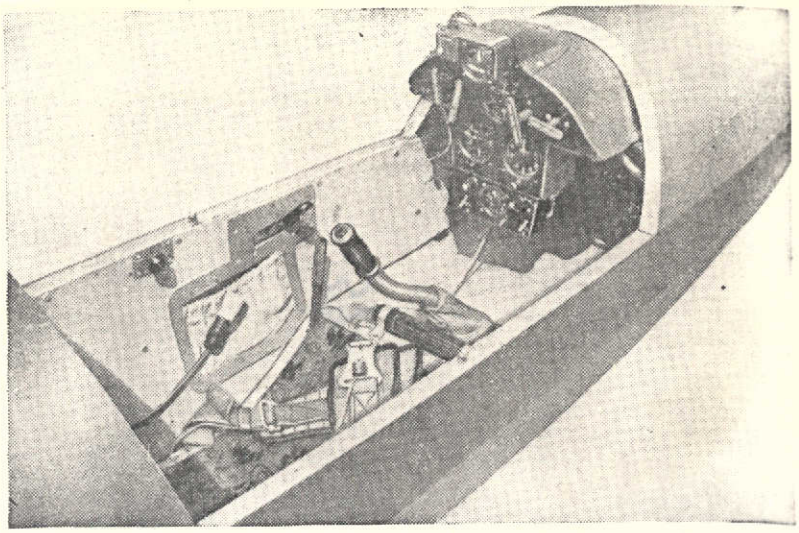

Figure 1.59. Interior View of the Pilot's Cockpit. The lock of the safety belt system is visible.

In the glider cockpit there are three more systems which are intended, respectively, for controlling the towing lock, for retracting and lowering the landing gear and for ejecting water ballast (Figures 1.60, 1.61. 1.62).

Modern gliders in most cases are equipped with radio communication systems which permit the pilot to have a two-sided conversation with a command post on Earth and with gliders in the air. These receiver-transmitter radio stations are installed not only on gliders flying for long distance flights and at high altitudes but also on training aircraft including gliders for basic training. The use of radio stations on board is obvious.

The absence of power sources for electric supply on board a glider limits radio activity. And at altitudes 5--7 km it is effective only for approximately 100 km.

Finally, among the so-called "permanent" systems, that is, systems which are permanently connected to the structure of the glider and its operation, it is necessary to include an electrical /56
system. Supplying energy to a glider is one of the most acute problems which a designer has to solve when designing and building engineless aircraft in general and sport gliders in particular. The absence of power units on board the glider and the requirements

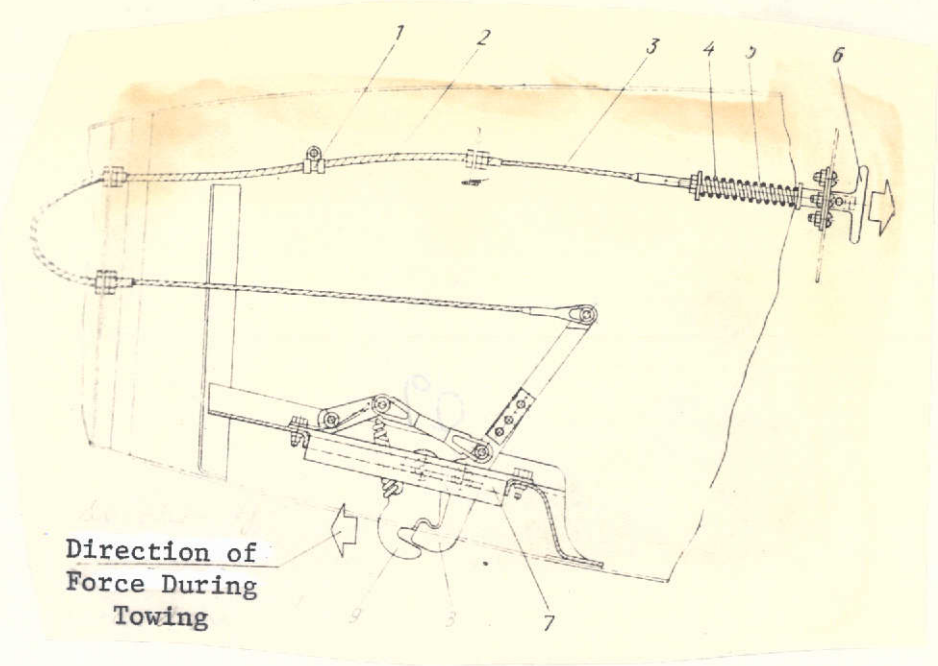

Figure 1.60. Diagram of the Towing Lock Control

1--Clamp; 2--Bowden sheath; 3--Cable; 4--Homing spring; 5--Rod; 6--Lever for opening the lock; 7--Towing lock; 8--Stop; 9--Hook.

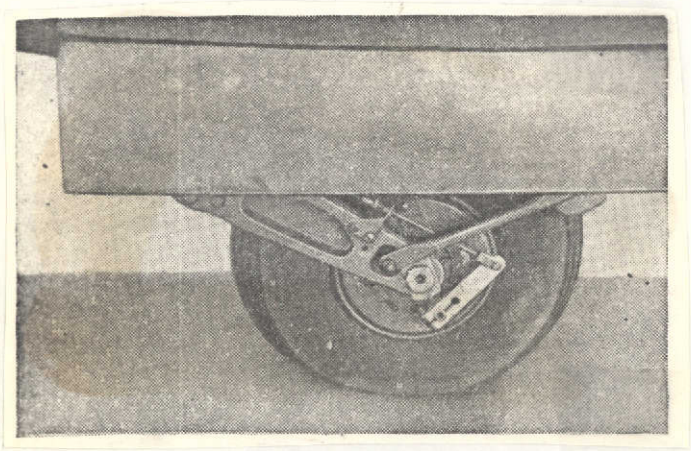

Figure 1.61. Glider Landing Gear With Brake Wheel Retractable in Flight

not to exceed its flight mass above a size determined by the operational task make it very difficult to provide energy in engineless flight. But energy is necessary for a number of requirements on board: for putting into operation gyroscopic mechanisms as indicators of turn and in the gyrohorizon for warming the pitot-static head (PSH) which operates the most important instruments (the airspeed and altitude indicators), for supplying the radio equipment, aircraft navigation lights (for night flights). Besides the regular requirements for electrical energy on a glider there is the control-recording system equipment (CRE) for recording air pressure in flight, deviation in control mechanisms, rate of rotation of the glider

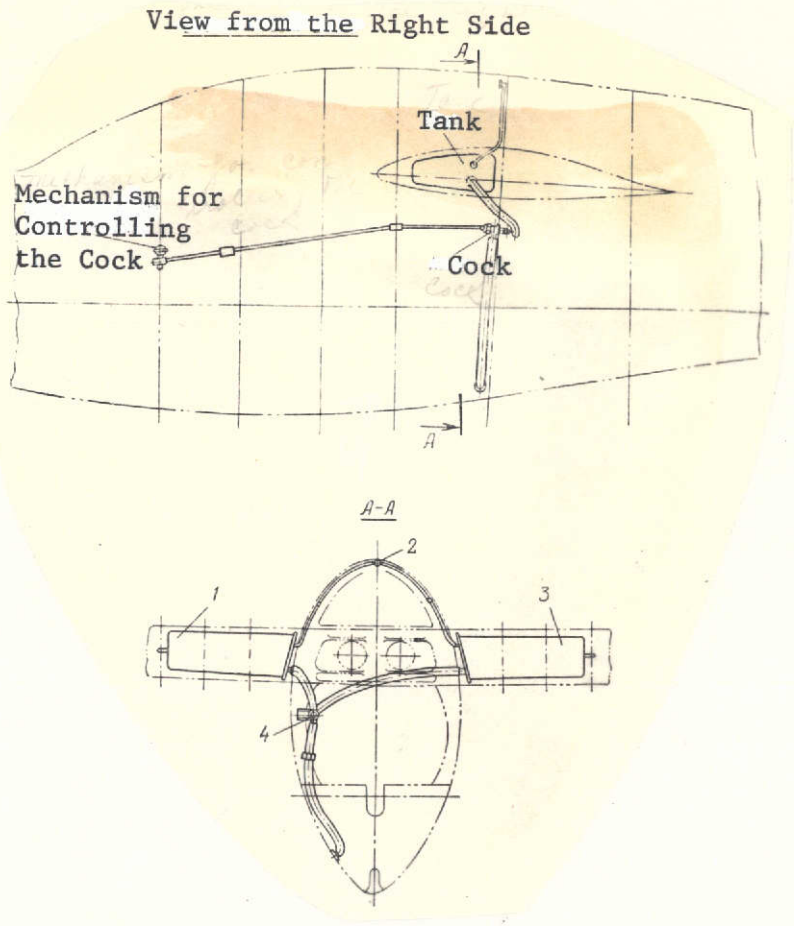

Figure 1.62. Diagram of the Location and Control of Water Ballast on a Glider:

1--Right tank; 2--Valve; 3--Left tank; 4--Cock

in a number of other parameters. CRE involves a single special electrical system with corresponding recorders.

The system of control measuring devices must be mounted on a glider during its test flights. After these are finished they are removed.

All of this multiple family of instruments and devices are supplied by electrical energy from a battery on board; its considerable weight, unfortunately, is a necessary and constant addition to the overall flight weight of the glider.

Of course not all gliders have a full complex of the enumerated electrical energy consumers. Thus, on a basic training glider not equipped with radio receiver and having as a rule only

an airspeed indicator, turn and slip indicator, variometer and altimeter, there is usually no electrical supply system mounted.[5] /58 Gliders used for soaring flight which involves long periods of time, distance and high altitude, have many requirements for electrical energy. Therefore such gliders must always be equipped with an electrical supply system.

Thus, modern gliders are comparatively complex aircraft, whose reliable operation can be provided with precise knowledge of the structure of the glider and all its systems both by pilots and by service personnel. Only such knowledge and skill in operating a glider can provide successful solution of an operational task of a given glider and safety in flight. It is natural that the role of the designer who creates the glider and equips it with certain systems is very great, inasmuch as the perfection of structural arrangement depends on him and this means the degree of reliability of operation of the glider as a whole and simplicity of controlling its movement in an extremely varied practical conditions of flight which can be very complex.

A description of a glider would not be complete without indicating the equipment for transporting it on the ground. Because landing without an airfield is natural for a glider, its operation uses appropriate equipment with which the glider in /60 partially dismantled state can be quickly returned to the airfield. Such equipment is as a rule some type of cart, towed by a vehicle. One such trailer is the "gun carriage" type shown in Figure 1.63.

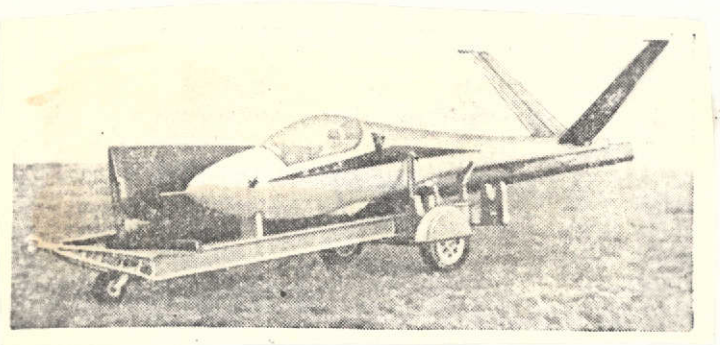

Figure 1.63. The Glider with Wings Disassembled, Mounted on a Transport Cart Which is Made in the Shape of a Gun Carrier

1.2.4. Arrangement of Mass of a Glider

Rational distribution of mass of all elements of the structure, the equipment and load is directly involved in the arrangement of the glider. So that the glider can successfully use controlled movement in space, its center of mass must always be located in a /61 certain position in relation to the mean aerodynamic chord of the wing. This

[5]In this case the gyroscope of the turn indicator gathers speed from a stream of air fed from a special intake of airflow, and there is no PSH heating.

requirement limits the possibilities of the designer when arranging a glider, both from the point of view that distributing the mass of the structural elements of the glider is predetermined by strength requirements, and on the other hand a number of elements of load primarily the pilot (his weight amounts to 20--40% of the flight weight of the glider) must be located, due to conditions not directly connected to the requirements of the position of the center of mass of the glider as a whole.

One way or another, the position of the center of mass of a glider with various variations of its loading is the object of intense attention by both designer and pilot because the actual position of the center of mass of a glider and any change in its position is always strictly regulated and must be held within certain limits.

1.2.5. The Aerodynamic Aspect of Arranging the Glider

The correct selection of aerodynamic shapes of its separate parts (wings, fuselage, tail, lift augmentation devices etc.) according to the operational task posed and the possibilities of combining them optimally, reducing additional harmful resistances to a minimum, that is their negative effect in relation to aerodynamic quality is of main importance in the makeup of a glider from the point of view of its aerodynamics. The shape of the airfoil is of greatest importance in the elements of make-up of a glider from the point of view of its aerodynamics. The selection of the airfoil is one of the most important design questions; the success of creating a glider from the point of view of the possibilities of solving a certain operational task depends on the correct solution of this problem. Based on the requirements /62 of aerodynamics, in a number of cases a glider wing has several profiles which transfer smoothly one from the other as one moves from the fuselage toward the wing tip.

Shape and dimensions in plan form (in particular, extension and contraction) are elements of the make-up of the wing from the point of view of its aerodynamics; also the shape and position of the lift augmentation devices--ailerons, flaps and spoilers. Questions of arrangement of lift augmentation devices include the selection of the length and chord of the aileron and flap, which type, the position of the spoilers on the wing span and the wing chord etc.

The shape of a cross section of the fuselage and position along its length, the shape of the cockpit canopy, the profiles of horizontal and vertical tail units, the shape and position of the tail relative to the wing and fuselage are also elements of aerodynamic arrangement. Not only attaining the planned flight data of a glider but also in general the capability for safe

operation in the glider also depends on correct selection.

The shape of transition of one part of the glider to another, for example, the area of the butt joints of wing and tail with the fuselage play a very important role in the make-up of the glider. A change in the character of streamlining connected with the shape of areas for joining parts of the glider is called interferences. A decrease of additional drag caused by interferences is facilitated by efficient joining of parts of the glider and use of a different type of streamlined housing and "fairings." Figure 1.64 gives an example of an arrangement of a glider which /63 has been well worked out aerodynamically.

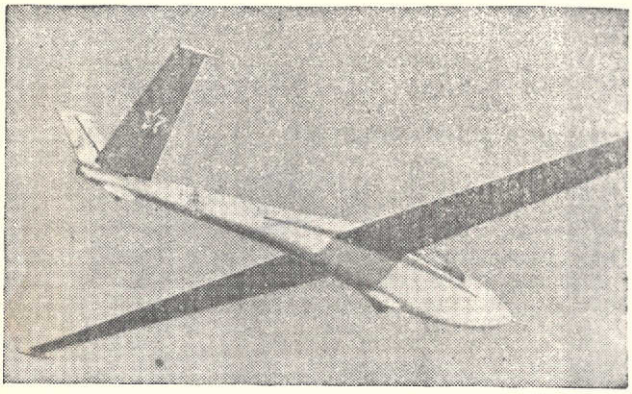

Figure 1.64. General View of a Glider with Good Aerodynamic Arrangement, in Which the Butt Joint Wing and Fuselage Does Not Require 'Fairings"

1.2.6. Materials from Which Gliders are Built

Twenty or thirty years ago most gliders were built of wood: pine, birch veneer and plywood. The assemblies for mounting separate parts and units of the glider and control systems were made of metal--mainly sheet steel, steel wire, steel cable and duralumin pipe. At the present time the assortment of materials used in glider construction is considerably broader.

Now many gliders are made entirely of metal. In this case all the support elements such as the edges of wing spars, longitudinal and lateral framing of the wing body, the fuselage and tail, and also glider skins are made from hard aluminum alloy sheet. The assembly units are mainly made from steel but because of the large loads which many modern gliders must support here the steel used is high-strength.

In recent years so-called composition materials have been widely used. Some of these are glass fiber and plastic reinforced with metal. Cellular amd foam fillers have attained wide use because one can successfully make very light, strong and rigid panels from wing skins and they can be used with the required degree of accuracy for enclosing wings, fuselage and tail units.

In characterizing these three groups of materials one should point out their basic advantages and disadvantages.

Wood is very convenient for manufacture and repair, is not

long lasting and requires careful observation of storage rules so that it will withstand the processes of decay, drying out and aging of glued joints.

Metal is a very long-lasting material which does not require such careful storage as wood. The use of metal is suitable from the point of view of the weight load which under modern conditions of glider building requires construction of engineless aircraft with very high strength and lightness simultaneously; it is therefore a very valuable property in this material. As to production processes, metal when building gliders in factories is as convenient as wood. However when glidermen make the gliders themselves as during repair, done in field conditions, metal is less convenient than wood.

Using plastic is especially advantageous when conditions require high precision for the exterior covering of a glider specified by certain designers. The modern level of technology /64
in building gliders using plastics and various glued non-metallic structures permits successful use of these materials both in factory production and under field conditions.

However, one should note that the answer to the question of which material is more suitable to use when building a glider from the point of view of strength, durability, cost and simplicity of production processes must be the intelligent complex use of many known and tested materials--metal, wood, plastic, composition materials each to a certain degree and in a certain structure, parts, units, where a given material will be the most suitable.

The method of improving the structure of a glider lies, obviously, in the complex utilization of various materials taking into account the advantages and disadvantages of each of them. Then each unit of the glider must be made from that material or those materials which provide its best operation with economy in weight. This means that the load ratio of the entire structure of the glider with the proper strength becomes larger.

1.3. The Medium in Which Glider Flight Occurs

The second of the three basic elements which determine glider flight is the medium in which the flight occurs. Such a medium for a glider is the Earth's atmosphere, that is, the air covering which surrounds our planet and besides this the layers which lie closest to the Earth's surface.

The range of altitudes of glider flight are comparatively great. The upper boundary of possible flights of engineless aircraft are determined by two basic conditions. In the first place,

the density of the air, because it determines (at specified air speeds of a glider) the size of aerodynamic resistance which is necessary for equalizing the weight of the aircraft. In the second place, the presence of kinetic energy in the atmosphere, the utilization of which allows the glider to maintain flight altitude at a certain level. This boundary of possible and actual altitudes of flight for sport and certain other experimental gliders is limited to about 15--20 km. We note that the maximum altitude attainable in free engineless (that is not on a tow) flight, consists of a little more than 14 km. At this time it is already known that a vertical change in air mass, that is, rising air flow, can permit a glider to ascend without using a tow to an altitude up to 20 km. Truly, attaining such altitudes and remaining under these conditions involves a whole series of still unsolved problems and primarily these involve the problems of life support and power supply for the crew and systems on board the glider. The solution of these problems is a matter /65 of time. The chief conditions of engineless flight up to 20 km (that is, the various phenomena of energy of the atmosphere, in particular the ascending air flow and its adequate density) are already established. Below we will look at the structure and basic physical properties of the atmosphere at altitudes from 0 to 20 km.

1.3.1. The Physical Properties of Air

The physical characteristics (properties) of air are those properties which are not involved with changes in its composition. And it is exactly these physical properties of the air which are of primary importance for engineless flight.

Weight of Air

One of the basic properties of air is its weight. This property is a phenomenon of the effect of the Earth's gravitation which is a result of interaction of two material bodies--the air and Earth.

The weight of air enclosed in a unit of volume, as is known has a specific weight. It is expressed by the relationship of the weight of a specified volume of air to its volume:

$$\gamma=\frac{G}{v},$$

where γ--is the specific weight in N/m^3, G--the weight of air in N, enclosed in volume v expressed in m^3.

The Capability of Air to Exert Pressure

The upper layers of air press on the lower and in the final

analysis on the surface of the earth under which these layers lie. Moreover, the molecules of air which are in continuous chaotic movement striking on the surface of a body in their path, also exert pressure on it. The total pressure of the air is a result of this interaction on the surface of the body and of molecular blows, and is called static atmospheric pressure. It is measured as a weight of specific size, in particular, the force affecting an area of 1 m^3.

Inertia of Air

Inertia of air is its capability to preserve the state of movement (relative quiet).

The measure of inertness of air is its mass.

The mass of air which is in the space around the Earth's surface is distributed unevenly.

Because of unequal distribution of the mass of air over the Earth's surface its measure of inertia is also varied at different points in altitude in the air space in which glider flight occurs. /66

It is more convenient to work with the parameter of inertia paying attention not to mass in general but only to that part which is limited to a unit of volume. Thus, we introduce the concept of density which is the relationship of the mass of a certain volume of air to its volume:

$$\rho=\frac{m}{v}$$

where ρ --is the density of air having dimensions kg/m^3, m--is the mass of air in kg enclosed in volume v expressed in m^3.

Utilizing the ratio between weight and mass of the body and by accelerating the Earth's gravitation, we can express the ratio between specific weight and density of air as

$$\rho=\frac{\gamma}{g},$$

where g--is acceleration imparted to the air, like any other physical body, by the force of the Earth's gravitation. The size g will be considered constant which in the case of a glider flight does not lead to noticeable error (g=9.81 m/s^2). The density of air is very important when determining a number of important parameters of movement of a glider primarily speed and altitude of its flight. There is still another value which is widely used when determining various characteristics of glider movement and composition of the atmosphere. This value is the relationship of density to two different altitudes. One of these densities is assumed as the base (initial, for example, density

at sea level), and the other--current, corresponding for example to the actual altitude H of glider flight.

The relative density of air is expressed by the symbol Δ and equals

$$\Delta = \frac{\rho_H}{\rho_o},$$

where Δ--is relative density of dimensionless size; ρ_H and ρ_o-- are specific densities of air corresponding to current and base altitudes.

The Capability of Air to Absorb and Give Off Heat

One of the most important properties of air is its capability to absorb and give off heat, that is, to heat up or cool down when coming into contact with other bodies. As a result of this, in particular, heat (thermal) currents are formed, the so-called /67 "thermals" which are one of the basic means of facilitating glider flight without losing or gaining altitude during a long period of time.

The peculiarity of air is that it heats up, mainly not by direct penetration of the sun's rays but as a result of heat exchange with the Earth's surface which is heated to a greater degree than the transparent air. Because the character of its surface is very different due to the presence of vegetation, water areas, various types of soil and shapes of the surface (ravines, hills, mountains), thermal air flow is varied in structure and intensity. The degree of heating up of the air expressed in the intensity of chaotic movement of its molecules, is directly proportional to the quantity of heat in a given volume of air, and is measured as air temperature. Thus, a rise in temperature also takes on importance when looking at glider flight.

Air Viscosity

Air has a property called viscosity. This property is expressed in the capability of air to resist the reciprocal transfer of adjacent layers or a layer of air lying next to the surface of another body (for example, the earth's surface, or the surface of a glider).

The forces of viscosity or the forces of internal friction are "harmful" forces from the point of view of the possibility of moving a glider in the air medium surrounding it.

Viscosity μ (dynamic) is a force which acts on a unit of surface and parallel to it with relative speed of movement of adjacent speeds, also equal to a unit. The dimensions of μ equal

$$[\mu]=\frac{N\cdot s}{m^2}.$$

In cases where it is necessary to compare the viscosity of air with the forces of its inertia, depending as was shown earlier on density, one introduces the concept of kinematic viscosity. The kinematic viscosity of air is thus connected to density and equals

$$\nu=\frac{\mu}{\rho}\ m^2/s.$$

This coefficient is very important when looking at methods of comparing the characteristics of glider flight in differing atmospheric conditions.

Air Humidity /68

This property of air consists of its capability to absorb water vapors. The humidity of air to a large degree affects meteorological circumstances associated with glider flight and to a lesser degree its flying characteristics.

The energy characteristic of the atmosphere is directly connected to the humidity of air. Therefore, knowledge of the substance of its properties, such as the dynamics and reasons for its changes, are necessary for looking at free glider flight.

Air humidity can be measured. The weight of a quantity of water vapor contained in one cubic meter of air is called absolute humidity. Relative humidity is the percent ratio of absolute humidity (actual) to humidity which is fully absorbed by a given volume of air at actual temperature and pressure.

Relative air humidity is a more complete characteristic of its moisture that absolute.

Air Compressability

The property of compressing includes the capability of air to change its volume, and this means density when measuring pressure and temperature.

Compressability of air is characterized by the relationship of its density Δ_ρ to the corresponding change of static pressure

Δp. Thus, compressability can be expressed in the following way:

$$\text{compressability} = \frac{\Delta \rho}{\Delta p}.$$

If, as a result of any cause, at a given point in space pressure and density of the air are changed then these changes ($\Delta \phi$ and Δp) are transmitted to neighboring points in space and thus, pressure and density in all of space or in a given volume of air have a tendency to equalize.

One of the reasons for change in density and pressure of air, that is, manifestations of its properties to compress, can, under certain conditions, be the movement of a glider in it. As is known, the process of propagation of not large, (small) changes (turbulences) of pressure is the process of propagation of a sound wave.

Compressability of air always affects the character of the streamline flow of a body (except for cases where the rate of movement of the source equals 0) and therefore must be looked at in principle as one of the most essential (in those for glider flight) properties of the atmosphere.

The degree of compressability of air, and this means, the degree of effect and compressability on the character of streamline flow of the body, is the speed of propagation of sound. The effect /69 of compressability of air begins to affect the character of movement of a glider when the relative speed equals one half the speed of sound. One can say that the speed of a glider, which can be attained practically at the present time, is so far from the speed of sound that there is no need to concern one's self with calculating compressability for glider flight. But if this judgement is true for comparatively low altitudes, then during flights in the stratosphere (and the record altitude at the present time is more than 14,000 m) when the practical attainable speeds of glider flight amount to 250--300 km/hour according to instruments, the actual speed relative to the air can amount to 0.55--0.66 of the speed of sound. And this is substantial. But we will discuss flights in the stratosphere in more detail below.

Transparency of Air

There is yet another property of air which does not directly affect the characteristics of movement of a glider but which is very important from the point of view of successful completion and safety in flight. This property is the capability of air to contain in suspended state a certain quantity of non-transparent particles of dust, water or ice. The presence in air of these particles makes the air non-transparent to a certain degree, that is it limits visability of external reference points by which the

pilot checks the spatial position of the glider and the flight path.

The degree of transparency of air is measured by distances at which the pilot can see external reference points, including the horizon.

1.3.2. The Structure and Basic Characteristics of the Troposphere And Lower Layers of the Stratosphere in Which Glider Flights Occur

Troposphere

The layer of air directly surrounding the earth and extending in central latitudes to altitudes of 11 km, and over the poles and equator, respectively, up to 7--8 and 16--18 km is called the troposphere. This variation in altitude at which the upper boundary of the troposphere is located is explained by the effect on the air mass of centrifugal forces which occur during the Earth's rotation and the thermal state of the air mass affected mainly by heating of the Earth's surface (and this means geographic latitudes, time of day and year) and the character of its surface, which is called "underlying."

One of the most characteristic properties of the troposphere is the presence in it of air currents which vary in direction in space and in force, that is, winds caused by inequality /70 in pressure and temperature distribution in the entire air space. The cause of vertical or sloped direction of movement of the air mass is uneveness--hills and valleys over which the air flows.

Another equally important property for glider flights in the troposphere is the concentration in this air space of practically all the water vapor which is contained in the air covering of Earth.

These properties result in the kinetic energy of the atmosphere which is used at the present time for executing lengthy, long term and high altitude engineless flights. The troposphere is the densest layer of the atmosphere and the most contaminated. Moreover, it is naturally the first and consequently has to be the field in which all glider flights begin and end; and most flights occur entirely in this field.

Then the troposphere is the region of the atmosphere in which the manifestation of all its properties is very active. During a flight in the troposphere a glider is subject to sharp, and in many cases unexpected to the pilot, shifts in the external conditions of the flight which can result in complicating the control of glider movement and make it difficult to carry out the flight in its entirety.

Stratosphere

The layer of Earth which begins over the troposphere and extends to altitudes approximately 80 km is called the stratosphere. We note that between the troposphere and the stratosphere there exists a small intermediate layer of air called the tropopause. Its properties are close naturally to the properties of the layers closest to it, that is the properties of the troposphere and stratosphere.

Due to the fact that in the altitude interval covered by the stratosphere (and more so at low altitudes of 11--20 km of interest to us) its properties, including pressure and density change insignificantly, glider flight occurs in comparatively stable conditions.

One of the properties of the stratosphere which is of interest for engineless flight is the presence of well regulated jet streams (very strong horizontal winds) which are located as a rule at altitudes of 10--12 km with significant (up to 200 and 300 km/hour) speeds of movement of the air masses.

Another property of the stratosphere, like the troposphere, is wave movement of the air.

Standardized Atmosphere

The multitude of different properties of the atmosphere and the endless quantity of actual atmospheric conditions are the reason that actual or projected aircraft with uniform precedures of actual or calculated flights carried out at different times and in various geographical locations can have different characteristics. These characteristics cannot be compared. /71

However, if a comparison were possible it would be difficult to say which aircraft and in what relationship would be better or worse than the others.

In order to make it possible to compare characteristics of aircraft obtained in varying atmospheric conditions, a model of the atmosphere is created which is not identical but close to the basic characteristics of the atmosphere at central latitudes with average temperature conditions. With the help of this model, one can more accurately adopt a standard for systems of initial data and principles of their change depending on altitude, and also by utilizing established methods of calculation one can reduce the characteristics of aircraft obtained under actual conditions to the conditions of this standardized atmosphere and compare them with each other. This artificial model of the atmosphere at the present time has been adopted as a standard

for many countries of the world and therefore is considered an international standard for atmosphere (ISA). In the USSR, ISA is presented in the All-Union Standard of GOST [All-Union State Standard] 4401--64.

The standardized atmosphere is presented in the form of graphs with tables which contain the meaning of a number of basic parameters which characterize this atmosphere at different altitudes [34].

1.3.3. Energy of the Atmosphere

As was shown earlier, the flight of a glider demands a certain quantity of energy. One of its parts is potential energy which a glider acquires after reaching altitude during launching. Another part consists of the kinetic energy of the atmosphere, used by the pilot to decrease vertical speed of required relative descent, carry out flight without loss of absolute altitude or even increase it.

Almost all of the phenomena which occur in the atmosphere develop, in the final analysis, due to the radiation energy of the Sun.

The most important effect of the Sun's energy on the atmosphere for glider flight, is the transmission of heat to it. The thermal effect of the sun on the air occurs basically not directly but by preliminary heating of the earth's (and water) surface, from which heat is transferred to the layers of air lying closest to /72 it and then is propagated to the entire volume by convection.

Inasmuch as, these days, for glider flights one directly utilizes only the kinetic energy of the atmosphere for reaching and maintaining altitude let us look at only two of its phenomena, namely, the vertical flow of air and its horizontal movement. The vertical flow of air can occur, be equalized and disappear as a result of two basic causes: thermal and dynamic. We immediately note that in the final analysis the thermal effect of Sun on Earth and air is the basis of dynamic causes for the phenomenon of kinetic energy of the Earth's atmosphere. We will look in more detail at the separately ascending currents connected directly with the thermal effect of the sun's radiation on Earth, and the ascending air currents caused by horizontal shifts of the air mass when encountering obstacles on the Earth's surface. Variation in heating the underlying surfaces is explained by the unequal heating of the layer of air around the Earth which in turn causes so-called convection transfer of the air mass vertically. Convection occurs on the Earth's surface in the form of small vertical directional streams which can be connected in a powerful ascending current which occupies a comparatively large area and expands

under certain conditions to the boundary of the troposphere /73
(Figures 1.65 and 1.66).

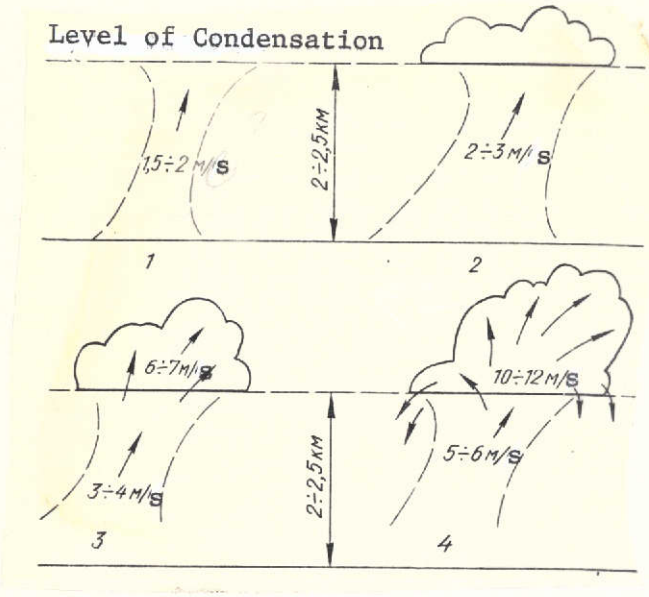

Figure 1.65. The Formation and Growth of Thermal Currents and Cumulus Clouds

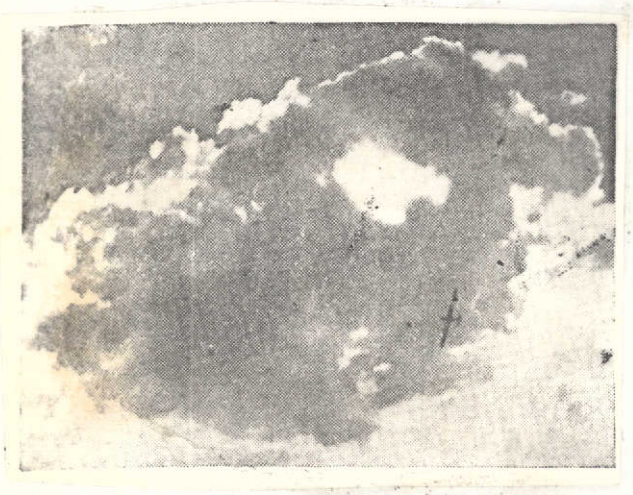

Figure 1.66. A View from Below of the Powerful Development of Cumulus Clouds Whose Ascending Current is Very Strong

If there are not favorable conditions for such development, the currents cannot exist vertically. However, the presence of convective movement of the air masses always makes the air mass turbulent and creates a so-called "bumpiness," whose intensity can be very great.

The speed of vertical movement of air depends on the difference in temperatures of it and the surrounding mass, and also on the degree of change of temperature with change in altitude, that is, on the vertical temperature gradient. Moreover, both the vertical shift of the air mass itself and its speed depend on the degree of stability of an air mass.

If air temperature decreases as it ascends to a lesser degree than the decrease in the surrounding air, the state of the rising air will be unstable. This causes an increase in the speed of the ascending current. When the condensation level is reached potential heat is given off and the rising air mass is heated. The heat prolongs its rise even with increased speed. This is why inside cumulus clouds one observes ascending currents which exceed by far the speed of vertical flow formed outside the clouds.

Naturally it is possible to have a stable equilibrium of the layer of air when the difference in temperature of the ascending air and the layers surrounding it is decreased (with altitude). In these conditions, the ascending air currents which occur do not have a tendency to expand. /74

Thermal air currents both outside and inside clouds are of

interest to glider flight,

Ascending air currents also have a frontal origin. In this case, kinetic energy occurs not only in the form of ascending air currents of warm air before a storm front, but also in the form of strong wind which moves the whole mass along the Earth's surface (Figure 1.67).

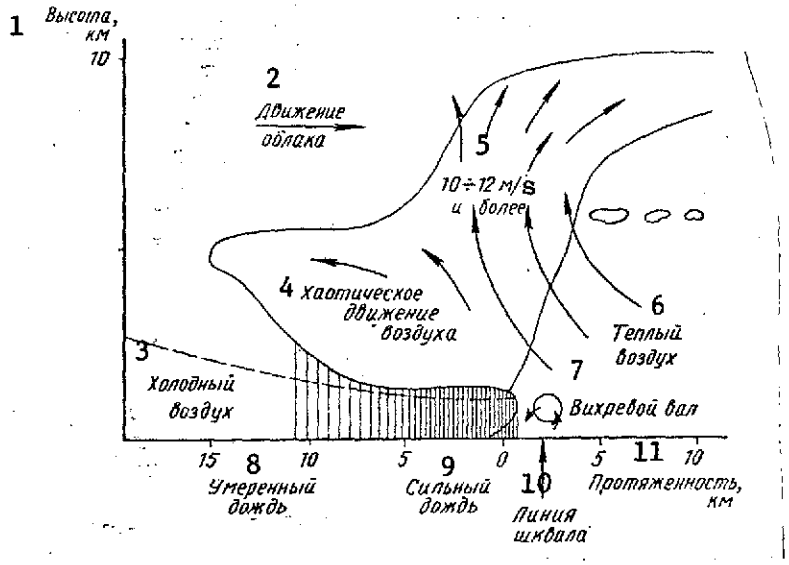

Figure 1.67. A Diagram of a Cold Front Storm Cloud

Key: 1--Altitude, km; 2--Movement of the cloud; 3--Cold air; 4--Chaotic movement of air; 5--And more; 6--Warm air; 7--Turbulent vortex; 8--Average rain; 9--Strong rain; 10--Squall; 11--Extent, km

Thermal ascending currents occur and extend also when rocky mountain slopes are heated by the Sun and with the additional effect on them of wind blowing over the slopes of the mountains. These currents are propagated up to altitudes of 6--7 km. But at present for soaring flight they are utilized only by birds.

Dynamic vertical airflows usually mean those movements of air which occur when flowing air masses, moving along the earth's surface, encounter any kind of more or less significant obstacle.

Horizontal movements of air masses (winds) occur, equalize and die away as a result of unequal distribution (in horizontal directions) of the atmospheric (static) pressure.

The simplest use of wind can be a location where air moves horizontally, acquires a vertical component of speed when flowing /75

over any kind of obstacle.

If these obstacles are adequately large, and the wind strong, then the vertical component of wind speed, that is, part of its kinetic energy, can be utilized for maintaining a glider at a certain flight altitude or lifting it to a higher altitude (Figure 1.68).

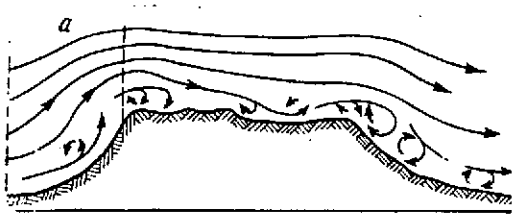

Figure 1.68. A Diagram of the Flow of an Air Current Over an Obstacle and the Formation of a Zone (a) of Ascending Air Currents

A more complex type of transfer of horizontal wind in a vertical air current are the so-called stationary waves. The mechanism for their formation includes the following. When large air masses moving at high speeds encounter mountain crests and ridges, an overflow of air current occurs over the tops of these protuberances. The speed of the air currents over the crest increases and pressure in it decreases. As a result of this, the upper layers of the air current drop somewhat to the mountains and are heated. Having passed the mountain, the speed of the air current decreases, the pressure in it increases and part of the air tries to move up. Such an oscillating impulse causes a wave-like movement of the air current behind the crest or ridge which gradually quiets down. Stationary waves are immovable relative to the obstacle which is the reason for their formation. The ascending part of the wave is the source of kinetic energy which is utilized by glider flight. One should note that similar wave turbulences can expand to very high altitudes, considerably exceeding the lower boundary of the stratosphere. Then vertical speeds of movement of air masses can reach several tens of meters per second.

The presence of stationary waves usually is determined by the phenomenon of lenticular clouds which form waves in the mountains as a result of condensation of vapor when the air mass rises. The height of the base or lower edge of such clouds usually is not less than 3 km, and their vertical expansion can reach 2--5 km (Figures 1.69, 1.70). /76

The wind, which causes stationary waves, forms a number of vortexes with horizontal position of rotation axes on the leeward side flowing over an obstacle. These "rotors" in their own windward parts also have upward directional speed of air mass movement which can be utilized by pilots.

The vortical nature of rotors explains the strong turbulence within them which makes it difficult for piloting a glider. If

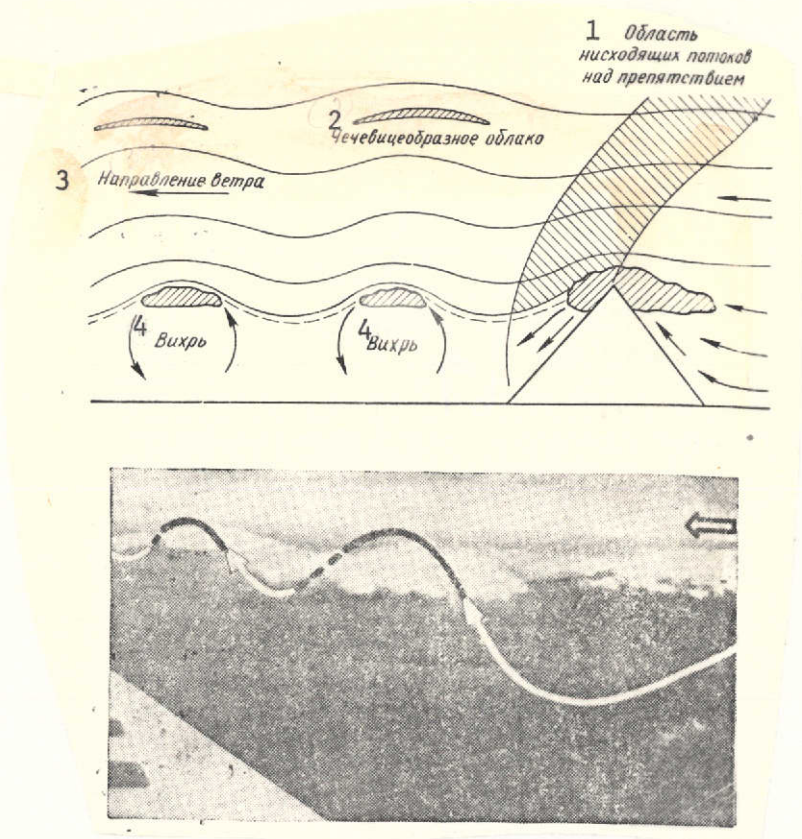

Figure 1.69. A Diagram of Formation and Shape of Stationary Waves

Key: 1--Region of descending air currents over the obstacle; 2--Lenticular cloud; 3--Wind direction; 4--Vortex

there are no lenticular clouds just as in the case of thermals without cumulus clouds it is difficult to observe waves and rotors.

There can be stationary waves over plains. The reason for their formation in such cases is a cold front or rotors which occur with varying rates of movement of two adjacent layers of air.

The phenomenon of kinetic energy of the atmosphere which in /77
principle can be utilized during flight is observed in jet streams. A jet stream can be in the form of an oblate tube undulatingly encircling the Earth's sphere. Inside this tube the winds have very high speeds. With a general direction from west to east the jet stream has local bends and turns which essentially change its general direction in certain areas. A cross section of such a jet stream is limited by its shape; in the heart of it are the highest speeds of air movement. The size of these speeds decreases from the center to the periphery and thus is subordinate to a

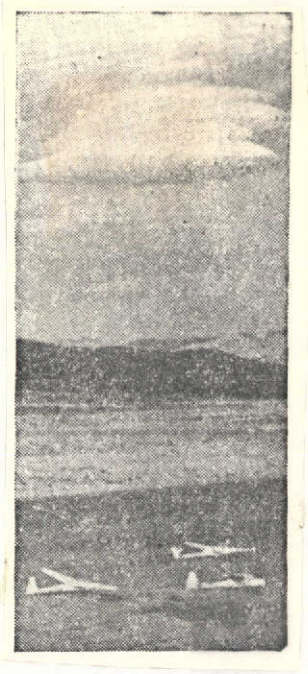

Figure 170. A Three-layer Lenticular Cloud Which Formed at the Top of a Strong Stationary Wave

certain law which can be utilized for carrying out glider flight.

Finally, let us point out one more phenomenon of kinetic energy of the atmosphere--its turbulence.

The essence of turbulence is included in the phenomenon of most ascending and descending currents or horizontal flow at varying speeds. Thanks to the viscosity of air and friction between adjacent layers or streams of air there are local votexes of air. Turbulence can be very intense, for example, in a storm cloud or inside a rotor under stationary waves. Turbulence of the atmosphere at the present time is not utilized directly for engineless flight. However, with the presence of turbulence which is perceived clearly by the pilot in a number of cases he can successfully evaluate the meteorological circumstances in a given flight region from the point of view of ascending air currents. The variable loads to which the glider's structure is subjected in flight are the chief significance of atmospheric turbulence or as it is called, "bumps." These loads can be very significant. But even if they are small, loads which are repeated many times which affect structure in flight quickly wear out a glider and therefore are a serious factor which must be considered when designing and operating a glider.

The long list of energy possibilities of the atmosphere explain the promising future for the development of long and high altitude flights in gliders and the reality of accomplishing in the future very daring concepts connected with engineless flight. /78

1.4. A Man and the Work Done By Him During Glider Flight

A man (pilot) who controls movement of the glider and is on board it is the third element in this combination which determines the possibility and reality of glider flight as a physical phenomenon.

In this section we will look at the man from the point of

view of work which he must carry out being on board the glider and controlling its movement.

Work in controlling a glider flight is done by a man and by his interaction with systems of the glider and primarily with the control system. Thus, the man himself is an element in the general (closed) system of controlling the glider. Thanks to the intelligent behavior of the man, movement of a glider in space becomes purposeful, controlled motion, that is, flight (Figure 1.71).

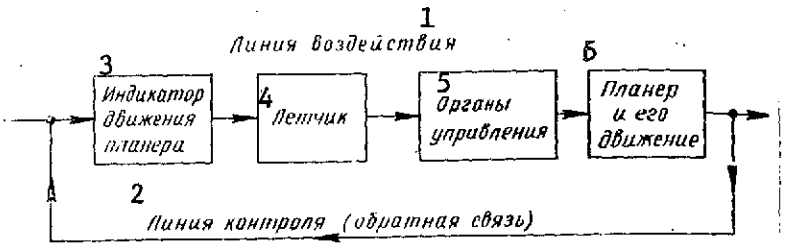

Figure 1.71. An Example of An Elementary Structural Diagram of One of the Loops of Controlling the Motion of a Glider

Key: 1--Line of action; 2--Line of control (reverse communication); 3--Indicator of the glider movement; 4--Pilot; 5--Control devices; 6--The glider and its movement

Man as a link in the control system of the glider has distinguishing characteristics in comparison with the other links of this system. In the first place, man is its most important link becuase he not only controls motion but programs it appropriately for the conditions and tasks of the flight. In the second place, limited capabilities in carrying out work on controlling glider motion are a peculiarity for man as a link in the control system as well as his universality. Therefore, so that a pilot can solve his problem for a certain glider, the glider as a whole (as a machine) must provide the pilot with the capability of simple and precise control of its motion and provide safety for accomplishing flight.

The functions of a man who controls glider flight are made up /79
of control and maintenance by him of a number of devices (systems) of the glider whose operation involves the necessary shifts and orientation of the glider in space. Moreover, besides, the functions of man in flight there is adaptation to factors associated with flight. Some of these are altitude and flight speed, the distance the glider flies, various emotions with which the pilot must deal and then, in a number of cases, suppress.

Accomplishing the entire combination of functions connected

with controlling the glider is the pilot's work done in flight. This work, thus, is determined on one hand by the characteristics of the glider itself, the conditions imposed by the operational task, the actual flight conditions, and on the other hand--the physical and psychological condition of the pilot.

The possibility and efficiency of operating the glider to a considerable degree is also determined by the glider as a machine equipped for pilot control. Even if it has very high flying and engineering characteristics these may not necessarily be realized in actual flights if the glider is not adequately equipped for pilot control. To say it another way, if the work of controlling such a glider is too great or even more if it is beyond the capabilities of a man, then realization of all the positive properties which went into the glider will be doubtful or completely impossible. Consequently, the solution of the operational task will not be complete. Moreover, emergency situations can arise which pose a threat to the entire flight and even more important to the safety of the pilot.

From what has been said it follows that the degree of equipment of a glider for pilot control can determine its controllability which is an important condition not only for the safety of flight but also for the possibility of completing it.

The functions of the pilot who controls the glider when solving an operational mission are tied to the characteristics of the glider through the concept of controllability.

Thus, controllability in addition to the capability of creating adequate lift, cruising and control forces for a given glider is an important condition for the possibility of completing the glider flight itself.

Controllability is defined as the work of a pilot which he must carry out during flight on the glider in the process of solving one or another operational task. Obviously, the more the pilot understands the glider the easier it is to control glider movement, and the less will be the fatigue the pilot suffers when controlling the glider. The easier it is to control the glider and the less pilot fatigue there is in the process of control the smaller will be the work necessary for controlling glider movement.

Let us look at the essence of a pilot's work in accomplishing glider flight.[6] /80

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[6]An analysis of the pilot's work is given in the light of positions presented in the work of N.V. Adamovich [2].

For solving an operational task it is necessary for the pilot to carry out a certain volume of work which is determined on one hand by the volume and character of the task and on the other hand by the degree of perfection of all control equipment and properties of the glider as a machine which provides the pilot with the necessary accuracy in control. The most important in the number of these properties in a glider is its stability in motion which will be discussed in more detail in Chapter 3.

The volume and character of an operational task consists of the goals of the flight, the actual mission for carrying out the flight, the equipment and conditions for facilitating it (means and methods of launching the glider, actual meteorological conditions which the pilot must utilize or avoid in flight), the time of day in which the flight will occur, its length and so forth.

The degree of perfection of control equipment during their operation in the process of glider flight determines the usability of the glider controlled by a pilot of average qualifications when solving an operational task.

The general condition of the pilot determines his capability to work. It depends on the general preparation of the pilot, that is special flying (including piloting, navigational and technical) and general physical condition and adaptability to space motion. One should also add to work capability his emotional susceptability and tendency toward illusions.

The work of a pilot when solving his mission is made up of a number of actions necessary for controlling glider motion.

The work of a pilot in the process of solving an operational task is extremely varied. Nevertheless all of its aspects can be combined into groups: the first group includes work expended for defining the necessary character of motion of the glider in relation to requirements of the operational task, the capabilities of the glider and external conditions of the flight. The other group combines types of pilot operation which lead to accomplishing this necessary motion of the glider.

These groups of work (defining the character of motion necessary and accomplishing this movement of the glider) in actual flight can be done one after the other, can be interwoven or accomplished simultaneously by the pilot. But in all cases of flight, when solving an operational task, both groups of operation are necessary and fully defined in all the work of the pilot in flight. Figure 1.72 shows a diagram of work expenditure by /81
a pilot during flight on a modern glider.

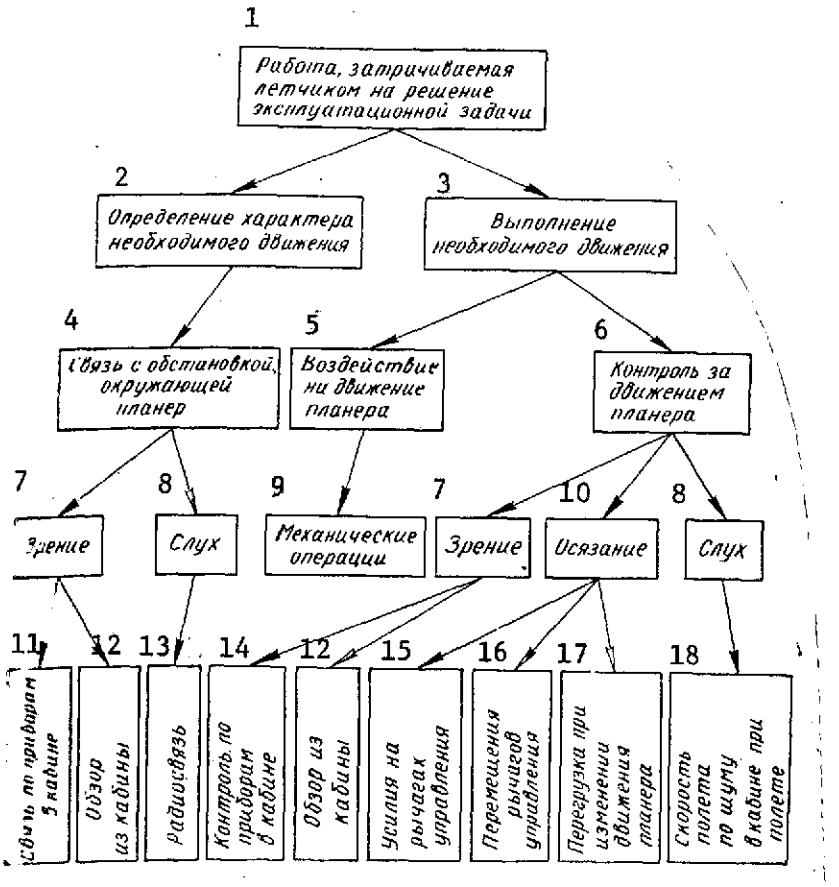

Figure 1.72. A Diagram of the Pilot's Work When Controlling Glider Flight (According to Adamovich [2])

Key: 1--The work expended by the pilot in solving the operational task; 2--Determining the character of necessary motion; 3--Carrying out necessary motion; 4--Communication with circumstances surrounding the glider; 5--Action in moving the glider; 6--Control for glider motion; 7--Vision; 8--Hearing; 9--Mechanical operations; 10--Touch; 11--Communication by instruments in the cockpit; 12--Observation from the cockpit; 13--Radio communication; 14--Control by instruments in the cockpit; 15--Forces applied to control levers; 16--Shifting control levers; 17--Acceleration when changing glider motion; 18--Flight speed according to noise in the cockpit during flight

The character of necessary movement of a glider[7] is determined by the pilot depending on the flight mission and on the actual circumstances surrounding the glider. For evaluating this circumstance on a modern glider the pilot can take advantage of the following types of communication with circumstances surrounding the glider:

--direct visual communication with space around the glider (through the cockpit canopy);

--communication with this same space using various visual devices in the cabin: speed indicator, altimeter, turn and slip /82
indicator, compass, gyrohorizon, rate-of-climb indicator, thermometer, ascending air current indicator, etc.

--radio communication (by ear).

Carrying out each of the types of communication enumerated requires a certain work by the pilot a quantity of which depends on the perfection of design of appropriate parts, units, instruments and systems of the glider.

Proceeding from the task of motion and paying attention to the results of the preceding part of motion of the glider, the pilot determines the character of the present stage of movement and in an appropriate way acts on the control devices for movement of the glider which are available to him. Thus, a pilot must continuously during flight, control motion of the glider and take action for its motion.

On modern gliders, the pilot has the possibility of acting for glider motion only using mechanical operations which include shifting various control levers located in the cockpit.

The pilot controls motion by the following methods:

--visually (control of the position of the glider in space and control of instrument readings and operation of units and systems of a glider which characterize and facilitate its movement);

--by touch (an evaluation of the character of movement of the glider according to the forces which must be overcome by the pilot when moving control levers, in accelerating, which are apparent when changing the sizes and directions of flight speed of the glider, and by air blowing on the face and head when there is no

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[7]Let's remember that under glider motion we specify its spatial shift and all changes of configuration and condition of the glider accompanying it.

canopy);

--by ear (control of flight speed by the force and character of noise caused by the stream of air flowing over the glider).

The conditions in the cabin in which the pilot is located have an effect on the actual size of work of the pilot. Some of the conditions of the cockpit in a modern glider are:

--the comfort of the working position of the pilot and his clothing;

--air temperature in the cockpit and its ventilation;

--illumination of the instrument panel, visibility and convenience of observation of instruments;

--convenience of observing exterior conditions of flight (distortion due to curved glass in the canopy, height of the cabin sides, completeness of the field of vision);

--noise from the headset in a poorly working radio receiver, noise from the air current encountered.

Knowledge of conditions in the cabin of a glider can be illustrated by an example of the so-called "recumbent" position of the pilot used in the makeup of a number of gliders in recent /83 years. As is known, this recumbent position has not justified itself and now cockpits are made more comfortably. Another example is incomplete deflection of control sticks in the lateral direction because of inadequate actual dimensions of the cabin. This results in the knobs hitting the leg of the pilot (especially if he is dressed in winter clothing). In this case, the lateral controllability of the glider cannot be fully utilized.

All of the conditions enumerated affect the size of the pilot's work. Therefore all of them also affect (to a certain degree) controllability of the glider. Conditions of the medium in which the pilot is located can be divided into a separate group of factors of maneuverability which effect the size of his work.

From the analysis of the pilot's work presented, it is apparent that on a modern glider, for control of its movement, three of the five human senses are utilized--vision, touch and hearing. Action is accomplished only by mechanical operations. The human organism does not have at its disposal other methods of sensing the environmental circumstances and moving the glider or affecting its movement.

The so-called "character of a glider," the features of which usually vary sharply with the pilots, sometimes even between various models of the same design, is the total result of comparing

operation in control for their movement (done on the basis of the three senses mentioned) and the effect on its motion (carried out by mechanical movements).

It is obvious that by selecting appropriate conditions for control and action one can provide the desired, that is the optimum "glider character," or to put it another way--simplicity and precision of its movement, ease in control and general ease in flight.

The best "character of a glider" will correspond to minimum work for the pilot which is necessary for controlling flight of the glider, that is, for a case of maximum controllability of it.

Conventionally this position can be described in the following form:

$$\text{Work to control glider flight} = \frac{1}{\text{controllability of the glider}}$$

The greater (better) the controllability of the glider the less work is required for controlling its flight.

Thus, the question of a man (pilot) who controls movement (flight) of the glider, leads to an inspection of the necessary work (its quantity and character) in controlling glider movement and the possibility of completing this work. Looking at the work expended by the pilot in controlling motion of the glider leads us to the question of controllability of the glider--the second basic property of the glider which determines the possibility of a certain glider being able to accomplish an operational mission. /84

Flight, in which there is no quiet, is characterized from the psychological point of view first of all by the need to continuously solve current questions of controlling the movement of the glider. In many cases, the pilot has limited (sometimes very limited, only seconds) time for an analysis of the situation, understanding and appropriate solution. This circumstance makes it necessary to train glider operators not only in the field of piloting habits but also in thinking.

During training for piloting, pilots develop automatic habits in the control of flight (especially movement) of the glider. Automatic actions of the pilot when controlling the glider free his brain from gathering unnecessary pieces of information (for example, on the position of the glider in space) and by converting this part of the information into decisions and actions provides safety and correct continuation of flight.

However, automatic behavior alone, when it means neglecting a conscious decision to a piloting problem can result in unthinking control of the glider which soon will cause errors and inexcusable complications of flight. Therefore, trying to attain

automatic behavior in glider control is necessary but along with the training there must be thinking. The task of controlling the flight of a glider, complex in principle, is solved by the pilot by thinking about past, present and probable future, the multiplicity of which become apparent to anyone in his first flights; they are analyzed, solved, and put into action. Then the automatic reactions when controlling glider movement are directed at retaining or changing separate particular elements of flight which make up, so to say, a permanent canvas of actions for the pilot controlling glider motion.

Instruction and training in emotionally determined qualities in the pilot are of great importance. He must have control over his emotions and not permit excess anxiety. This depends on his moral and sef-control training. With the help of will power he can suppress excess agitation or on the other hand, use it to increase force and energy. Combatting undesirable emotional states (for example, fear), skill in overcoming one's feelings are a complex phychological process. Success in this battle and mastery of one's emotions is attained by systematic training of the will and body as a whole. Such training, in particular, occurs in the process of physical education and sport training. We shall point out one of the sporting equipment types which, if /85
you please, should be noted as the best for training glider personnel. This is the so-called "Ronskiy wheel" (Figure 1.73).

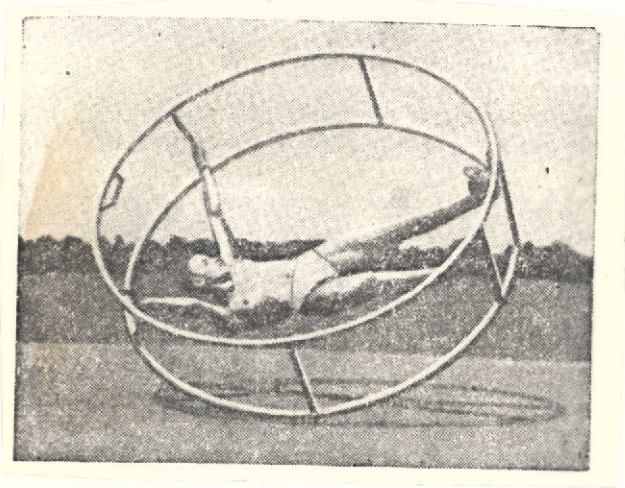

Figure 1.73. Exercise on a Ronskiy Wheel

Let us look at some of the illusions which occur in flight and whose appearance is very dangerous. They're in the form of various apparent events. For a pilot who is flying a glider illusions which involve spatial orientation are of especial importance.

With a sudden entry of the glider into a cloud loss of reference points can occur, fear, possible increase or, decrease in load and as a result a breakdown in the normal course of the flight with a loss of altitude or (in a worse situation) with failure of the glider and a jump with the parachute necessary.

When executing spirals in a glider, centrifugal force acts on the pilot which added to the weight of the glider operator presses him into his seat. This sensation is similar to that which occurs with tail heaviness of a glider and therefore can confuse

him if there is no adequate control for completing these maneuvers by the horizon or by instrument. This same kind of confusion, but in reverse, can occur when coming out of a spiral or bank. In the first case one wants to push the control stick "forward," as a result of which coordination of glider movement is destroyed and there is an inexcusable increase in flight speed.

In the second case, pushing the stick "forward" can cause a significant decrease in flight speed which in some cases is also undesirable.

Illusions of counter-rotation involve fast changes of direction /86
in rotation or speed of rotation of the glider and the pilot begins to perceive rotation in the opposite direction. Such a phenomenon can be observed during high speed exits from spirals or from a spin.

A position similar to that described above can be created also during incorrect operation of the turn indicator, for example, if the electrical turn indicator confuses polarity.

A glider operator can also be confused about his position if when he loses reference points as a result of swift thrust of the glider it seems "upside down."

Combatting illusions must be done ahead of time by preventing the effect of illusions on the consciousness of the pilot.

Chapter 2 Theoretical Bases of Glider Flight

(Certain Questions of the Aerodynamics of a Glider)

In this chapter we will look at those conditions in which, as a result of the interaction of a glider with the environment, forces (lift and cruise) arise which give it its prescribed movement. We will consider a priori that the forces and equipment for controlling movement provide the necessary position of the glider in space. /87

Relative movement of a glider in the air can be presented as the penetration of a glider in immovable air surrounding it or as a flow of air over an immobile glider. It seems that the values, direction and location of points of application of aerodynamic forces does not depend on whether it flows over an immovable (for example, relative to Earth) glider with a flowing stream of air or whether the glider itself moves at a (relative) speed with the air immobile relative to Earth.

Proceeding from this, in all further discussions the movement of a glider relative to immovable air or the movement of air relative to an immovable glider will be used depending on the convenience of presenting the process of movement as a whole. This principle, called the principle of reversibility or the principle of inversion is the basis for a large field of aerodynamic research done in wind tunnels and under natural conditions. However, for obtaining a complete identity in conditions of interaction of a glider and air one needs to observe a number of additional rigid conditions which sometimes are difficult to fulfill.

Keeping in mind the principle of reversibility let us turn our attention to certain basic laws of aerodynamics the knowledge of which is necessary for explaining the possibilities and laws governing glider flight.

2.1. Full Aerodynamic Force of Resistance /88

Turning our attention to the specifics of glider flight, namely, the comparatively low speed of its motion and comparatively low altitudes at which a large part of engineless sport flights are done at the present time, we look first at certain particular cases relative to motion of a glider.

One of these particular cases of such movement is steady-state motion. By steady-state we mean that motion under which at any point in space occupied by a gas, the parameters of the gas (translational velocity, density, pressure, temperature)

are assumed for these basic characteristics to be unchanged with time. Naturally, at various points in space these characteristics can be different.

The condition of immovable air is characterized by three basic parameters: pressure p, temperature T, and density ρ. Moving air, moreover, is characterized by translational velocity V. Let us suppose that the air flow over a glider consists of separate streams of gas. Let us suppose that each of these is parallel to the plane of the longitudinal cross section of the current. Assume a small flat closed contour, the plane of which is perpendicular to the direction of movement of the air and whose area equals f. Then, follow in your imagination a path of air particles moving simultaneously through the points of the contour defined. The routes of these particles form the surface of a certain tube (in a general case, curved and with variable cross section). The part of the general current of gas thus limited makes up a filament band which can be discussed (Figure 2.1).

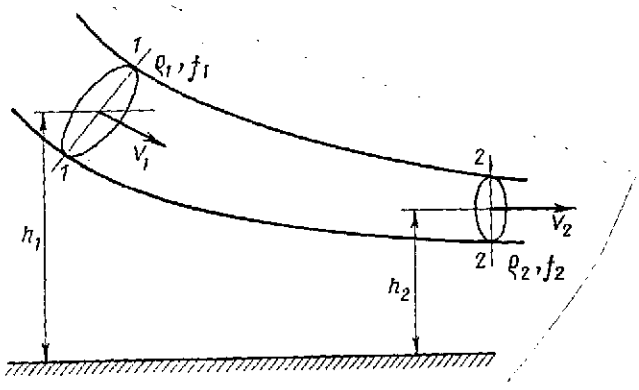

Figure 2.1. For the Concept of a Gas Filament With Conservation and Bernoulli Equations

One should note one important property of these filaments assumed in defining them. In steady-state motion, air cannot move from one filament to another because the velocity of the air particles form an imaginary tube wall tangential to it. Therefore, one can look at each filament of the current separately as if it has impenetrable walls which also considerably simplifies the total picture of motion of the air current without destroying the correctness of the concept. /89

2.1.1. Conservation Equation

Let us determine the mass quantity of gas which flows through two arbitrarily selected cross sections of the filament perpendicular to its axis when there is steady-state air movement. For the cross section *1*--$m_1=\rho_1 f_1 V_1$, and for cross section *2*--$m_2=\rho_2 f_2 V_2$.

The existence of a law of conservation of mass permits expressing the following equality: $m_1=m_2=m$, where m can be written as any cross section of the filament. Then $f\,V=\text{constant}$ for each cross section of the filament which is the conservation

equation or one of the forms of describing the law of the conservation of matter.

Because, at low movement speeds, the coercibility of air does not have a noticeable effect on the character of air flow (and at speeds of glider flight this includes a fairly large range of altitudes, approximately from 0 to 10,000 m) then by simple conversion excluding density ρ from the relation one can write it as:

$$\frac{V_1}{V_2} = \frac{f_2}{f_1}.$$

Consequently, if the filament is constricted the speed of flow in it will increase and the reverse.

Bernoulli's Theorem

Let us look at the law of conservation of mass (matter) but from an energy point of view for a case where there is no coercibility. In conditions where heat does not go through the walls of the filament band, the energy which the filament band has in cross section *1* will equal its energy in cross section *2*

$$E_1 = E_2.$$

All the energy of the filaments in cross section *1* consist of kinetic and potential. Kinetic energy of a certain mass of gas is expressed by the known relation: $\frac{m\Delta t V_1^2}{2}$, where m-- is the mass of air passing in a time interval Δt, and V--the velocity of movement of this mass.

The potential energy of mass m consists in this case of two /90
components: the energy of the force of pressure (static) and the energy of weight (or the force of gravity) of air mass m. We write the expression for these types of energy in final form.

The energy of the force of pressure p_1 equal to the work of these forces, is expended in the displacement of mass m of gas through cross section *1*.

$$\frac{p_1}{\rho} m\Delta t$$

The energy of the weight of gas equals the work of this force $m\Delta tg$ during possible lowering of the center of mass of cross section *1* to a certain distance h calculated vertically (from the center of mass of cross section *1* to the center of mass of cross section *2*):

$$m\Delta thg.$$

Thus, the total energy of mass m of gas passing through cross section *1* in time Δt, and this means through cross section *2* for the same time, will equal

$$E_1 = \frac{m\Delta t V_1^2}{2} + \frac{P_1}{\rho_1} m\Delta t + m\Delta t g h = E_2 = E.$$

After certain simplifications the expression of the general energy of mass m of gas which passes through any cross section of the tube is described in the following way:

$$\frac{\rho V^2}{2} + p + \rho g h = \text{const.}$$

In particular cases, this expression will be adopted in even simpler form. For a case of a horizontal tube or tube (gas filament) with small lift, where the size of h can be disregarded, the equation will take on the form:

$$\frac{\rho V^2}{2} + p = \text{const.}$$

It is interesting that the terms in these expressions have dimensionality of specific pressure which makes it possible to formulate the physical concept of Bernoulli's Theorem for filaments: the total velocity pressure (dynamic pressure) q, static pressure p and hydrostatic pressure (pressure of the weight of gas) $\rho g h$ has a constant value.

Peculiarities of the Formation of Aerodynamic Resistance Forces of a Glider

Every material body moving in air is subject to aerodynamic resistance.

Let us look at the nature of this resistance; then for simplification we will consider the movement translational, that is, occurring only in planes parallel to the plane of symmetry of the glider. /91

Let us suppose that a certain body of arbitrary shape moves in air with translational velocity. Then the current of air through which it goes must flow over it because one understands that it cannot penetrate it. That part of the air, whose velocity vector is pointed directly toward the body will be slowed down by encountering obstacles in its path. The kinetic energy of this part of the air is converted to potential energy of pressure and partly to thermal which at speeds of glider flight are negligibly small.

The potential energy of braking is expressed in an increase in air pressure in front of the body in relation to the pressure of non-braked air. The increased pressure in front of the body forces the layer of air adjoining that which is slowed down to curve, and thus creates conditions for the entire stream to flow around the body. The stream divided into two parts by the body, flows around the body, again joins behind it and acquires its initial velocity and direction. The pressure at various points of the current which flows over the body, including the points on the surface of the body itself will correspond to various velocities and to the character of flow of streams of the current which are explained by the shape of the body, its orientation in the current, the degree of roughness of the body's surface which comes in contact with the air, and the parameters of the air.

The total pressures which affect the body (which occur as a result of the streamline flow of air currents over the body) consists of a certain general force (acting equally) which is the total force of aerodynamic resistance. The direction of this total force of aerodynamic resistance in a general case will not coincide with the direction of current velocity as much as the arbitrarily selected shape of the body and its orientation relative to the flowing current.

The basic task of the glider is moving in the air over the earth's surface with minimum possible descent which is the "cost" of such movement. It is natural, therefore, that the glider as a whole must be a body whose vector of total aerodynamic resistance forces will deviate from the flight path angle with as large an angle as possible (90--θ). This means that for a glider it is best if the largest component of total aerodynamic resistance forces is directed perpendicular to the direction of the glider flight path and the smaller other component of this force is directed opposite the flight path (Figure 2.2).

The first of the components mentioned of total aerodynamic resistance forces usually is called lift force Y, although, because of its inclination toward the horizon this component will not equalize the entire weight of the glider. It will be equal in size and counteract in direction only the appropriate component of weight. /92 The second of the components named of the total forces of aerodynamic resistance of a glider which is usually called drag of a glider will equalize the cruise force, that is the weight component directed along the forward movement of the glider.

We note that while we are looking at the glider according to previous calculations the total force and moments affecting it are equal to zero. Therefore we can match up (conditionally) the point of application of total aerodynamic resistance forces of the glider with its center of mass.

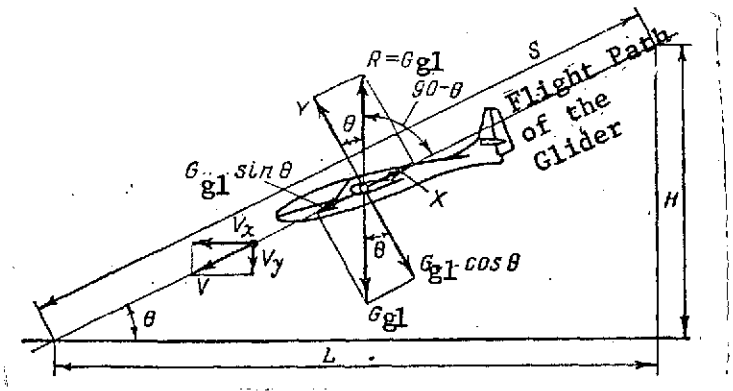

Figure 2.2. Toward an Equation of Glider Movement: L--Horizontal component of the path made by a glider when losing altitude H; V_x--the horizontal component of glider velocity; V_y the vertical component of glider velocity (the velocity of descent of the glider).

The shape of the body which satisfies to the greatest degree the requirements expressed is the shape of the wings of modern gliders and primarily the shape of its cross section or so-called airfoil, inasmuch as, in most cases of sport aircraft, the lift force is created only by the wing.

It is natural that all parts of a glider over which the air current flows create their own resistance forces. By adding them to the resistance force of the wing they make up the full aerodynamic resistance force of the entire glider. However, the fuselage, landing gear, struts, braces and so forth mainly affect the component of resistance which is equalized by the cruise force increasing its required size. Therefore force R equalizes the weight of the glider G_{gl}, and consequently they lie on a single straight perpendicular to the earth's surface, then the flight path angle of force R (in the direction of movement of the glider) is connected to the flight path angle toward the horizon by the relation:

$$\phi = 90 - \theta.$$

2.1.4. The Boundary Layer Close to the Surface of the Streamlined Body (Glider Wing) /93

Thanks to viscosity, the velocity of air particles (relative to the glider wing) which come in contact directly with its surface becomes equal to zero (Figure 2.3). But in the layers of air located next to those lying on the surface of the wing, the velocity of the particles will not be zero in relation to the wing, though they will not immediately attain the velocity size of non-braked current. Thus, that part of the air which washes over the wing where its viscosity is apparent is characterized by a change in velocity from zero at the surface of the wing to a velocity of air flow not slowed down due to friction but disturbed by the body. This part of the air is called the boundary layer.

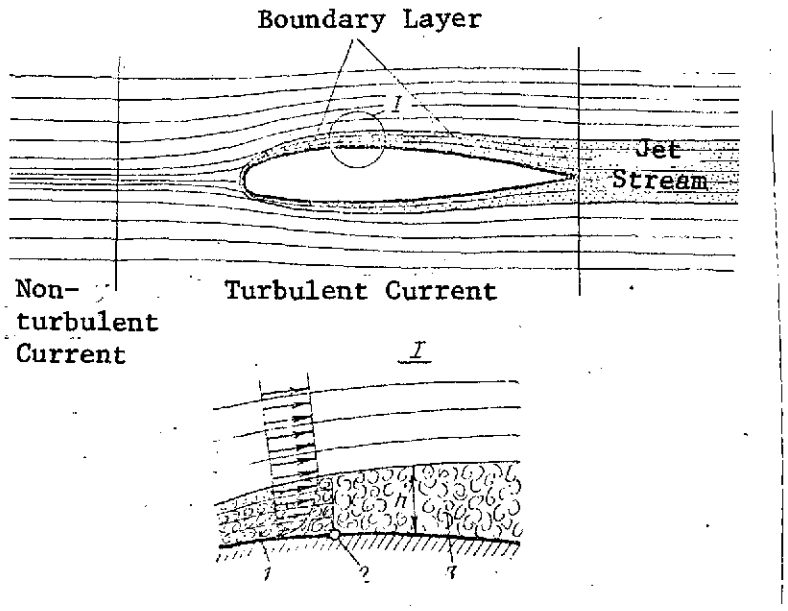

Figure 2.3. The Boundary Layer at the Surface of the Wing and the Projection Diagram of Velocity in the Boundary Layer and in the Air Current Where the Velocity of the Layers of Air are Equal to Each Other:

1--Laminar boundary layer; 2--Point of transfer; 3--Turbulent boundary layer

The boundary layer is limited by a surface which is a certain distance from the surface of the wing and is characterized by the fact that the velocity of air in it and further on becomes and remains in an even rate of flow not slowed down by the forces of friction in the air on the surface of the wing.

The thickness of the boundary layer which on the wing of a glider can reach several millimeters changes as the air passes along the airfoil and depends also on the rate of movement of the airflow which has not been slowed down, the smoothness of the surface, the length of the chord and the orientation of the wing in the air current. Then, on the bearing surface of the airfoil the thickness of the boundary layer is minimum, and at the end of the chord--maximum. Because of the comparatively small thickness of the boundary layer, the gradient, that is, the change in velocity of the air movement along its altitude, is very great.

In the boundary layer the change in velocity of the air particles (according to height of the boundary layer h) occurs basically due to the effects of viscosity and has practically no connection with pressure change. To say it another way, the kinetic energy of these particles when slowed down is converted

not into an increase in pressure (as would happen when an air flow encounters a wing) but is used up in overcoming viscosity forces (friction).

Thus, the pressure inside the boundary layer is limited almost exclusively by the pressure of the air over the boundary layer in this area of the wing. The pressure in the boundary layer for such an area (on a vertical to the streamlined surface of the wing) is considered constant and the boundary layer itself is the transmitter of the air pressure on the streamlined surface of the wing.

We note that outside the boundary layer, the air particles move (in a steady-state air flow) at practically uniform velocity. Therefore, the viscosity there cannot become apparent in a noticeable way and has an essential effect on pressure. Bernoulli's Theorem which applies to the layers of air over the boundary layer makes it possible for us to determine the law of distribution of pressure over the streamlined surface of the wing because the /94 boundary layer is a transmitter of static pressure of the air flow which flows over a given point of the airfoil. We note that Bernoulli's Theorem is not suitable for the boundary layer.

Let us look at the shape of the boundary layer. The movement of the actual air in the boundary layer is different in character from movement outside the layer. In the boundary layer because of the gradient of velocity according to its height (thickness), the air particles are at the same time in a forward moving and in a rotational movement. The effect of the friction forces which occur between the air layer moving with different forward-moving velocities results in the formation of vortexes. But the vortical movement of air inside the boundary layer is not uniform on the expanse of the airfoil. At first where there is acceleration of air particle movement, vortexes travel over the surface of the wing, not mixing with each other, and form their own type of vortex layer. This character of air flow in the boundary layer is called laminar. Beginning with a certain distance, measured from the bearing edge of the airfoil and observed as the so-called "point of transition," the boundary layer changes its character. The coordinate of the transition point depends on the shape of /95 the airfoil, the area of its greatest thickness, the condition of the wing surface and its orientation in relation to the flow of air.

Behind the point of transition, the vortexes have, besides movement along the surface of the wing and rotational around their own axes, still another movement according to the height of the boundary layer, that is, they begin to mix with each other destroying in this way the vortical layer structure of the laminar part of the layer. The part of the boundary layer located behind the point of transition extends to the rear edge of the wing and has an aspect noted above called the turbulent part of the boundary layer.

Owing to the increase (especially after the transition point) of the internal dynamics of the boundary layer it becomes thicker and according to how close it is to the rear edge of the airfoil begins to have a tendency to break away from the surface of the wing. Moreover, as a result of the decrease in the forward velocity of the air particles (especially on the surface of the wing) an increase in pressure and increase in volume which occupies the boundary layer occurs. Finally, the pressure on the wing surface and at the end of the airfoil becomes equal and then larger than at points on the airfoil close to the bearing surface. This means that on the surface of the wing at the end of the airfoil the air first overcomes zero velocity and then begins to move in a direction opposite the general movement of the airflow.

Thus, conditions are created for a counterflow and formation of a boundary layer of a powerful vortex. Pushed back from the surface of the wing by air flowing over the trailing edge, the vortex is carried off in the air current forming a so-called slip stream behind the glider wing.

2.1.5. Free Vortexes Behind the Wing of a Glider

Besides the slip stream at the tips of the wings free vortexes also form; they are of the following nature. The pressure over and under the wing in general is not uniform. In normal flight, the pressure over the wing is smaller than under it.[8] Because of this, the air tries to flow through the ends of the wings from the field of higher pressure to the field of lower. This movement of the air along with the basic movement of the air current relative to the wing is the reason for the formation of the free vortexes mentioned. The vortexes and slip stream are transformed into two powerful vortical cores which have an essential effect on the character of the streamline flow of air /96
over the glider wing.

2.1.6. Forces and Coefficients of Aerodynamic Resistance of the Glider Wing

The value of a full aerodynamic resistance force of a glider wing is accepted as being characterized by the following expression:

$$R = c_R \frac{\rho V^2}{2} S.$$

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[8]When there is pressure equilibrium above and below (which corresponds to a complete absence of lift force of the wing) there will be no tip vortexes.

Here $\frac{\rho V^2}{2}$ --is the form drag, S--is the area of the glider wing, c_R--is the coefficient which takes into account most factors affecting the size of force R, but are not entered in the formula in the form of separate symbols and numbers. Among these factors are the shape of the airfoil, its orientation in the air flow, the character of the surface of the wing (degree of its roughness) and also the geometric (besides S) dimensions of the wing and their relationship. The expression presented of the total force of aerodynamic resistance of a wing is semiempirical because a number of very important factors which affect the vector of force R (its size and direction) do not lend themselves at the present time to determination by calculation. These factors can conveniently and reliably be calculated by determining the coefficients c_R or its components--the coefficient of lift force c_y and the coefficient of drag c_x using experiments with a model of a wing or an entire glider in a wind tunnel.

Having used semi-coupled axes, we continue looking at the forces of resistance of wing movement having begun with its component directed against the velocity of movement of the glider. This component of the total force of resistance of the wing is especially interesting because it (besides the corresponding components of resistance of the fuselage and tail unit) must equalize in flight the wing component of the glider which plays a role in cruise force. Naturally, the greater the force of resistance of movement of a glider along its path the greater will be the corresponding weight component. And its increase can occur only as a result of increasing the flight path angle of the glider which contradicts the basic conception of aircraft of the glider type which require as small as possible an angle of flight path of the glider to the horizon at all flight speeds.

2.1.7. Glider Wing Drag

As was mentioned earlier, the force of resistance R is explained by the presence of a difference in pressure on various parts of the wing surface, the presence of friction forces and vortex systems which form behind the wing when air flows over and around it. In conformity with these three factors, the component of total resistance force, force X, called drag of the wing consists of a total of three components--pressure, friction and induced drag. /97

The larger the relative thickness and curve of the airfoil the greater is pressure resistance. But pressure resistance will also increase and at absolute (that is not depending on a sign) increase of the attack angle of the wing. Pressure resistance is one of the components of airfoil resistance.

Another component of airfoil resistance occurs when there is air friction on the surface of the wing. The greater the viscosity of the air the larger will be the size of this type of resistance. The character of air flow in the boundary layer also affects the size of drag. With a laminar character of flow, resistance is smaller and with turbulent--larger. And so long as during streamline flow over the wing there is some sort of boundary layer, then it is advantageous that the field of the laminar part of the layer occupy as large an area as possible. However, the greater the velocity of air flow, the larger the angle of attack and relative camber of the airfoil, the greater the roughness of the surface of the wing the smaller will be the laminar section of the expanse and the larger will be the turbulent. In these cases, the point of transition of the laminar boundary layer to turbulent is shifted toward the leading edge of the wing.

The size of airfoil resistance is similar to the size of force of total resistance determined by the expression:

$$X_{\text{airfoil}} = c_{x\,\text{airfoil}} \frac{\rho V^2}{2} S$$

2.1.8. Induced Drag of a Glider Wing

The third component of wing drag is its induced drag (Figure 2.4).

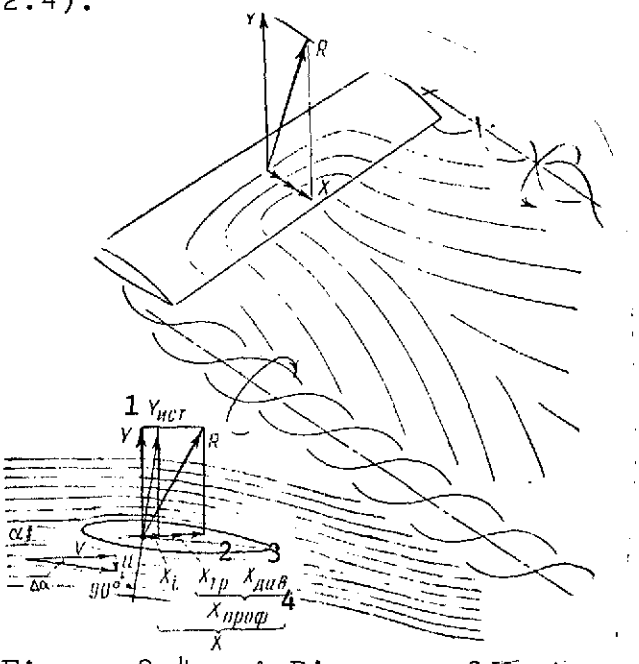

Figure 2.4. A Diagram of Vortexes and Resistances Which Develop During Movement of a Glider Wing.

Key: 1--Origin; 2--Friction; 3--Pressure; 4--Airfoil

As was seen earlier when air flows over and around a wing a vortical system forms behind it and two free vortexes which converge at the tips of the glider wing. The vortical system is unstable in its movement. Under the effect of the powerful free vortexes at some distance behind the wing it convolutes, joining with the free vortexes. A vortex under actual conditions is a somewhat limited mass of air, and the general movement of the particles in it are a collection of forward moving and rotational. Thanks to the viscosity of the air mass of the vortex it carries behind it a layer of air which surrounds the vortex. The effect of rotation in free vortexes is reflected in the formation of a new component

of the velocity vector directed vertically down during positive angles of attack of the wing and up with negative.

Along with the vector of forward velocity this new component /98
called induced drag forms the total vector of velocity deflected downward at a certain downwash angle $\Delta\alpha$, which is defined by the expression:

$$\Delta\alpha \approx \operatorname{tg} \Delta\alpha = \frac{u}{V_\infty} .$$

The rate of turn of the air flow on the downwash angle $\Delta\alpha$ causes a turn in this direction and lift force Y which, as is known, is perpendicular to the vector of flow rate flowing over the wing. As a result of this, a projection of force Y is formed in the direction of glider flight, that is, the creation of still one more addition to the two components of drag of the wing already looked at-- pressure and friction resistances. The new component of drag is called induced drag of the wing because the reason for its formation involves the effect of free vortexes which collect at the tips of the wing.

The size of induced drag on the wing depends on two basic factors: on the size of the coefficient of the lift force pro- /99
portional to the angle of attack and on the size of the aspect ratio of the wing $\lambda = \frac{l^2}{S}$. The angle of attack determines the intensity of the vortexes. Consequently, it determines also the size of induced velocity on which the downwash behind the wing depends and this means the size of additional projections of resistance force in the direction of velocity rate of wing V_∞. Let us look at two wings which move at uniform speed which create uniform forces of resistance R, but which have different aspect ratios. The secondary quantity of air which is thrown down by the wing which occurs because of the presence of induced velocities u, must in this case also be uniform. But to throw down one and the same secondary quantity of air with different aspect ratios of the wing requires accordingly different induced velocities. Therefore, the greater the aspect ratio of the wing the smaller velocity u needs to be. This means, with large aspect ratios, the intensity of vortex formation behind the wing will be smaller. Induced drag will also be smaller (Figure 2.5).

2.1.9. The Component of General Force of Resistance of a Wing Directed Perpendicular to Flight Speed (Lift Force)

In normal (not inverted) flight the greater the lift force of the wing the larger will be the pressure on it from below and the less from above. For this, one selects an appropriate camber of /100

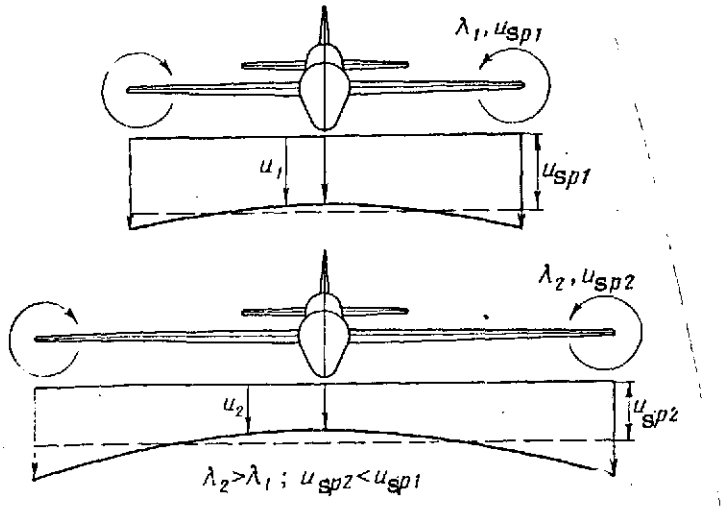

Figure 2.5. Distribution of the Vertical Rate of Flow Along the Wingspan and the Relationship of the Mean Vertical Rate of Flow Behind the Wing to the Ratio Aspect of the Wing

the upper and lower surfaces of the airfoil and the location of maximum relative thickness of the airfoil (and in flight--the angle of attack). When any position of the lift augmentation devices of the airfoil is unchangeable this becomes a constant shape and a change in the size of the lift force is attained by turning the wing (the entire glider) at various angles of attack in relation to the flow of air going over the wing. The lift force of the wing of a glider is directly proportional to the size of the angle of attack within its range, where the streamlining of the wing is even, without significant flow separation.

The optimum shape of the airfoil of a glider form the point of view of obtaining maximum lift force and minimum drag, that is, maximum aerodynamic quality, is determined by a whole range of requirements for its configuration, part of which contradict each other.

Historically, the development and perfection of the shape of the airfoil of a glider wing went from flat plates to complex in double-convex contour. Thus, gradually, after many experiments and calculations new airfoils were developed which were called laminar. Their name is evidence of the fact that part of the boundary layer with laminar structure extends much farther along the length of the contour than in ordinary airfoils, for example, type R-III. For this, airfoils were made with a sharp forward part and maximum thickness extended much closer to the trailing edge of the wing--approximately 40--50% of the length of the airfoil chord (Figure 2.6).

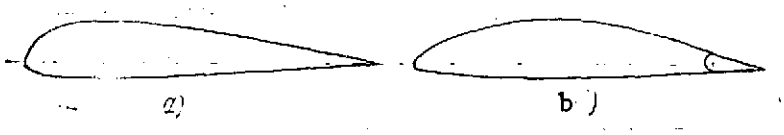

Figure 2.6. R-III Airfoils (*a*) and the Vortmann "laminar" (*b*)

Such laminar airfoils actually permitted obtaining a considerably greater speed of movement of the glider along the flight path with insignificant sink speeds. However, the range of these increased speeds was not great. And this circumstance made it impossible to use powerful lift augmentation devices in the wing in order to provide acceptable flight speeds and a decrease in spirals when landing.

2.2. The Aerodynamic Forces of Resistance of the Fuselage and Tail Unit of a Glider

The total force of aerodynamic resistance of the fuselage and tail of a glider in general does not coincide with the direction of movement of the glider. Consequently, the resistance of the fuselage and tail produce appropriate components of this force both in the direction of the flight path of the /101
glider and perpendicular to it. But because the lift force of the fuselage is very small in comparison with the lift force of the wing, and the drag commensurate with wing resistance we will disregard the projections of aerodynamic resistance of the fuselage in a direction perpendicular to the flight path of the glider considering for the total of all resistances that the fuselage is only drag. At the same time we will look at the lift force of the tail unit in connection with is comparatively small size only from the point of view of moment which it creates relative to the center of mass of the glider. But this factor is important for questions of controllability of the glider and its stability which we will discuss in subsequent sections.

Drag of the tail unit will be considered on a level with the fuselage drag (drag of the tail unit increases particularly with deflected rudders).

The sizes of drag of the fuselage and tail unit depend on the same factors as resistance of the wing. However, in the fuselage, thanks to its shape, the angle of attack at which it encounters the flow of air plays a role which is relatively smaller than the area and roughness of the surface washed by the air flow. Therefore, the glider fuselage must be made as narrow as possible with

very smooth (like the wing) surfaces and moreover a shape which to the greatest degree will correspond to the direction of air streams under basic operating procedures of glider flight.

There is still one more factor which must be considered in order to correctly evaluate the design and air flow dynamic make-up of a glider; it has an important effect on the size of total drag of the glider during its forward movement. The essence of the factor involves the peculiarities of the inflow of air over a glider in areas where the wing joins the fuselage and the fuselage the tail unit. The mutual effect of these parts of the glider, as a result of which aerodynamic forces during operation in the whole complex are distinguished from the forces in an isolated form, is called interferences. The point is that the joining of wing and fuselage, for example, can have an inadequately thought out arrangement and create conditions of streamlining under which a zone of flow can occur with decreased pressure in the zone of trailing edges of the wing around the fuselage. The increased difference in pressure here in front of the glider and behind it can cause an increase in pressure resistance of the glider.

In order to avoid this phenomenon, the joined parts of the glider should be placed so that the area of the cross section of the stream of air which occurs in these areas will be approximately uniform for the entire expanse of the joint.

2.3. Polar of Coefficients of Aerodynamic Forces of Resistance. /102

Polar of Glider Flight Speed

Similarly to the total force of aerodynamic resistance of a glider wing the expressions for calculated definition of components of this force are described in the following way.

The force of airfoil resistance:

$$X_p = c_{xp} \frac{\rho V^2}{2} S.$$

The force of induced wing drag:

$$X_i = c_{xi} \frac{\rho V^2}{2} S.$$

The force of wing drag:

$$X = X_p + X_i = (c_{xp} + c_{xi}) \frac{\rho V^2}{2} S = c_x \frac{\rho V^2}{2} S.$$

Wing Lift force:

$$Y = c_y \frac{\rho V^2}{2} S.$$

The force of fuselage drag:

$$X_\Phi = c_{x\Phi} \frac{\rho V^2}{2} S.$$

Using these expressions one can graphically express the sizes of the coefficients of all components resulting from the forces of aerodynamic resistance of the wing and glider as a whole depending on the angle of attack. An expression of the components of force themselves are unnecessary because such a graph would be tied to one certain speed and one definite area of the wing and density of the air (Figure 2.7).

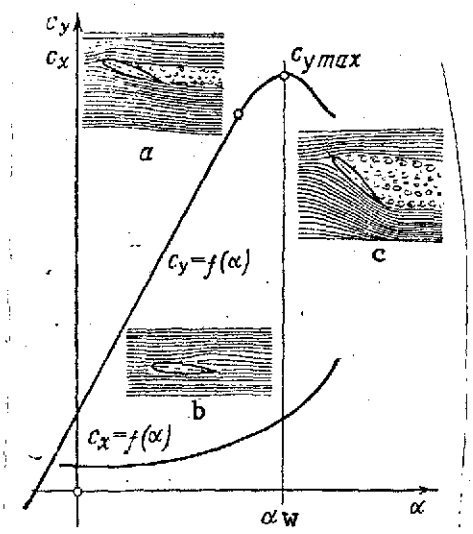

Figure 2.7. The Dependence of Coefficients c_y and c_x on the Angle of Attack α:

a--Partial separation of flow; b--Smooth streamline flow; c--full separation of flow

However, separate relationships of the coefficients of resistance forces to the angle of attack do not show visually all their characteristic relationships. These relationships determine a whole series of procedures which have a bearing on glider flight. Therefore, along with separate relationships with the coefficients to the angle of attack, generalized graphs are constructed called coefficient polars or moving to an actual glider and speed,--polars of glider speeds. Figure 2.8 gives an example of the relationship of coefficients of resistance force and glider speed.

These dependences of three values (two dependencies--c_y and c_x or V_y and V_x and one independant variable α or V) visually illustrate certain very important characteristics of a glider.

The polar of coefficients of glider/103 resistance has a number of characteristic points which permits one to evaluate a number of important aircraft data for a glider.

Point $c_y = 0$ determines the procedure of a steady-state vertical dive. In most cases, this procedure can be looked at as only hypothetical because the speed of glider flight appropriate to

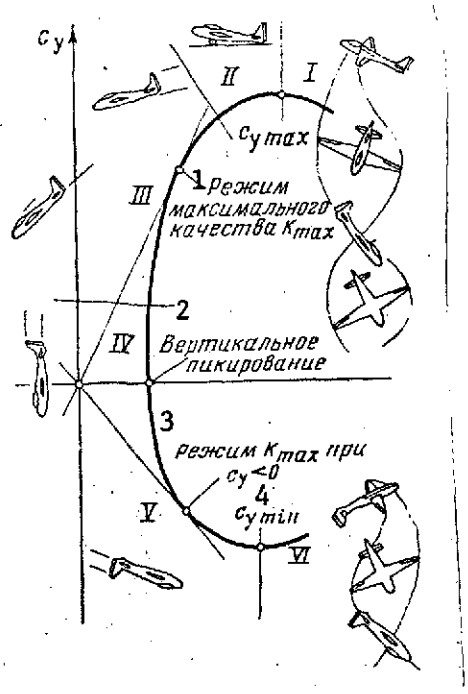

Figure 2.8. Distribution of the Zones of Dependence $c_y=f(c_x)$ According to the Group of Procedures of Glider Flight

I--Takeoff and normal spin; II--Low speeds and landing; III--Normal flying, average flight speed; IV--Normal dive; V--Inverted flight; VI--Takeoff and inverted spin:

Key: 1--Procedure of maximum quality K_{max}; 2--Vertical dive; 3--Procedure K_{max} at $C_y < 0$;

4--C_y minimum

it, as a rule, exceeds the maximum speed specified by strength of the structure. However, there are gliders calculated in strength of design and capability of control systems exactly for fulfilling vertical steady-state dives, for example, gliders created especially for doing aerobatics. In these cases the polar point $c_y = 0$ determines the actual speed of such an operation.

The point obtained when drawing a vertical tangent to the polar characterizes the procedure of sharp diving with highest speed which can provide a cruise force for the glider, that is, the component of its weight directed along the flight path of the glider. This speed is close to that /104 of steady-state diving and therefore is interesting, as a rule, only when looking at special gliders of the aerobatic type.

If the graph $c_y = f(c_x)$ is constructed in a coordinate system, the beginning of which corresponds to $c_y = c_x = 0$, then the tangent to the polar, reading from the origin of the coordinate determines still another characteristic point called the point of maximum aerodynamic quality of a glider.

The horizontal tangent to the polar determines two important characteristics of the glider. In the first place, the minimum speed of vertical descent. By the size of this speed one evaluates the possible landing speed of a glider (it should be somewhat greater than minimum) and the minimum speed of its movement, acting as a limit beyond which the glider has worsened controllability.

Because the points of the polar of coefficients and glider correspond to a certain flight velocity if one assumes a constant

specific load on the glider wing and altitude of its flight (air density ρ), the polar $c_y = f(c_x)$ is easily reconstructed as the polar of velocity $V_y = f(V_x)$. This curve has the same characteristic points as the polar coefficients. However, for practical purposes it is more graphic and permits a simpler further analysis of aerodynamic (speed) properties of a glider (even in actual conditions) and permits making actual calculations of its flight under various conditions.

The Polar Line of Glider Velocity

The polar line of glider velocity according to its name is constructed in polar coordinates. One of these coordinates in this case is the size of velocity vector of a glider along the flight path, and the other the angle of inclination toward the horizon of this vector, that is, the flight path angle θ toward the horizon of the glider (Figure 2.9). But the interrelationship of components (vertical and horizontal) of flight velocity of a glider expressed by a relationship essentially between the velocity vector and the angle of its inclination toward the horizon can be constructed in rectangular coordinates. To do this one must place the horizontal component of glider flight velocity (flight velocity along the earth's surface)--V_x, along the axis of the abcissa; and along the ordinate axis--the vertical component, V_y. Then, all the vertical components corresponding to any flight velocity of a glider will be negative. /105

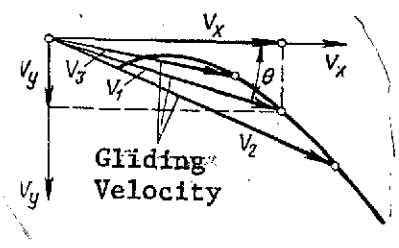

Figure 2.9. For the Construction of Speed Polars

If the components of glider velocity are expressed in the same scale and are translational velocity of a glider relative to air and if the origin of the coordinate corresponds to point $V_x = V_y = 0$, then each point constructed in these conditions of the polar line will define (show) the size and direction of the vector of glider velocity along the flight path. Therefore, the velocity polar is also an indicator of the glide path, that is the glide path of the glider corresponding to varying velocities.

Here in order to look at and correctly understand the essence of the relationship of gliding speed and descent of the glider, we first suppose a hypothetical case of glider flight for all angles of attack from 0 to 360°. This case can be reproduced in a wind tunnel experimenting with a glider model. The polar line of velocity constructed in conditions shown earlier takes on the aspect

of a closed curve as shown in Figure 2.10.

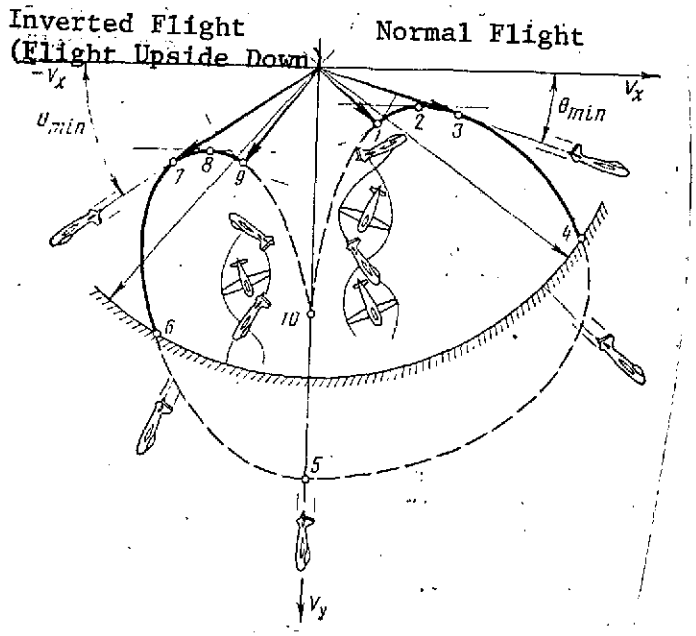

Figure 2.10. The Polar Line of Glider Velocity When Changing the Angle of Attack of the Wing in a Range 0--360°

Let us look at the right, (from the V_y axis) part of the polar. Here it is not difficult to observe the characteristic points similar to those which we noted when looking at the polar of coefficients. The point of tangency of the circle drawn from the origin of the coordinate, with polar line 1 defines the minimum /106 gliding velocity (along the trajectory) carried out in certain conditions, that is, under certain specific load on the wing and flight altitude. This point defines the corresponding velocity of descent V_y and the horizontal component of flight speed V_x. Point 2 of the tangency of a straight line drawn parallel to the V_x axis, with the polar defines the gliding velocity at which the speed of descent V_y is minimum. Point 3 of the tangency of a straight line drawn from the origin of the coordinate, with the polar shows gliding velocity at which the gliding angle θ is the smallest, that means the ratio of the path made by the glider along the earth's surface to the loss in altitude is the greatest. This point determines the flight procedure for maximum aerodynamic quality of the glider. Point 4 of the intersection of the polar lines with the circle drawn from the origin of the coordinate with a radius equal to the maximum attainable (under strength conditions) speed of glider flight defines the appropriate velocities of descent, the flight path

angle of a glider and the permissible size of velocity V_x. Point 5 of the intersection of the polar with V_y axis determines the hypothetical velocity of vertical steady-state diving where the entire weight of the glider is equalized by its drag:

$$G=X=c_{x_0}\frac{\rho V^2}{2}S$$

Here c_x of the glider corresponds to the angle of attack of the wing at which $c_y=0$. The branch of the right section of the polar line which continues to the left after the points corresponds to the minimum velocity V_{min}, curves below and intersects the V_y axis at a certain point which lies above the intersection of the polar with the V_y axis. However, the second intersection like the first designates the procedure of vertical diving but only tail first.

The part of the polar line which lies to the left of the V_y axis has a configuration and characteristic points similar to the right section. But the left part corresponds to conditions of an inverted flight. Therefore, as a rule, it extends less along the V_x axis than the right, because of the smaller aerodynamic quality of the glider in inverted flight than in normal flight.

Which sections of this curve are an expression of the actual possible procedures for glider flight? It is obvious that first of all among these sections would be the segment of the right part of the polar line between points V_{min} and V_{max}. And when accomplishing the aerobatic figure called "falling tail first," glider movement will be characterized by the section of the polar line which lies to the left of point V_{min}.

It is natural that similar sections of the polar line will be completely real for all gliders in inverted flight. Thus, in general the entire polar line is of interest from the point /107
of view of attaining the most complete velocity characteristics and evaluating aerodynamic possibilities of gliders in conditions of flight without side slip.

In usual practice the polar line construction is limited in a range V_{min}--V_{max} or an even smaller range of velocity. Then, the origin of the coordinate is shifted to the right along the V_x axis so that one does not have an empty space on the graph to the left of V_{min} point. Moreover, various scales are used for

velocities V_x and V_y (for the first--km/hour, for the second--m/s). And finally, one does not put the horizontal component of flight speed of a glider along the flight path along the V_x axis and not the true speed itself (of the glider relative to the air) but the instrument, that is the speed shown by the visual indicator mounted on the control panel in the pilot's cockpit.

In all these conditions the points of the polar line and the new origin of the coordinates will not define the size and direction of the velocity vector of the glider flight path. Therefore, looking at the polar line of a glider one must thoroughly study the conditions of its construction and determine flight path angles and coordinates of characteristic or desired points of the polar line not drawn geometrically but by calculations. In cases where the geometric method seems more convenient than calculation (for example in the case of calculating soaring flight which will be discussed further) the polar line must be reconstructed ahead of time putting it into appropriate form (the origin of coordinates at points $V_x=V_y=0$, real velocities, uniform scales, G_{gl}/S and ρ correspond to actual load and flight altitude). If the velocity scale of V_x and V_y are different, than the angle will be distorted, however the graphic methods of defining characteristic points of a polar line described above will remain the same.

Let us look at how the polar of glider velocity changes with the changes in flight altitude, specific load on the wing G_{gl}/S and configuration of the glider connected with operating the flaps and interceptors (here G_{gl}--is the flying weight of the glider). Speed and altitude of glider flight are one of the most important parameters of its movement. Knowledge of their nature and methods of specifying them and also the relationships and methods of calculating them are duties for the pilot and designer of gliders.

Glider speed is defined relative to a certain object which is considered immovable. These objects can be the air surrounding the glider or the earth's surface. However, with the instruments which are used to equip all gliders at the present time, glider speed is defined indirectly and therefore when converting its value it is necessary to keep in mind the method by which it is determined. A system by which glider flight speed is determined is presented in diagrammatic form in Figure 2.11.

Such a system measures essentially not the glider speed itself relative to the air but form drag. Because of this the speed fixed by such an instrument is called <u>instrument speed</u> (V_{inst}) and has its own peculiarities which must be taken into account when studying conditions of glider flight. We will look at these peculiarities. It is natural that PSH and the speed indicator itself /108

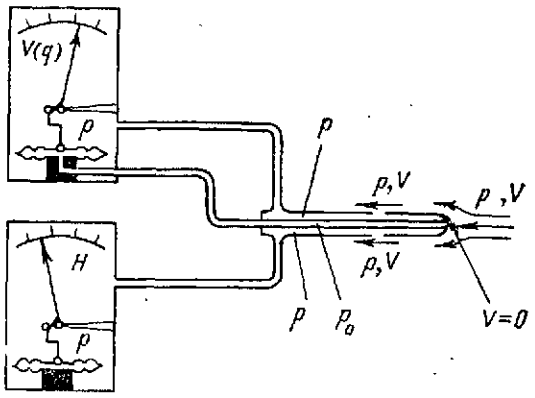

Figure 2.11. A Barometric System of Measuring Speed and Altitude of Glider Flight:

p--Total thrust; p_0--Static pressure

like all instruments operate with a whole series of errors. This means that the size indicated by the indicator arrow on the dial does not correspond to the real size of the parameter measured. And so to find out the actual size of the parameter it is necessary to introduce corrections into the instrument indication. These corrections are of various types. In the first place, one must correct for "instrument" error of the speed indicator itself. This correction can be taken from a calibration graph, that is, the relationship of the instrument readings on board the glider with the readings of a standard instrument, whose instrument error is known. In the second place, in the indications of the speed instrument on board one must introduce aerodynamic corrections. These corrections eliminate errors in the readings of the speed instrument which appear as a result of installing the PSH on the glider and from changing the conditions of its operation at various flight speeds (this means for various angles of attack of the wing). These corrections can be very significant if the PSH is mounted in an inappropriate place where during flight it can be distorted considerably by static pressure. One more correction in the readings of the speed instrument must be introduced in a case where real speed of glider flight (relative to the air) corresponds to an adequately large number of M ($M \geq 0.5$). This correction calculates the compressability of air which is dictated /109 by the differences in flight conditions from conditions of ground calibration made on the instrument. At substratospheric altitudes (up to ≈ 10,000 m) at ordinary glider flight speeds, this correction like the corresponding error is not great. Special graphs exist for aerodynamic correction and for correcting for compressability. Aerodynamic correction is defined for each glider experimentally in flight. Corrections for compressability are presented in standard graphs independently of the glider. They depend on the number of M and the altitude of the flight. Thus, reading the size of instrument speed on the dial of the indicator one must correct it and obtain a new value for this parameter of movement which is called indicator speed V_i:

$$V_i = V_{\text{inst}} + \Delta V_{\text{comp}} = \Delta V_{\text{a}}.$$

Here V_{inst} --is speed according to the instrument changed for instrument correction, and ΔV_a and ΔV_{comp} --respectively, aerodynamic correction and correction for compressability of the air.

Indicator speed thus (like instrument speed) is obtained by measuring form drag $\frac{\rho V^2}{2}$. This means, that for real speed, that is the speed of movement of a glider relative to air, it will be equal only at one flight altitude at which (or at the density ρ of which) calibration of the instrument was made, that is the marks on the scale of the indicator correspond to an assigned flight speed.

At all other altitudes the "PSH--indicator" system at uniform form drag will show the same instrument speed as at the initial altitude at which calibration was made. However, this form drag will correspond to other real speed (that is the speed of the glider relative to air). However, calibration of the speed indicator is done for zero altitude, that is at sea level with standard atmospheric conditions (see [30]). Then for increasing flight altitude the readings of the speed instrument will always be too low in comparison with sizes corresponding to actual speed because for creating the necessary form drag at decreased density of the air one needs a larger real speed than at a lower altitude. Thus, one and the same form drag corresponding to the same indication on an instrument at different altitudes are written in the following way:

$$\frac{\rho V_i^2}{2} = \frac{\rho_H V^2}{2}$$

Here V_i^2--is indicator speed measured at $\rho=\rho_0$. From this equality it is easy to obtain the relationship of real speed to indicated /110
or with the appropriate calculation of corrections--to instrument (for any defined altitude H):

$$V_i = V\sqrt{\frac{\rho_H}{\rho_0}} \quad \text{or} \quad V_i = V\sqrt{\Delta}.$$

Just such a relationship will be between a vertical speeds of descent of a glider V_y at different altitudes. And if flight speed at Earth V_o corresponds to descent speed V_{yo}, then at altitude H the corresponding speed of descent amounts to:

$$V_{y_H} = V_{y_o} \frac{1}{\sqrt{\Delta}}$$

There is still another glider flight speed which is of primary importance for navigational (navigator's) calculations of glider

flight but about which we have limited our references. This is ground speed, that is, the speed of forward movement of the glider relative to the surface of the Earth. It is obtained as the total of the vectors of real (we emphasize--real, not instrument and not indicator!) glider speed and wind velocity.

We note that at altitudes of approximately up to 2000--3000 m with a known approximation, that is, a certain error assumed ahead of time, one can consider instrument speed close to actual. But then one must always keep in mind the relationship of these velocities which involve relative density, and take into account their effect even though qualitative.

Thus, with an increase in flight altitude at one or another angle of attack a decrease in V_{yH} and flight along the V_H trajectory will occur with increased speeds. The size of aerodynamic quality with an absence of the effect of compressibility of air remains as before inasmuch as the preceding angle of attack of the wing is retained and this means the sizes of c_y and c_x and their relationship

$$K = \frac{c_y}{c_x}.$$

Now let us look at how the polar line of velocity changes with a change in the specific load on the glider wing G_{gl}/S. It was shown earlier that the same glider which discharges the ballast in flight, and has pilots of different weight in it can have essentially different values of specific weight on the wing. This, in turn, affects the velocity of descent and flight along the flight path If flight at varying loads occurs at one and the same angle of attack and at the same altitude, then

$$V_2 = V_1 \sqrt{\frac{\left(\frac{G_{gl}}{S}\right)_2}{\left(\frac{G_{gl}}{S}\right)_1}},$$ /111

and analogously--the vertical speed of descent (Figure 2.12)

$$V_{y2} = V_{y1} \sqrt{\frac{\left(\frac{G_{gl}}{S}\right)_2}{\left(\frac{G_{gl}}{S}\right)_1}}$$

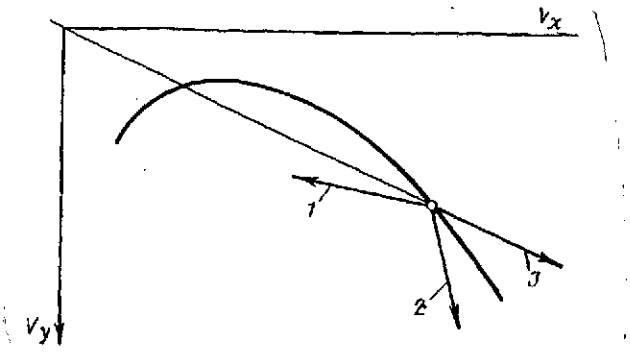

Figure 2.12. Shift in Points of the Polar Line of Glider Speed with Changes in its Configuration, Specific Load on the Wing and Flight Altitude:

1--Shift of points of the polar line when lowering the flaps; 2--Shift in points of the polar line when lowering the interceptors; 3--Shift in points of the polar line when increasing $\frac{G_{gl}}{S}$ and decreasing density ρ

Here, as in a case of changing flight altitude, the sizes of aerodynamic quality of the glider which are properties of each angle of attack remain unchanged.

The polar line of glider velocity and the polar coefficients undergo changes also during changes in configuration of the wing, when lowering and retracting interceptors and operating flaps (see Figure 2.12).

In the first case, the interceptors are basically a means of decreasing the lift force of the wing and partly a means of increasing drag forces. When the interceptors are lowered the polar line of speed moves down, shifts somewhat to the right and becomes steeper. This change, naturally because of using interceptors purposely decreases, and significantly, the aerodynamic quality of the glider which is required for precision in calculating landing and a number of other operating procedures for flight including managing bumps during flight on a tow behind an airplane.

Changes in the polar velocity in connection with operating the flaps can be complex. Looking at these changes first of all one should clarify the essence of operating the flaps which are different and depend on their designs. A method of optimizing /112 airfoils includes using the simplest flaps (not extensible, but imagined as the tail, along the chord) part of the wing--(see Figures 2.12 and 2.13) which are deflected not only down but also up. This permits although rather roughly changing the camber of the airfoil not only for greater bending which is needed at low speeds but also the opposite which is extremely necessary at cruising and greater speeds. Thus, flight occurs as if with different airfoils which give the best effect (from the point of view of the size of K with the smallest possible descent speeds for each angle). It is natural that each fixed position of the flap has its own polar line of velocity. But deflection of the flap at an angle which corresponds to the required flight speed of the glider permits utilizing the most suitable point of each of the polars. The geometric location of such points which correspond

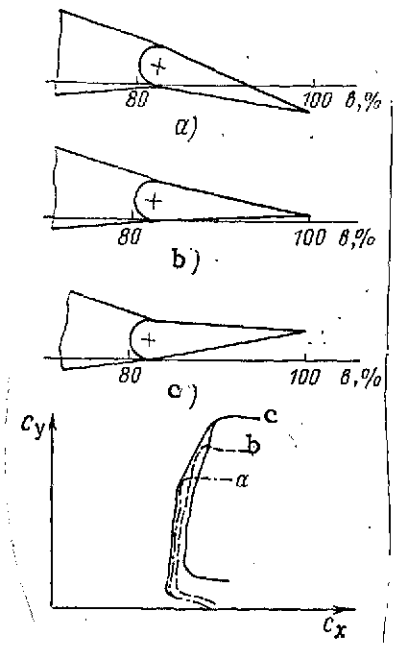

Figure 2.13. The Formation of an Envelope Polar Line For Varying Positions of the Flap on the Wing with Laminar Airfoil

now not only to the angle of attack of the wing but also a specific angle of deflection of the flap is a so-called "bending" polar line. Flight in a glider utilizing the optimized polar in such a way is called envelope flight.

Clarification of the ideas of such optimization of polar lines of a glider are made in the works of F.Kh. Vortmann who proposed a series of wing profiles and simplest flaps on them which are widely used in glider construction today.

The shift of a glider from straight line flight (that is from an endless spiral with large radius) to a spiral with radii of finite sizes is used in the practice of soaring flights.

Let us look at the forces which affect the glider in the spirals and force it to complete this complex movement.

So that the glider will begin to move along a curved path it is necessary to have the appropriate forces which are called centripetal. This force which acts in the direction of the lateral axis of the glider Z_1 is formed as soon as the glider manifests an angle of bank γ. Because of this, lift force Y makes the projection on the horizontal direction $Y \sin \gamma$, /113 perpendicular to the flight path (Figure 2.14). This is centripetal force. As a result of this, the path of the glider flight begins to curve and the glider swings around on the bank side describing a spiral around a certain vertical axis. Then the basic principle of glider movement (obtaining speed along the path at the cost of descending relative to the environment) remains in force during spiral movement. We note immediately that in connection with the deflection of the vector of lift force Y at angle of bank γ the weight component $G \cos \theta$ will be equalized not by the entire force of Y but only by its projection $Y \cos \gamma$. From this the size required in the spiral of lift force is defined from the expression:

$$Y \cos \gamma = G \cos \theta,$$

$$Y = G \frac{\cos \theta}{\cos \gamma}.$$

If the glider's flight path angle toward the horizon is not /114

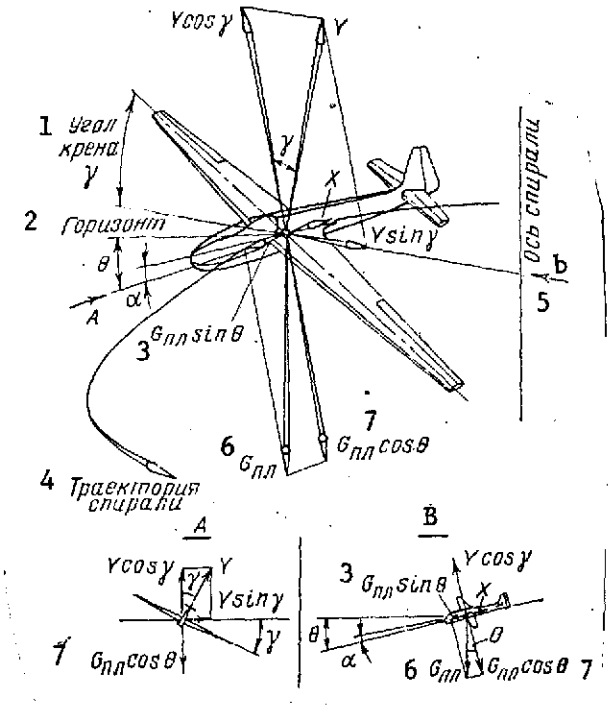

Figure 2.14. A Diagram of Forces During Flight of a Glider Along a Curved Path

Key: 1--Angle of bank; 2--Horizon; 3--G_{gl} sin θ; 4--Trajectory of the spiral; 5--Axis of the Spiral; 6--G_{gl}; 7--G_{gl} cos θ

great, then cos θ can be considered approximately equal to one, and the formula for the lift force of the wing in a spiral is described in the form:

$$Y \approx \frac{G}{\cos \gamma}.$$ [9]

By simple calculations one can obtain an expression which defines glider velocity in a spiral path V_c the corresponding speeds of descent V_{yc} and sizes of the radius of the spiral R_c.

The size of descent speed of a glider in a spiral is determined from the same force triangle. The aerodynamic quality of the glider in a spiral can be expressed by the formula:

$$K_c = \frac{Y \cos \gamma}{X}$$

The aerodynamic quality of a glider in a spiral will be decreased and defined by the formula

$$K_c = K \cos \gamma.$$

The vertical descent velocity of a glider in a spiral will equal

$$V_{yc} = V_y \sqrt{\frac{1}{\cos^3 \gamma}}.$$

All of our reasoning is made for the same angle of attack both in a spiral and in straight line gliding.

---

[9]Such a hypothesis is usually made in limits of the gliding angles $\theta \leq 10°$, which corresponds to cos value 10° = 0.98 and aerodynamic quality $K = 5.6$.

We will introduce still one more important concept[10] without which a study of spiral movement of a glider would not be complete. The relationship of lift force to the weight of a glider called vertical acceleration g is the mathematical expression of this concept. It characterizes the size of the lift force in relation to the weight of the glider and in this way determines the relative load affecting the glider. Acceleration g involves a number of parameters of the spiral and can be expressed by the following relationship:

$$n_y = \frac{Y}{G_{gl}} .$$

/115

But because in a spiral

$$Y \simeq \frac{G_{gl}}{\cos \gamma} ,$$

the acceleration g of a glider in a spiral will be inversely proportional to the cosine of the angle of bank (Figure 2.15):

$$n_y \simeq \frac{1}{\cos \gamma} .$$

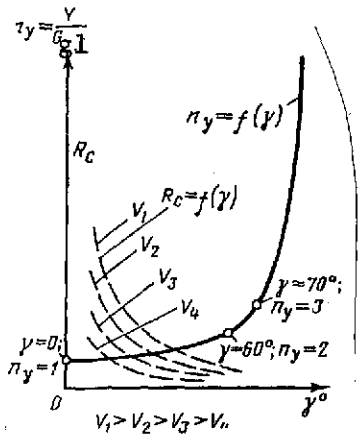

Figure 2.15. A Graph of the Dependence of the Vertical Component of Acceleration g on the Angle of Bank γ: R_c--the radius of the spiral

Flight velocity in a spiral and descent velocity can be written according to the following formulas:

$$V_c = V \sqrt{n_y} \quad \text{and} \quad V_{yc} = V \quad n_y^3 .$$

The radius of the spiral is determined from the expression for centripetal force (Figure 2.16):

$$R_c = \frac{V_c^2}{g \operatorname{tg} \gamma} .$$

By using the expressions obtained one can define (of course, for a definite specific load on the wing, configuration of glider and altitude of flight) a family of polar lines which complete the initial curve $V_y = f(V_x)$,

[10]The nature of this concept--acceleration g, will be discussed in detail in the section which covers loads affecting a glider in flight.

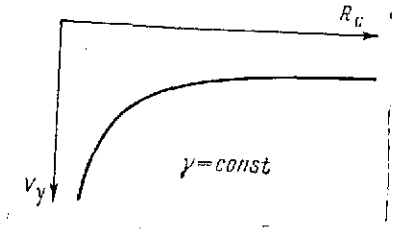

Figure 2.16. A Graph of the Dependence of the Rate of Descent of the Glider on the Radius of the Spiral

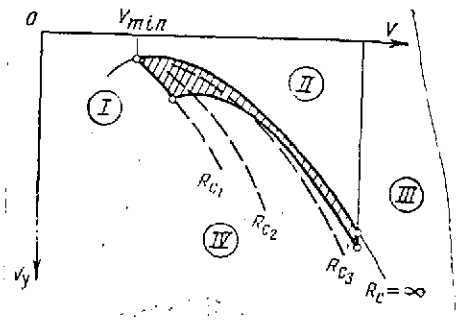

Figure 2.17. A Generalized Polar Line of Glider Speed [44]:

I--The field of glider speed not attained in practice because of their smallness; II--The field of glider flight speed not attained in practice because of inadequate source of energy; III--The field of glider flight speed not attained in practice because of too great sizes; IV--The field of glider flight speed not attained in practice because of too large acceleration factors endured by the pilot.

appropriate, as was mentioned, to a spiral with endless large radius.

The picture of spiral movement of a glider would not be complete without a grid of curves obtained for definite boundaries made by the certain operating field of flight speed, descent and appropriate banks, acceleration g and radii of spirals (Figure 2.17.). These boundaries can be laid out in the following way. The upper boundary of the field can naturally be only the initial polar line. It is the geometric location of those points which characterize the best possible combination of flight path speed and the speed of descent of the glider during glider flight in a straight line without bank or the same in a spiral with infinite large radius without slip ($\beta = 0$). The boundary on the right is determined by the size of maximum speed which can not be increased, limited by the strength of the glider. The boundary on the left is a curve drawn for a spiral made at minimum possible speed dictated by the maximum size of the coefficient /116 of lift force c_y. Finally, the lower boundary of the region of possible spirals is made by the physiological conditions of the capability of the pilot to endure the long term effect of the load factor n_y on him. This curve and its opposite which form the grid are like modifications of the initial constructed not for the constant radius but for a constant acceleration factor.

One can continue the calculations and construct, by using a polar grid, graphs of speed in assumed soaring flight calculating certain select conditions. Having considered the speed of various gliders for certain uniform conditions one can draw up a concept about a number of aircraft under actual (although assumed) circumstances.

Only with the help of a number of detailed generalized characteristics which illuminate the degree of perfection of a glider as an aircraft can one adequately objectively and not in a preconceived way form an opinion about a glider and say which aircraft is better for which problems. All attempts to evaluate gliders by two or three values, for example, maximum aerodynamic quality, minimum speed of descent and corresponding to that the flight path speed, cannot help but give a false picture of the glider.

2.4 Peculiarities of Maneuvering a Glider

Every glider's mission always includes a whole series of maneuvers, that is maneuvering in the air. This conditions for flying the glider is obvious. However, gliders made for different /117 purposes vary in their capability to be maneuvered and in a number of cases can complete only take-off, landing, turns, acceleration and slowing down. Aircraft intended for soaring flight under complex conditions and aerobatics at present can complete all aerobatic figures in normal and inverted flights. To put it another way it is possible to use a large part of the polar of velocity of a glider both to the right and to the left of the axis of vertical velocities V_y.

2.4.1. Take-off and Gaining Altitude on a Tow Behind an Airplane. Gliding While Being Towed. Landing a Glider

Take-off of a glider must be looked at at the same time as operation of the towing device. Methods of launching the glider can be extremely varied: by releasing by hand, towing by a running crew, by "shooting" using a rubber shock cord, with the aid of a moving vehicle, being towed behind an airplane, helicopter, using a fixed winch, by lifting the glider on a balloon or rocket launcher with subsequent ejection and transfer to free flight and finally, by using a power unit mounted on board the glider being started itself. Let us look at two methods of take-off--on a tow behind an airplane and using a special winch fixed on the ground.

We define two essential values by which one can judge the capability and character of flight of towing travel of "airplane--glider." For this case the required power of a power unit in the airplane can be expressed by the following relationship:

$$N_{\text{nec}} = \frac{P_{\text{nec}} \; V_{\text{tko}}}{75 \, \eta_B} .$$

Here P_{nec} --is the necessary thrust of the power unit of the airplane

equal to the total resistance of airplane and glider (aerodynamic friction of the wheels on the take-off strip), V_{tko} --take-off velocity, η_B--the coefficient of the useful effect of the aircraft propeller of the towing aircraft.

When gaining altitude the towing craft must increase the necessary power N_{nec} in comparison with the size required in horizontal flight in order to equalize the components of weight of the glider and of the aircraft directed opposite the flight speed travel:

$$N_{lift} = \frac{(G_{airpl.} + G_{gl}) V_y}{75\eta_B}$$

Where V_y--is the vertical component of flight speed of towed travel. /118

Descending in glider towed travel if this maneuver must be made on a tow is a more complex process than ascending. In ascending in order to maintain the same flight path angle θ as the airplane the pilot flying the glider can without difficulty decrease the aerodynamic quality by moving the glider to a smaller angle of attack and thus making his flight path coincide with the path of the towing airplane. The necessary lift force of a glider then will be provided in spite of the decreased c_y of the glider thanks to the corresponding speed of movement of travel. During descending travel, the same angle of flight path θ will correspond to different angles of attack and coefficients of the lift force of the aircraft and glider which follows from compiling a polar of one or the other (Figure 2.18). There is only one single flight speed at which the flight path angle and the speed of the airplane and the glider are correspondingly identical. This single gliding speed cannot be met by the pilots because it as a rule is impossible for the glider pilot to attain and sometimes even for the towing pilot. But if it is attainable then in practice there can be cases when other flight speeds and descent speeds (that is, other angles of θ) become necessary. At the present time the question of descending in towed travel "airplane--glider" can be solved comparatively simply if the glider is equipped with powerful interceptors which change its aerodynamic quality within a sufficiently wide range.

Maneuvering a Glider During Flight on a Tow Behind an Airplane

During towing, the maneuvering of a glider on the whole is very limited. However, curves and turns must be made in every flight. The conditions for a turn carried out in a horizontal plane have the following equality:

$$Y_{airp} \cos \gamma = G_{airp}, \quad Y_{gl} \cos \gamma = G_{gl}$$

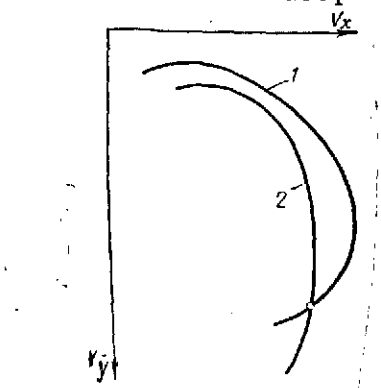

Figure 2.18. Polars of the Velocities of Glider and Towing Airplane:

1--Glider polar;
2--Polar of the towing airplane; V_x--the horizontal projection of flight speed of the glider and towing airplane during gliding; V_y--descending speed during gliding

For constancy of the curve radius it is necessary, so that the centripetal forces of the airplane and glider will also be unchanged, to provide a constant angle of bank γ. Finally, in the horizontal curve established of towed travel there must be provided equilibrium of thrust forces of the towing airplane's engine of the total resistance forces of the airplane, glider and towing cable: /119

$$P = X_{airp} + X_{gl} + X_{cabl}$$

Going from the relationships of force which affect the airplane it is not difficult to obtain a relationship between towing speed in a straight line horizontal flight and the necessary velocity of a horizontal curve.

$$V_{cur} = V_{h.f.} \sqrt{n_y} .$$

The radius of the curve in travel can be determined from the equality of centripetal force of the airplane of the projection of its weight on the horizontal axis

$$R_{cur} = \frac{V^2_{cur}}{g \ \mathrm{tg}\, \gamma} .$$

2.4.2. Take-off Using a Winch Fixed on Earth

The principle of operation of a winch when launching a glider includes imparting speed to the glider by winding the tow cable on a drum. This operation determines the necessary power of the winch.

Figure 2.19 shows a qualitative picture of using the power of a winch, the thrust forces of the tow cable during take-off and ascent of the glider using the winch. /120

2.4.3. On Carrying Out Certain Maneuvers (Aerobatics) on a Glider in Free Flight

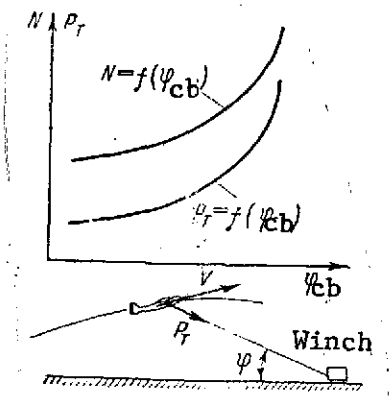

Figure 2.19. The Dependence of the Necessary Power of the Towing Winch on the Deflection Angle of the Tow Cable

Let us briefly look at certain basic maneuvers of a glider in free flight.

Diving or accelerating. The equations for movement of a glider when diving or accelerating are similar to the equations for gliding flight:

$$m_{gl} \frac{\Delta V}{\Delta t} = G_{gl} \sin\theta - X$$

$$Y = G_{gl} \cos\theta$$

Here $\frac{\Delta V}{\Delta t}$ --is the increase in velocity of movement of a glider along the diving trajectory per unit of time (linear acceleration); m_{gl}--is the mass of the glider.

As a result of solving these equations one can easily obtain four given characteristics of a glider (initial speed and flight path angle) the time for accelerating to a certain speed and altitude lost in this acceleration.

A Glider Going Into a Dive and Coming Out of It

Putting a glider into a dive can be done differently: by curving the flight path down to attain the necessary angle to the horizon θ or by rotating around the wing which creates a large bank with uniform energy in the turn toward the down wing.

Coming out of a dive it is necessary to increase the angle of attack which entails increasing the lift force and the positive difference of the lift force and the weight of the glider begins to curve the dive path bringing the flight angle toward zero.

The equation for this glider movement is similar to the acceleration equation.

These equations make it possible to construct a flight path of a glider when coming out of a dive, determine altitude lost by a glider when going into a dive, and the time which is necessary for this maneuver.

Wingover [Nesterov's Loop]

When doing a wingover (at $\gamma=\beta=0$) the glider movement can be described by equations which are similar to those presented earlier. Going from similar premises one obtains the following simple expressions for initial speed of gliding which must be maintained when carrying out a loop:

$$V_{beg} = (1.5--2.0)V_{min} .$$

"Stall Turn" and Certain Other Maneuvers /121

These so-called "stall turn," "half-loop with roll," loops with shifts along the horizontal points of going out of a loop in relation to the point of entering a loop, slip on the wing, sheet drop, drop on the tail and so forth (and also those figures for inverting the initial position of the glider) can be done on a glider with the following imperative conditions. First, the strength of the glider must be adequate so that its structure will withstand very high loads on all of its elements which occur in the process of doing aerobatics. In the second place, the control devices of the glider must be very efficient and provide precise gliding and the glider itself in its aerodynamic properties (here we're talking about the possibility of fast acceleration and adequately slow expenditure of the kinetic energy of the glider acquired in acceleration) must be at a very high level. One should keep in mind the difficulty of coordinating some of these requirements with the basic requirements necessary for a glider in general.

Chapter 3 Controllability and Stability of a Glider

3.1. Controllability of a Glider

Let us look at the conditions for carrying out glider flight which include the necessity to control its motions. According to the example of preceding sections we will assume a priori the presence of the necessary aerodynamic shapes of the glider which make it possible for it to move over the Earth's surface with small inclination of the flight path in relation to the horizon.

What does controllability mean? Often this concept is interpreted as the capability of a glider "...to respond to forces applied by the pilot and shifts of the control stick knobs which correspond to changes in position in space,..." [28]. In this connection, at the present time, the enumerated (quantitative) characteristics by which one can evaluate controllability of a glider are limited to the field of movement of the glider in space. However, this motion of the glider by itself as we have seen earlier does not encompass the entire flight as a phenomenon. Because of this, these characteristics cannot give us a full picture of the controllability of glider movement.

Questions of controlling motion of a glider involve each of three flight elements mentioned earlier--the glider, as an aircraft, the atmosphere, as the medium in which flight occurs, and the man, who accomplishes the flight on the glider for solving one or another operational task.

Under controllability of a glider we will remember the concept of control by a pilot with average qualifications when solving all operational tasks assigned to him.

Thus, the role of controllability of a glider includes providing the pilot with appropriate conditions for realizing all the capabilities of the glider which determine its maximum mobility (that is the capability to move when solving an operational task in a case of irreproachably correct control of its motion by the pilot). To put it another way, maximum mobility is /123
attained during complete realization in flight of all the capabilities of a glider dictated by the structural and aerodynamic solutions of this machine.[11] Achieving all the flying

[11] Often in published advertising data on gliders, factors are presented which are reliable from the point of view of calculation and attainment under ideal conditions but which are exaggerated from the point of view of practical operation (they are impossible to accomplish because of poor controllability).

engineering capabilities of a glider in practice is limited by the imperfection of conditions under which a pilot carries out his work in controlling the motion of the glider. Some of these factors which characterize a man from this point of view have to do with his qualifications (the degree of preparation for solving an operational task) his physiological capability (the quickness of his reactions, fatigue, etc.). Therefore, under practical conditions of operation one does not achieve maximum mobility of a glider but something less than that. The combination of capabilities actually attainable in flight determine the operational mobility of a glider. Consequently, controllability is determined by how close one can come to the maximum values of the flying engineering factors which a glider nominally possesses.

Some of the characteristics which are specified in the combination of controllability of a glider are:

--stability of motion of a glider or as is often said,--glider stability;

--ease and efficiency of the control system;

--comfort of the pilot in the glider cabin during flight (life support and providing operating capabilities for the pilot);

--safety of the flight on the glider (in the concept of safety in particular we mean strength of the glider and rigidity of its construction);

--the possibility of controlling motion of the glider precisely.

Each of these elements which has an effect on controllability of a glider must be looked at from the point of view of its effect on how close one can come to achieving the maximum mobility in operation of the glider.

We note that at the present time, in a number of cases, especially when designing record-breaking gliders, a great deal of energy is directed primarily at broadening the maximum mobility of the glider. At the same time its operational mobility (as a result of inadequate controllability) is noticeably far from maximum.

The use of a recumbent position for the pilot or extending the wing tremendously are examples of this phenomenon. The use of a recumbent position for the pilot is intended to decrease the /124
size of the drag coefficient but complicates considerably the pilot's work in flight. The use of a wing with tremendous elongation results also in improving the aerodynmaic quality of the glider but at the same time decreases rigidity of the wing, increases

its moment of inertia and as a result of this increases the time expended for maneuver involved in turning the glider relative to the longitudinal and vertical axes. Thus, a certain gain in aerodynamic quality in the glider (which generally speaking is desirable but not at all necessary) in turn noticeably worsens the working conditions of the pilot and has a noticeably bad effect on rigidity and controllability of the glider as well. On the whole, this worsening of controllability (as a result of trying to improve one of the characteristics of the glider) often results in the fact that the glider becomes impossible to fly by any but the most qualified pilots or even results in making it impossible to completely solve an operational task on such a glider.

3.2. Stability of Motion of a Glider

Travel of a glider in space in which its flight path is determined, its speed and spatial position dictated by certain laws which involve their change with time, all make up the so-called basic motion of a glider.

If, at a certain moment in time, a glider is affected by the forces which change its basic motion, then after the effects of these forces stop a new motion called perturbed begins. After a certain time, the perturbed motion can bring the glider back to its initial motion. Then all the movement of the glider (basic and perturbed) is considered stable. But if as a result of the perturbed motion the glider does not return to its initial (basic) motion, the glider motion (both basic and perturbed) is considered unstable.

Thus, the stability of motion of a glider means the properties which characterize the kinematic parameters to return motion to its initial value in basic motion after their deviation from these initial values and the stopping of the causes resulting in these deviations. The person who initiated the theory of stability of motion of a body is our fellow countryman, A.M. Lyapunov.

3.2.1. The Concept of Equilibrium

To clarify the essence of the concept of stability of motion of a glider it is necessary to recall the concept of equilibrium. It is considered that a body is in equilibrium if the total of all forces and moments acting on it equals zero. Naturally equilibrium /125
of a body can be in a state of rest or during its motion.

Let us look at a few elementary examples of equilibrium states of a body (Figure 3.1).

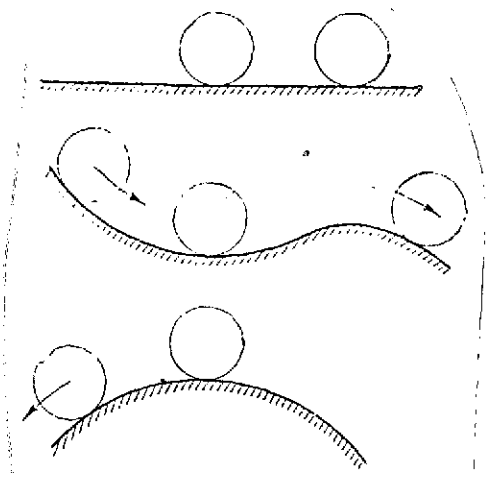

Figure 3.1. A Sphere on Various Surfaces

A sphere on a horizontal plane is in equilibrium (an equilibrium state of quiet or movement), if only its weight and the reaction forces of the bearing surface act on it. In this case the weight of the sphere is equalized by reactions of the plane on which it rests. And because the direction of weight and the forces of reaction coincide and occur through a single point (support) then the moment of these forces equals zero.

If an external force is applied to the sphere we are looking at, which destroys (disturbs) its equilibrium state, the sphere begins to move along the plane with a certain acceleration. When the effect of the perturbing forces stops, the sphere will continue to move due to inertia. And if one disregards the friction resistance of the sphere on the surface and the environment, the motion will be in equilibrium and in a straight line which will determine its new equilibrium state (in motion). If a disturbing force is applied to a moving sphere without friction, then after this effect stops the sphere begins to move usually in a new direction and at a new speed but also in equilibrium. In most cases the sphere will return to a state of rest but in a different location.

Then, both in the case of an equilibrium state of motion and an equilibrium state of rest, the parameters of these states will have a tendency neither to return to their initial values (according to the initial speed of motion or location) nor to further deviation from them.

These equilibrium states of a sphere on a horizontal plane are states of so-called <u>neutral</u> equilibrium. And they are characterized by <u>neutral stability</u> of rest and motion.

Now let us look at this same sphere but lying at the top of a convex surface. The sphere will be in equilibrium for the same reason that it was on the horizontal surface. However, this /126
aspect of equilibrium will be unstable as well as the motion of the sphere which begins after the end of the perturbing force effect on it. Actually from this one gets an unstable equilibrium; the sphere begins to move from its initial position all the time increasing its motion. And being placed on an inclined surface and again let go it will move again away from the area where it was forced to stop.

Finally, when the sphere is at the lowest point of a concave

surface it will be in a state of stable equilibrium. Even after the perturbing forces stop, the sphere will try to return to its initial position. And its motion will always be accelerated on approaching its initial position and slow down when leaving it.

It is necessary to have the following conditions so that the motion of a sphere will have not only the tendency to return but also after the perturbing forces stop will return in the end to its initial state of rest and initial position. Besides force and moment which dictate motion of the sphere after the perturbing forces cease (these forces and moments are called forces and moments of stability) there must also be certain other forces and moments active, called damping forces. If there were no damping forces, then although the sphere would have a tendency to return to its place because of the forces of stability, the sphere would always travel to its initial position because of inertia.

Thus, it is clear that the motion of the sphere will be stable if after the perturbing forces stop in the first place there is a tendency to return to its initial position, and in the second place, the perturbing motion will quiet down and return the sphere to its position in the end.

The speed and character of return of the sphere to its initial position depend in our case on the slope of the surface upon which the sphere rolls to its initial position of stable equilibrium and on the size of damping forces which do not permit the sphere to oscillate. Then, the steeper the surface the more quickly the sphere will return to its initial position. But the larger the damping forces the faster the return motion will be damped around the position of stable equilibrium of a sphere. We note that with extremely large sizes of damping forces the motion of a sphere will stop before it reaches the initial point of its motion. This means, for stable motion under certain forces of stability and inertia that certain sizes of damping forces are also very important. Thus, the slope of a concave surface will characterize the degree or measure of stability of motion of a sphere. The sizes of damping forces and moments characterize the degree (speed of damping) of a perturbing motion or the measure of its damping. /127

If one considers that the height of the concave surface looked at is limited then it is possible to suppose this perturbing force which removes the sphere from contact with the surface and causes a new state (motion or rest), whose degree of stability will be characterized by other factors completely unconnected with the initial conditions of motion. Therefore, when looking at stability of motion of a sphere one must differentiate among the questions which apply to its motion, independent of the size of perturbations and questions which apply only to so-called small perturbations. These small disturbances are those which will not take the sphere beyond the boundaries of its supporting surface.

3.2.2. Peculiarities of the Characteristics of Stability of Glider Motion

In most technical problems including those involving stability of motion of a glider one works mainly with small perturbations.

An example of a small perturbation during glider flight can be the transfer from one speed to another or putting the glider into a spiral. In this and other cases the perturbing cause will be a change in the control devices of the glider. An example of a perturbation as a result of which the glider leaves its initial flight conditions, and increase in motion not connected directly with these conditions can, for example, be stall in a spin which occurs as a result of dropping the glider into a strong vertical air current. This current will be the cause of perturbing the initial equilibrium state of the glider (in motion).

Although in actuality there exists one single stability of motion of a body, and in particular, motion of a glider, at this time we will utilize certain concepts of stability each of which characterizes the perturbing motion from different points of view and in different fields.

Historically there are two concepts of stability: static and dynamic. The latter also means stability as a whole.

Static stability is defined as the aerodynamic righting moment which occurs during deviation of a glider from its original trim right after stopping the effect of the perturbing cause. It is like the example of a sphere on a convex surface, its motion (or the sphere itself) will be statically unstable, on a concave surface--statically stable.

Dynamic stability considers the character of the entire perturbing motion right up to return of the body to its initial state (under stable motion) or until the moment of final exit from initial conditions of motion to new conditions, although not connected with the initial motion (during unstable motion). /128

In the example of the sphere on a convex surface, its motion (or the sphere itself) will be dynamically (just like statically) unstable.

In the case of a concave surface (with the presence of damping) it is dynamically (just like statically) stable. The perturbed motion of the sphere on a concave surface will be dynamically neutral (although its static stability is retained), if the damping conditions disappear, that is, the sphere will continue to roll endlessly from one side of the surface to the other never stopping in its initial position.

Thus, the concept of static stability is extremely essential although it does not cover all aspects of motion stability as a whole.

Let us sum up the concepts with which we have become acquainted in the examples of motion of a sphere.

The body can be in a state of equilibrium of rest or motion. This equilibrium state is characterized by the zero equality of the total vector of all external forces and moments which affect the body.

The equilibrium of a body can be stable, neutral (unvarying) and unstable. The character of motion of a body is determined by the size or degree of stability of its perturbed motion which begins after the perturbing cause (force, moment) stops affecting the body. To have stable motion of a body, in the first place, at the initial motion after the perturbing cause stops, the changes of parameters of motion must be directed toward a return to the initial size. Such a tendency is called static stability, and its size--the degree of static stability. In the second place, the perturbing motion as a whole in a case where it has a stable character must provide return of the parameters of the body state (including the parameters of perturbed motion) to their initial values. For this, the perturbed motion of the body must be damped. These conditions are called dynamic stability of motion of a body (or stability as a whole). The character or speed of damping of a perturbed motion of a body characterizes the degree of its dynamic stability.

Spatial motion of a glider is very complex and diverse. Therefore, it is customary to look at it by dividing the perpendicular movements whose directions correspond to the directions of coupled /129 or semi-coupled coordinate axes of the glider into three parts.[12]

Having divided the motion of a glider in space in three directions, it is possible to look at them separately and the properties of each of these components of motion. However, one must keep in mind that the bank and yaw movements are interconnected (we will speak about this further). In the same way a tight bond exists between the stability of these motions which are combined in the concept of lateral motion.

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[12]Such a division of the total complex motion of a glider includes not only its forward but also its rotating motion. It is assumed that the vector which represents the angular speed of rotation of the glider is directed along the same axis relative to which rotation of the glider occurs. Then, the positive speed of rotation is considered a couterclockwise motion if one looks at the end of the vector in the direction of the initial coordinate.

Longitudinal Static Stability of Glider Movement

The motion of a glider in its plane of symmetry is called longitudinal, and the corresponding moments which affect the glider in this plane just like the stability of this motion are called longitudinal (see Figure 2.2).

Let the basic movement of a glider be free flight along a straight line path with constant speed. Then let the section of the flight path on which the perturbing motion which is being considered be an insignificant change in altitude, but at the same time be adequate in length of time. For the flight of a glider these are usual conditions. And changes in air density will be disregarded.

Under such conditions of glider flight, the following forces and moments will act on it which determine its motion and position in space: the component of weight playing a role in cruising force and compensation of drag of the glider.

$$G_{gl} \sin \theta = X = c_x \frac{\rho V^2}{2} S,$$

Y--is the lift force of the wing which is equalized by the other weight component of the glider

$$G_{gl} \cos \theta = Y = c_y \frac{\rho V^2}{2} S,$$

$M_{zwoht} = M_{zw}$--is the longitudinal moment of the wing which equalizes the longitudinal moment of the tail unit M_{zht} (Figure 3.2)

$$M_{zwoht} = m_{zwoht} \frac{\rho V^2}{2} S b_A = M_{zht}.$$

The effect of the lift force of the tail unit is considered in this case only through the effect of momentum M_{zht}: /130

$$M_{zht} = -Y_{ht} L_{ht}.$$

The effect of drag forces of the tail unit usually is considered only when calculating the total force of the drag of the glider because of its comparatively small size. The lift force, drag and longitudinal moment created by the fuselage are assigned to the appropriate forces and moments of the wing. Thus, the glider conventionally is divided into two parts: the combination of the wing and fuselage without the horizontal tail unit and the separate tail unit.

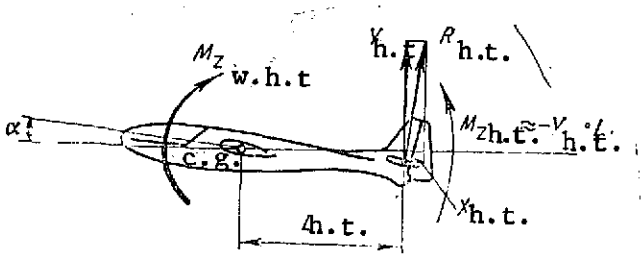

Figure 3.2. The Longitudinal Moments Which Affect a Glider. The Aerodynamic Forces Acting on the Wing and M_{zwoht} Formed, Conventionally Not Shown

The longitudinal moment of the wing relative to any lateral axis can be described in the following form: $M_{zw} = m_z S b_A q$. Here $M_{zw} = (\bar{x}_d - \bar{x}_T) c_{y1} = c_m + \bar{x}_T c_{y1}$, $\bar{x} = x_d / b$ -- and is the relative distance from the forward edge to the center of pressure of the wing, and $\bar{x}_T$ -- is the similar distance to the center of mass, c_m -- is the coefficient of moment of the wing relative to the axis going through its leading edge.

Because we will look at the movement of a glider at the angles of attack where there is a linear relationship of c_y and c_m to α, the coefficient c_m can be expressed in the form of an equation of this dependence:

$$c_m = m_{z_o} + \frac{\Delta c_m}{\Delta c_1} c_1.$$

Here m_{z_o} -- is the coefficient of moment of the wing with $c_{y1} = 0$, and $\frac{\Delta c_m}{\Delta c_1} c_1$ -- is the coefficient of moment created by the lift force of a certain arm, the relative size of which equals $\frac{\Delta c_m}{\Delta c_1}$.

This arm is of great importance because in the range of linear dependencies c_{y1} and c_m to α and with the numbers M /131
which correspond to speeds at which gliders usually fly ($M \leq 0.5$), it is constant and this means determines the mean aerodynamic chord of a certain constant point called the focus of the wing (Figure 3.3).[13]

[13] When looking at stability of the motion of a glider as a whole (that is, the combination of wing with fuselage and the tail unit) the position of the focus on the chord of the wing is defined from the combined operation of wing and horizontal tail unit.

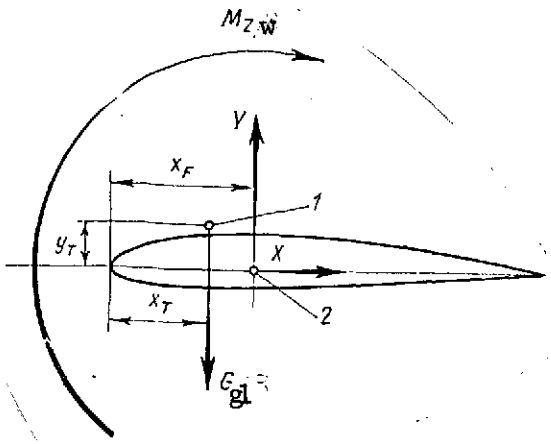

Figure 3.3. For Defining M_{zw} of a Glider. The Value of Y_T in Practice is Not Large. And, if $Y_T \leq 0.1$ (or $\bar{y}_T \leq 10\%$ of the M.A.C.) and This Covers Most Cases, the Size of y_T Can Be Disregarded:

1--The center of mass of the glider; 2--The aerodynamic focus of the wing

From what has been said the coefficient of moment of the wing relative to any lateral axis will be equal to:

$$m_{z_w} = m_{zo} - (\bar{x}_F - x_T) c_{y_1}.$$

Thus, the coefficient of longitudinal moment of the wing m_z is the function of the coefficient of lift force c_{y_1} and, consequently, in linear sections of the relationship $c_{y_1} = f(\alpha)$-- is the linear function of the angle of attack of the wing.

Because longitudinal stability of glider movement is determined for given m_{z_o} and c_{y_1} only for the mutual position of the center of mass of the glider and its aerodynamic focus, then for giving the character of longitudinal motion stability it is necessary to place the focus of the plane in such a way that during all possible shifts of the center of mass during flying operation (mainly occurring from the /132 varying weight of pilots and to a lesser degree from the ballast load of the glider), it (the center of mass) always lies in front of the focus of the glider. Then, as is seen in Figure 3.4, an increase in the angle of attack with an equilibrium state of the glider results in diving moment, and when decreased--in tail heaviness. In both cases these moments which occur act to re-establish the initial state of balance.

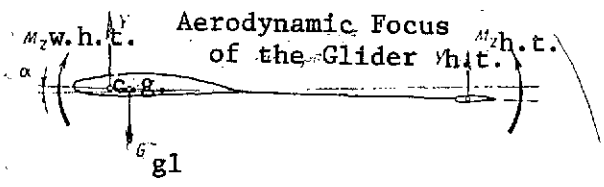

Figure 3.4. Conditions of Longitudinal Static Stability of Glider Movement

When the center of mass is at the focus of the glider, its longitudinal motion will have a so-called neutral character. This means that after the effect of a perturbing cause has stopped longitudinal motion will remain unchanged, not returning to its initial character but not changing to a larger degree than was caused by the disturbing effect.

Which factors influence the size of longitudinal static stability of glider motion which is determined by the slope of

curve $m_z = f(c_{y_1})$ measured at the point of intersection with the c_{y_1} axis?[14]

From the diagram in Figure 3.5 it is apparent that glider motion will have greater static stability if the righting moment Δm_z, dictated by a change in c_{y_1} or the angle of attack α, is greater.

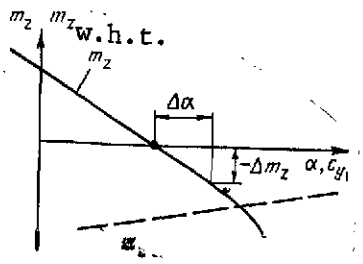

Figure 3.5. Dependence of the Coefficients of Longitudinal Static Stability of Glider Movement m_z on Angle of Attack α

This means the absolute value of the slope of curve $m_z = f(c_{y_1} \cdot \alpha)$ (when when the static stability present is negative) determines the degree of longitudinal static stability of the glider. Then numerically the slope (and this means the degree) of longitudinal static stability equals $\frac{\Delta m_z}{\Delta c_{y_1}}$ which is the measure of the distance of the actual center of mass of the glider from its aerodynamic focus:

$$\frac{\Delta m_z}{\Delta c_{y_1}} = -\bar{x}_F + x_T.$$

Thus, one of the most important factors which affects the size of longitudinal static stability is the position of the center of mass of the glider relative to its focus. /133

Other factors which also affect longitudinal static stability of a glider are the size of the area and the arm of the horizontal tail unit. The larger the area of the tail arm the greater is the shift back of the focus of the glider. This means that with one and the same alignment a larger area and arm of the horizontal tail unit give a larger righting moment (relative to the center of mass). And curve $m_z = f(c_{y_1})$ will have a larger negative slope.

The position of the horizontal tail unit relative to the wing of the glider can affect longitudinal static stability. This occurs in those cases (mainly during flights with large angles

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[14]When evaluating longitudinal static stability of glider motion the slope of curve $m_z = f(c_{y_1})$ is measured at point $m_z = 0$, because the equilibrium state of the glider ($M_z = 0$) from which any kind of disturbing cause occurs is considered initial.

of attack α), when the tail unit is in a slipstream behind the wing. In a slipstream the rate of air flowing over the glider is less than outside the stream (thanks to friction from the surface of the glider) and is directed at a smaller angle toward the horizontal tail unit. This is another reason for the decrease in lift force of the horizontal tail unit and means the righting moment.

The fuselage has an effect on longitudinal static stability of glider movement by certain of its geometric dimensions. If the glider is greatly elongated in front of the cockpit its focus, because of such a fuselage, shifts forward which decreases stability. A small elongation of the fuselage measured in relation to its length to maximum width in plan form shape has this effect:

$$\lambda_{\phi} = \frac{l_{\phi}}{b_{\phi}},$$

where l_{ϕ}--is the length of the fuselage, and b_{ϕ}--is its maximum width in plan form.

The effect of the fuselage on longitudinal moment of the "wing--fuselage" moment is relatively small. The main part of this moment is the wing moment. However, the size of the fuselage moment cannot be disregarded and requires calculation when evaluating the slope of curve $m_z = f(c_{y1})$.

The position of the flaps and in certain cases the spoilers has a significant effect on the size of longitudinal moment of the wing, and this means on longitudinal static stability. The lift /134
augmentation devices of the wing not only change its lift force and drag, but also (in particular the flaps) change longitudinal moment of the wing and longitudinal static stability. When operating the flaps and spoilers the character of streamlining of the wing is changed and the distribution of pressure and this means longitudinal moment.

The position of the focus of the glider, and along with this its longitudinal stability, are changed when the position of the control stick or elevator (stabilizer) is fixed and can freely deflect up and down depending on the direction of the air flow which comes over the tail unit of the glider (in cases when the pilot does not fix the control stick, it is freed, and the handle "is dropped"). During flight with a fixed control stick an increase, for example, in the angle of attack (involuntary, that is, occurring due to an external cause) respectively increases the lift force of the horizontal tail unit and the righting longitudinal moment. If then there is a perturbing cause, the longitudinal control will be free (not fixed), and the position of the elevator will be determined by the direction of air flow coming over the horizontal tail unit which changes in turn the

camber of the airfoil of the tail unit and by doing this the lift force becomes smaller than in the first case. This means, the righting moment (the stability moment) will be smaller than when the control is fixed.

From here there are still two more concepts of static stability which essentially are only characterized by the conditions in which only static stability of the glider is apparent (longitudinal static stability with fixed and free control). As was explained, static longitudinal stability with fixed control is usually greater than with free.

One should keep in mind that when studying longitudinal movement of a glider, its stability will be uniform in cases of slow and fast changes in flight procedure. With a slow change from one flight procedure to another, the angle of attack of the wing, changing, remains all of the time relative to changed speed in straight line established flight. In this connection, the force of full aerodynamic resistance of the glider R will remain equal to its weight. The relationship of these two forces which are acceleration g[15] will be equal to one. When there is a swift change in procedure of longitudinal movement of the glider, the speed of the flight cannot change in the time of change of the angle of attack of the wing because of which the force of the entire resistance of the glider is equal to the weight of the /135
glider and acceleration g will be different from one.

Because of these peculiarities the stability of longitudinal movement of a glider with constant acceleration g (then it is called stability according to speed) and stability of movement of the glider at constant speed (then it is called stability according the acceleration g) are different. The coefficients which determine longitudinal stability of one or another type of longitudinal movment of a glider are named accordingly. The importance of such separate study of stability of longitudinal movement of a glider is dictated by the fact that the appearance of one or the other type of longitudinal stability involves either a change in speed with large time period for the perturbed motion or a change in acceleration g with the process occurring very quickly.

Therefore, in the first case, the pilot may have to "soar" that is, eliminate longitudinal oscillations of the glider by moving the elevator if they are undesirable and by increasing then indicate instability of motion. Thus, longitudinal instability according to speed of the glider, although

[15]A detailed explanation of the concept of acceleration g is given in the section on strength of the glider and load which affects it in flight.

undesirable, cannot be completely eliminated (when it is small) in flying operation.

In the second case, the speed of the process does not give the pilot time to adjust the elevator for changing the glider from a given flight procedure. And the change in acceleration g creates new complex flight conditions which the pilot doesn't have the power to deal with.

Having become acquainted with the essence of static stability of longitudinal motion of a glider, one comes to a number of conclusions. The degree of longitudinal static stability determines mainly the availability of the glider for operation by a pilot of average qualifications. The degree of longitudinal static stability is apparent in the stability of motion of the glider: the larger the resistance to change, the greater is the stability. Thus, large longitudinal static stabilty is a positive factor assuming the correct selection of the degree of damping. However, high stability requires appropriate selection of characteristics for the longitudinal control system, because when the elevator (stabilizer) is inefficient, the large forces on the control and effort required for moving it are out of proportion to it and the pilot has difficulty in changing or reestablishing the character of motion of a glider. But because flight, in a equal degree, is made up of both established and changing procedures then stability of glider motion must be provided and so-called good "responsiveness of the glider to the stick," that is, the property of the glider to follow the changes in the control devices.

Thus, one can conclude, that the larger the static stability /136
of the glider the better will be its controlability under conditions with adequate damping of the glider, efficiency and ease of moving the longitudinal control devices for motion which dictate the "responsiveness of the glider to the stick" (Figure 3.6).

Static Stablity of Lateral Motion of the Glider

Static stability of lateral motion of a glider is considered as a single property of two motions: lateral and forward. These two motions are dictated by the presence of lateral forces and moments which occur and are in effect during the presence of angle of slip, that is the angle between the direction of the vector of speed of motion of the glider along the flight path and its plane of symmetry.[16] Thus, lateral and forward motion of a glider are interconnected and practically inseparable.

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[16]This angle β, when considering longitudinal motion of a glider, is assumed to be equal to zero.

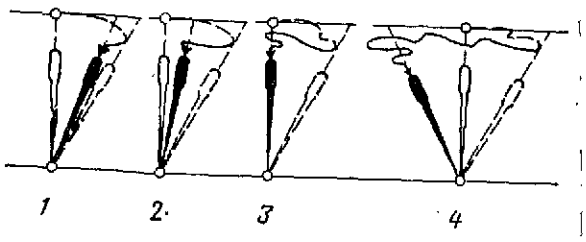

Figure 3.6. The Character of Shifting the Control Stick When Carrying Out a Maneuver Which Involves Changing the Position of the Glider in Space with Varying Degrees of Glider Stability. (According the I.M. Pashkovskiy [31]): 0--Initial position of the control stick; – – – –straight course of the control stick made for giving the glider a certain angle of speed in order to turn it at the required angle; ——— Subsequent movement of the control stick making it necessary to hold the glider in the required position, 1--Stable glider; 2--Stable glider with decreased stability; 3--Neutral glider; 4--Unstable glider.

Actually, if there is no sideslip, then any changes in the vector of speed in size or direction (in the plane of symmetry of the glider) can cause forces and moments acting only in the plane of symmetry. Sideslip and bank can occur as a result of this or that independently of each other. If lateral motion of a glider should begin, from a bank or sideslip, the shift and /137 deflection of the total forces of resistance R caused by unsymmetrical motion of the glider is explained by the phenomenon of its components (projection) which act perpendicular to the plane of symmetry of the glider. The lateral force which occurs causes lateral moments (relative to the Oy_1 and Ox_1 axes). The effect of these moments can be directed toward the side where bank and sideslip form or to the opposite side. Depending on these directions the M_{x_1} and M_{y_1} moments caused by the sideslip will either increase the bank and sideslip or decrease them, that is, reestablish the original (initial) type of motion of the glider (Figure 3.7).

Just like longitudinal static stability of a glider which we looked at, in a certain case, the degree of lateral and forward static stability are characterized by the slope of curves of the relationships $m_x = f(\beta)$ and $m_y = f(\beta)$ (Figure 3.8). Then the statically unstable character of lateral motion of a glider will correspond to the positive slope of these curves, and stable--to the negative. One should note that the sideslip angle β does not reflect completely the directional changes of the flight path during sideslip. In this case travel stability is looked at only as a capability to eliminate β or add to it after stopping the effect of perturbing causes, but not returning the glider to /138 its former direction, that is, to its former course.

It is also very important that in looking at the moment of bank M_{x_1} and the moment of sideslip (yawing moment) M_{y_1} to

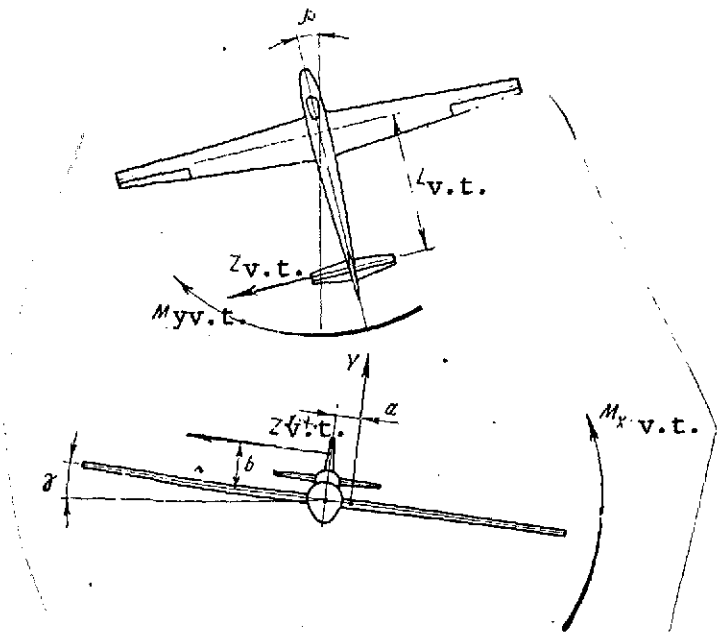

Figure 3.7. Conditions for Forward and Lateral Static Stability of Motion of a Glider

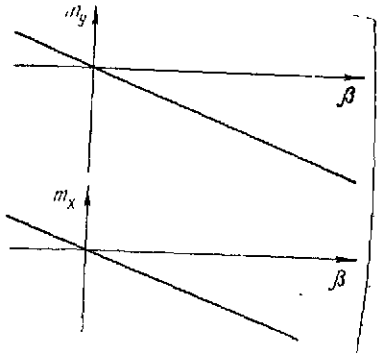

Figure 3.8. Graphs of the Dependencies of Coefficients of Lateral and Forward Static Stability of Motion of a Glider m_x and m_y on the Angle of Sideslip β

understand that they are the result of one or another cause--the occurrence of the sideslip angle β and they are thus interconnected. Looking at the stability of lateral and forward motion of a glider must be done in combination and has the form of a general stability of lateral motion appearing as the capability (or incapability) of the parameters of this glider motion to return to their initial size after the effect of any kind of lateral perturbation has stopped. Then, lateral and forward static stability like two types of a periodic lateral motion of a glider (the motion of a bank and spiral motion) are component parts of stability of actual lateral motion of a glider.

The value of $M_{x_1 w}$ moment, which occurs during sideslip, and means the stability of lateral motion of the glider, depends mainly on the cross sectional V-shape and dimensions of the wing. We note that as the result of non-rigidity of a glider wing (the cause of which is very large elongation), the angle of cross sectional V in flight and especially during maneuvering can change noticeably in comparison with calculations indicated on the drawings. Therefore, the factors of lateral stability can in actual flight become somewhat different than those which were calculated.

An arrow-shaped wing of a glider can also essentially affect $M_{x_1 w}$ and $M_{y_1 w}$ moments which occur during sideslipping. But we will

refrain from looking at this effect because glider wings almost always are made with zero or insignificant arrow-shape which as a rule is not calculated when considering the stability of lateral motion of a glider.

3.2.3. Stability of Motion of a Glider as a Whole (Dynamic Stability)

When evaluating the dynamic stability of a glider one looks at its perturbed motion as a whole. Dynamic stability is evaluated by the character of motion of a glider in so-called transient processes and according to the character of the corresponding motion of control devices which are necessary for implementing /139 these processes. Transient processes are those parts of the total motion of a glider which involve separately established flight procedures. Some of these transient processes are, for example, the processes of putting a glider into a spiral or pulling it out, transfers from one speed of soaring to another, aerobatics or unsteady movement and so forth. The stability of longitudinal motion of a glider as a whole is judged according to the character of change of the vertical component of acceleration g and the corresponding load of deflecting the elevator, the character and speed of damping longitudinal free oscillation of the glider, and the frequency of these oscillations. The elements enumerated of motion are encountered in flight constantly because control of longitudinal motion of a glider consists of changes in the elevator, which differ in character and size, made by the pilot for changing or holding a flight procedure.

Lateral and forward motions of a glider are considered from the point of view of their stability together. Therefore, for evaluating stability as a whole during a lateral motion one adopts special criteria. These involve lateral oscillations of the glider which are characterized by the speed of damping of these oscillations, the length of time of the period and the relationship of stability of motion of bank and yaw. This latter criterion is very important. In flight it is not in the least neutral as the glider reacts to bank when there is any angle of sideslip. In practice it has been established that this criterion which numerically is expressed by the relationship of the rate of bank and yaw and designated as

$$x = \frac{\omega_x}{\omega y},$$

corresponds to satisfactory stability of lateral motion of a glider if it is close to one or less than one. To explain this condition one can assume a hypothetical glider having $\chi > 1$. Then even an insignificant involuntary sideslip which can occur with a small bump (occurring practically all the time) will cause a large bank. This makes piloting difficult and has a bad effect on the state of the pilot. Frequent banks require intervention by the

pilot and controlling motion of the glider and this contradicts /140
the idea of stable flight. In relation to the lateral motion of actual gliders one should say that the sizes of χ, as a rule, are not great. And from their point of view lateral stability is provided (Figure 3.9).

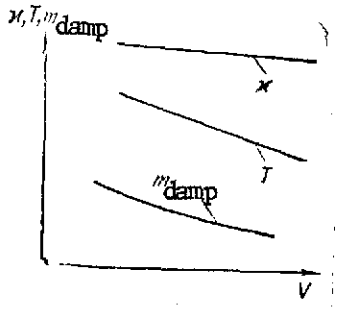

Figure 3.9. Criteria of Lateral Dynamic Stability: T--The period of lateral oscillations of the glider and m_{damp} --the coefficient which indicates how many times in one period T amplitude of lateral oscillations of the glider is decreased

3.3. Control of Glider Motion

In accordance with the accepted criteria of controllability of a glider, when looking at questions on controlling its motion, we will keep in mind only that part of controllability which involves the capability of the glider to change its position in space (under the effect of forces and moments which occur when moving control devices) and in this connection--change the flight procedure.

The operation of control devices for motion of a glider is based on the principle of changing the character of streamlining of part of the wing or tail unit over which the air flows. This causes a change in the forces of resistance and moments and an appropriate turn of the glider relative to its center of mass around which motion of the glider occurs in relative motion.

An important factor in operating control devices of the glider are the articulation moments which are formed as a result of redistribution of pressure on the surface of the rudder or ailerons in all cases when they are deflected in flight. In this connection in order to deflect a rudder or aileron, the pilot must apply a certain force to the stick or pedal and thus equalize articulation moments. The forces applied by the pilot to the control stick for deflecting rudders and ailerons are extremely important to the controllability of a glider because it is mainly in this (to a lesser degree in the size of deflection of the levers) that the pilot judges requirements and adequacy of his actions. It is obvious that too large or too small forces on the control sticks just like movement of the control sticks which are complex in character (which exist when there is inadequate stability of movement of the glider) are undesirable in actual control of glider flight. Therefore, when designing a glider and also when refining it in the process of test flights, one takes a number of measures of structural character directed at seeing that the forces applied by the pilot to the control stick will be close to certain standards established on the basis of practice and flights,

and the form of movement will be the simplest. This can be expressed as the requirement for the least work by the pilot in controlling glider flight when solving an operational task.

We will consider for a moment certain structural methods of solving questions of forces introduced on the control stick for /141 longitudinal[17] movement of a glider of the required size.

If, on the elevator, close to its trailing edge, one mounts a small additional rudder which operates independent of deflection of the main rudder (that is, the one controlled by the pilot) or on the other hand, in relation to the deflection of the rudder, then the articulation moment which determines the longitudinal forces on the stick will be changed. If for example, when deflecting the rudder down, the supplemental rudder goes up, the articulation moment will be decreased and the reverse. Usually they make it possible to decrease forces on the stick to zero. The supplemental rudder whose operation is done by the pilot is called a trimmer. A supplemental rudder whose character of motion is made for good by the mechanism and which is not controlled by the pilot is called a servo-tab.

If one includes control springs in the system then the forces applied by the pilot for shifting the control stick (and this means for the necessary shifts in the rudder) will be determined not only by the articulation moment of the rudder, but also by the rigidity of the spring and the size at which it is extended at a given moment. It is obvious that by shifting the position of the stick with the tension of one spring equal to the tension of the other, one can obtain the same effect as when setting the trimmer.

The use of a trimmer, servo-tab and spring can change the so-called "expenditure" of effort applied by the pilot for changing flight path speed of the glider.

In order to change the size of the effort necessary for obtaining the required acceleration g it is necessary to create a weight imbalance of the control stick by setting up a load (its size and position are determined by calculation). It is natural that the acceleration g which occurs when deflecting the elevator will affect the load (counterbalance) which creates an additional moment on the control stick and then increases the effort required by the pilot for creating this acceleration g.

How does one evaluate controllability which involves shifting the center of mass of a glider in space?

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[17]Special devices for such a change in forces on the stick most often are set up in the longitudinal channel of the control system of the glider.

In relation to the longitudinal shift of this characteristic there are "expenditures" in deflecting the levers, and required forces applied to them by the pilot for their deflection. Expenditures of deflection and appropriate forces looked at as functions of flight speed are reflected in the shape of so-called balancing curves. The shape of these curves gives an idea of static stability in speed with fixed control if the functions of /142 speed start with balanced deflections of the rudder and with free control if the appropriate forces on the stick are begun with unchanged position of the trimmer. Such relationships are called balanced because each point on them corresponds to the deflections and forces which are balanced, that is, which equalize aerodynamic moments characterizing a given flight procedure. Balanced curves which are connected to the forces and deflections of the elevator (levers) with speed involve the center of gravity of the glider and the acceleration g under which this relationship is obtained.

The center of gravity at which the relationship P_B, $x_B = f(V_{lng})$ starts, usually has three (maximum permissible forward and rear and certain average) load factors of the glider corresponding to the most frequently used conditions. The relationship P_B, $x_B = f(V_{lng})$ is constructed, as a rule for a case $n_y = 1.0$ (Figure 3.10).

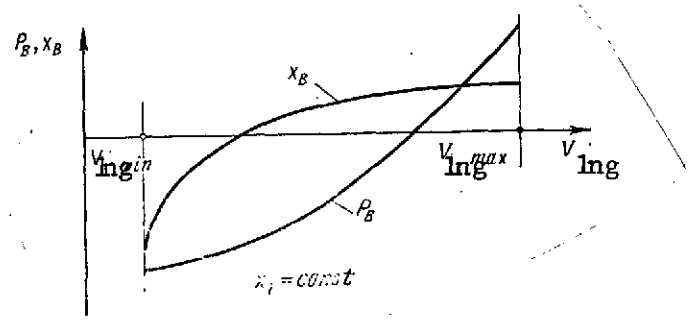

Figure 3.10. Balancing Curves of Longitudinal Motion of a Glider

If the shifts of the elevator (control stick) and the effort are looked at not as a function of speed but as a function of acceleration (which supposes a constant speed because in the balancing curves of speed one supposes constant acceleration g), then the relationship gives us an idea of the stability of motion of the glider according to acceleration with fixed control if one assumes deflection of the rudder (lever) and with free control if one starts with forces on the lever as a function of acceleration g.

However, these relationships like P_B, $x_B = f(n_y)$ are usually presented in unified form. For this, one looks not at the forces themselves or deflections as the function but at the effort expended on the stick or the effort on the control stick required for changing acceleration g to one $\left(\frac{\Delta P_B}{\Delta n_y}, \frac{\Delta x_B}{\Delta n_y}\right)$. Flight speed of the glider is assumed to be an independent variable. Then one /143

obtains the relationship $\left(\frac{\Delta P_B}{\Delta n_y}, \frac{\Delta x_B}{\Delta n_y}\right) = f(V_{lng})$. This characteristic also corresponds to only one specified center of gravity. For other positionings of the center there will be other curves

$$\left(\frac{\Delta P_B}{\Delta n_y}, \frac{\Delta x_B}{\Delta n_y}\right) = f(V_{lng}).$$

Controllability of a glider forward and laterally is characterized also by balancing curves which involve deflections of pedals and levers and the corresponding forces applied by the pilot to the pedal and stick (in lateral control) and the angle of bank at a certain specified flight speed of the glider (Figure 3.11).

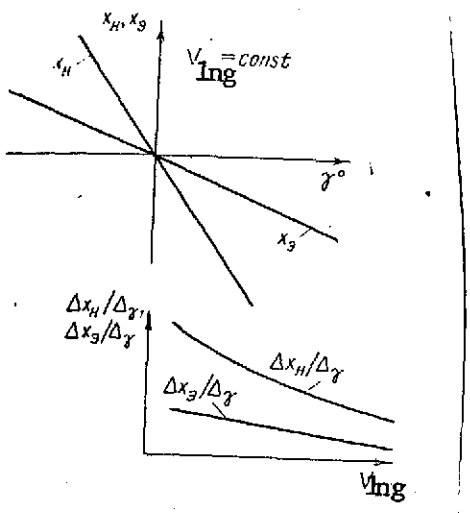

Figure 3.11. Balancing Curves of Lateral Movement of a Glider

Besides those mentioned we construct still other combined balancing curves which involve the expenditure of effort on the pedals and lever and deflection of the rudder and ailerons (pedals and levers) required for obtaining a bank at a certain degree, with flight speed of the glider. This relationship is expressed in the form (Figure 3.11).

$$\left(\frac{\Delta P_r}{\Delta\gamma}, \frac{\Delta P_a}{\Delta\gamma}, \frac{\Delta x_r}{\Delta\gamma}, \frac{\Delta x_a}{\Delta\gamma}\right) = f(V_{lng}).$$

For banking relationships exist which involve expenditure of effort and shifts of levers in lateral direction per unit of sideslip speed angle ω_x. They are expressed in /144
the form (Figure 3.12):

$$\frac{\Delta P_a}{\Delta\omega_x}, \frac{\Delta x_a}{\Delta\omega_x} = f(V_{lng}).$$

The characteristics presented often have added to them another one which involves time required for obtaining an angle of bank $\gamma = 90°$, $\gamma = 60°$, $\gamma = 45°$, and flight speed V_{lng} with maximum deflection of ailerons.

We will indicate the importance of friction forces in control

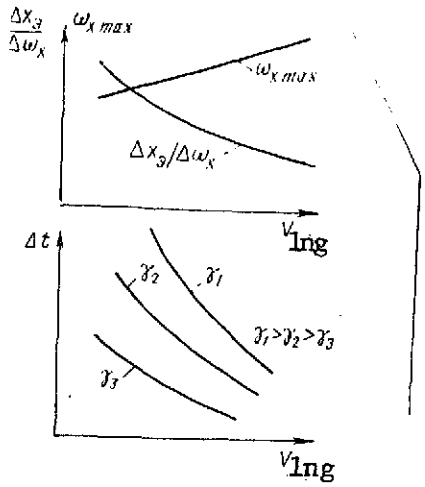

Figure 3.12. The Dependence of Speed and Time of the Formation of a Bank When Deflecting Ailerons on Flight Speed of the Glider

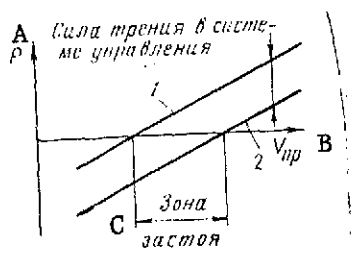

Figure 3.13. The Relationship of Forces Applied to the Control Stick When Changing Flight Speed of a Glider and the Presence of Friction in the Control System of the Rudder:

1--Straight forward;
2--Reverse

Key: A--The force of friction in the control system; B--V_{lng}; C--Stall zone

systems of a glider. Friction forces which are overcome by a pilot when shifting levers and pedals increase not only the volume of his physical work, but make controllability worse due to the impossibility of controlling small changes in flight procedure which the pilot perceives through the forces coming to him from rudders and ailerons by the lever and pedals. Figure 3.13 shows that in a certain range of flight speed (the zone of stall in speed) where friction forces can be greater than balancing forces on stick and pedals required for equalizing articulation moments of the rudder, the pilot will not sense any aerodynamic loads on the control levers. He can simply throw the control and this is not alway necessary.

If there is an air gap in the control systems then in this case the pilot just as when he's overcoming friction forces in it, cannot control a change in flight procedure which corresponds to the deflection of the lever or pedal which is absorbed by the air gap.

Thus, due to the presence of friction and air gaps in the control systems of rudders and ailerons the controllability of the glider is made worse on the whole and primarily the precision of holding a certain flight procedure is decreased.

3.4. Concerning Precise Control of Glider Motion

Many procedures and maneuvers envisaged by an operational task for a glider must be fulfilled precisely. Then, fulfilling actual procedures and maneuvers corresponds to a maximum degree to those procedures and maneuvers which theoretically are necessary for given flight conditions (Figure 3.14).

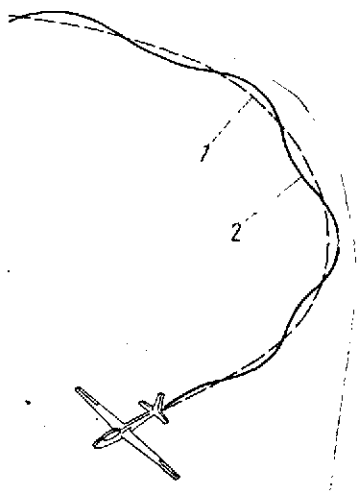

Figure 3.14. An Example of Deflections of Actual Flight Path of a Glider from That Required Which Can Exist with 100% Precision of Control:

1--Required flight path of the glider; 2--Actual glider flight path

Among the procedures and maneuvers /145 requiring precise execution is launching on a tow behind an airplane (especially with small and unprepared fields or when one airplane is towing several gliders), flight on a tow (especially in rough air), spirals in weak and narrow air currents, soaring in a large group of gliders, soaring under complex meteorological conditions (especially when flying blind and at high altitude), landing etc.

It isn't difficult to note that the list of maneuvers and procedures presented whose fulfillment must be precise is very long and involves maneuvers which all gliders must make. But this only points out the importance of the question of precise control of glider movement.

A pilot is able to control the position of a glider in space only by actuating the glider system connected to the control stick in the cabin (on which the pilot operates directly) with the angle of pitch, bank and with his course (these parameters give the pilot a measure of correctness of control and corresponding to actual movement of the glider--to the plan). N.V. Adamovich in his work [1] calls an airplane which is controlled by a pilot a system of " 'power-driven mechanism' or 'drives,' connected to the control stick in the cockpit with the angle of pitch, with the course and with the angle of bank" and adds further-- "the delay in action of these 'drives,' that is, the lag in time in changing angles from the shifts of the levers and pedals is a basic difficulty in piloting all modern aircraft."

Expanding this valid judgement to gliders, one can say that the difficulties of piloting a glider because of lag of action of the "drives," becomes especially perceptible, and in a number of cases is even dangerous when a maneuver or procedure must be carried out precisely.

Thus, the essence of the question of precision of control of glider movement leads us to a determination and analysis of the causes of lag and the discovery of those measures which can decrease it.

Lag is connected to peculiarities of the "drives," and with the characteristics of their operation. Familiarity of the pilot /146

with these peculiarities, that is, with how the glider and its systems respond to the actions of the pilot on the control stick and how the pilot must control the glider in order that its actual movement shall be maximally close to that desired comes to each pilot "by touch" in the process of learning and training. The work is made more complicated by the fact that quantitative characteristics of the "drives" depend on the design of the glider (this means they vary for different aircraft although they have a single use) and on the flight procedure (which only intensifies these differences).

We will look at a system for controlling the angle of pitch which can be evaluated by the pilot visually, continuously and to a considerable degree, precisely.

In passing we note that the basic control parameter of glider flight longitudinally is the angle of pitch. The perception of acceleration g which we spoke about earlier, in spite of its importance, is only a supplemental means of control.

The angle of the pitch is fixed (determined) by the pilot by the position of parts of the cockpit and the forward part of the fuselage relative to the natural horizon visible. If a gyro-horizon instrument is mounted on the glider than it serves as a secondary means of controlling the angle of pitch and in blind flying as the primary. However, the angle of the pitch cannot directly characterize either the angle of attack α or the angle of the flight path θ (which in essence, are necessary for the pilot for controlling procedures or maneuvers), because $\Theta = \alpha + \theta$. Therefore, these two important parameters mentioned (α and θ) must be fully evaluated indirectly by the pilot and with a lag which is explained by the character of operation of the "drives."

Let us look at the simplest case of free flight of a glider where the pilot must move the glider with a single angle of pitch $\Theta_1 = \alpha + \theta_1$ at another angle Θ_2. Let us assume that the glider flies in a straight line with constant speed at a certain angle of attack α. Then for carrying out a given maneuver the pilot must deflect the control stick in a longitudinal direction having applied to it a certain force ΔP_B and having moved it (the point of applying this force) an appropriate distance Δx_B. The movement of the control stick causes deflection of the elevator (stabilizer), a change in longitudinal moment $M_{z\,ht}$ and finally, a change in the angle of attack α to a certain angle $\Delta\alpha$. The new angle of attack ($\alpha + \Delta\alpha$) determines the new flight procedure which will maintain longitudinal stability of the glider.

Because the curve of the flight path is a function of the increase of the angle of attack $\Delta\alpha$, in order to stop the change in the angle of pitch it is necessary to eliminate the increase

in the angle of attack. And for a precise result in the required angle Θ_2 the pilot must, by eye, determine the beginning, the character and rate of its return movement by the stick so that at the moment of attaining angle Θ_2 the excess angle of attack $\Delta\alpha$ returns to zero and the increase in the flight path angle $\Delta\theta$ stops. /147

During glider flight, these manipulations of the stick, as a result of which the angles θ and Θ are changed, in the end, result in a new flight procedure which is characterized by a new speed and new angle of attack. The entire process of control of the angle of pitch of the glider is included in these manipulations (back and forth movements of the stick).

In practice, the connection of $\Delta\alpha$ with shifts in the control stick and the force applied to it are evaluated using the values $\frac{\Delta P_B}{\Delta n_y}$ and $\frac{\Delta x_B}{\Delta n_y}$, obtained from test flights on the glider. Therefore, when evaluating the precision of longitudinal control in an actual or planned glider, one looks in detail at two combined diagrams presented in Figure 3.15. As is seen from these diagrams, the optimum size of coefficients c_1 and c_2 correspond to a definite series of values $\frac{\Delta P_B}{\Delta n_y}$ and $\frac{\Delta x_B}{\Delta n_y}$, which diminish with an /148 increase in speed. Then, the glider in a whole range of flight speeds will be the best from the point of view of convenience and precision of longitudinal control of glider movement.

One should keep in mind that the objectively existing change of θ when changing the angle of attack $\Delta\alpha$ makes the process of control more complicated and less convenient.

Eliminating the peculiarity of the "drive," which involves the necessity to calculate an increase in θ when piloting a glider, explained by the presence of $\Delta\alpha$, can, for example, be done by mounting a "drive" from the control stick in the cockpit on the glider rotating around the z_1 axis of the wing (relative to the fuselage). When flying on such a glider, independent of the angle of attack, the angle of pitch will always be equal to the angle of the flight path θ. Therefore, when transferring from one angle of pitch to another, the movement of the stick will be the simplest and this means from the pilot's point of view will require the least. But it is necessary to have in mind that control by the angle of pitch using rotation of the wing requires of course new habits of piloting which have not yet been adequately studied.

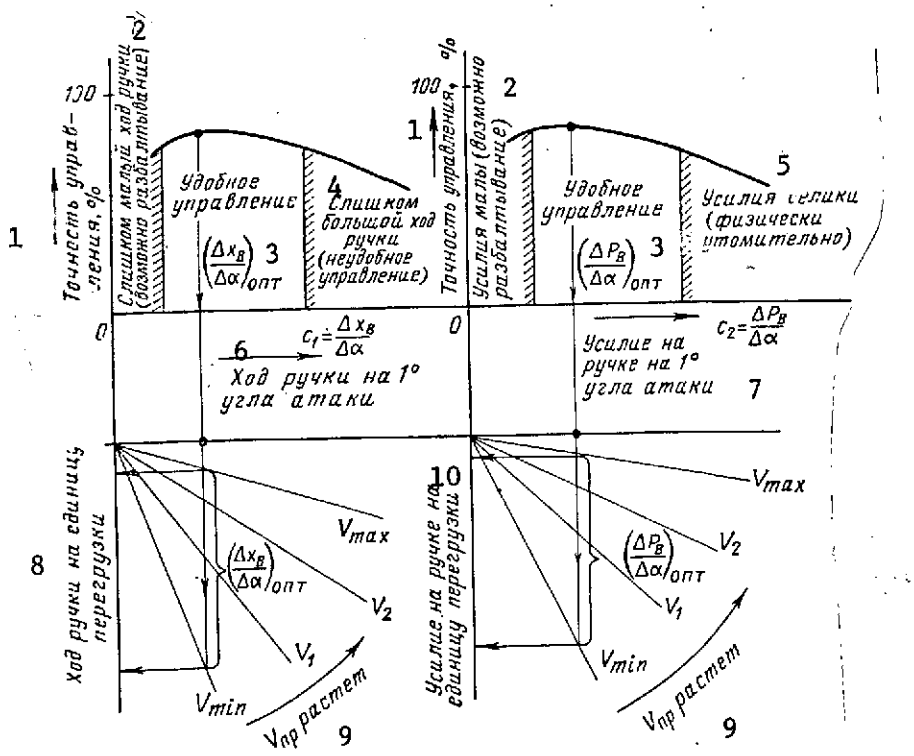

Figure 3.15. The Relationship of Precision and Comfort of Control in Moving a Glider (according to N.V. Adamovich [1])

Key: 1--Precision of a control; %, 2--Too little motion of the stick (possible shaking lose); 3--Convenient control $\frac{\Delta x_B}{\Delta}$; opt

4--Too great motion of the stick (inconvenient control); 5--Force great (physically fatiguing); 6--Motion of the stick for 1° angle of attack; 7--Force on the stick for 1° angle of attack; 8--Motion of the stick per unit of acceleration g; 9--V_{lng} increases; 10--Force on the stick per unit of acceleration g.

We note that in the thirties gliders with such a control were built in our country. However, this experiment has not been developed.

Besides the properties of the "drive" which we noted, which complicate control of the angle of the pitch, there is still another which involves non-rigidity (springiness) connecting the control stick with the angle of attack. The springiness is connected to the determined realtionship of the mass of the glider

(or precisely, its moment of inertia relative to the z_1 axis) and the aerodynamic moment which occurs (which is a phenomenon of longitudinal static stability of the glider). Therefore, the actual characteristic of the "drive" will include besides the connections already mentioned still one more--the period of intrinsic longitudinal (relative to the z_1 axis) vibrations of T and damping relative to it---η_{damp} [18]. A physical concept of these values becomes clear from the following. With relative damping equal to zero, longitudinal vibrations of the glider with fixed stick would be undamped. Therefore, the ratio of the two following amplitudes of vibration of the angle of attack to each other would equal $\frac{\alpha_n}{\alpha_{n+1}} = 1.0$. With the appearance and increase of damping, relative damping η_{damp} increases, and the vibrations begin to be damped more and more quickly. When $\eta_{damp} = 1$ vibrations do not occur. It follows from this that the "drive" in the /149
system "control stick--angle of attack" will be more difficult to control the smaller the longitudinal static stability and the smaller the damping. Continuing this thinking one can make the following important conclusion.

For the best control of a glider longitudinally it is necessary to have static stability and damping in a certain relationship and if possible large. This means, that the statement frequently heard that too large stability of a glider has a bad effect on controllability of the glider (see for example [14]), is not justified because it is best to have large static stability, large damping with adequately efficient control devices whose movement in the process of control is simple and does not require large effort on the part of the pilot.

But inasmuch as static stability along with damping characterizes stability as a whole it is obviously correct to try to design a glider which is stable with efficient and adequately easy controls and then it will handle well.

N.V. Adamovich [1] presented a diagram of generalized characteristics of precision of control based on reasoning /150
formulated by him which can be expanded for free glider flight.

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[18] Here $\eta_{damp} = \frac{h}{k}$, where h--is the coefficient which characterizes the damping of the glider, that is, the speed of damping its vibrations, and k--is the coefficient which characterizes the frequency of intrinsic vibrations of the glider.

This generalized characteristic is a net of curves constructed on coordinates T and η_{damp}. The curves of constant precision show how precision of control changes with the angle of pitch Θ and convenience of control depending on the period of intrinsic vibrations T and relative damping η_{damp} (Figure 3.16).

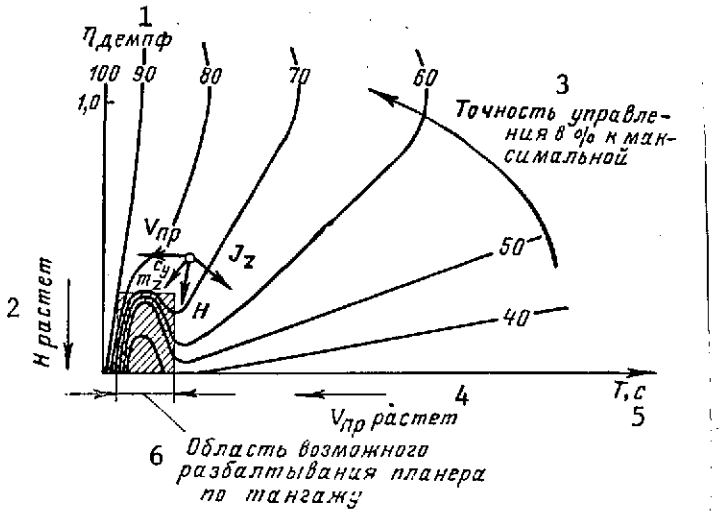

Figure 3.16. A Diagram by Which One Can Evaluste the Perfection of a Glider from the Point of View of the Possibility of Making Precise Maneuvers With It and Also Establish Which Structural and Aerodynamic Characteristics of a Given Glider Will Change and in What Direction So That Precise Piloting of It Becomes A Reality:

Key: 1--η_{damp}; 2--H increases; 3--Precision of control in % of maximum; 4--V_{lng} increases; 5--T, s; 6--Field of possible shaking of the glider in pitch.

Let us look at the diagram $\eta_{damp} = f(T)$. If $T=0$, then there can be a rigid connection of the stick with the angle of attack (for example, in the case of a turning wing), then on the diagram this value of T corresponds to maximum precision of control of the angle of pitch Θ, assumed as 100%. Deviation from the vertical axis of the diagram to the right indicates a decrease in control precision due to tension in the system of "stick--angle of attack." With relative damping close to one (large damping) this occurs more slowly than with small η_{damp}. From the pilot's point of view the worsening of controllability in this case is

reflected in the poorer "following the stick" of the glider: the glider reacts more slowly to fast movements of the control stick. If relative damping is close to zero (small damping) then with a deflection to the right of the η_{damp} axis (with an increase in the period of intrinsic vibrations of the glider) at first a sharp worsening in the convenience of piloting will occur due to the appearance in the glider of a tendency to "shake" at the angle of attack. The cause of this is the closeness of the period of intrinsic vibrations of the glider to the maximally possible small period of deflection of the control stick which the pilot must move forward and back trying to ward off involuntary vibrations of $\Delta\alpha$. With further withdrawal form the η_{damp} axis, with η_{damp} close to zero, control becomes somewhat more conventient but then again steadily worsens.

The field of "shaking" which we have just mentioned covers periods of intrinsic vibration of the glider which are comparatively small in size. If the size of T is smaller than in this area, the pilot does not try to ward off (damp) the vibrations (small in amplitude). By eye, he centers and sets the rudder for an average size. If the size of T is larger than the field of "shaking", then the pilot can with swift and timely movement of the control stick damp the vibrations of the glider in the vertical plane. Attempts to damp intrinsic vibrations if they are in the "shaking" field results in the fact that movement of the stick falls in resonance with the vibrations of the glider and not only does not ward them off but increases them (increases their amplitude).

A certain average point is shown in the diagram (see Figure 3.16) which characterizes glider flight at average altitude and average speed. Let us look at how these points are shifted /151
if the characteristics of the glider itself or the characteristics of its movement are changed.

With an increase in flight speed (according to instrument-- V_{lng}) at constant altitude, period T decreases, and damping η_{damp} remains practically unchanged. A time delay in changing the angle of attack therefore decreases which improves convenience in precision of control.

With an increase in flight altitude (with constant instrument speed) the period of intrinsic vibrations of the glider remains practically constant. However, as the damping decreases the angle of attack begins involuntarily to change (from external perturbations with fixed control stick). And for this one must make necessary additional movements of the stick which decreases convenience and precision of control. When increasing static stability of a glider (for example, when shifting its center of mass forward by moving the pilot) all the characteristics of

controllability are changed because as one can note on the diagram the point of "average" glider flight began to shift to the right at the beginning of the coordinate of the diagram.

Damping of a glider depends mainly on altitude. And inasmuch as at the present time on gliders there are no automatic controls which change the coefficient of damping depending on the conditions and requirements of flight, the change in characteristics of maneuverability (from the point of view of damping) will occur depending on the change in altitude of the flight: with its increase--poorer controllability, with its decrease--improved controllability.

An increase in the moment of inertia J_z of the glider, in all cases has a harmful effect on controllability of the glider because then the delay in reactions of the glider to moving the control stick increases and the deflection itself has greater requirements with an increased moment of inertia.

Thus, the diagram of $\eta_{damp} = f(T)$ with the field of "shaking" applied on it and curves of various precision of control, are common for all gliders, and permit making essential conclusions for each existing or planned glider.

Applying the field of actual speeds and altitudes of flight of an existing or planned glider on the diagram, in the first place, can evaluate its longitudinal controllability (convenience and precision of control of the angle of the pitch) in the entire range of operating speeds and altitudes. In the second place, knowing the essence of the effect of various characteristics of the glider on precision of piloting, evaluated according to the diagram $\eta_{damp} = (T)$, one can determine the most rational way of improving longitudinal controllability and precision of control of the glider. But it will be mainly relative in a planned glider. /152

Finally, in the third place, planning an actual glider flight is possible ahead of time utilizing the diagram of $\eta_{damp} = (T)$ to determine when pilot will have to pay special attention so that his flight will go as planned.

One should mention that diagrams similar to that mentioned can be compiled for two other "drives"--forward and lateral. Then these generalized characteristics of controllability and precision of control of all three "drives" make it possible to evaluate a glider very completely.

We will note one more time that correct and full evaluation of a glider can be done only by an analysis of a number of its generalized characteristics and not completely using two or

three numbers which characterize its maximum aerodynamic quality, corresponding to flight path speed, and with minimum sink speed as is often done.

3.5. Concerning Maneuverability of a Glider

G.S. Kalachev in his work [18] points out that 20--30 years ago the concept of maneuverability of an airplane was essentially considered to be its "turnability;" thus, for example, maneuverability was defined as "the capability of an airplane to complete in a specified time interval one or another maneuvers prescribed for an aircraft of a certain type with tactical and wngineering requirements." They considered that an airplane had adequate maneuverability if the time and space required for completing an aerobatic figure was small. However, the practice of flying operations of aircraft indicated the necessity for a broader concept of maneuverability. In this work one could say that the definition of maneuverability must be formulated as the capability of an aircraft to quickly change direction, altitude and flight speed. This definition of maneuverability will be utilized for evaluating the mobility of a glider. Note again that an aircraft is considered as a moving material point assumed to be its center of mass.

Like controllability of a glider its maneuverability can be considered from the point of view of structural strength and aerodynamic capabilities obtained by calculation and from the point of view of the characteristics of the person who controls the glider flight. The first point of view allows one to judge the maximum, the second--the operational mobility of the glider. Maneuverability of a glider can be evaluated correctly and completely (like its aerodynamic perfection and controllability) if one looks at a whole series of its characteristics in combination, like a machine, and the properties of its movement. G.S. Kalachev proposes the following system of such general factors (in /153
connection with a glider):

--the relationship of acceleration g directed tangentially to the flight path of the glider and perpendicular to it with opened and closed spoilers, flaps and landing gear, to speed and altitude of flight;

--the relationship of the time required for banking a glider at various angles also to speed and altitude of its flight;

--the relationship of the time necessary for opening and closing spoilers and flaps which characterize the speed of changing acceleration g directed tangentially to the flight path of the glider;

--the relationship of changes of the vertical component of acceleration g to times which characterize the speed of creating its predetermined sizes;

--curves of maximum possible sizes of acceleration g directed along the lateral (coupled) z_1 axis and the corresponding curves of maximum possible angles of sideslip;

--the curves which characterize the rate of creating lateral acceleration g.

Inasmuch as the vector of acceleration g can be placed along three velocity axes of coordinates, the first of which coincides with the center of mass of the glider, the components n_x, n_y, n_{x_1} just like the sizes which characterize the speed of their change can be considered as generalized factors of maneuverability of a glider.

An example of the graphic expression of general indicators of maneuverability is the diagram presented by G.S. Kalachev of the relationship of longitudinal acceleration $g\ n_x$ to flight path speed with varying vertical acceleration $g\ n_y$ (Figure 3.17). /154

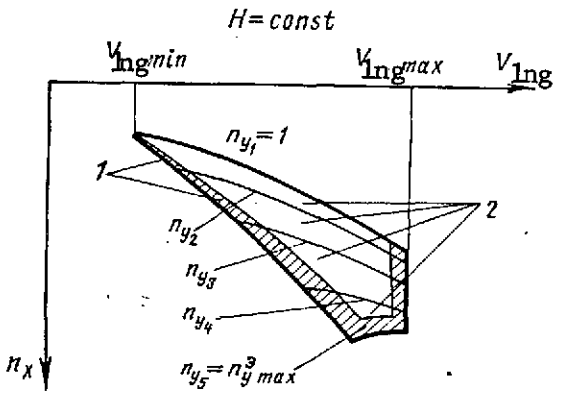

Figure 3.17. An Example of the Character of Generalized Curves of Maneuverability of a Glider (longitudinal Movement):
1--Loss in maneuverability due to operational defects of the glider, of its system; 2--The field of operational maneuverability of the glider.

This graph is similar to that presented earlier of the generalized graph of polar lines of speed. Unfortunately, up until now such diagrams have not been constructed for gliders and this is apparently because generalized characteristics of a glider have come into use only in recent times and most evaluations of glider up until now have been made with separate numerical characteristics. And they not only cannot characterize a glider totally from the point of view of its suitability of operation (for solving its operational task) but, what is even worse can lead to pilot or designer error.

Chapter 4 Glider Flight at Large Sub-critical [Before Stalling] Angles of Attack of the Wing and in Their Super-critical [Beyond Stalling] Range /155

Up until now in looking at normal and inverted glider flight we have assumed that the wing, in relation to the incoming air flow, is at small angles of attack at which there is a linear dependence $c_y = f(\alpha)$ with a positive gradient. The small positive angle of attack corresponds to conventional field *A* in Figure 4.1.

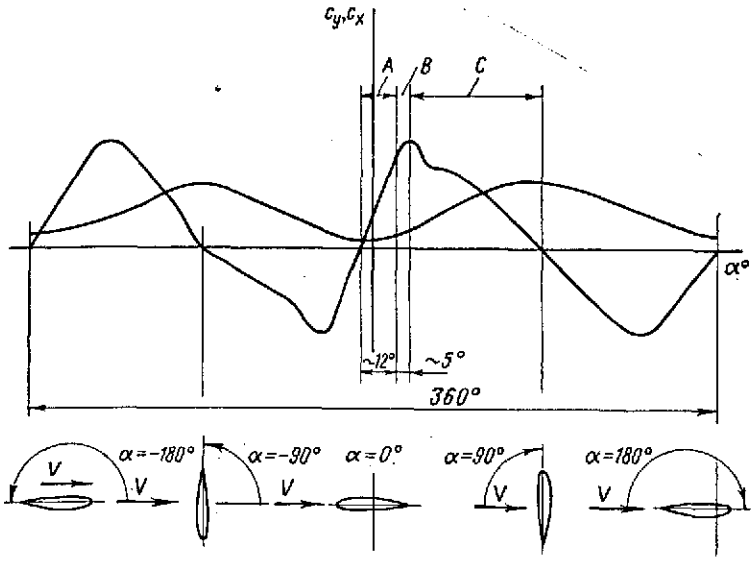

Figure 4.1. An Approximate Dependence $(c_y, c_x) = f(\alpha)$ During a Change in the Angle of Attack in the Range 0--360° (0--±180°)

In the case of landing and carrying out certain elements of piloting, including spirals, the glider can fall into field *B*. /156

A study of glider flight at angles of attack of the wing which change in the limits shown above is important because the overwhelming majority of procedures which involve decision of actual operational tasks is executed exactly at such α. However, it is possible to carry out glider flight in number of cases at all the remaining angles of attack which amount to a total of about 95% of the possible range of change of α, equal to 360° (see Figure 4.1). One of the examples of flight at angles of attack of the wing which change in very broad limits is

so-called "zooming" with subsequent "fall" on the tail.[19] This aerobatic figure is known as the "bell" and is executed both on gliders and on aircraft which have sufficient strength and controllability for such aerobatics.

In this chapter we will limit ourselves to looking at glider flight at angles of attack within fields *B* and *C* which correspond to procedures of stalling and normal spin.

We will call the angles of attack of field *B* large sub-critical, and of field *C*--super-critical.

Both the fields of the angle of attack looked at are characterized by the fact that the dependence $c_y = f(\alpha)$ stops being linear. The increase of c_y in degrees of the angle of attack in field *B* continues to be positive, but becomes smaller and smaller because of the ever larger intense increase of stall on the wing.

At the critical angle of attack, c_y reaches maximum size and increased Δc_y equals zero. At super-critical angles (field *C*) the increase of c_y becomes negative.

Longitudinal movement of a glider at angles of attack limited by fields *B* and *C* is characterized, basically, by a sharp decrease in the size of aerodynamic quality with the growth of α. The characteristics of controllability, and also lateral stability, during flight at angles of attack limited to fields *B* and *C* undergo certain changes which make it difficult (in the right part of field *B*) and practically exclude (in field *C*) the possibility of executing symmetrical longitudinal movement of the glider and even more execution of aerobatics. On certain gliders a certain moment can set in where the effectiveness of control devices becomes inadequate to control longitudinal movement of the glider. This can cause spontaneous change in the character of glider movement in comparison with the desired.

However, such spontaneous changes in flight procedure, if they are intentionally maintained by the pilot in order to trace their character or if the pilot cannot change the movement of the glider to the necessary degree because of inadequate /157

[19]Here the word "fall" characterizes only the direction of movement of the glider which continues to remain under control, that is, primarily it is an element of flight according to the definition accepted earlier.

controllability, in the end, result in a certain type of average of established periodic movement.

Such movement can be periodic stalling of the wing or nose-dive with subsequent shift to curved movement made by alternating stalling or diving. The movement toward which the glider will tend in the conditions of flight described can be of course a spin. Longitudinally the beginning of a dive is practically uncontrollable. Therefore a dive close to the earth can end in crashing the glider.

Eliminating the consequences of a dive (if there is loss of altitude) or preventing it (if the appropriate tendency of movement of a glider is noticed in time) is not difficult for a pilot because it requires only timely moving of the elevator (stabilizer) into a position corresponding to the trimming of the glider at small angles of attack with subsequent transfer of the glider to the required flight procedure.

4.1. The Process of a Glider Falling Off on One Wing

Let us look at glider movement during falling off on one wing.

Assume that the glider moves forward at $\omega_x = \beta = 0$ and that the angle of attack of the central section of the wing is close to α_{cr}. Then, after a certain impulse as a result of which speed ω_x occurs, the picture of the distribution of $c_{y\,sec}$ along the wing span is presented in Figure 4.2.

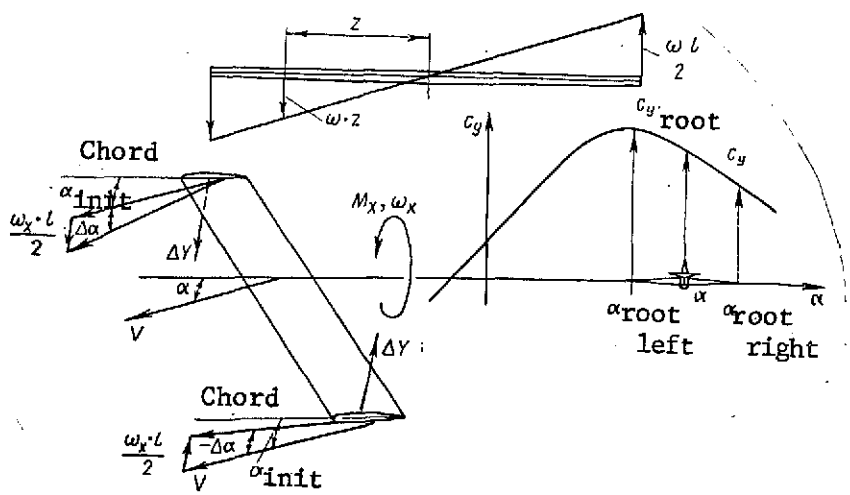

Figure 4.2. The Mechanism of Formation and Effects of the Moment of Bank During Forward and Rotating (Relative to the Longitudinal Axis) Motion of the Glider

For visual clarification of the mechanism of the formation and effect of lateral moment which occurs in this case on the drawing, a diagram of a glider gives appropriate forces and speeds. The appearance of lateral moment directed at continuation and growth of rotation of the glider which has begun (auto-rotational movement) indicates a transfer to spin by the glider. The glider can go into a critical angle of attack at different flight speed beginning with minimum and ending with a speed at which at the output of $c_{y\,st}$ will be at the same time as at the output of maximum acceleration g permissible in operation.

One should note how important the fact of decreased acceleration g is during transfer from a maneuver carried out at sub-critical angles of attack in stalling. This is due to the fact that when banking a glider and when it dives, the aerodynamic force which equalizes the weight of the glider deviates from the vertical. Its projection on the vertical produces less weight on the acceleration factor. Therefore, acceleration g will be less than it was in the initial procedure. This extremely important factor must be taken into account in flight because the perception of the smallest acceleration g along with a sharp increase in the rate of rotation ω_x (this is easily /158 noticed in turning a glider around the longitudinal axis) serves as a reliable signal of stalling and permits quickly understanding at the beginning an involuntary transfer from a deep spiral to a spin.

Stalling can occur when a glider encounters a vertical air current which is not strong enough. Thanks to the complexity of the flight path speed of a glider and the air current, an angle between the vector of total velocity and the wing chord can be equal to or exceed α_{cr}. This is an adequate reason for stalling, and must be taken into account in soaring flight. The dependence of the velocity of the vertical air current on corresponding speeds of glider flight, at which stalling occurs, can be described in the form of the following general relationships:

$$\omega_{st} \simeq V\Delta\alpha_{st}.$$

As to control of movement of the glider during stalling, the deflection of the elevator or stabilizer down (stick forward, at $\Delta\delta_a \simeq 0$ and $\Delta\delta_r \simeq 0$), made at the very beginning of stalling, immediately moves the glider to small angles of attack which eliminate the cause of auto-rotation. It is true there is a loss of altitude in this case. But spirals, as a rule, are made at a certain altitude in order to eliminate accidents during stalling. However, stalling close to the Earth's surface is just as undesirable as diving. If the beginning of the stalling process is overlooked by the pilot then /159

nothing remains for him to do except use any kind of method for getting the glider out of the spin. We'll talk about this further.

4.2. Glider Spin

In this case, if the pilot doesn't take measures to prevent stalling, the glider as a rule will go into a spin.

A spin is that motion of a glider in which the auto-rotation procedure in which a large part of the cross section of its wing is at super-critical angles of attack and the glider rotates relative to its three axes moving in space in such a way that its center of mass moves in a steep spiral with small radius.

The necessity for such a comparatively long and detailed definition of a spin is explained by the complexity of this type of glider movement. From the definition presented it follows that spin is an example of a most common case of spatial movement of a glider. However, such a definition in spite of its completeness covers only the central part of its characteristic movement which as a whole consists of several elements: entering or stalling the glider into a spin, the spin itself, lag when coming out of the spin and the exit itself of a glider from a spin.

The elements (or stages) enumerated are interdependent and very closely connected to each other. But each of them has its own peculiarities. This makes it necessary to study how the elements combine and also each of the elements but taking into account their dependence on each other. Knowledge of all the elements of a spin is obligatory both for a designer and for pilots because it is basic, making it possible to study this complex form of motion (imaginary for the designer and real for the pilot) to provide control over it and to guarantee beginning or stopping at the proper time.

The radius of a spiral flight path of the center of mass of a glider is considered small inasmuch as its size is commensurate with the size of the wing span. The axis of the spiral in a general case is a curve and can be directed toward any side. This means that a spin or at least its beginning is connected either with a descent of the glider (the direction of the axis of a spiral most often encountered) or is ascending and then flight altitude during a spin increases (for example when doing a climbing spin roll, Figure 4.3). Or, finally, a spin occurs at unchanging altitude which occurs in the case of the so-called ordinary spin roll, and is, like the climbing roll, an aerobatic figure.

Each new glider (especially a glider of an unusual design), /160
that is, the combination of its structural elements and

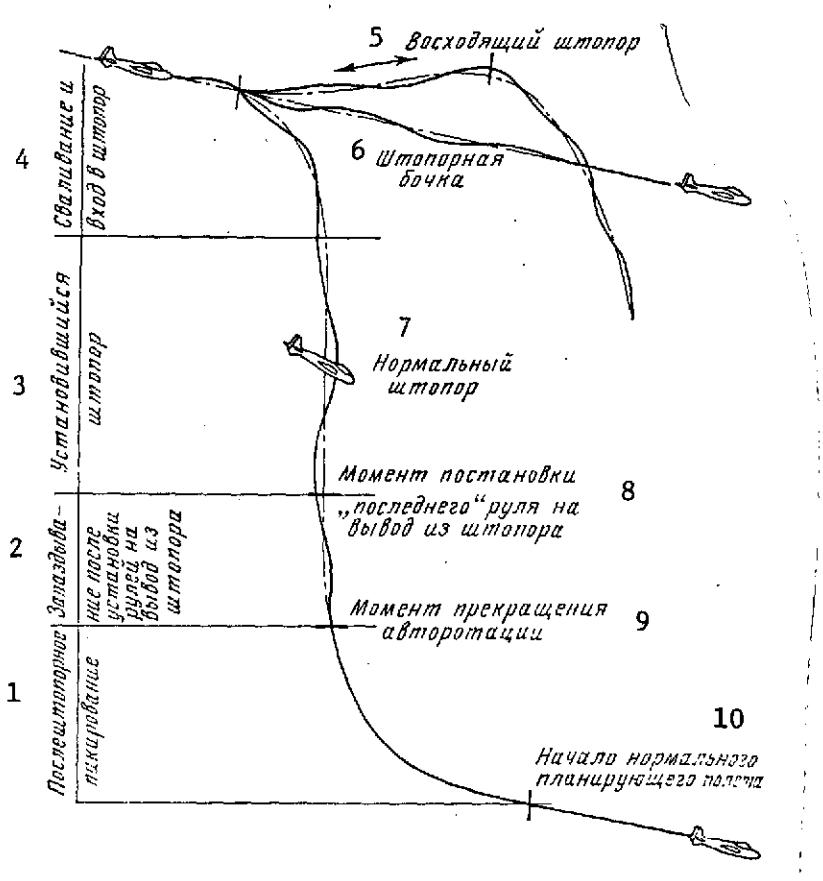

Figure 4.3. The Flight Path of a Glider During Stalling, Spin and Exit from a Spin. Characteristic Stages of This Movement

Key: 1--Post-spin dive; 2--Delay after setting the rudder for exit from a spin; 3--Sustained spin; Stalling and going into a spin; 5--Ascending spin; 6--Spin roll; 7--Normal spin; 8--Moment for setting the "last" rudder for recovery from a spin; 9--Moment for stopping auto-rotation; 10--The beginning of normal gliding flight

configuration, weight, inertia and aerodynamic characteristics, just like the combination of conditions for its flight make each spin procedure, to one or another degree, and one or another stage of movement, original, unique. A factor which also explains the presence of unanswered questions about spin is that the cause of the occurrence and development of spin in a glider usually takes into account the special conditions of operation only of the wing

of the glider. At the same time, in analogous (special) conditions, other parts of the glider operate--the fuselage and the tail unit. Therefore, operation of these parts of a glider cannot but have an effect (sometimes apparently very noticeable) on the character of the spin itself. However, at the present time, the degree of this effect of the fuselage and tail unit of a /161 glider is considered only when analyzing the process of stopping a spin. Along with the depth of development in the general theory of this phenomenon, the result of experimental work and tests of practical glider flights in spin permit at the present time presenting fairly accurately the essence of glider spin (of all its stages) and adequately objectively evaluating the correctness of selecting its design, weight and aerodynamic arrangement from this point of view. On these bases, at the present time one can formulate recommendations for the selection of the most efficient engineering for piloting an actual glider at any stage of a spin.

One of the extremely essential characteristics of auto-rotation (auto-rotation of the wing) is increasing angles of attack on its tip sections which under the complexity of vectors of velocity and glider flight on the flight path and linear speed of movement which lower and lift the wing:

$$\Delta\alpha = \frac{\omega_x l}{2V} .$$

With a certain value of $\Delta\alpha$ the lateral moment can become zero, and rotating motion of the glider--is sustained.

Because the main task of a pilot in a spinning glider is to stop auto-rotation, and consequently the spin itself (this applies equally to one which occurs involuntarily and one made intentionally), it is necessary to look at those parameters of motion which the pilot can use when bringing the movement of the glider under control.

Let us look at the effect of the angle of slip β on the rotation of a glider in spin, which began for any reason. The angle β causes a change in the character of the flow over the right and left wings and then in this way the wing "going forward" is in somewhat improved conditions of air flow (this means the formation of a lift force) in comparison with a wing "going backwards" overshadowed by the fuselage. This dissimilarity of air flow causes a sideways displacement of the points where total lift force over the entire wing is applied. The lateral moment M_x which forms in relation to this direction and to the direction of rotation of the glider can inhibit (slow down) the development of rotation or intensify (speed up) it. For example, during right rotation of the glider, right slip decreases the moment of auto-rotation, and left increases it. The pilot, by

creating an appropriate slip can to some degree affect the rate of rotation of the glider in the spin. In a number of particular cases, when the efficiency of the rudders is adequate for creating slip by the correct order and size of their deflection,/162 the rate of rotation of a glider can be decreased to zero. But inasmuch as the glider wing then is at even greater super-critical angles of attack, the pilot, for eliminating the cause of autorotation, must correct the glider in still another way so that the wing will have a sub-critical angle of attack in relation to the incoming air. This is done by deflecting the elevator down.

Thus, for bringing a glider out of a spin two actions are necessary for the pilot done in sequence: first--creating wingslip toward the side of the rotation (deflecting the control stick "opposite" the spin), and second--transferring the glider to sub-critical angles of attack by deflecting the elevator (stabilizer) down. Or as is usually said "nose opposite spin" and then "stick forward."

These elementary actions in actual flight on a real type (and sometimes an individual specimen) of a glider will be in conjunction with a whole series of conditions whose observation is just as important for successfully bringing a glider out of a spin, like executing various actions on pedals and levers already mentioned. These include primarily the size and rate of deflecting the control stick and the elevator (stabilizer) and the amount of time at which they must be held in a deflected (against the spin) position. One should keep in mind that the rudders deflected "against the spin" in any direction naturally will be deflected "toward the spin," if the glider changes the direction of rotation to the opposite. Therefore, it is important to know how long to hold and maintain the rudder in a deflected "opposite spin" position so that the glider will not go from a spin in one direction into a spin in the other.

The effect of the ailerons on a spin which in the preceding discussions have been considered neutral (not deflected) when they are deflected (unintentionally or intentionally) in a number of cases can affect the course of the spin and have an important effect on the process of coming out of it. Ailerons deflected from a neutral position create immediately two aerodynamic moments: M_x and M_y. These moments are of a size, but M_y markedly depends on the angle of attack of the wing and on the degree of deflection of the ailerons. In a spin, the angle of attack of the wing changes along the wing span and depends on the forward velocity of the glider V and the rate of its rotation ω_x. Therefore, moments created by the deflection of the ailerons in a spin added to a number of other acting moments (auto-rotation, damping and inertia) can variously affect the spin process either helping to stop it or make it worse or finally, not have any effect on

such a procedure, meaning coming out of the spin.

On the basis of large practical experience obtained from test flights of gliders in a spin and also from the practice of these flying operations at the present time, four basic practical methods of bringing a glider out of a normal spin have been formulated (Figure 4.4). /163

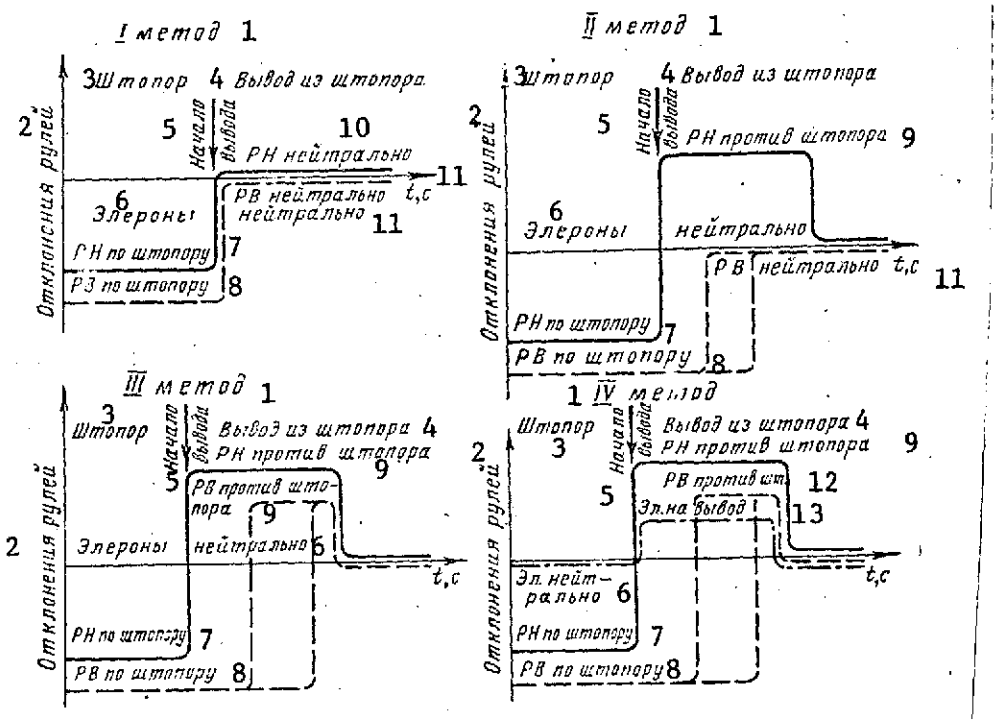

Figure 4.4. Methods of Bringing a Glider Out of a Normal (Not Inverted) Spin of Varying Intensity and Resistance

Key: 1--Method; 2--Deflection of rudders; 3--Spin; 4--Coming out of a spin; 5--Beginning of exit; 6--Ailerons neutral; 7--Rudder toward spin; 8--Elevator toward spin; 9--Rudder opposite spin; 10--Rudder neutral; 11--Elevator neutral t, s; 12--Elevator opposit spin; 13--Ailerons on exit.

These methods are used in practice and vary depending on the actual characteristics of the spin of one or another glider and on the actual conditions in which a given concrete procedure occurs.

The first method involves simultaneously setting the rudder and the elevator in neutral position with neutral ailerons. (If they were deflected in the process of the spin then they are also put in the neutral position along with the rudders). This method is used when bringing a glider out of an unstable normal spin when, for stopping auto-rotation and transfer of the glider to small sub-critical angles of attack of the wing one does not need to create special aerodynamic moments using the rudders and elevators, but the glider itself has a tendency to come out of the spin and one must only not interfere to stop rotation and bring it to small angles of attack.

The second method involves sequential deflection of the /164 rudders completely opposite the spin and then putting the elevator in neutral position. The pause between completing movement of the rudder and beginning movement of the elevator as a rule is 2--3 s (if you are calculating by turns this amounts to approximately 0.5 of a turn); the ailerons in the second method are in neutral as in the first method. The second method is used for a more resistant spin when one has to create wingslip on the lower wing in order to stop autogyration and at the same time the glider transfers to small angles of attack practically independently.

The third method involves, like the second sequential deflection of the rudders and elevators but completely opposite the spin with neutral ailerons and holding, as in the preceding method, the same pause between deflection of these rudders. The third method is used for bringing a glider out of a resistant spin when it is necessary to create significant aerodynamic moments of bank and pitch in order to stop autogyration and bring the glider to sub-critical angles.

The fourth method of bringing a glider out of a spin involves sequentially full deflection of rudders and elevators (maintaining the necessary pause between these deflections) and full deflection of ailerons simultaneously with the elevator. The direction of deflection of the ailerons in this case is determined experimentally and for gliders of the sport type as a rule it is opposite the spin. The fourth method of bringing a glider out of a spin is used in those cases where the pilot must use all means at his disposal for stopping the spin, that is, rudders, elevators and ailerons.

When determining ways and means of bringing a glider out of a spin the flaps and spoilers and also special anti-spin parachutes are not taken into account because actions of flaps and spoilers can complicate operation in bringing the glider from a spin, not having an essential effect; and the parachutes are used only during test flights in gliders. Thus, in spite of the large variation in the types of spin, bringing a glider out of

this type of movement is actually done using one of the methods enumerated above.

After all the necessary and adequate measures have been taken for stopping autogyration and moving the glider to small angles of attack, one needs, as a rule, certain times so that the glider will not over-react to these. This time is called the lag time for bringing a glider out of a spin or simply lag. Lag can vary according to the length of time and character of movement of the glider after deflecting the rudder for exit from a spin.

Lag time is calculated from the moment of deflection of the /165
so-called "last" rudder which means in our cases the moment of deflection of the elevator or stabilizer until the moment of actual stopping of rotation of a glider. Gliders most commonly used have a lag which rarely exceeds 4--5 s which translated into loops of a spin amounts to about one loop.

It is necessary to keep the lag time which varies for each type of glider in mind so that it is not assumed as natural lag and failure of the glider to come out of a spin.

After auto-rotation has stopped and the glider has shifted to small angles of attack, normal straight gliding has still not been achieved. This is because the small angles of attack do not yet correspond to the actual forward speed of the glider which is still close to the speed of the spin. Moreover, the glider is in a position with nose down and the angle of its slant is very great especially if the pilot exceeded the required sizes and length of time for deflecting the elevator down.

As a result of this it is necessary to accelerate the glider speed to correspond to the small angles of attack spaced adequately far from α_{st}, which must guarantee safety of bringing the glider from a deep dive to normal soaring flight. When there is inadequate speed when one attempts to bring the glider from a dive this re- /166
sults in a new stalling into a spin. Movement of the glider when coming out of a spin after stopping auto-rotation is called post-spin diving. In distinction from lag, post-spin diving is characterized not by time, but by the amount of altitude of the glider flight which is necessary for increasing the speed and transferring to normal gliding flight. Besides normal spin for a glider there is also so-called "inverted" spin which ocuurs at negative super-critical angles of attack. Essentially, inverted spin is like normal. Its distinction basically is in the perceptions felt by the pilot in the spinning glider.

Methods of bringing a glider out of an inverted spin are similar to the methods for bringing it out of a normal spin. They are presented in Figure 4.5.

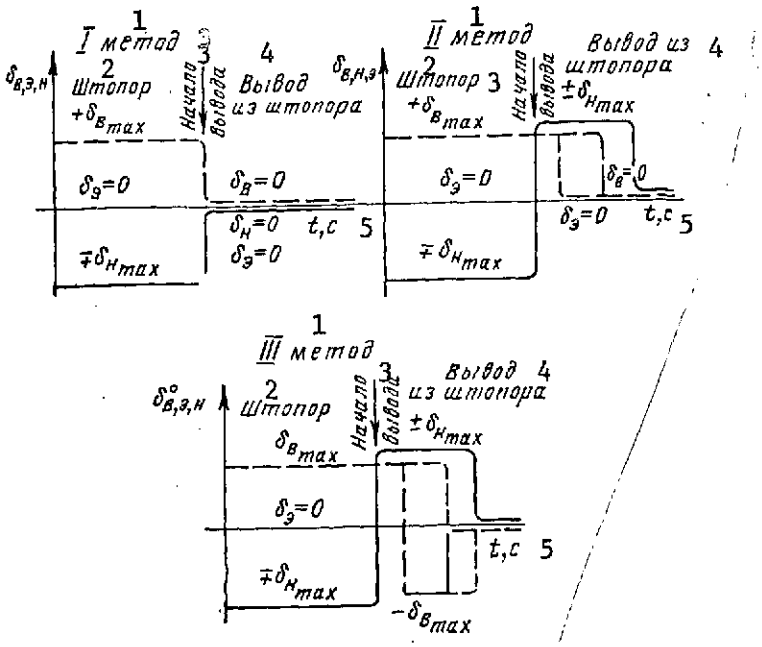

Figure 4.5 Methods of Bringing a Glider Out of an Inverted Spin

Key: 1--Method; 2--Spin; 3--Beginning of exit; 4--Exit from the spin; 5--t,s

4.3. Quantitative Characteristics of Glider Spin

For simplifying our discussion let us assume the following diagram of movement of a glider in spin without losing precision in the presentation. We will assume that the spin is established, the axis of the spin directed vertically down. Then the weight of the glider will be equalized by the projection on the vertical of the aerodynamic force which affects the glider. When operating the wing in a stalled air flow (Figure 4.6) the direction of the full force of aerodynamic resistance is approximately perpendicular to the surface of the wing. It follows from this that the equilibrium state of the glider can be expressed by the relation:

$$G_{gl} \simeq R\sin\alpha = c_R \frac{\rho V^2}{2} S \sin\alpha,$$

where α is the angle of attack of the wing, and c_R is the coefficient of full aerodynamic force which affects the glider.

The equation presented makes it possible to determine the velocity of the glider flight path (in the spiral), that is, the velocity of its center of mass which is close to

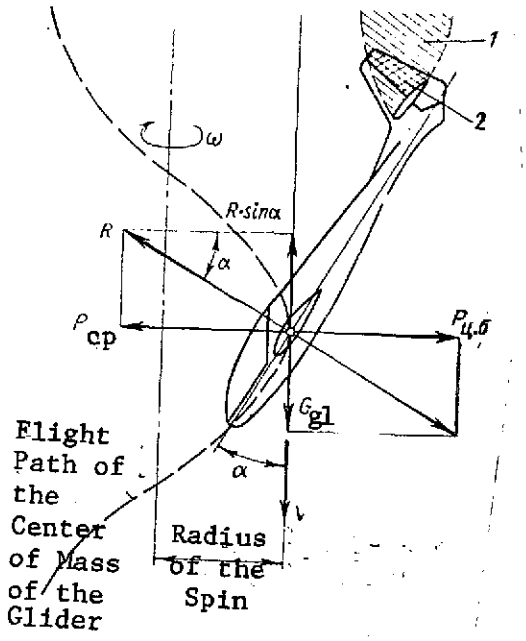

Figure 4.6. A Diagram of Motion of a Glider in a Spin Assuming Straight and Vertical Axes of the Spin:
1--Zone of decreased speed; 2--Section of the rudder shadowed by the horizontal part of the tail.

the speed of vertical descent because the spiral is steep:

$$V_{sp} = \sqrt{\frac{2\frac{G_{gl}}{S}}{\rho c_R \sin\alpha}}.$$

For angles of attack of glider spin $c_R = \sqrt{c_y^2 + c_x^2}$ differs insignificantly from $c_{y\ max}$. A decrease in c_y to super-critical angles of attack in this case, when evaluating c_R according to the formula presented, is compensated to a considerable degree by an increase in c_x. Therefore, glider flight speed in spin and its vertical component are close to the minimum speed of normal gliding flight, but are $\sqrt{\frac{1}{\sin\alpha}}$ times greater than it, that is, approximately by 15--20% in so-called "flat" spin /167

and by approximately 40% in the case of a "steep" spin. One should keep in mind that it is impossible to fix this speed on the instrument because the air pressure receiver in spin angles of attack does not operate normally, has large error whose size is unknown to us.

The complex movement of a glider in a spin can be considered as the total of two independent elementary motions: one relative to rotation around the vertical axis of a spin and the other moving forward along this axis (down). When looking at these two movements it is easy to establish the connection and to calculate the dimensions of other parameters for movement of a glider in spin.

Thus, vertical acceleration g which occurs during spin and affects the glider and the pilot can be determined from the following expression:

$$n_y = \frac{Y}{G_{gl}} \approx \frac{R}{G_{gl}} = \frac{G_{gl}}{G_{gl} \sin \alpha} = \frac{1}{\sin \alpha} .$$

This means that acceleration g in spin is not great. In a steep spin it reaches two units and in flat--1.5--1.2. Small acceleration g in spin makes it possible to fix the moment of transfer (intentionally or involuntarily) of the glider from a spiral to a spin which occurs due to error in piloting techniques or so-called "over-pulling of the stick." Another important circumstance is the fact that thanks to small acceleration g the structure of the glider in spin is not subjected to a large load /168 factor. But of course this doesn't mean that when going into a spin and coming out of a post-spin dive, that unacceptable operational load factors cannot be created. Entry into and exit from a spin by a glider remain elements of flight in which acceleration g can by carelessness of the pilot reach unacceptable sizes.

From the expression written for acceleration g and even earlier for glider speed in spin, it is not difficult to see that the relationship of spin speed to minimum speed is the square root of acceleration g. From here speed in a spin is minimized by $\sqrt{n_{y\,sp}}$ times.

The radius of the spiral around which the center of mass of a spinning glider moves can be defined in the following way. The component of force R directed toward the spin axis is centripetal which dictates relative movement (rotation) of the glider in a spin. Therefore one can write:

$$P_{cp} = \frac{G_{gl}}{\operatorname{tg} \alpha} = \frac{G\omega^2 r}{g} ,$$

where P_{cp}--is the centripetal force, ω--is the angular velocity of the glider, r--is the radius of the spin.

Then

$$r = \frac{g}{\omega^2 \operatorname{tg} \alpha} .$$

In practice, most often, the angular velocity rotation of a glider in spin amounts on the average to about 2 radii/s, and the angle of attack in spin is equal to approximately 40°. Then the radius of the spiral is obtained by

$$r = \frac{9.81}{4 \cdot 0.84} \simeq 3\text{M}.$$

The angle of inclination of the spin flight path toward the horizon is determined from the expression:

$$\cos \theta = \frac{\omega r}{V_{sp}} .$$

Actual angles are in limits 70--80°

An important characteristic of spin is a loss of altitude for one loop, that is for one rotation of the glider around the axis of the spin. The loss of altitude per loop equals the product of the vertical component of glider velocity and the time of one loop. Because the vertical component of spin velocity is very close to the size of velocity of the glider flight path, it can be written:

$$h_{loop} \simeq V_{sp} t_{loop} ,$$

where h_{loop}--is the loss of altitude per loop, V_{sp}--the velocity of the glider along the flight path, t_{loop}--the time of one loop. If one assumes that V_{sp} = 80 km/hour and t_{loop} = 3 s, the loss in /169 altitude for one loop will be equal to:

$$h_{loop} \simeq 70 \text{ M}.$$

Let us look at the effect of certain structural characteristics of the glider on spin.

The position of the center of mass of the glider (center of gravity) has an important effect on the character of spin. Thus, if the center of gravity is forward--the full force of aerodynamic resistance which occurs on the wing creates a large diving moment. And the glider will have a tendency to shift to small

angles of attack. This is a very important circumstance because on the one hand such a tendency will in general facilitate pulling the glider out of a spin. But at the same time with a forward center of gravity, if the glider is not at super-critical angles of attack and the rudder is deflected, the glider can go into a spiral. The spiral in this case will be steep and acceleration *g* can increase to a very significant size.

If the center of gravity is back, then during spin the moment of full aerodynamic force tries to move the glider to large angles of attck, that is to a flatter spin which is more difficult to stop. The distribution of mass of separate parts of the glider, that is the structural and weight arrangement has an effect on the character of spin.

During rotation of a glider in spin, aerodynamic and inertia moments affect it. Usually the moment of inertia force of a glider attempts to increase the angle of attack and shift the glider to a flatter spin.

Aerodynamic arrangement has a great effect on controllability of a glider in spin also. Aerodynamic characteristics of a glider wing mainly determine the character of its spin but the so-called "aerodynamic shadow" of the tail unit is of great importance for successfully bringing a glider out of a spin. The tail as a whole can be shadowed by the wing, both the vertical part of the tail, and moreover, the horizontal. This considerably decreases (sometimes completely eliminates) the efficiency of the rudder and can make it very difficult to bring the glider out of a spin. Therefore it is extremely important when designing a glider to subject its aerodynamic make-up not just to simple requirements but also to the requirements of controllability in spin.

The study of spin in each new glider must precede its wide flying operation, and the results of this study formulated in instructions to the pilot must be unconditionally and basically mastered by anyone who intends to fly such a glider.

Chapter 5 Loads Which Affect a Glider in Flight. Glider Strength

Inasmuch as each glider is intended for solving a certain operational task it must possess flying characteristics appropriate to it. These flying characteristics involve the need to retain a certain configuration of the glider for a given movement and the capability within certain known limits to be changed by the pilot or to maintain a flight procedure without subjecting the glider to the danger of breaking down. Therefore, flying characteristics presuppose in the design of a glider the presence of certain strengths and rigidity which can withstand certain loads with minimum possible mass. The capability of the glider as a whole and the capability of each of its parts separately to take load determined by the requirements of flying conditions and not break up is called the strength of the glider, that is it retains its operating capability. Deformations of the glider structure which occur as a result of the effect of certain loads must be elastic, that is, they must completely disappear after the load is removed and the structure must return to its initial shape. This is also a requirement for the structure to provide work capability in the glider. The strength of a glider naturally, cannot be limitless. It is limited by boundaries which are applied to strength on the basis of calculations and is based on the properties and materials used in constructing the glider.

A glider's capability to deform when receiving load in certain boundaries dictated by the requirements of adequate work capability for multiple solutions of operational tasks during the time period of operating the glider is called the rigidity of the glider structure. These boundaries are within the limits of elasticity of the materials used in the glider's construction.

So that the obvious and necessary requirements for strength and rigidity of a glider are fulfilled, it is necessary first /171
of all, to correctly calculate the strength of the glider and construct it according to this calculation. In the second place, it is necessary to have correct operation of the glider, that is, selection or creation of those flight conditions and ground conditions for operation (one or another determined by the operational task of the glider) in which the strength of a given glider corresponds to the load affecting it.

To calculate the strength of a glider means to find those materials and dimensions of all the elements of its structure (basically the dimensions of its cross sections) which will provide the required strength of each element and the entire structure as a whole.

For making correct calculation for strength one must correctly select loads which affect all the elements of its structure:

the wing, fuselage, tail, cockpit canopy, landing gear, control systems, attaching devices and parts, the pilot's seat, safety belts, instrument panel, towing hooks and so forth. The loads selected for calculation must be equal to the actual load which are determined by separate elements of movement of the glider according to its operational task. These elements of glider movement or, as they are called "cases," under which characteristic loads of the glider and its separate parts occur are combined in so-called "standards" for glider strength. Thus, strength standards are the rules for the glider designer, for the pilot who controls movement of the glider, and for all other persons who are involved with its on-the-ground and flying operation.

One should keep in mind that flight conditions of a glider, and with this naturally one means its load as a whole and on each of its parts separately, can occur as a result of pilot action (for example, as a result of deflecting the rudder, during flights with pilots of different weight or during flights with ballast) or be changed from causes not directly connected to the pilot. One of these latter for example is movement of air masses through which the glider flies. Moreover, when looking at questions of load and glider strength it is necessary to take into account that the structure of a glider "fatigues" with time, uses up its safe life. This occurs as a result of wear of the structure and its aging which can be considerable the more intense or careless is the flying or ground operation of the glider (including its storage).

5.1. Acceleration *g* and Form Drag

Loads or forces which affect a glider during its operation usually are classified in the following manner. In the first place--it is weight and the force of inertia.

In the second place, it is forces which are the result of the interaction of the glider and the air coming in over it. /172

Using both groups of forces mentioned, being in equilibrium, the load capability of the glider structure is evaluated.

5.1.1. Acceleration *g*

Weight, which we will look at later on is the total weight of separate elements of the glider structure and its load (pilot, parachute, ballast, equipment etc.). The forces of inertia of a glider are the forces which occur when changing flight procedure of the glider, that is, when slowing down or accelerating it.

Such changes in speed occur during acceleration, braking or curving of the flight path.

Weights which affect the structure of a glider are known ahead of time insofar as the weights of the structure and the load itself are known. The forces of inertia depend on the procedure of movement controlled by the pilot and on external conditions of flight and can be calculated ahead of time by using arbitrarily assumed conditions. It is natural therefore that in actuality these conditions must be observed.

All forces which affect a glider change continuously. Thus, forces affecting an established straight line glide can be changed by the forces which occur when transferring to a spiral with changed speed or radius. The forces which affect a glider with a weight of one pilot and the presence of water ballast will differ from forces which affect it under these same flight procedures with the weight of another pilot or the absence of ballast. Finally, when moving the glider from a region of air space which is characterized by one state of the atmosphere to a field with other characteristics, the forces also will be changed. This change in force which affects the glider is defined as acceleration g.

Let us look in more detail at the physical essence of acceleration g, its mathematical expression. According to the basic law of dynamics, at each moment of movement, the vector of force which is characterized by the product of the vector of acceleration of the basic movement of a glider and its mass $m \cdot \bar{j}$ equals the geometric total of the vector of the force of gravity of the glider $m \cdot \bar{g}$ and the vector of total force $\bar{R}$, which in turn equals the total of vectors of general aerodynamic force and other external forces which affect the glider. Included in the latter are the pull of the towing craft, the force of reaction with the Earth's surface (when the glider comes in contact with the Earth), the pull force of the drag line of the braking parachute (when using it, for example in landing) etc. This equality is described in the form

$$m\bar{j} = m\bar{g} + R \quad \text{or}$$
$$m\bar{j} - m\bar{g} = R. \qquad /173$$

The relation of the total of vectors $m\bar{j}$ and $(-m\bar{g})$ to the size of weight of a glider mg is called the vector of acceleration g and is designated by the symbol n. Like any vector, acceleration g is characterized by size and direction. Because, on the basis of the expression of acceleration g presented earlier it is expressed through vector $\bar{R}$

$$\bar{n} = \frac{\bar{R}}{mg},$$

it is possible to conclude that, in the first place, the size of acceleration g by how many times vector $\overline{R}$, expressed as the total of all external forces which affect a glider (except its weight) is greater than the weight of the glider. In the second place, the vector of acceleration g has the same direction as vector $\overline{R}$.

Acceleration factor $\overline{n}$ like any vector, can give an appropriate projection in any direction. Therefore, the direction of these projections or the components of acceleration g, will always be the same direction as the appropriate projection or component of force R (Figure 5.1). In the simplest case, for example, when bringing a glider out of a dive, acceleration g which affects the speed of flight in a perpendicular direction will equal

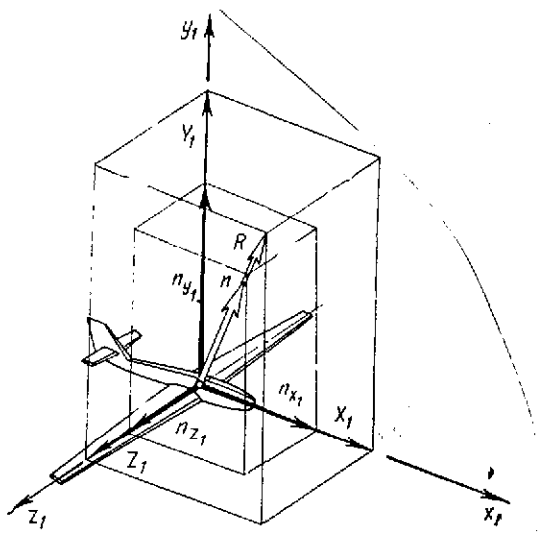

Figure 5.1. The Vectors of Acceleration g and Appropriate Components of Force R in Connection with the Coordinate Axes of a Glider System

$$\overline{n}_y = \frac{\overline{Y}}{G_{gl}} .$$

Here $\overline{Y}$--is the vector of the lift force which is the projection of general force of resistance of the glider $\overline{R}$ perpendicular to the direction of velocity, G_{gl}--the weight of the glider.

In practical calculations it /174 is convenient to utilize not the vectors of acceleration $\overline{n}$ themselves, but its projections on the coordinate axes of the system which seems preferable when solving a given actual problem. Thus, for example, one can plot a vector of acceleration g on the axis of a coupled system. Then acceleration g in a longitudinal direction (corresponding to $\overline{n}_{x_1}$, or $\overline{n}_x$) will equal the relation of projection of vector $\overline{R}_x$ to the weight of the glider

$$\overline{n}_{x_1} = \frac{\overline{R}_{x_1}}{G_{gl}} .$$

The acceleration factor in vertical and lateral directions (normal and lateral) are determined analogously:

$$\bar{n}_{y_1} = \frac{\bar{R}_{y_1}}{G_{gl}},$$

$$\bar{n}_{z_1} = \frac{\bar{R}_z}{G_{gl}}.$$

We note that acceleration g is the relation of size with uniform dimensions. Consequently, acceleration g itself is considered a dimensionless size. And consequently the often used expression of the type "acceleration g equals so many g's" is mainly incorrect. /175

In accordance with the accepted system of symbols the component of acceleration g which acts in particular on the longitudinal axis of the glider x_1 which for brevity is called longitudinal acceleration g, is considered positive when it is directed forward, that is, the pilot is pressed to the back of the seat (for example, when accelerating in towed flight) and negative if the pilot is pushed forward from the back of his seat, for example, when braking (Figure 5.2)

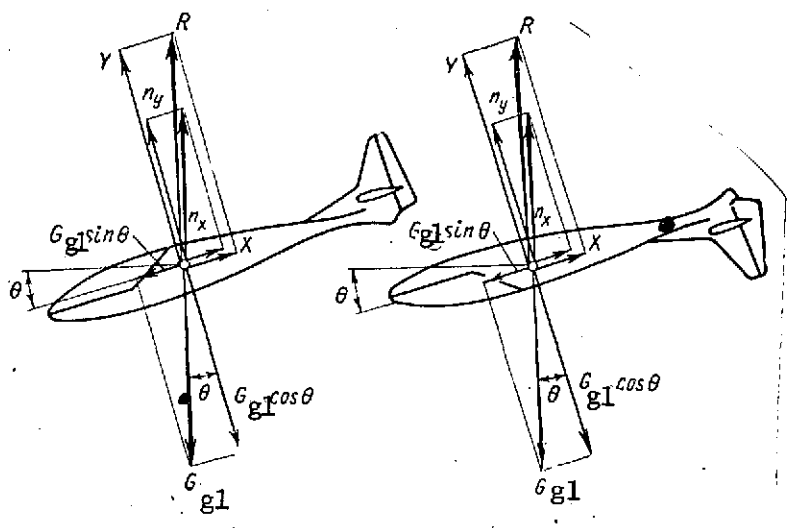

Figure 5.2. Load and Acceleration g in Straight Line Upright and Inverted Flights. The Vectors of Forces and Acceleration Factors Applied at a Single Point. For Visual Purposes They are Conventionally Placed at a Small Distance From Each Other.

The component of acceleration g which affects the vertical axis is considered positive when its direction is upwards in relation to the glider. This facilitates pressing the pilot to his seat. The negative vertical acceleration g directed down corresponding pulls the pilot away from the seat.

When gliding in an inverted position of the glider, vertical acceleration g will be negative because although it is directed upwards in relation to the ground in relation to the glider it is directed "down." At the upper point of a loop made without hovering, vertical acceleration n_{y_1} is positive, because in relation to the glider it is directed "upwards" in the direction of the lift force (Figure 5.2).

The component of acceleration g which acts along the lateral axis is considered positive when its direciton is to the right of the pilot and negative when it is directed to the left. This corresponds (in the first place) to a sharp deflection of the right pedal forward, that is the rudder is to the right; in the second case, the deflection of the left pedal is forward, that is, the rudder is directed to the left (Figure 5.3)

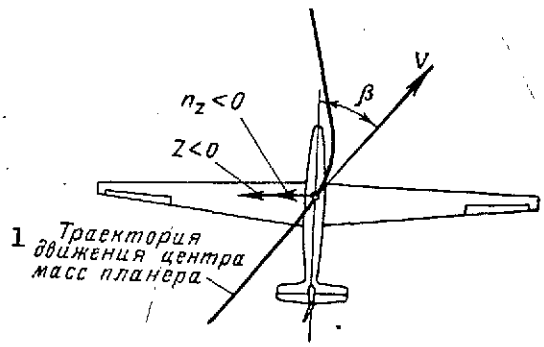

Figure 5.3. The Appearance of Lateral Force and Acceleration g

Key: 1--Path of the center of mass of a glider

Longitudinal and lateral acceleration (n_{x_1} and n_{z_1}) change during free glider flight in a comparatively small range.

Vertical acceleration factor /176 n_{y_1}, permissible in glider flight can change in very broad limits.

Control of Acceleration g

The measurement of each of the three components of the total vector of acceleration g is done by instruments called accelerometers (in the case of a visually fixed sensor indicator of acceleration g) and accelerographs (recording accelerometers).

But in ordinary rather than test flights on a glider the accelerograph is not installed. The indicator of acceleration g (accelerometer) is frequently not used also. Therefore, an evaluation of acceleration g qualitatively which the pilot must do by his perceptions is no less important in flight. Such an evaluation by the pilot is necessary because it helps him control movement of the glider and acts as one of the methods by

which pilots evaluate the condition of a glider and the character of the flight procedure.

The pilot who is in a glider and connected to his seat by seat belts always feels the same acceleration as the glider itself.

The pilot senses acceleration g from the affecting forces applied to him: especially the weight and force of reaction of the glider is transmitted to the pilot through the seat and sides of the cockpit if the pilot touches them and through his seat belts.

5.1.2. Form Drag

In Chapter 2 it was shown that the size of aerodynamic forces depends on form drag. The size of local pressure on the surface (skin) of the wing, the tail and fuselage of the glider also depends on this. Then the occurrence of these forces is explained by the fact that the pressure of air directly flowing over these or other parts of the glider is different from atmospheric (static) pressure.

Local pressure affects separate parts of the skin of the wing, pressing it to the frame or pulling it away. Thus, separate parts of the structure of the wing of the glider are under load. The difference in local and atmospheric pressure Δp is considered positive in a case of increased (relative to atmospheric) pressure and negative in case of decreased. This total load on the wing, fuselage and tail as a whole is defined as total pressure created by the incoming air flow on the entire surface of the glider as a whole.

The character of distribution of pressure on the surface (the skin) of a glider changes depending on the orientation in the air current of one or another part of the glider. For example, in straight line flight without bank and slip, the character of distribution of pressure along the surface of the wing changes depending on the angle of attack. If the angle of /177 attack is fixed and unchanged, then the character of distribution of pressure in this case does not change but the size of such pressure is proportional to the form drag.

An increase in form drag results not only in an increase in localized load but also in an increase in load on the entire main parts of the glider. Then, the moments are increased just like the forces, proportional to form drag.

Control of form drag. As was shown in Chapter 2, the principle of measuring the speed of flight used on gliders includes

measuring form drag. From the point of view of evaluating flight speed this method is inconvenient in that at high flight altitudes the speed shown by the indicator becomes considerably different from the actual flight speed of the glider relative to the air.

However, in relation to control of form drag the method used for measuring flight speed is completely suitable. Because glider instruments for speed are calibrated at zero altitude (according to pressure) and with density corresponding to this altitude under standard conditions, then the flight speed indicated by the instrument will always (at any altitude) unequivocally correspond to actual form drag q. Therefore, having calculated according to maximum permissible value of form drag the corresponding maximum values of flight speed by instrument (for various configurations of a glider they will naturally be different) it is not difficult at any altitude to establish the maximum permissible flight procedure in relation to q.

5.2. Loads Which Affect the Glider Under Actual Flight Conditions

5.2.1. Forces Which Affect a Glider in Straight Line Steady Flight

Steady flight is one in which all the values which characterize movement of a glider remain unchanged in time. In actual glider flight, altitude and density change continuously. But because even over a relatively lengthy segment of time the change in altitude of a glider flight and corresponding density are not great, straight flight or a spiral with a constant angle of bank of the glider can be considered steady if one assumes a constant flight speed. Inasmuch as, in steady straight movement, speed is constant and the glider moves forward (without rotation) the total of all the forces and total of all the moment which affect it equals zero.

Thus, one can write an equation of forces for straight line steady glider flight:

$$R = G_{gl}.$$

In practice we look not at the forces R and G_{gl} but at their components. Load on the glider perpendicular to flight speed equals /178

$$Y = G_{gl} \cos \theta = c_y \frac{\rho V^2}{2} S.$$

Vertical acceleration g in straight line steady gliding equals

$$n_y = \frac{Y}{G_{gl}} \approx 1.0,$$

Because angle θ is small. The load acting in the direction of speed:

$$X = -G_{gl} \sin \theta = c_x \frac{\rho V^2}{2} S.$$

Acceleration g in this case will be insignificant, but the pilot will always perceive it as a tendency to slip forward:

$$n_x = -\sin \theta$$

For movement of a glider in a spiral it is necessary to apply yet another force besides weight and general aerodynamic resistance, the curved path. This force is a centripetal force. It occurs only when the glider exceeds a certain angle of bank γ. As a result of this, lift force Y gives a projection perpendicular to the flight path of the glider. This projection will be a centripetal force compelling the glider to go into a spiral (see Figure 2.14).

From looking at the relationship of forces which affect a glider in steady spirals, it follows that the lift force in the spiral equals

$$Y = \frac{G_{gl} \cos \theta}{\cos \gamma}$$

that is, must be greater than the lift force on steady gliding by $\frac{1}{\cos \gamma}$ times.

Consequently, in a given case, acceleration g is expressed through the angle of bank:

$$n_y \approx \frac{1}{\cos \gamma}.$$

Thus, in steady spirals, vertical acceleration g is inversely proportional to the cosine of the angle of bank (see Figures 2.14, 2.15).

The graph of $n_y = f(\gamma)$ allows one to come to the following conclusion which is very useful in practical flying. As is apparent, when there are sufficiently large angles of bank, vertical acceleration g is comparatively small. Thus a bank of /179
60° corresponds to acceleration g 2, and 70.5°--acceleration g

3. For sailplanes such angles of bank are fairly ordinary (they are used in extremely strong compatatively narrow ascending air currents). And acceleration $n_y = 3$ is fully permissible. However, with a further increase in the angle of bank which can occur quickly as a result of pilot error, acceleration g will increase very rapidly and then there is a danger of too great acceleration load factor and breaking of the glider.

5.2.2. Forces Which Are Active When There is a Sharp Longitudinal Deflection of the Control Stick

Such a deflection of the control stick (and consequently of the elevator or stabilizer) results in unstable movement of the glider in the vertical plane which will continue for some time and is characterized by a number of peculiarities of the load factor of the glider (Figure 5.4).

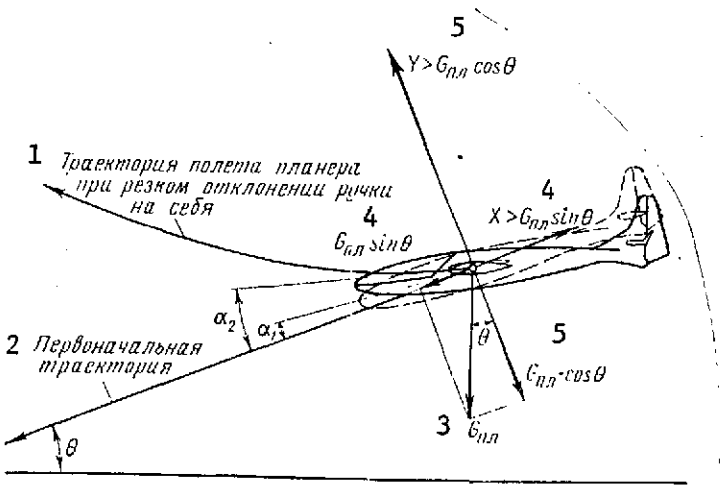

Figure 5.4. An Increase in Lift Force With a Sharp Deflection of the Elevator Upwards:
α_1--The initial angle of attack; α_2--The angle of attack after moving the stick forward

Key: 1--Flight path of a glider with a sharp deflection of the stick forward; 2--Initial flight path; 3--G_{gl}; 4--$G_{gl} \sin \theta$; 5--$G_{gl} \cos \theta$

Let us assume a glider which is moving in a steady glide. If, at a certain moment in time, the elevator (stabilizer) is deflected upward suddenly and fairly fast, then the angle of attack of the wing is increased and the glider will fly at its previous speed for some time due to inertia. Due to this

the speed of glider flight at the first moment will not correspond to the new angle of attack (will be greater than it would be with the elevator deflected), the lift force will increase in comparison with the lift force of the initial procedure. The difference of forces $Y - G_{gl} \cos \theta$ in this case is a centripetal /180
force which begins to curve the flight path of the glider. Its size is determined by the following equation

$$Y - G_{gl} \cos \theta \simeq Y - G_{gl} = G_{gl} (n_y - 1)$$

The equation shows that an excess of load on the glider which is a centripetal force is directly proportional to the weight of the glider and to the excess of actual acceleration g over acceleration g of a steady straight line glide from that speed at which the elevator was sharply deflected.

In truth, during a short time, thanks to any increased resistance of the glider (with an increase in α) and decreased angle of glide a decrease in the component of weight occurs which plays a role in the cruising force, flight speed decreases and begins to correspond to the new angle of attack, but acceleration g decreases to a size

$$n_y \simeq 1.0.$$

However, the load on the glider although it is brief does occur and can be considerable. This must be kept in mind by the pilot and the designer.

It is obvious that the largest load (and acceleration g) at a given flight speed of a glider will be when, as a result of such a sudden and fast deflection of the elevator, the glider has an angle of attck corresponding to maximum value c_y:

$$c_y = c_{y\max}.$$

Then the lift force and the vertical acceleration will, respectively, be expressed in the following way:

$$Y_{\max} = C_{y\max} \frac{\rho V^2}{2} S;$$

$$n_{y\max} = \frac{Y_{\max}}{G_{gl}} = \frac{c_{y\max}}{(c_y)_{n_{y=1}}} \simeq c_{y\max} \frac{\rho V^2}{2} \frac{1}{\frac{G_{gl}}{S}}.$$

It is natural that when there is a sharp deflection of the stick "forward," the picture of this phenomenon will be similar

to the one just looked at. But acceleration g will be decreased. And if it travels through a zero value, then the glider will undergo load in the reverse direction which naturally deserves no less attention.

5.2.3. Forces Affecting a Glider When There is a Sudden Drop Into a Vertical Air Current

During glider flight it is always possible to encounter ascending or descending air currents. Then, acceleration g which /181 occurs, sensed by the pilot provides him with good information about changes in flight procedure, but in such a case there is lag.

Consequently, when dropping into an ascending air current (with a descending air current the picture of the phenomenon will be similar, but the change in angle of attack will be opposite) the speed of the vertical air current ω will be added to the flight speed of the glider along flight path V. If the size of speed ω is small relative to speed V, then the total speed of glider movement V_{sum} will differ little in size from speed V. However, a change in direction of flight speed of the glider V_{sum} which occurs when adding V and ω, even if ω is small, all the same causes a certain change in the angle of attck and consequently the lift force of the glider:

$$\alpha_{i.a.} = \alpha_{sty} + \alpha_{\omega}$$

where $\alpha^{\circ}_{\omega} \approx 57.3 \frac{\omega}{V}$, and α_{sty} is the angle of attack corresponding to the speed of steady gliding flight of a glider at which it enters the air flow (Figures 5.5; 5.6).

An increase in α (and in general any change in α on any side in relation to the direction of the vertical air current) by the size of α_{ω} results in a corresponding increase (change) in the lift force coefficient. In order to determine quantitatively this increase it is necessary to know the deviation of the dependence c_y on α, designated by the symbol c_y^{α} which indicates how many units (or parts of a unit) coefficient c_y has for one degree of changed angle of attack α. Then an increase in c_y as a result of a change in the angle of attack when the glider /182 enters an ascending air current is determined by the expression:

$$\Delta c_{y\omega} = c_y^{\alpha}\alpha_{\omega} = 57.3\ c_y^{\alpha}\ \frac{\omega}{V}\ .$$

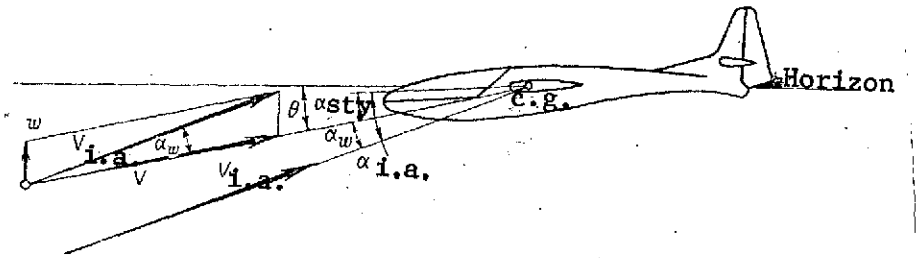

Figure 5.5. A Change in the Angle of Attack of the Wing When the Glider Enters an Ascending Vertical Air Current:
V--Velocity of the air incoming to the glider at the moment the glider encounters the vertical ascending air current; $V_{i.a.}$--Is the velocity of air incoming over the glider when the glider enters a vertical ascending air current; ω--Is the vertical velocity of the ascending air currents; α_{sty}--Is the angle of attck in the initial steady flight; α_{ω}--Is the increase in the angle of attack of the wing when entering a vertical ascending air current; $\alpha_{i.a.}$--The total of the angle of attack when entering a vertical ascending air current; θ--The angle of inclination of the gliding flight path.

And the increase in lift force will equal:

$$Y_{\omega} = c_{y\omega} \frac{\rho V^2}{2} S = 57.3\, c_y^{\alpha} \frac{\omega V}{2} \rho S.$$

Now let us look at how the vertical acceleration g of a glider is changed as it enters a vertical current of air. On encountering the air flow the lift force of the glider will equal

$$Y = G_{gl} \cos \theta \simeq G,$$

and vertical acceleration g amounts to

$$n_y = \cos \theta \simeq 1.0.$$

On encountering a vertical air current, the lift force is changed due to the addition of Y_{ω} and then equals

$$Y_{v.p.} = G_{gl} \cos \theta + Y_{\omega} \simeq G_{gl} + Y_{\omega}$$

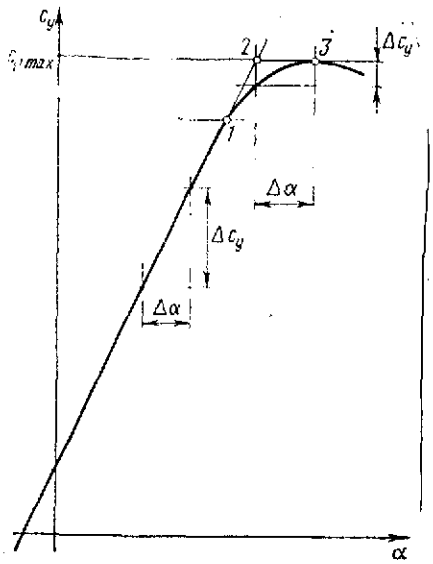

Figure 5.6. The Increase of c_y on Linear and Nonlinear Sections of the Dependence $c_y = f(\alpha)$ With One and the Same Change of the Angle of Attack

and vertical acceleration g is

$$n_{y\,v.a.} = \cos\theta + \frac{Y_\omega}{G_{gl}} \approx 1 + \frac{Y_\omega}{G_{gl}}.$$

Substituting for Y_ω its expression in the formula for the increase of α, we obtain:

$$n_{y\,v.a.} \approx 1 + 57.3\, c_y^\alpha \frac{\rho\omega V}{2\,\frac{G_{gl}}{S}}.$$

Consequently, the vertical acceleration g of a glide when entering a vertical current of air will be greater the greater is the speed of glider flight, the greater the vertical air current speed, the larger the deviation of dependence $c_y = f(\alpha)$, which depends on the shape of the airfoil and the position of the lift augmentation devices of the wing (see Chapter 2) and, finally, the smaller is the specific load on the wing.

When considering questions of load capability of a glider on entering a vertical current of air it is necessary to take into account the following circumstances also.

The formulas presented can be used for three angles of attack of a glider wing α, which correspond to the linear part of the dependence $c_y = f(\alpha)$. If the size of c_y goes beyond the limit of the linear section of the $c_y = f(\alpha)$, limited by the point, then the increase of $c_{y\omega}$ must be determined directly along the curve $c_y = f(\alpha)$ (see Figure 5.6). /183

Another circumstance which must be kept in mind involves the fact that the actual entry of a glider into an air current does not occur instantaneously as would be assumed when looking at the character of the load of the glider but occurs over a certain length of time. Moreover, the vertical current itself always has imprecise boundaries and a certain large or small zone in which the vertical air current increases from zero to maximum characterized by the air current being considered (Figure 5.7).

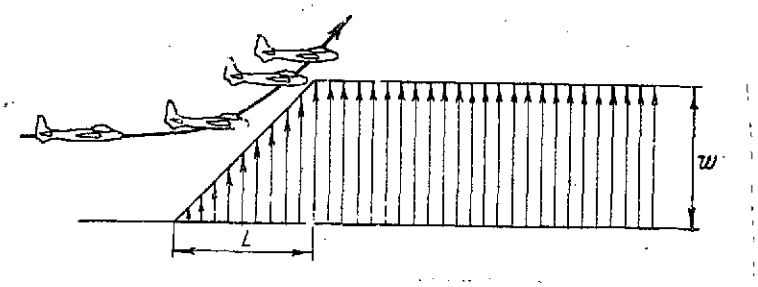

Figure 5.7. The Character of Entry of a Glider into an Actual Ascending Air Current Presented Diagrammatically

This and another circumstance facilitate a certain decrease in the size of change of acceleration g of a glider when it enters a vertical air flow as opposed to what would happen if a glider entered an air current instantaneously, and the dependence $c_y = f(\alpha)$ would be linear everywhere.

Finally, there is still one more circumstance. When determining the increase in the angle of attack α_ω in the formula one should substitute the initial values of glider flight velocity and density, that is V and ρ_H. Substituting instrument speed causes a significant error, especially at high altitudes where V and V_{inst} are considerably different from each other.

5.3. The Generalized Strength Characteristic of a Glider, Calculating the Possible and Permissible Vertical Acceleration g With Sharp Longitudinal Deflection of the Control Stick and an Encounter in Flight with a Vertical Airstream

As was shown earlier, maximum vertical acceleration g in case of sharp deflection of the elevator or the glider dropping into a vertical air current at a given flight velocity and specific load /184 on the wing depends on the size of $c_{y\,max}$

$$n_{y\,max} = c_{y\,max} \frac{\rho V^2}{2} \frac{1}{\frac{G_{gl}}{S}} .$$

If instrument speed is used in this equation then density must correspond to zero altitude. But naturally one

can substitute the initial speed (for example from preliminary calculations). Then density must be taken according to flight altitude.

By using the expression presented for $n_{y\,max}$, one can construct a graph of $n_{y\,max} = f(V)$ using in the calculation the maximum positive coefficient of lift force $c_{y\,max}$, and in absolute size the maximum negative c_y indicated by the index of $c_{y\,min}$ (Figure 5.8).

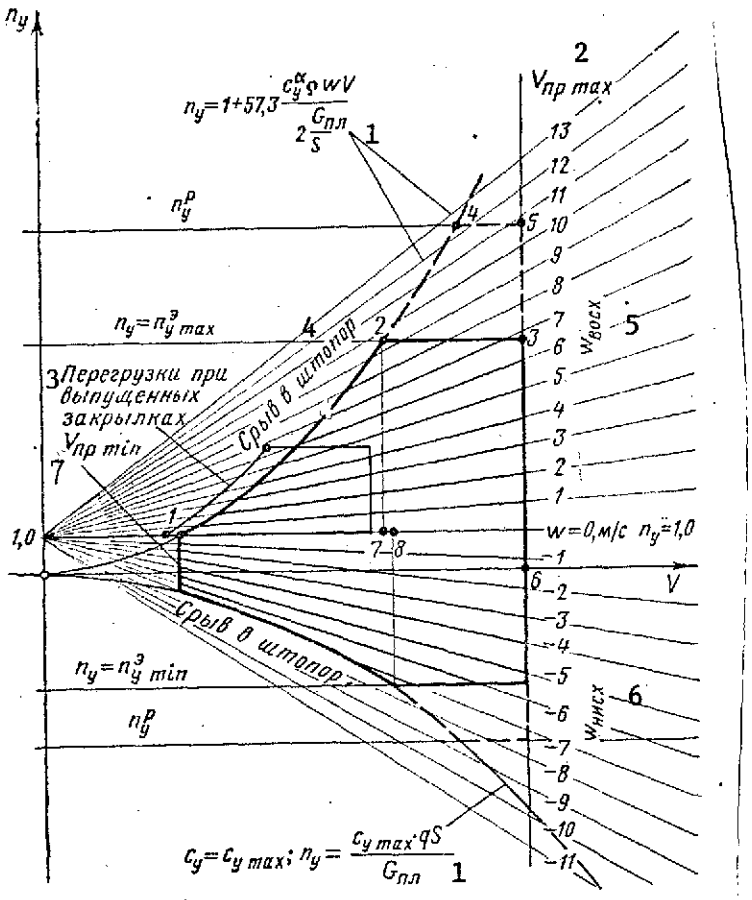

Figure 5.8. Limited Dependencies of Vertical Acceleration g and Flight Speed When the Glider Enters a Vertical Air Flow

Key: 1--G_{gl}; 2--$V_{lng\ max}$; 3--Acceleration g with lowered flaps; 4--Stall in spin; 5--$W_{asc.}$; 6-- $W_{des.}$ 7--V_{lng} min

But because the strength of the glider is not unlimited, on this graph it is necessary to apply boundaries of permissible vertical acceleration $n_{y\max}$ and $n_{y\min}$ and flight speed $V_{\max}$.

On the graph one gets a certain closed contour whose dimensions and boundaries characterize the strength capability of a given glider from the point of view of flight with sharp longitudinal deflection of the rudder and when entering a vertical air flow.

Let us look in detail at the boundary of this diagram. The parabolic curve in the field of positive acceleration g is the dependence of those maximum acceleration factors which can be attained with the glider at $c_{y\max}$ or, similarly--at α_{cr}. At speeds which correspond to this section of the contour, the glider will not be subject to acceleration g which exceeds the permissible. Reaching acceleration g determined by the boundary of the curve tells us only about α_{cr} and the possibility of stalling with further transfer to spin.

The point of intersection of the parabola with the horizontal boundary of the contour, designated by 2, characterizes attaining permissible vertical acceleration g with simultaneous possibility of stalling. The horizontal boundary of the contour located between points 2 and 3 defines (according to the standards of glider strength) the constant of permissible vertical acceleration factors in flight at speeds from corresponding point 2 to the maximum permissible (according to the size of drag form). However in this section 2--3, the appearance of permissible acceleration g will occur earlier than entry to α_{cr}. Consequently, the threat of stalling in this section is nil. On the other hand there is the possibility of involuntarily exceeding the permissible acceleration load.

The vertical section of the boundary of the contour 3--6 /185
corresponds to one unit of maximally permissible flight speed at which stalling can occur only after the glider reaches permissible accelration g.

The negative field of the contour is similar in character to the positive field but corresponds to a sharp longitudinal deflection of the control stick "forward" or dropping into a descending air current.

The left vertical boundary of the contour corresponds to minimum possible flight speed.

We note also two characteristic points on the diagram. These are points on the axis of the abcissa (the V axis) which correspond

to points 2 and 3 of the contour. The two speeds determined by these points are those boundary values of flight speed before which any longitudinal, respectively, positive or negative deflection of the rudder or dropping into a vertical air flow of any intensity has the danger of stalling in spin. At the same time, at speeds larger than those corresponding to points 2 and 3 it is necessary to carefully see that one does not make too abrupt a longitudinal deflection of the rudder or drop into too intense an air current (given actual flight speed) to exceed permissible vertical acceleration g. /186

A difficulty of the practical holding of boundaries of strength capability of a glider, looked at in the diagram, involves the fact that the pilot can know precisely only one coordinate of each of the points which make up the boundaries of the diagram. This coordinate is the actual flight speed of the glider which he fixes using the indicator (V_{lng}) or determines according to a calculation of V_{lng} on V. An approximation of these same boundaries for stalling can be determined by the pilot only at the beginning of glider flutter, and the possibility of approximating the boundary of strength in vertical acceleration g is only indirect (according to the character of the state of the surrounding atmosphere and clouds, or by deflection of the stick and the force applied to it by the pilot). These actual conditions can to a certain degree orient the pilot as to the intensity of the vertical air current which he must not encounter on the glider flight path.

The formula defining the size of vertical acceleration g when encountering a vertical air current shows that with any kind of single constant speed of this current acceleration g depends linearly on flight speed V. Therefore, it is not difficult in the diagram known for $n_y = f(V)$ to apply a net of straight lines calculated according to the formula for $n_{y\,v.f.}$. The points of intersection of the contour with the rays of $n_{y\,v.a.} = f(V, \omega)$ gives those sizes for the speed of vertical air currents which with flight speeds corresponding to them on the graph will cause the glider to be either at α_{cr} (stall and spin), or at the maximally permissible accelration g (Figure 5.9).

It is natural that the characteristic points and sections of the contour of the diagram will have similar points and sections on a new diagram constructed on the coordinates of ω, V. The pilot must try hard to remember the two speeds which determine the boundary between speeds which are safe from the point of view of strength and therefore are permissible in encountering air flows of any intensity, and speed during which the pilot must couple his actual flight speed with the possible speeds of vertical air currents which he figures on encountering (judging by

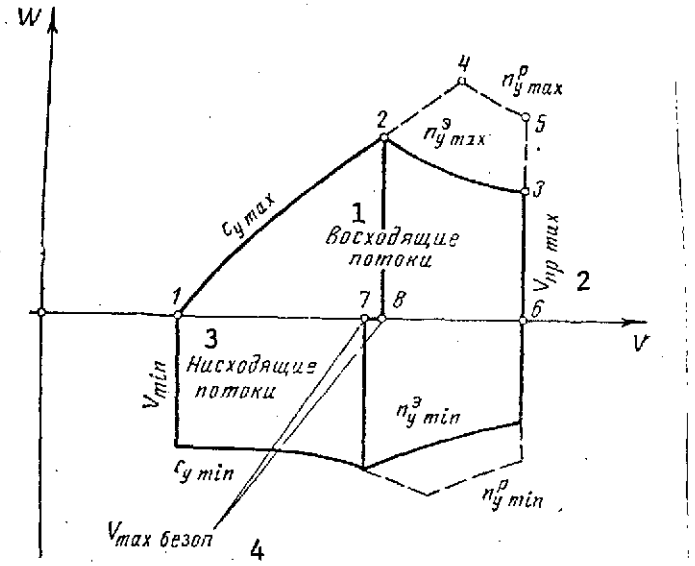

Figure 5.9. The Dependence of Vertical Air Flow Speed on Speed of Glider Flight and Characteristic Boundary Points

Key: 1--Ascending air current; 2--V_{lng}; 3--Descending air current; 4--Safe

a qualitative evaluation of the state of the ambient atmosphere on his route).

Figure 5.10 shows diagrams of strength capabilities when encountering vertical air currents for three gliders--a special piloting (high-strength) glider and two ordinary sailplanes. A comparison of the diagram clearly shows the advantages and disadvantages of each glider from this point of view. /187

A method of determining the speed of a vertical current taking a glider out at $c_{y\,max}$ which was utilized is approximate because it presupposes a linear dependence $c_y = f(\alpha)$ in the entire range of α down to α_{cr} or $c_{y\,max}$, that is, down to point 2 /188

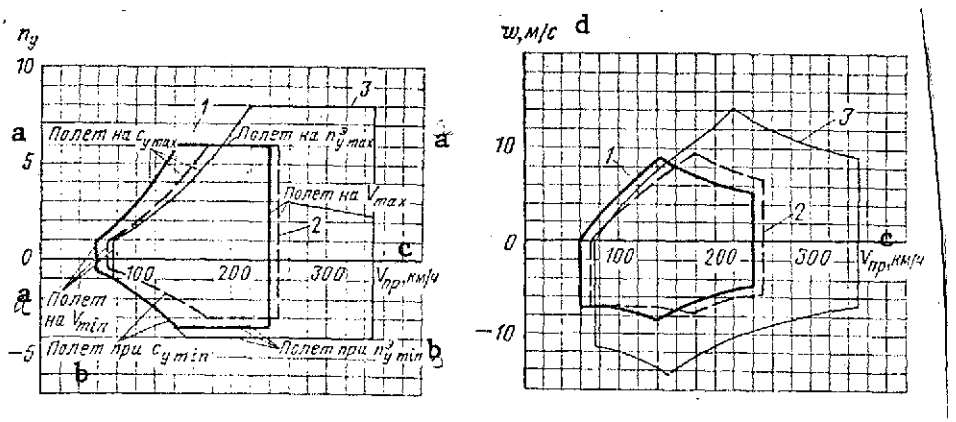

Figure 5.10. A Comparison of Strength Capabilities of Three Sport Gliders: 1 and 2--Sailplanes; 3--A glider built especially for aerobatics

Key: a--Flight at; b-- Flight during; c--V_{lng}, km/hour; d--ω, m/s

(see Figure 5.6).

In order to attain $c_{y\,max}$ with linear dependence $c_y = f(\alpha)$ requires a speed of vertical air current greater than in actuality, by size

$$\Delta\omega = \frac{1}{57.3} V\Delta\alpha^\circ,$$

where $\Delta\alpha^\circ$ is determined by points 2 and 3 (see Figure 5.6). This difference in speeds of vertical air currents will be in reserve.

The graph of type $n_y = f(V)$ can be constructed calculating not only the vertical accelration g permissible in operation but also breaking load. Then they will give an even more complete picture which characterizes the load capability of a glider.

5.4. Loads on a Glider During Launching

Let us look at two methods of launching a glider from the point of view of the loads which affect it: launching using winches mounted on the ground and towing a glider behind an airplane. The first method involves the largest loads in comparison with loads on a glider which occur when using other methods of launching. The second launching method for a glider is very widespread nowadays.

Take-off of a glider using winches attached to the ground can be divided into three stages: take-off run, holding the glider at low altitude and gaining altitude. During the take-off run and holding (for gaining speed before moving to high altitude) the speed of the glider is still not large and acceleration g is small. However, after gaining altitude (Figure 5.11) the vertical loads on the wing become very significant although accelration g does not increase as strongly. The reason for this character of increase of the acceleration factor which occurs when gaining altitude involves the fact that the glider begins to be affected by the vertical (in relation to the flight path) component of force of the tow cable $P_T \sin\psi$, which together with the appropriate component of weight of the glider $G_{gl} \cos\theta$ explains the necessity for the presence of increased force of the wing Y. At the same time, the vertical acceleration g of the glider is expressed by the formula

$$n_y = \frac{Y - P_T \sin\psi}{G_{gl}}$$

increases to a smaller degree. (In the formula, ψ--is the angle between the cable and the tangent to the flight path). This circumstance is very serious from the point of view of load capability of the glider (primarily the wing) and further because /189 the lift force affecting the wing will be greater than with similar acceleration g in soaring flight, acceleration g will not be proportional and cannot be evaluated by the pilot because he cannot sense the acceleration factor. Moreover, take-off of a glider done using a winch is an unstable procedure as to speed and flight path which is a curved line with variable camber. Finally, when looking at a method of launching a glider the very probable jerks of the tow cable which create additional acceleration g are assumed in calculations to equal $n_{y\,cab} = -3.8$, that is, act downwards.

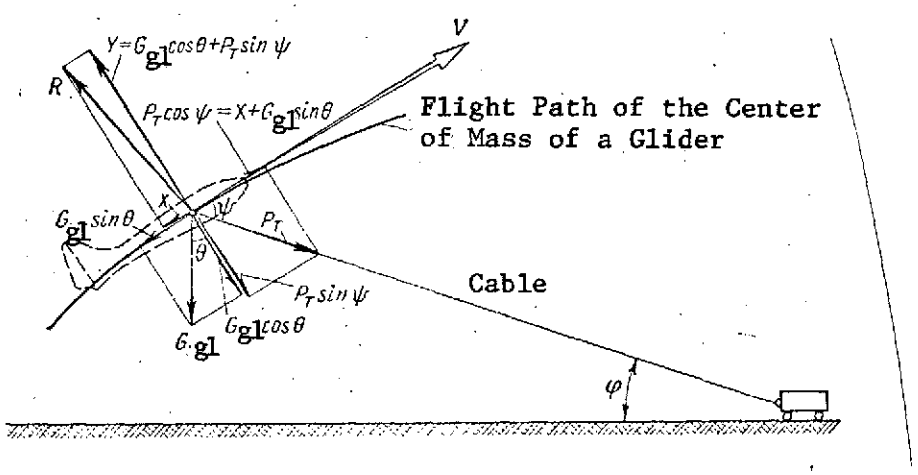

Figure 5.11. A Diagram of Courses Which Affect a Glider During Launching Using a Winch

Thus, finally one assumes the following expression for permissible acceleration g of a glider during launching using a winch

$$n^{a}_{y\,\mathrm{lnch}} = \frac{c_{y\,\max} S_{q\,\mathrm{lnch}}}{G_{gl}} - 3.8.$$

A decrease in acceleration g as a result of the pull of the cable (with unchanging lift force) makes the work of the wing heavier.

During launching using a winch acceleration g is smaller and in a number of cases can be negative. Therefore, the mass forces will relieve the load of the wing less or (with negative acceleration g) even add to it.

Going forward somewhat let us note that when launching a

glider using a winch when the tow lock is mounted in the forward part of the glider and not on the sides close to the center of mass, the tail unit, fuselage and tow lock are subjected to large /190 loads.

During launching by towing behind an airplane, load on the glider will be smaller than when using a winch. However, if launching is done when the air is not quiet ("bumpy"), strong jerks of the cable which affect the flight path of the glider will be important if during take-off the height separation above or "the height separation below" of the glider is not great (Figure 5.12).

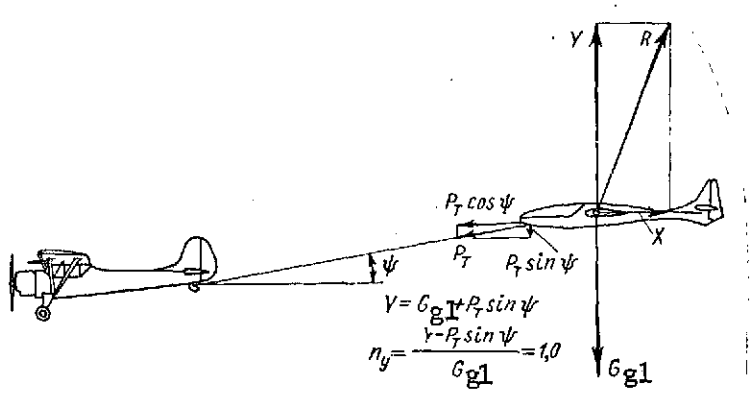

Figure 5.12. Loads Affecting a Glider During Launching Using a Tow Airplane

5.5. Loads on a Glider During Landing

When calculating a glider for strength one looks at a number of aspects of landing which differ from each other in the character of the approach of the glider to the ground and the direction of pre-landing movement and also the locations where the glider will come into contact with the Earth's surface.

When landing a glider equipped with a parachute, vertical speed of descent increases (as opposed to the minimum possible) and at the moment of contact with the Earth a certain reserve of kinetic energy accumulates. It is obvious that at the moment of touching the Earth all this energy must be received by the structure of the glider (primarily by the landing gear) which by deforming elastically is able to accomplish this. Landing with a parachute is considered safest from the point of view of load capability of the glider as a whole and of course primarily its landing gear and wings.

Another case of landing a glider with an increase in vertical speed of descent as opposed to the minimum possible size is a case of landing on a slope.

When calculating glider strength one looks at other cases /191
of landing: landing using a cross wind, landing on the forward part of the skis (in the case of a ski landing gear) landing with forward shock on the landing gear wheel. Let us also look at a combination of separate cases of landing.

5.6. Loads Which Affect a Glider in Cases of Flutter and Reversal of Ailerons

Up until now we've looked at the load capability of a glider with an increase of just the acceleration factor or an increase in acceleration g accompanied by form drag (flight speed and descent).

Now we will become acquainted with loads and their effect on the structure of a glider during the effect on it only of form drag with initial acceleration g affecting the glider close to $n_y = 1$.

5.6.1. Aileron Flutter

Flutter is the elastic oscillation of separate parts of the structure of a glider with increasing amplitude. The oscillations themselves and the increase in amplitude occur due to the inflow of energy from incoming air currents on the glider (Figure 5.13). The increase in flutter is very fast. Therefore, combatting flutter by reducing speed has practically no positive results. Two methods remain by which one can back away from the speed of the beginning of flutter in a field not intended for the operational task of a given glider: increase rigidity of the structure of the glider and include in the designs special devices which change the distribution of the mass and thus change the character of operation of the structure.

Flutter oscillations can affect various parts of the glider and in turn those which have the greatest elasticity. Thus, there can be wing, rudder and aileron flutter. Flutter can have different forms. Let us look at one of the forms of flutter widespread in gliders--bending-aileron flutter of the wing (Figuer 5.14).

Let us assume that glider flight occurs at a speed adequate for the development and increase of flutter. Then let us assume at the time of such movement for any cause, for example, the course of the glider enters an ascending air current affects the glider wing as a result of which the wing bends elastically

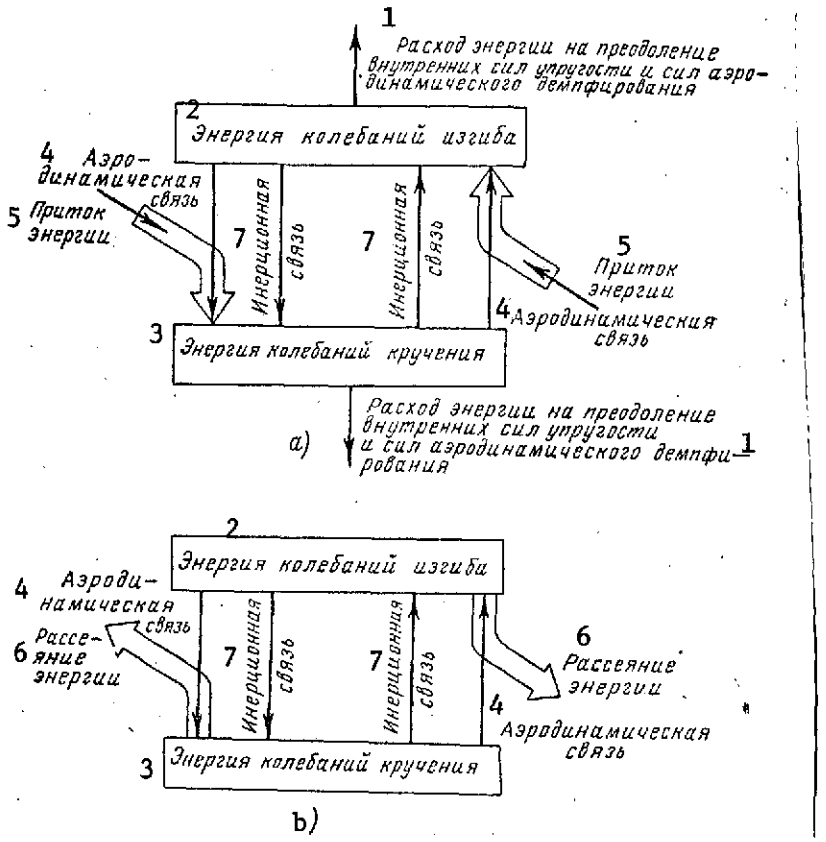

Figure 5.13. General Cases of Energy Exchange During Vibrations of the Wing: a--The structure has a tendency (according to its elastic, inertia and geometric properties) to flutter; b--When there is an absence of a tendency of the structure to flutter (according to Ye. P. Grossman--[12]).

Key: 1--The expenditure of energy in overcoming internal forces of elasticity and the force of aerodynamic damping; 2--The energy of vibrations of bending; 3--The energy of vibrations of twisting; 4--Aerodynamic connection; 5--Inflow of energy; 6--Dispersion of energy; 7--Inertia bond

downward. Then after the cause of the deformation is eliminated the wing under the force of elasticity affecting the elements of its structure begins to rise in order to assume its initial state. Then the aileron of such a wing, if its center of mass is behind the axis of rotation (that is, the axis on which the points of

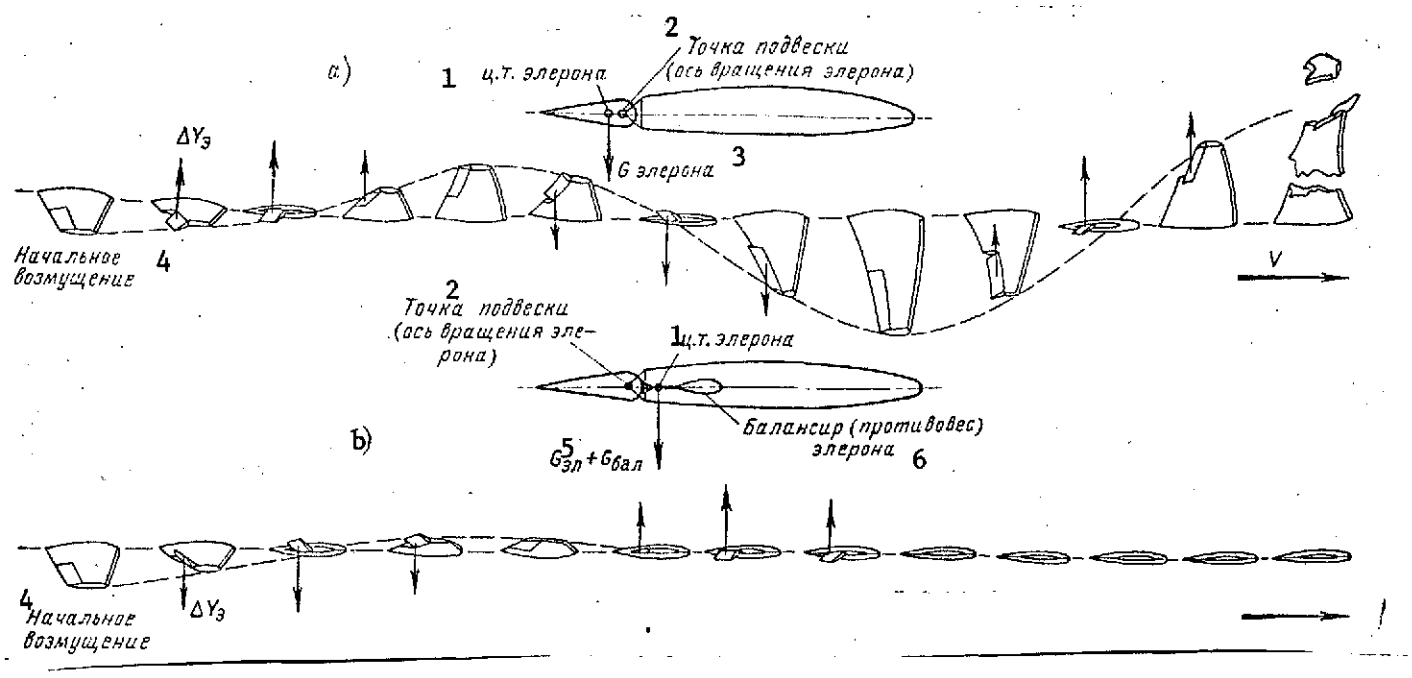

Figure 5.14. A Diagram of the Growth of Bending-aileron Flutter of a Wing (a) and One of the Methods Preventing It (b)

Key: 1--C.g. of the aileron; 2--Point of suspension (axis of rotation of the aileron); 3--G of the aileron; 4--Initial perturbation; 5--G_{ail} + G_{bal}; 6--Balancer (counterweight) of the aileron

support suspending the aileron lie), will lag behind the wing as /192
a result of the forces of inertia. The delay of the aileron will be possible because of the non-rigidity of the system of lateral control. As a result, during movment of the wing down the aileron will be deflected up.

Returning to the initial equilibrium position the wing does not remain there but because of inertia will continue to rise. Now this movement will gradually slow down due to the effects of the forces of elasticity of the structure. As the movement of the wing slows down the aileron will catch up with it and at the greatest deflection of the wing upward will occupy approximately a neutral position in relation to the wing.

From its extreme upward position the wing attempts to resume its initial equilibrium because of the forces of elasticity of the structure, that is, it will move downwards. The aileron /194
lagging behind the wing because of its inertia and the elastic deformation of the system of lateral control will remain deflected upward.

This oscillating movement of the wing, aileron and system of lateral control can be damped if the inflowing current of air on the wing does not have high velocity. The aerodynamic force which occurs on the deflected aileron is always directed on the side away from its equilibrium position, that is, toward increasing the amplitude of oscillation of the wing. It is natural that when this aerodynamic force becomes larger that the force which damps the vibration of the wing (and included here first and foremost is the force of elasticity of the structure of the wing and the system of lateral control), the amplitude of oscillation increases so much that deformation of the wing exceeds the springiness of the material from which the wing is made and begins to operate outside the limits of elasticity and the wing breaks. Then the process of flutter is very short-term and in character reminds one of an explosion as a result of which part of the glider subjected to flutter oscillation and often the entire glider is broken into many pieces.

The speed at which oscillation occurs resulting in breakdown of the structure is called the critical speed of flutter for a given glider or a given configuration. The critical speed of flutter is always greater than the maximum permissible speed of the glider flight. The size of the difference between the critical speed of flutter and the maximum permissible is established as adequately large so as to guarantee the pilot from getting into a dangerous auto-vibration procedure during flight at speeds close to maximum.

Other forms of flutter are similar to those looked at above and differ from it only in those elements through whose springy

deformation the energy of the air current inflowing on the glider are received as vibrations of the structure.

Thus, for example, in bending-twisting flutter of the wing, the role of such an element is played by the wing itself periodically twisting during bending and then creating an aerodynamic force which operates on shaking the wing in a rhythm of its bending vibration.

5.6.2. Aileron Reverse

Reverse is a phenomenon like flutter directly connected to the effect of form drag on the structure of the glider wing. Let us look at the phenomenon of reverse and an example of operating ailerons with inadequate rigidity of the wing in twisting (Figure 5.15).

Reverse of the ailerons involves a reverse effect of ailerons which occurs with considerable twisting of the wing.

During deflection of the ailerons, the character of streamlining of the wing (in that area where the aileron is located or as they say on the part of the wing served by the ailerons) is changed. /195

The total lift force changes in size and the point of its application is shifted along the chord of the wing. Each cross section of the wing has a certain imaginary point which is characterized by the fact that the forces applied to it do not create a bending moment. These points called centers of rigidity of the cross section of the wing together make up a certain geometric place which is called the line or axis of rigidity of the entire wing. Because the point of application of the lift force of the wing in a general case is not on the line of its rigidity, this force will twist the wing more strongly the farther away is its point of application. If the point of application of this force is behind the line of rigidity, the wing is deformed in such a way that the angle of attack will be decreased with deflection of the aileron down and will be increased with its deflection upwards.

When rigidity of the wing structure is inadequate for twisting and large drag form, this twisting can reach such dimensions that the effect of deflecting the ailerons becomes zero. This means that the ailerons stop creating lateral moment in spite of their deflection. With a further increase in drag form a reverse effect of the ailerons occurs. This means that /196
moving the control stick, for example, to the right will correspond not to a right but to a left bank and the reverse. Naturally such a reaction of the glider in bank by deflection of the aileron

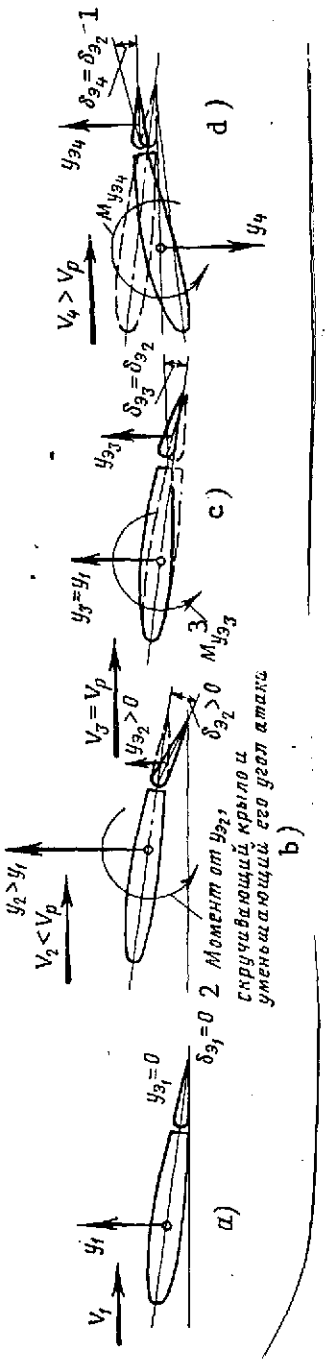

Figure 5.15. A Diagram of Reverse of the Ailerons (The Solid Line Shows the Position of the Wing with Different Degree of Elastic Twist, the Dashed Line Shows the Initial Position of the Wing and Aileron): a--Ailerons neutral; b--Normal effect of ailerons; c--Beginning of aileron reverse (deflection of ailerons does not create bank); d--Growth of aileron reverse (opposite effect of ailerons).

Key: 1--δ_{a_2}; 2--Moment from Y_{a_2}, twisting the wing which decreases its angle of attack; 3--$M_{y_{a3}}$

is completely impermissible. One of the methods of combatting aileron reverse is increasing rigidity of the wing against twisting, the other (simpler) is selecting a structural arrangement of the cross section of the wing which will provide a position of the center of mass behind the point of application of the lift force of the wing or, at least, close to its average position.

5.7. Loads on the Structure of the Glider When Moments Occur

5.7.1. Load From Pitching Moment

Pitching moment of the glider is created by the wing, by the horizontal part of the tail and fuselage. The aerodynamic resistance force of the glider generally does not go through the center of mass of the glider. The point of intersection of this force with the mean aerodynamic chord of the wing, as is known, is called the center of pressure. If the center of pressure is located in front of the center of mass, then the lift force creates a tail heaviness moment which will tilt the glider toward the side of an increase in the angle of attack (Figure 5.16).

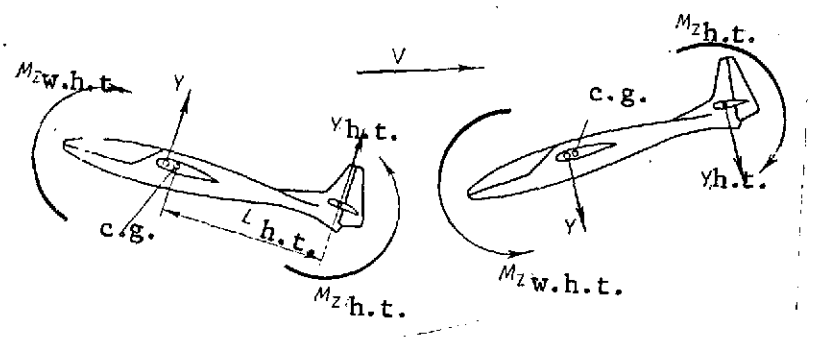

Figure 5.16. Load on the Glider From Pitching Moment at Various Angles of Attack: a--Positive; b--Negative

The force of any resistance also creates pitching moment positive (tilting) or negative (diving) depending on the interpositioning of the center of pressure and the center of the mass of the glider. However, this moment on gliders is insignificant in size and will be ignored in further discussion of the question.

Let us use the concept of focus and constant moment along the angle of attack M_{z_o}. Then the formula for pitching moment /197

of the wing has the form:

$$M_{z_w} = M_{z_o} + YL_{f.w},$$

where Y--is the lift force of the wing and $L_{f.w}$--is the distance between the focus and the center of pressure of the wing.

If one adds the fuselage moment M_{z_f} to the wing moment M_{zw} one obtains a total moment of the combination of "wing plus fuselage" without the horizontal tail:

$$M_{z\ w.h.t.} = m_{z\ w.h.t.} \frac{\rho V^2}{2} Sb_A = M_{z_w} + M_{z_f}.$$

As a result of the effect of lift force of the horizontal tail relative to the center of mass of the glider the moment occurs:

$$M_{zh.t.} = -Y_{h.t.} L_{h.t.}$$

Here $L_{h.t.}$ is the distance from the point of application of the lift force of the horizontal tail where the elevator (stabilizer)

is hinged, to the center of mass of the glider.

The moment of the horizontal tail can be changed in size and symbol by deflecting the elevator (stabilizer) at different angles (δ_e, ϕ_{st}).

In flight, the moment of the horizontal tail equalizes the pitching moment of the wing and the fuselage. Therefore, one must express the equality:

$$M_{zw.h.t.} + M_{zh.t.} = 0$$

or

$$M_{zw.h.t.} - L_{h.t.} Y_{h.t.} = 0.$$

From this it is not difficult to obtain the size of load on the horizontal tail:

$$Y_{h.t.} = \frac{M_{zw.h.t.}}{L_{h.t.}} = \frac{m_{zw.h.t.} \frac{\rho V^2}{2} S b_A}{L_{h.t.}}.$$

This expression of load can be used when calculating the strength of the horizontal tail unit. The distribution of load $Y_{h.t.}$ on the area of the horizontal tail (which is necessary for calculating the components of its structure) is made correctly by applying the standards of strength of gliders. This force is one of the calculated loads for the fuselage.

5.7.2. Loads from the Yawing Moment

The yawing moment M_y is created basically by the vertical part of the tail and by the fuselage. The role of the wing and the horizontal tail unit in creating yawing moment is insignificant (Figure 5.17).

The size and direction of the yawing moment effect depends /198
on the angle of the slip of the glider β. The yawing moment depends on the angle of deflection of the rudder.

The moment of yawing is expressed by the product of lateral force which occurs on the vertical tail unit with the presence of angle β and deflection of the rudder--δ_R, and the distance from the center of mass of the glider to the rudder hinges which receive at this point the lift force of the vertical tail unit.

Load from the yawing moment affects the vertical tail unit and the fuselage. In the case of lateral force Z which occurs

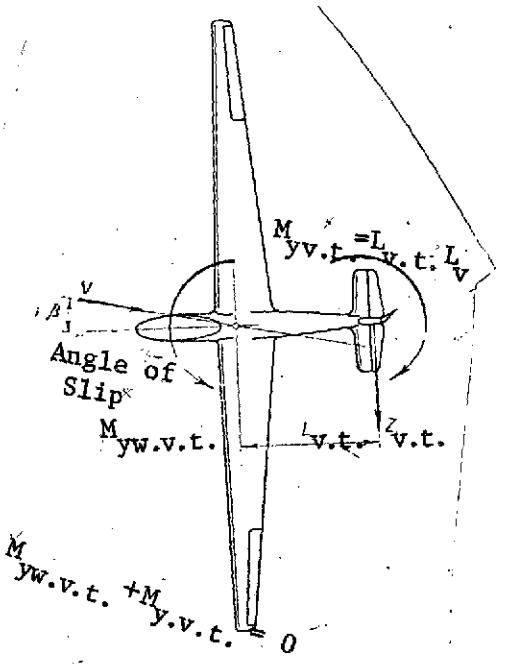

Figure 5.17. Load on the Glider from Yawing Moment

on the vertical part of the tail, the fuselage, besides a bending also has a twisting load. This load is formed due to the fact that force Z is applied on the shoulder $Y_{v.t.}$ from the longitudinal axis of the fuselage (more precisely the axis of its rigidity):

$$M_{f\ twis} = Z_{v.t.} Y_{v.t.}$$

Thus, with the presence of M_y, $M_{f\ twis}$ and M_z moments the fuselage operates simultaneously under bending on two surfaces and under twisting. This circumstance forces designers to give special attention to that part of the fuselage which goes from the rear of it to the cockpit. With a monocoque structure of the tail part often one must transfer to a truss or spar structure for the forward part of the fuselage where the pilot's cockpit is located. With stressed skin on the fuselage, in the area indicated there can be sections with double camber which makes operating conditions of the structure worse.

5.7.3. Load From the Banking Moment

The banking moment is basically created by the glider wing. It occurs with deflection of the ailerons (Figure 5.18) and is a phenomenon of the angle of slip. In truth, an insignificant addition to the moment created by the wing will occur as a result of the operation of the vertical tail (with an angle of slip or deflection of the rudder). But this addition will not be considered. /199

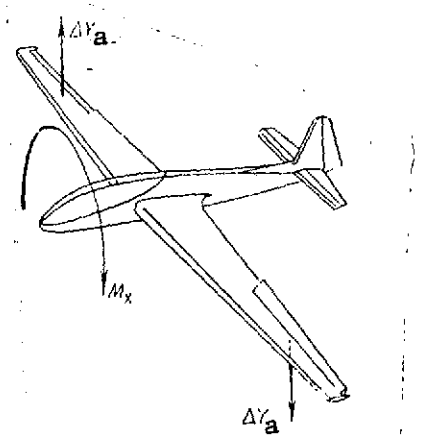

Figure 5.18. Loads on a Glider from a Lateral Moment When Operating the Ailerons

Deflection of the ailerons is the cause of a significant load on the wing. When the ailerons are deflected the bending moment of the wing as a whole changes (in particular can be increased). This increase in moment requires special attention if the corresponding deflection of the aileron occurs with a large acceleration factor n_y. Then on one of the wing cantilevers which already has a

load such an addition of moment can result in its going beyond the limit of calculated strength in the design of the wing.

When the ailerons are deflected, the wing structure is under load from the turning moment and also additionally always has a turning moment of the wing from the non-alignment points of application of the lift force with its axis of rigidity. The turning moment which occurs when deflecting the ailerons is a considerable part of the load taken into account when calculating wing strength.

Besides deflected ailerons, a reason for the occurrence of lateral moment is also the angle of slip. Because moments which cause the presence of an angle of slip β can reach considerable size they also are taken into account when calculating wing strength in the design.

5.8. Types of Load Which Affect Elements of the Glider Structure

Let us look at the mechanism of forming loads which occur in flight and affect elements of the glider structure.

All loads on a glider can be divided according to character into two groups--concentrated and distributed. A load which can be considered to affect one point is considered concentrated. Such loads include for example the weight of the pilot, reaction of supports on which control devices of the glider are mounted, the force of reaction of the Earth's surface when the landing gear wheels come into contact with it, etc. Load distributed over a relatively large area is called distributed load: for example, pressure on the surface of the glider from the incoming air current.

5.8.1. Impression of Load on the Wing of a Glider /200

The effect of load on a wing generally is expressed as was shown earlier by bending and twisting of the wing. But besides this load, is one which attempts to separate one part of the wing from the other. This displacement (shearing) will be felt by the structure of the wing anywhere in its cross section. The shifting part of the load has the name shearing forces and is designated by the symbol Q_{shr} (Figure 5.19).

The moments and forces about which we've been talking during normal operation of a wing will be equalized by the forces of elasticity of the wing structure, that is, by the elastic forces of reaction of materials from which the structure is made.

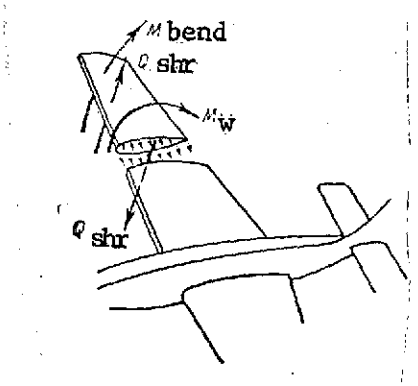

Figure 5.19. Load on the Wing and Its Structure

Then the structure will be in a so-called stress state and each of its elements will undergo stress characterized by the relation of the effects on each element of force for an area of operation cross section of a given element, that is, by the size of the force of elasticity affecting a unit of area of the working section of a given element.

5.8.2. Impression of Load on the Tail Unit of a Glider

The largest loads on the horizontal part of the tail and in particular on the elevator occur during maneuvers when at the largest angles of attack of the wing, according to absolute size, the rudder is fully deflected for transferring the glider to smaller (also according to absolute size) angle. This is called maneuver load (Figure 5.20). /201

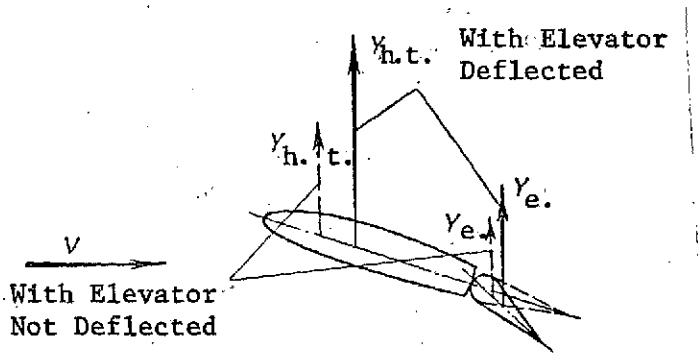

Figure 5.20. Loads Which Affect the Tail During Maneuvers

During flight on a tow, loads on the horizontal tail can also reach large sizes as a result of equalization of the moment from the towing forces along the tow cable. This exists during glider flight with a large height separation above the aircraft or when remaining coupled during launching using a winch. Loads on the horizontal tail can reach large sizes in a case where a glider drops into a powerful vertical air stream (similar to the wing).

The character of impression of load on horizontal and vertical tails is similar in character to the impression of load in the wing. Operation of these parts of the glider are essentially the same.

Load on the ailerons reaches maximum when they are fully deflected and there is the largest form drag.

5.8.3. Impression of Load on the Fuselage of the Glider

The glider fuselage is affected by aerodynamic loads received on its structure from the tail unit and moreover from the effect of weight of the structure and weight of all objects located in the glider. Here, it naturally is necessary to take into account acceleration g which increases these weight by n_x, n_y and n_z times (Figure 5.21).

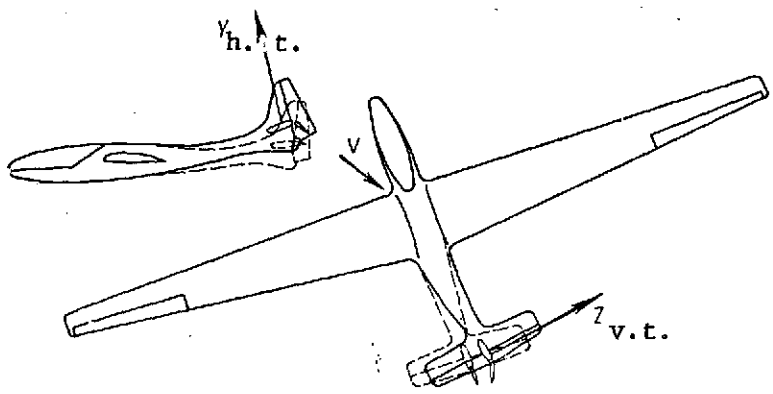

Figure 5.21. Operation of the Fuselage Under the Effect of Load on the Tail:
——————Under the effect of $Z_{v.t.}$ and $V_{h.t.}$
- - - - - - - - - Initial shape of the fuselage

The tail part of the fuselage receives bending moments and shearing forces in vertical and horizontal planes transferred to its structure by the horizontal and vertical tail units. Moreover, the fuselage is affected as mentioned by turning moment from the vertical tail. /202

5.8.4. Impression of Load of Take-off and Landing Devices (Landing Gear) of the Glider

The take-off and landing devices of a glider absorb kinetic energy which the glider has when coming in contact with the Earth on landing, during take-off and moving along the Earth. All the

landing devices receive load from forces of reaction of the Earth which occur when coming in contact with the Earth and when encountering unevenness in launching and landing fields (Figure 5.22).

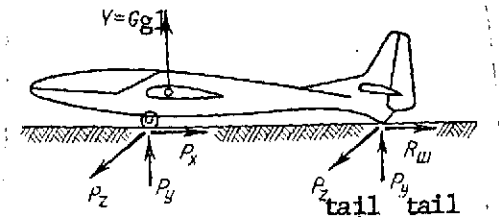

Figure 5.22. A Diagram of Forces Affecting a Glider During Landing

5.9. Glider Strength

Depending on the operational task, for which a certain glider is built, this strength can be greater or lesser. It is dictated by the requirements of maximum load ratio of the structure of the glider, that is, making it without excess weight which is not necessary from the point of view of the actual loads which are encountered by the glider in an actual situation. All the many types of sport planes are divided into four classes according to demands on the structure. Each of these classes embraces a large group of gliders united on the principle of the closeness of their operational tasks. However for all the classes of gliders there is one single most important requirement for all sport planes. It involves the fact that a sport plane for any use must be able to complete a spin, naturally, including exit from a post-spin dive, and also--soaring flight under varying conditions--simple for the first and second class and complex for the third and fourth. This single requirement for all the classes of gliders is considered of primary importance for soaring flights and is always essential for the objective possibility of stalling in a spin especially when soaring. Gliders of the first class are training gliders intended primarily for /203
instruction and training. Acrobatics and steep gliding are prohibited on these. The second class is non-maneuvering gliders intended for sport flights and training. Aerobatics are also forbidden on these. The third class includes sport glider with limited maneuverability on which flights for setting records and appropriate training for pilots including doing aerobatics in a limited speed range and flights in complex meteorological conditions are allowed. Finally the fourth class combines maneuverable sport gliders on which all aerobatic figures in the entire range of flight speeds permissible in operation are permitted.

Before calculating the strength of a glider, the maximum permissible flight speed and maximum permissible operational speed, the so-called "operational" acceleration load, are all defined and these speeds and acceleration g are defined depending on the operational task of the planned glider. During flying operation of the glider, the size of maximum speed and maximum operational acceleration g must not be exceeded in any case.

However, loads on the glider permissible in operation must be smaller than those which the structure will withstand. This is necessary so that all elements of the glider structure will be working in limits of elastic deformation (Figures 5.23, 5.24, 5.25). The materials used for constructing gliders have the property of deforming to a larger or greater degree before being destroyed by accumulated loads. Deformation which precedes breaking up is divided into two types. First, under loads comparatively far from those which break up a glider (these are in limits approximately of two-thirds of breaking load), the structure deforms in such a way that after the load is removed it returns to its initial position. These deformations are elastic. An increase in load above two-thirds of breaking involve the possibility of the appearance of so-called plastic or residual deformations. Under such deformations, after removing the load from the structure it does not return to its initial state and what is more important the strength of the structure then is decreased in comparison with its initial condition. With small residual deformations, breakdown of a glider does not occur yet and the pilot generally speaking is able to complete the flight without abandoning the glider. But, of course, in this case carrying out abrupt maneuvers in the process of descent and landing must be excluded. This is because such maneuvers would result in breaking up of the glider at an altitude too low for using a parachute. /204

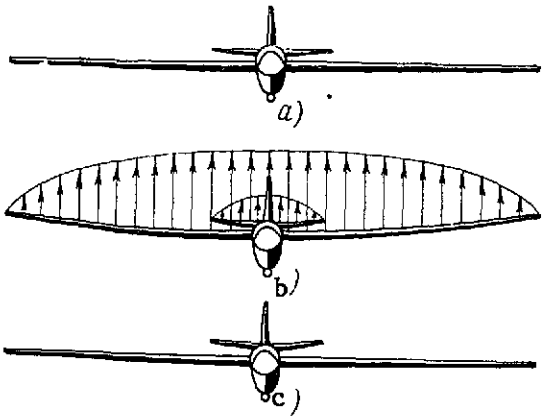

Figure 5.23. Elastic Deformation of a Glider Under the Effect of Loads Which Do Not Exceed Maximum Operation:
a--Glider before load;
b--Glider under load which does not exceed maximum operational (elastic deformation); c--Glider after removing the load (no deformation)

Residual deformations always indicate unsuitability of the glider for further flying operation. Therefore, for a pilot (and for the designer as well) the boundary which determines the size of maximum permissible operation acceleration g is a rule which must never be broken neither when planning (calculating) proposed flights on a given glider, nor when carrying them out.

Looking at questions of glider strength it is necessary to note still one more requirement for its design. This requirement includes attaining so-called "equal strength" of its parts

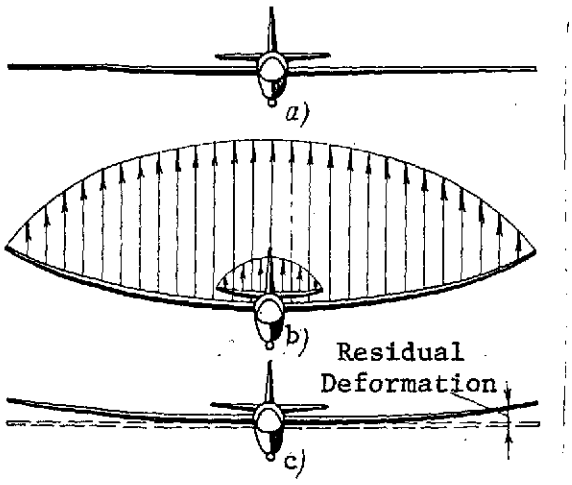

Figure 5.24. Residual Deformations of the Glider Which Occur as a Result of Loads Greater than Maximum Operational But Less Than Breaking Load:
a--Glider before load;
b--Glider under load exceeding maximum operational, but less than breaking load (plastic deformation);
c--Glider after removing the load has residual deformation).

and components when planning and building a glider. This means that each part or component must be calculated and made precisely according to the loads which are defined as strength standards for them. When this condition is observed the glider will not be overweighted (will not carry any excess material (mass) not justified by the requirements necessary for strength and rigidity of the structure).

Thus, it was established that when increasing load on the glider first the maximum of elastic deformations was advanced. It is characterized by the maximally permissible operational acceleration g (the vertical component of this acceleration g is designated by the symbol $n^{o}_{y\ max}$). /206 Further, when the load is increased there are residual deformations whose growth results in the end in the destruction of the structure. This maximum load is characterized by acceleration g of breaking (vertical component of breaking acceleration load is designated by the symbol n^{b}_{y}). The relationship of breaking and maximum permissible acceleration g is characterized by the reserve of strength of the glider structure which is numerically expressed through the coefficient of safety f, equal to (for vertical loads):

$$f = \frac{n^{b}_{y}}{n^{o}_{y\ max}}.$$

The sizes of the coefficient of safety are defined in strength standards of sport gliders and are in a range from 1.5 to 2--2.5 depending on the character of load capability and on the part of the glider which directly comes in contact with a given load.

5.9.1. Calculated Cases of Glider Load

In calculating strength of a glider for possible future operation loads and thus provide safe flight the most serious

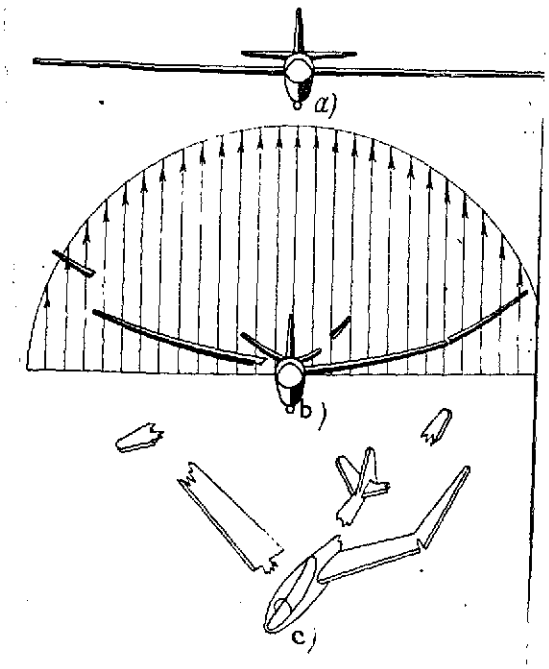

Figure 5.25. Breaking of a Glider as a Result of the Effect of Loads Equal to or Greater Than Breaking Load:
a--Glider before load;
b--Glider under load exceeding the breaking load;
c--Glider after removing the load.

cases of load are selected from the endless multitude of combinations of parameters of flight.

Strength standards for sport gliders contain a list of the most serious cases of load and also those methods of defining actual loads which correspond to each case.

Strength standards as a whole, like the list of calculated cases of load of glider structure in flight are made up on the basis of an analysis of many years of practice in operating gliders and also by looking at a number of theoretical works which present a scientific basis from laboratory results and flight tests of gliders. From practice it is known that a glider calculated and built according to the requirements enumerated in a strength standard is adequately strong and in all other operational conditions if flights are kept within the calculated limits. Let us look for example only at certain cases of load on a glider.

Case *A* corresponds to a glider at $c_{y\ \max}$ and at given operational acceleration n_y^o. Form drag in this case will not be maximum and is determined according to the given $n_{y\ \max}^o$ and $c_{y\ \max}$. Bear in mind that in case *A* the lift force of the glider equals the product of its weight and acceleration $n_{y\ \max}^o$, and we have:

$$Y_A = G_{gl} n_{y\ \max}^o,$$

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$$c_{y\ \max} q_A S = G_{gl} n_{y\ \max}^o,$$

$$q_A = \frac{G_{gl} n_{y\ \max}^o}{c_{y\ \max} S}.$$

This case, from the point of view of piloting a glider, is an example of bringing a glider out of a dive at $c_{y\ max}$, but at a speed less than the maximum permissible.

Case A' corresponds to glider flight also at a specified load $n^o_{y\ max}$. But instead of the maximum value for the coefficient of lift force $c_{y\ max}$ when defining the load $Y_{A'}$ one introduces maximum permissible size of drag form q_{max}. Then

$$Y_{A'} = c_{yA'} S q_{max} = G_{gl} n^o_{y\ max}$$

$$c_{yA'} = \frac{G_{gl} n^o_{y\ max}}{S q_{max}} .$$

In spite of the fact that total lift forces are uniform (as naturally acceleration $n^o_{y\ max}$ is the same introduced as maximally permissible operational in both cases), case A differs essentially from case A' because of the varying distribution of load on the wing span (and, consequently on separate parts of its structure).

Therefore, the wing roots have total bending moments which occur at the wing root attachment and will be different in these cases. It is difficult to predict ahead of time which of these cases A or A' will be the most serious from the point of view of operation of the wing structure. And when calculating load strength must be checked in both cases. The coefficient of safety for both cases A and A' is assumed to equal $f_A = f_{A'} = 1.5$.

Here, at negative angles of attack there can be procedures similar to coming out of a dive. Strength centers for sport gliders are envisaged for cases D and D'. In these cases, the acceleration factor is assumed to equal $n^o_{y\ min}$ (maximally permissible according to absolute size in the negative field of acceleration g), and form drag is the same as in case A and A'-- equal, respectively to q_D and q_{max}. The coefficient of safety in cases D and D' is assumed to be the same as in cases A and A', equaling

$$f_D = f_{D'} = 1.5.$$

Cases A, A', D and D' define the largest load of the wing causing its bending.

In cases B and C glider flight is looked at with maximum drag form q_{max}. Then in case B acceleration n_{yB} is assumed to equal

$$n_{yB} = 0.5 n^{o}_{y\,max}$$

and the coefficient of lift force--corresponding to the average positive angle of attack.

In case *C* we are looking at a vertical dive of a glider with zero coefficient of lift force, and this means zero acceleration *g*

$$n_{yc} = 0$$

In order to test glider strength in these cases with the heaviest loads, in the calculations one assumes that the ailerons are deflected fully ($\delta_a = \delta_{a\ max}$). This explains the appearance of the largest turning moments of the wing.

The presence of two cases (*B* and *C*) in which one looks at wing strength for twisting is because when looking at its bending it is clarified by the fact that various parameters of movement of a glider can be the most serious case with one or another type of load. And this is just as necessary when calculating glider strength.

Strength of the wings is also tested for non-symmetrical load in flight case *A*, *A'*, and *B*. Then one considers that one half of the wing is affected by the full load and the other by 20 to 30% less.

When calculating strength one considers a number of landing cases of glider structure load and also load which affects it during launching using a winch or flying on tow.

The horizontal tail is considered for strength by calculating equalized loads in cases *A*, *A'*, *B*, *C*, *D* and *D'* and also in cases of load with unquiet air and during maneuvers (maneuver loads). Calculation is done on loads which occur during flight on a tow and in a number of cases of non-symmetrical load and simultaneous load of horizontal and vertical tail.

The vertical tail is considered for maneuver loads and loads which occur during flight in unquiet air.

Fuselage strength is calculated for loads which occur during all cases looked at for wing and tail and also under all landing cases.

Chapter 6 Experience in Gliding /209

6.1. The History of Gliding in Our Country

Anyone seriously occupied with building and flying operations of gliders must know the history of gliding. All of the achievements in this field of aviation, like the possibility of further development of engineering and experience in engineless flight, are based on experience of preceding work and essentially are the result of this experience.

We will discuss briefly the period of development of gliding beginning in the last decades of the nineteenth century to the present day.

6.1.1. The Origin of Gliding. The 1890's

From time immemorial man has occupied himself with the problem of dynamic flight, that is flight of craft heavier than air. However, attempts to solve it practically as it is known now, appeared only with the high development of man's general culture, in particular, natural sciences and primarily mechanics could make it possible to obtain the desired results.

Professor N.Ye. Zhukovskiy, scientific author, worked on developing the theoretical bases of dynamic flight of aircraft with fixed wings at the end of the nineteenth century; this became the basis for all aviation science in the future. It is important to note that N.Ye. Zhukovskiy's work is applicable today and has a direct relationship to glider flight. The article "On Soaring of Birds" [15], in which he proved, in the first place, the possibility of dynamic flight of heavier-than-air aircraft and secondly the possibility of carrying out aerobatics in gliders. In these same years, eminent Russian scholar A.M. Lyapunov did a great deal of fundamental research in the field of hydrodynamics and the theory of probability and created the modern theory of stability of motion. He presented this theory in his classical work called "The General Problem of the /210
Theory of Stability of Motion."

In talking about the early period of development of domestic gliding one should not neglect the effect made by the work of German scientist, glider designer and pilot--O. Lilienthal. An eminent aviator and test pilot of engineless aircraft, O. Lilienthal in the last ten years of the nineteenth century studied the actual motion of gliders (of his design) making gliding flights from hills and heights. O. Lilienthal experimentally showed that the size of lift force of a wing made with a curved surface is several times greater than the lift force of a flat

plate operated under the same conditions as a curved wing. Moreover, O. Lilienthal established the relationship of the lift force and drag of the wing to its angle of attack and established that this relationship has a definite form connected with the geometric parameters of the wing.

The dependence of lift force and drag of the wing on its angle of attack expressed graphically in the form of diagrams as is known, is called Lilienthal's Polars. The polar line was one of the most important characteristics of aerodynamic perfection of gliders and aircraft and the whole period of development of aviation and, of course, remains so today.

The activity of N. Ye. Zhukovskiy and other scientists in the field of theory and practice of engineless flights on heavier-than-air craft attracted numerous enthusiasts of his work to gliding. The aspects of this work quickly became broader and deeper.

6.1.2. The Change From Balanced Gliders to Craft With Control Sticks. 1900--1910

During the first ten years of the twentieth century the construction of gliders reached broad dimensions in many countries of the world. And also this period marked large qualitative steps in the development of the theory of flight and in flying and designing practice. N.Ye. Zhukovskiy's work "On Bound Vortexes" [16] appeared in which the mechanism of the formation of lift force of a wing and a formula for quantitatively determining it appeared for the first time. As is known, the discovery of the law of formation of the lift force of a wing was a turning point in the entire development of the aviation of this time. Today this law naturally continues to be one of the basic laws of aviation science.

As to flying and designing, a large step in the development of gliding involved the transfer from balanced control of movement of a glider to flight using a control stick. The extremely /211 difficult controllability of the balanced gliders was a principle obstacle in the path of the development of gliding.

Replacing balance with the operation of a lever made it possible to improve control of movement of gliders basically, to make flights on them considerably safer and thus to make further study on engineless flight possible both in operating the glider

and in designing it.[20]

The first free (wihout tethers) balanced flights in our country were made in 1908 by A.V. Shiukov on a glider of special design and structure. 1909 became in Russia the year of the beginning of mass building of gliders and flights on them. The most successful designers and flights made at this time we have mentioned already by A.V. Shiukov, K.K. Artseulov, G.A. Bekshin, G.S. Tereverko, N.B. Delon and a number of other aviators, designers and glider pilots. It is curious that in this period the highest aerodynamic quality of a glider was $K_{max} \approx 5$, and sinking velocity was $V_y \approx 2.5$ m/s.

The gliders of many designers were also being flown abroad at this time. Among these were the Wright brothers' glider with a control stick.[21]

Finally, there is still one more event which occurred in the first decade of the twentieth century and this was a large step in the development of flight and aviation as a whole. We are speaking of the organization in 1905 of the International Aviation Federation (Federation Aviation Internationale--FAI). As is known, this union which exists to the present day is a unified organization which registers international achievements in the field of aviation and cosmonautics, and which also regulates the order for conducting record flights and international competitions.

The turbulent development and successes of gliding in the first decade of the twentieth century, naturally, resulted in the following step in aviation--replacing the method of obtaining a cruising force. Instead of using the weight component of the aircraft they began to mount on the aircraft light engines which by rotating propellers created a thrust force. Thus, it became possible to complete flights without sinking, without resorting to either flapping wings or to soaring on fixed

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[20]One should note that balance control of a glider is now beginning to be used again but naturally on a new technical basis. Such a control system was used for example on on a soft wing glider of the "Rogallo" type.

[21]Ailerons were often used at this time and in particular on the glider wings of the Wright Brothers, simply tail parts of the wing that were bent up and down. This design now has been used not without success on a new scientific basis in building the NKS-3 glider (see Figure 1.36).

wings. Moreover, gliders equipped with power units (airplanes) /212
could complete autonomous take-offs without using a tow or without being raised ahead of time to a considerable height.

Two independent directions for aviation were created: engineless and engine-powered. These directions, tightly interwoven, complemented each other at the time and to a large degree complement each other today.

6.1.3. The Experiments of P.N. Nesterov and K.K. Artseulov. The Second Decade of the Twentieth Century

The second decade of the twentieth century was characterized by no less intensive construction and perfecting of aircraft, both gliders and airplanes. The techniques of piloting naturally were perfected. However, preparation for the First World War, and then participation in it directed this process toward perfecting mainly aircraft building and air navigation for military use in these aspects of aviation.

Nevertheless, the period of the second decade of the twentieth century is marked by two events which occupy a distinguished place in the history of our aviation and that of the world as a whole both in the history of gliding and in the field itself.

On August 27, 1913 the Russian military pilot P.N. Nesterov who was also a glider expert (not only in flying but also as a designer) on an airplane of the "N'yupor" type first executed the so-called "wingover." This was the beginning of aerobatics, that is the complex of specified "figures" (for both planes and gliders equally), whose knowledge and skill in use and practice in our days is required for all pilots and gliders. Without mastering aerobatics it is impossible to develop the necessary habits of piloting a glider or aircraft and precise piloting in particular.

Another event of this decade no less important in concept, value and effect on the further study of the behavior of aircraft in flight and also on methods for controlling their movement was the first intentional execution of a spin. This was done by a military pilot and designer (we note also glider expert)--K.K. Artseulov.

The whole purpose of this famous flight was testing the correctness of a control method of a plane in a spin developed theoretically by K.K. Artseulov.

K.K. Artseulov's experiment was made in 1916 on a N'yupor-XXI type aircraft with a "Ron" engine with 80 horsepower.

At this time, a spin into which aircraft and gliders fell /213
involuntarily was observed many times form the ground and from airplanes. But up until Artseulov's flight the spin always ended disastrously, for the spinning airplane and disastrously for the pilot because parachutes at that time were not used for saving aircraft crew. As a result of an analysis of physical movement in an airplane in a spin, Artseulov noted the movements of the rudder which in his opinion would make the airplane come out of a spin. Theoretically a spin was not yet sensible. But its practical mastery decreased the number of catastrophes which occurred from lack of the knowledge required in those cases by piloting techniques. It was very important that pilots, having mastered the spin, began to fly more intelligently, not being afraid of stalling. This increased their military capability, that is, made it possible for them to solve their operational task in military planes more completely and then operational tasks of aircraft for other purposes. Later on, after the theoretical side of spin[22] had been developed, the techniques of piloting an airplane or glider proposed by K.K. Artseulov underwent a number of changes and perfections. This was the logical expression of the general process of development of one of the fields of aviation science in flying practice--flying at large sub-critical and super-critical angles of attack of the wing.

6.1.4. The Beginning of Organized Gliding in Our Country 1920--1930

The third decade of the twentieth century was marked by the organization, in 1920, in Moscow of the first Soviet Gliding Society "Soaring Flight." The society was under the leadership of the well-known glider expert, pilot and designer, K.K. Artseulov. The society had the purpose of uniting gliding in our country and, naturally, the further study of engineless movement, the construction of new gliders and perfection of methods of gliding and soaring flight.

In 1923, as a result of the activity of glider specialists in the USSR the First All-Union Gliding Tests were made in the Crimea near the city of Feodosiya. K.K. Artseulov's choice of the location was extremely fortunate. Soaring flights in air streams from the first were more popular and quickly began to be

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[22]The beginning of theoretical and laboratory experimental development of spin occurred considerably after Artseulov's flight. This subject was clarified in the works of Professor V.S. Pyshnov in 1925 and in a later period by Professor A.N. Zhuravchenko and a number of other scientists, engineers and pilots.

mastered by many gliderists.

From the engineering point of view, the first gliding tests /214
were of great interest as the beginning of the study in depth of the structure of engineless aircraft, their operation under actual flight conditions, the development of flying test methods. The results of tests permitted compiling the first strength standards for gliders.

The technical end flying results of the First All-Union Glider Tests were published at that time: pilot L.A. Yungmeyster kept his A-5 glider designed by K.K. Artseulov in the air for one hour 20 min (Figure 6.1). Flight distances of 1.5 km and altitudes of 100 m were accomplished. As to the design one should note the use on one of the best gliders shown at the test of a thick airfoil of the wing although it was still braced and not cantilevered.

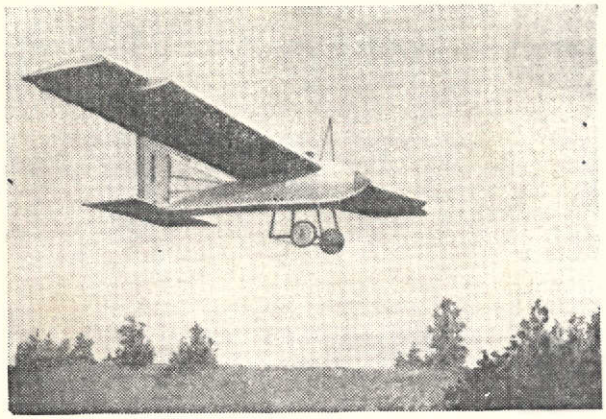

Figure 6.1. Flight of the A-5 Glider Designed by K.K. Artseulov. The First All-Union Gliding Tests, 1923

Later on, during the All-Union Gliding Tests and Formations the powerful Technical Committee was created to which a number of famous scholars and engineers belonged including Professor V.P. Betchinkin, Engineer M.A. Tayts, S.P. Korolev, N.N. Fadeyev, O.K. Antonov, scientific co-workers of the Air Force Academy im. N.E. Zhukovskiy, V.S. Pyshnov, S.V. Ilyushin and a number of others. The tests of the gliders and work of the formations were directed by the well known pilots L.G. Minov, V.A. Stepanchonok, D.A. Koshits and many others. In 1925 the command of the Soviet Pilots and Designers including K.K. Artseulov, L.A. Yungmeyster, A.V. Chesalov and /215
several others, were the first to very successfully compete on their gliders in international competitions held in Germany in the Vasserkupp mountains.

The technical and flying results of the development of gliding in that decade were characterized by the following:

--they began to use skis as landing devices instead of the huge wheeled landing gears;

--the adoption of a shock cord as a means of launching gliders;

--equipping the pilot's cockpit with devices on board was adopted: speed indicator, altimeter, variometer and turn and slip indicators.

A class of gliders began to appear intended for soaring flight characterized by large for that time dimensions and length of wing (l = 16--17 m, λ = 16--18), increased specific loads on the wing and size of maximum aerodynamic quality (p = 15--18 kg/m^2, K_{max} = 19), with decreased minimum sink velocity ($V_{y\,min}$ = 0.85 m/s). On the I-3 glider designed by Ivensen, the length of the wing even reached a size λ = 26.7. For the first time in the history of glider building, in 1925 a metallic glider was built. But this innovation was not widespread at that time although objectively of course it was a step forward in the development of glider technology.

In this same decade (1923) a monthly journal was started Samolet [Airplane]--an organ of SFAA (Society for the Friends of the Air Force) and later of the Society for Promotion of Self Defense and Aero-Chemical Industry.

Samolet played an important role in popularizing gliding and in the propagation of technical and flying knowledge, in information on the society about domestic and foreign gliding and avaition as a whole.

6.1.5. The Development of Gliding in the USSR and the Mastery of Gliding Flights in Thermal Air Currents. 1930--1940

The beginning of the fourth decade of the twentieth century was marked by the adoption of aerobatics in the practice of glider flights. At the Seventh All-Union Fly-down in 1939, pilot V.A. Stepanchonok on a S.P. Korolev glider "The Red Star" built especially for aerobatics completed the first Nesterov loop [wingover] on an engineless aircraft (Figure 6.2). The "Red Star" glider at that time had improved strength and load per square meter of wing area. However, it retained high flying characteristics putting it in a class with the best soarers of that time.

Figure 6.2. The Glider Designed by S.P. Korolev the "Red Star" in Flight

At this same fly-down flight tests of a training glider of O.A. Antonov the "Standard" were successfully made, it is like the US-4 or A-1 (see Figure 1.25) /216 and the "Upar" (a training

soarer or PS-1) shown in Figure 6.3. These gliders were mainly unquestionably design successes. Simplicity, strength, reliability, cheapness in production and good (for training purposes) flying characteristics permitted their wide adoption in teaching and training practice for gliderists. The "Standard" and "Upar" series produced later on served well in the work of training several generations of gliderists and pilots. Of the gliders of this period one must note the very successful designs of V.N. Sheremetev (the Sh-5 glider), V.K. Gribovskiy (G-9 glider) and many others (Figure 6.4).

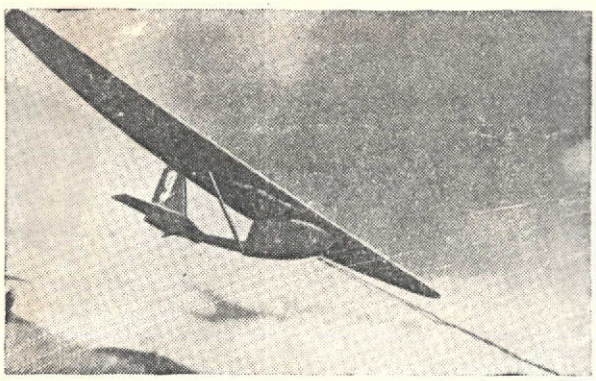

Figure 6.3. Training Sailplane "Upar" Designed by O.K. Antonov

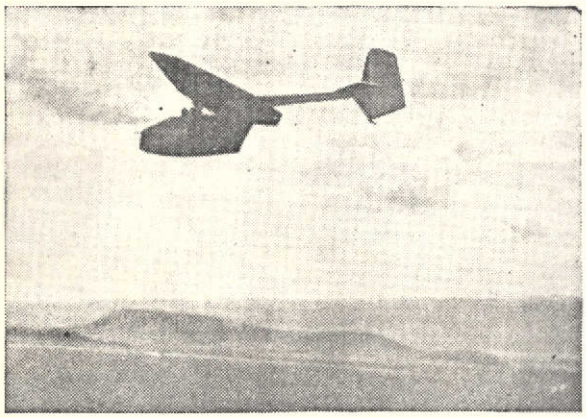

Figure 6.4. Training Two-place Sailplane Designed by B.N. Sheremetev

In 1931, in the Society for Promotion of Self-Defense and Aero-Chemical Industry there was organized and begun a specialized glider design bureau and factory for manufacturing training and record-setting aircraft. This event along with the creation that same year of the Higher Glider Pilot School (HGPS) on a mountain near the city of Feodosiya in the Crimea where the glider tests and fly-downs had occurred, naturally became an excellent foundation and stimulus for the flowering of domestic gliding. Many talented designers and pilots appeared in those same years. 1930--1940 saw hundreds of gliders built of original design (not counting the series of aircraft manufactured by factories) and 32 world records set. All of this testified to the high flying capability of Soviet gliders and the great mastery by our glider pilots. Unfortunately, after the end of World War II neither the HGPS nor the glider factory nor the glider design bureau was reestablished. In those years for the first time radio communication was used on board gliders.

S.N. Anokhin was the first to make a parachute jump from a two-place glider. /217

Towing a single or a whole group of gliders behind an aircraft was mastered. The safety parachute began to be obligatory equipment for pilots on glider flights. A method of launching gliders was adopted using an automatic winch. The hydroplane was built and it was successfully launched from the water. Unique flights in storm fronts and at night were accomplished. Finally, a unique experiment was made whose purpose was to study the behavior of a glider at speeds corresponding to the moment of occurrence of flutter and testing a method of theoretically determining its critical speed. This experiment superbly carried out by S.N. Anokhin ended in accelerating the glider and intentionally putting it into a flutter procedure with subsequent breaking up in the air. The pilot was saved by his parachute.

Research led to special gliders such as the flying "Parabola" of B.I. Cheranovskiy, the TsAGI-2 glider of V. Belyaeva (Figure 1.12) and some others.

But, if you please, an important step made in our gliding in the thirties was the transfer to so-called "plain" gliding. Up until then, gliding had been done basically in air currents which naturally limited the region for pilots and gliders had become connected with certain localities and with the presence of wind. In the 1940's experience was accumulated on using thermal air flow in the locality of plains and also flight under clouds. This permitted taking off from mountain slopes and beginning to perfect flights not only at considerable altitude /218
and for a considerable length of time but what was especially important for long distances.

At the time little thought was given to the fascinating promise of long plain flights needing to be combined with further development of flights under mountain conditions. And because such a combination did not begin then instead of joy in new great achievements, coarse errors in the conception of engineless flight itself occurred. A one-sidedness about gliding occurred reflected not only in the narrowness of methodological views on the entire development of gliding but also in errors when designing gliders and executing engineless flights.

The technical and flying results of the development of gliding in this ten year period can be characterized by the following factors.

An airfoil was developed (still not laminar) more suitable for operating conditions of the wing in engineless flight at comparatively low speeds.

The optimum wing span (approximately 17 m) was discovered for sailplanes (this wing span is retained now on most sailplanes of the record setting class).

The need arose to construct sailplanes in two classes--light training and record setting speed. The necessity in gliders of both classes at the present time attained formal support in requirements of the FAI in the so-called open and standard class of engineless sport aircraft. The reverse arrow-shaped wing was first used causing the need to observe the center of /219 gravity placement and observation from the pilot's cockpit. Ballast for changing the specific load on the wing in flight was used. The monocoque wing structure was introduced. The gliders began to have wing elongation up to 22, maximum aerodynamic quality up to 30 at flight velocity up to V = 90 km/hour, and minimum sink speed to 0.7 m/s. The canopy of the cockpit began to be made in the contour of the fuselage.

6.1.6. Gliding in World War II. The Appearance of Gliding Sport After the End of the War. 1940--1950

The 1940's are characterized in relation to gliding by two periods. World War II demanded the development of the applied branch of glider building--the creation of landing and cargo gliders. A number of such aircraft were designed, constructed, tested and put into action and were used successfully to solve problems of equipping partisans with materials, rescuing soldiers who were wounded. But the field of military glider construction and the utilization of cargo and landing gliders primarily was done by old glider design and flying cadres: V.K. Gribovskiy (Gr-29 glider), O.K. Antonov (RF-8 glider) and many others. O.K. Antonov made an interesting experiment designing a glider-tank (Figure 6.5).

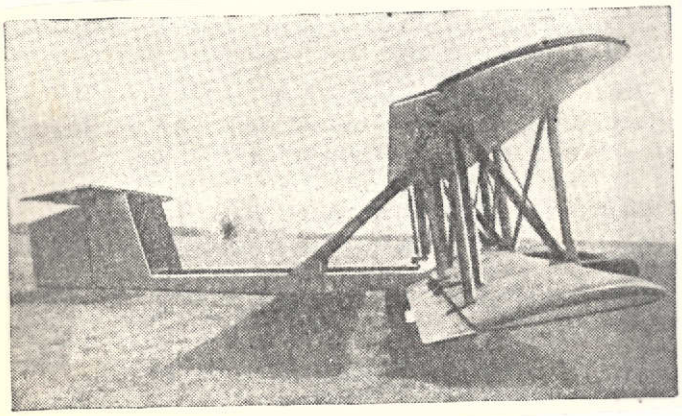

Figure 6.5. A Cargo Glider Intended for Carrying a Light Tank

A family of cargo gliders was made in the postwar years. The glider of S.V. Ilyushin the Il-32 has an interesting design.

One of the foremost problems again posed to the designers and pilots after the war was the problem of /220 increasing speed in free engineless flight.

At first they took the route of a further increase in load per square meter of wing area. Gliders began to be made heavier. However this meant that, even a somewhat improved method of pouring

ballast in flight, was not the proper way of improving the polar. At the end of the 1940's they began to use flaps which broadened the polar line on the side of minimum speed.

However, these methods of optimizing the polar lines though they are considerable are not adequate methods to use in changing the speed characteristics of gliders to the necessary degree. It became clear that such a method must consist of finding new wing airfoils.

The technical and flying results of developing gliding in this decade were characterized by the following data.

Wing span of a sailplane was established in limits 16--17 m, specific load on the wing increased 30 kgf/m^2, elongation of the wing approximately to λ = 20 and minimum sink velocity was on a level of $V_{y\,min}$ = 0.7--0.8 m/s.

6.1.7. The Battle for Speed. A Complex Method of Flying Tests of Gliders. The 1950's

At the beginning of the 1950's in the USSR an actual change from wooden glider construction to metallic was accomplished. As has already been said the construction of the first all-metal glider was done by us in 1925. However, when industry began to widely provide glider builders with aluminum materials primarily for airfoils, tubes and sheets, interest in a metallic glider found a real and strong base.

The end of the 1950's were marked by one more important event. A method of complex flying tests of gliders was developed and adopted which permits obtaining objective quantitative and qualitative evaluation of new aircraft. In accordance with this method tests of a number of sailplanes were carried out. The work was done under the direction of Doctor of technical sciences G.S. Kalachev and candidate in technical sciences I.M. Pashkovskiy. Test pilots V.V. Vinitskiy, S.N. Anokhin, V.V. Ivanov[23], L.D. /221
Rybikov, V.I. Kirsanov, V.I. Perov, engineer pilots M.I. Afrikanova, D.V. Dvoyenosov, engineers Yu. I. Sneshko, L.I. Solovova, V.M. Zamyatin and a numer of others all participated in research and development of a complex method of flying tests.

In the 1950's the mastery of high stratospheric altitudes

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[23] One should note the very interesting work done by test pilot V.V. Ivanov on gliders with a disk-shaped wing designed by M.V. Shkhanov. Flights on these original aircraft permitted making a number of useful conclusions concerning the work of a circular wing in plan form in various movement procedures (see Figure 1.13).

began. At this time the whole course of the history of gliding showed the need for utilizing our resource of energy in the atmosphere. However, with all the enticements for flights at high altitudes the many difficulties of accomplishing this which basically involve energy supply for glider systems and life support for the pilot did not yet permit making massive ascents into the stratosphere on gliders.

The technical and flying data of gliders of this decade were characterized by the following factors: sailplane wing span remained in limits 16--18 m, elongation--in ranges 22--25, specific load on the wing--33--35 kgf/m^2 and minimum sink speed 0.6--7 m/s.

6.1.8. New Methods of Attaining High Aerodynamic Quality in Gliders With Increased Flight Speed and Decreased Speed. 1960--1970

The 1960's will go down in the history of gliding as the period of continuing battle for speed but with a new clearly expressed tendency including the improvement of aerodynamic shapes of a glider, primarily the airfoil and lift augmentation devices of the wing. This approach to the problem of optimizing the polar of the glider immediately has positive results. With comparatively small specific loads varying at this time in a stable range 25--30 kgf/m^2, successfully obtained a polar which is more shallow, retains a wide range of flight path speed and is characterized by small sink speeds on basic flight speeds. All this was achieved thanks to the wide adoption and practice of glider building with laminar airfoil of the wing which have a smaller size of coefficient of drag (basically of the airfoil).

The first record setting glider in our country with a laminar airfoil constructed at the beginning of the sixties, was the A-15 sailplane designed by O.K. Antonov.

Finally, the sixties were a sharp division of the glider fleet into certain groups intended to solve their own operational tasks. These groups at the present time are training single- and two-place gliders, training--also single- and two-place (these and others are built as a rule in large or small series) and record setting gliders, mainly single-seat unique aircraft on which all the newest achievements of glider science and engineering experience in building engineless aircraft have been /222
installed.

Technically the gliders of our time having achieved recognition and wide distribution are characterized by fairly established sizes for their basic parameters: wing span l = 15--18 m,

wing elongation λ = 20--24, specific load on the wing p = 25--32 kgf/m^2, minimum flight velocity V_{min} = 60--70 km/hour, minimum sinking velocity $V_{y\,min}$ = 0.6 m/s, flight velocity with maximum aerodynamic quality K_{max} = 35--42, V_{Kmax} = 90--110 km/hour, sinking velocity with velocity of maximum quality $V_{y\,Kmax}$ = 0.8--1.0 m/s, the sink velocity with flight velocity V = 150 km/hour, $V_{y\,V=150}$ = =1.5 m/s, sink velocity with maximum permissible flight velocity V_{max} = 250 km/hour, $V_{y\,max}$ = 6--10 m/s.

The strength of such gliders is characterized by maximum permissible operational acceleration g

$$n^{o}_{y\,max} = 6\text{--}8.$$

6.2. Soaring Flight of a Glider

At the present time, "soaring" is usually considered as the free flight of a glider in which altitude is gained or an altitude is maintained at least unchanging relative to a certain constant barometric level accepted as zero. However, one should keep in mind that a glider always descends relative to its surrounding air because this sinking is the cost of its staying in flight (see Chapter 1).

Flight distances of gliders explained by the simple use of only one of its aerodynamic qualities essentially has never satisfied man. Therefore, for increasing distance, and this means, the length of time of flight, one must find and utilize an external source of energy which for the glider is its ambient atmosphere.

6.2.1. Soaring Utilizing Thermal Ascending Currents

The task of calculating soaring flight for a glider results essentially in determining that flight path speed (and correspondingly, sink speed) at which the relationship of the distance the glider covers along the Earth's surface (the length of the route on Earth) between two neighboring ascending air currents to altitude lost will be the largest under actual atmospheric conditions. Therefore, in the first place, it is necessary to look at the concept of so-called "relative distance" of flight between ascending thermal air currents (thermics) and its connection to aerodynamic quality of a glider and, in the second place, conditions for gaining altitude in thermics.

It was shown earlier that during glider flight in immovable /223
air, without calculating a change in air density, with the glider losing altitude, the aerodynamic quality and relative distance is determined as the relationship of compatible size of similar triangles:

$$\frac{L}{H} = \frac{Y}{X} = \frac{c_y}{c_x} = K.$$

Here L--is the distance traversed by the glider along the Earth's surface; H--is the altitude lost in covering this distance; Y, X and K--are respectively lift force, drag and aerodynamic quality of the glider.

However, when looking at glider flight in a nonstationary atmosphere the work is done differently.

The head wind and descending air current will decrease the possible flight distance, a tail wind and ascending air current will increase it. Therefore, the triangle of aerodynamic forces and the triangle of distance will be similar and relative distance of glider flight, retaining its physical concept will not yet correspond to aerodynamic quality of the glider which depends only on characteristics of the glider and the angle of attack of the wing and does not depend on external factors which are wind and vertical air current.

Let us look at the effect on relative distance and corresponding flight speed of a glider with head and tail winds ascending and descending air currents (Figure 6.6).

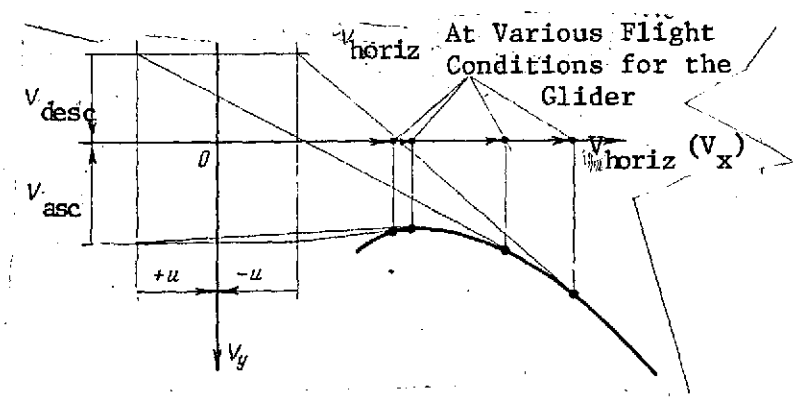

Figure 6.6. For Determining the Best Flying Speed for Soaring Under Various Conditions:
$+u$--Velocity of the tail wind;
$-u$--Velocity of the head wind

It is obvious that the best flying speed and this means the largest relative distance is determined if the total vector V is tangent to the velocity polar. Then vector V will be drawn from points which characterize the total of vectors--velocity of the wind, of vertical air currents and of the horizontal component of glider velocity. The tangential point defines the best flying speed for certain conditions of flight speed of the glider. It is not difficult to obtain the corresponding distance of flight with the velocity obtained and the selected size of altitude lost from the following relationship: /224

$$L = \Delta H \frac{V_{horiz}}{V_y} .$$

One can come to the following conclusions on the effect of wind and vertical currents on the optimum size, from the point of view of distance, for flight speed of a glider. When there is a head wind and descending air current from one thermal current (cloud) to another, the flight speed of the glider must increase. And on the other hand, when there is a tail wind and ascending air current--the speed must decrease. It is natural with vertical velocity of the ascending current with the value attained (according to absolute size) for sinking velocity of the glider relative to the air (according to indications of the rate-of-climb indicator $V_y = 0$) the angle of the flight path of the glider toward the horizon becomes equal to zero and the relative distance increases infinitely (of course, only theoretically, because the conditions themselves at which $V_y = 0$ are by no means infinite in length of time and distance).

The greatest growth in velocity of the vertical air current indicates lift of the glider, and the concept of relative distance in this field of vertical velocity currents in not applicable. However, the tangential point of the velocity vector of flight along the flight path with the polar line of glider velocity will as before indicate the best flying speed procedures. But this greatest advantage relates to gaining altitude because the tangent in this case fixes the gain according to the steepest path. Thus, during flight between two ascending air current, all the time, the pilot encounters both changing vertical currents (basically) and changing winds (to a lesser degree) and for maintaining optimum conditions for cross-country flight, the speed of the glider must all the time change according to the conditions encountered. But this cannot be successfully done in practice. Therefore, the pilot can evaluate the situation during cross-country flight between two ascending air current only approximately (averaged) and must utilize the approximate values of the speed obtained keeping in mind which changes in reserves of c_y and strength can be utilized when encountering the vertical air currents at various flight speeds.

A gain in altitude in thermal ascending air currents is also the transfer from current to current by the element of soaring flight, the glider, whose purpose is to cover the greatest possible distance. It is obvious that in the ascending air current glider flight for the purpose of the greatest and fastest gain in altitude expediently executes a procedure with minimum sink velocity along the polar line of the glider[24] (with $V_{y\,min}$). The lift velocity of a glider in this case will equal /225

$$V_{y\,lift} = V_{y\,cur} - V_{y\,min}.$$

Here $V_{y\,lift}$ --is the velocity of lift of the glider in an air current (indicated by the rate-of-climb indicator), $V_{y\,cur}$ -- is the velocity of lift of the air (current), $V_{y\,min}$ --is the velocity of sinking of the glider according to its polar line and configuation.

However, for the largest and fastest lift of a glider in an ascending air current, besides of the velocity necessary one also selects the appropriate best radius of the spiral. One can consider that maximum vertical velocities of the air current are at its center. Therefore, the radius of the spiral of the glider inside the air current must be smaller. Thus, with a decrease in the spiral's radius, the vertical velocity of sink of the glider increases, and then the selection of the best radius must be made taking into account both the structure of the air current and the polar of the glider. The structure of the air current in a number of cases predetermines the best utilization of vertical velocities of lift in extremely small radii of spirals in spite of somewhat increasing the minimum speed of descent of the glider. It is natural that at the small radii and low speeds it is necessary to use flaps.

Let us look at one more important parameter which characterizes the correctness of selecting flight speed and radii of spirals. This parameter is average glider speed during cross country flight. The greater this average speed the larger distance the glider will cover.

The size of average speed during cross country flight depends on time expended in gaining altitude (spirals and ascending current) and the time expended in transferring from one ascending

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[24]Looking at the spiral movement of a glider one should use not the ordinary polar velocity which is constructed for straight flight but the polar constructed calculating the increase in descent speed when the glider is executing a spiral. This was discussed in detail in Chapter 2.

current to another.

Average velocity during cross country flight can be expressed by the following relationship:

$$V_{av} = \frac{L_{trav}}{t_{climb} + t_{trav}},$$

where L_{trav}--is the path (horizontally) travelled by the glider, t_{climb} and t_{trav}--respectively, climbing time in the air current and the time expended in travelling over the path.

Because climbing time ΔH in an ascending air current equals/226

$$t_{climb} = \frac{\Delta H}{V_{y\,lift}},$$

and the time expended in transferring, utilizing altitude ΔH, between two ascending air currents, is expressed by the formula:

$$t_{trav} = \frac{\Delta H}{V_{y\,desc} + V_y + V_{y\,lift}},$$

and after simple conversions one can obtain the final formula for average cross country flight speed:

$$V_{av} = \frac{V_{trav} V_{y\,lift}}{V_{y\,desc} + V_y}.$$

Here the following symbols are applicable in the expressions:

V_{av}--is the average velocity of the glider relative to the air;

V_{trav}--is the velocity of travel from one ascending air current to another;

$V_{y\,lift}$--is the average climb velocity of a glider in an ascending current (according to the rate-of-climb indicator);

$V_{y\,desc}$--is the vertical speed of the descending air current between ascending currents;

V_y--is the vertical velocity of sink (of a glider relative to the air (in accordance with the velocity polar).

From the expression presented for the average velocity of cross country flight V_{av}, it follows that flying over the required distance can be done more quickly the larger is the speed of climb ΔH and the speed of travel. The increase in the average

velocity of flight will also facilitate decreasing the sink velocity of the glider corresponding to velocity V_{trav} (along the polar), that is, V_y, and the smaller the velocity of descending air currents ($V_{y\,desc}$) encountered on route. The contradiction involved in the expediency of simultaneously increasing V_{trav} and decreasing V_y is solved by selecting the optimum flight speed V_{trav} according to actual flight conditions.

We note that all the discussion has been laid out on the supposition that V_{trav} is a horizontal component of flight speed of the glider along the flight path and that the flight occurs without wind. As to the first supposition one should say that replacing the size of flight speed along the flight path with its horizontal component does not result in an essential error up to a speed of approximately 120 km/hour. However, at high speeds and where the polar begins to slope sharply toward high speeds of sinking such a substitution will produce noticeable error. For calculating flight velocity with lateral wind, its velocity must be added to the velocity of the glider geometrically, which makes up to triangle of velocity. /227

Simple devices so-called "calculators" have been proposed in a number of countries which can be used to determine which travel speed to maintain by the indications of the rate-of-climb indicator and the indicator of flight path speed. One should keep in mind that the calculator is used for each type of glider individually, according to the actual polar of velocity and the actual size of $\frac{G_{gl}}{S}$.

Figure 6.7 shows an example of bariograms of soaring glider flight which show the necessity for multiple lifts and descents made by the pilot in a long-term soaring flight.

Figure 6.7. An Example of the Bariogram of Soaring Flight in Thermal Air Currents

Key: A--Altitude; B--Flight time (hours)

6.2.2. Soaring in Currents of Streamline Flow and Certain Other Conditions

Flights in streamline currents made today on the basis of new techniques and methods is by no means a simple return to the old. The newness of flights in streamline flow involves first of all the modern strong gliders necessary in operation including those intended for primary training which permit the best utilization of each angle suitable for soaring and for developing precision in piloting techniques. Moreover, modern gliders have much greater capability than formerly of transferring from streamline flow currents to thermal and the reverse. This combination in a single flight of various methods of soaring flight is not the only method broadening the way in which a pilot increases distance and length of time for soaring flight. The utilization in a single flight of several types of phenomena of energy of the atmosphere is also an excellent school for developing techniques of piloting and for broadening and deepening the knowledge of the pilot in the field of qualitative evaluation of meteorological and geographical flight situations. /228

In the second place, flights in streamline flows at the present time directly train the pilot (and the designer of the glider as well!) for flight in stationary waves wose mastery is essential to remaining in the vanguard of gliding.

A diagram of soaring flight over a slope with streamline flow of wind is shown in Figure 6.8. So that a glider will be able to soar in these conditions there must be the necessary determined relationship of glider and wind velocities. These relationships whose necessity is apparent from the drawing presented are evidence of the fact that over a small not very steep slope one can soar with low wind speeds on slow gliders with small specific load on the wing. Such gliders are, as a rule, aircraft for primary training or sailplanes with powerful mechanizations of the wings.

For soaring in mountain conditions where steep, occasionally vertical slopes of hundreds of meters exist, blown by winds with velocity tens of meters per second gliders are required with considerable flight path speed which is reached with comparatively large specific loads on the wing (Figure 6.9).

With adequate windspeed, steepness and height of the slope, in the streamline flow one can select an altitude at which the power of the appropriate thermal air current would be adequate /229 in order to continue gaining altitude even independent of the slope.

Thus, for example, the practices of flights can follow the principle of developing soaring on gliders beginning with utilizing

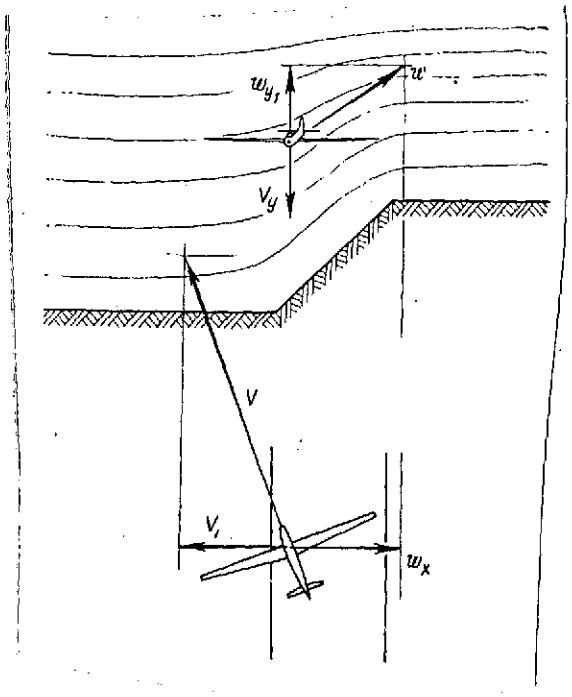

Figure 6.8. A Diagram of Soaring Over a Slope

ω--Projection of the velocity of the air current over a slope on a vertical plane; ω_{y_1}--Vertical component of the velocity of the air current over a slope; V_y--The velocity of sink of a glider relative to the air (current); V--The projection of glider velocity relative to the air on a horizontal plane; V_1--The horizontal component of the velocity of glider flight relative to air; ω_x--The horizontal component of the velocity of the air current over the slope.

streamline flow, through thermics and clouds to wave and complex utilization of all conditions known at the present time which permit executing engineless flight.

6.2.3. The Possibility of Soaring Flight With the Absence of Ascending Air Currents

Let us look at one of the types of phenomena of atmosphere energy which offers wide possibilities for further engineless travel and let us introduce one of the important methods of using certain properties of this type of energy for soaring flight of a glider developed a few years ago by engineer M.M. Azarkh and published in his work [3].

The principle possibility of utilizing the horizontal flow of air which has variable horizontal velocities according to altitude, was pointed out by N.Y. Zhukovskiy/230 "On Soaring Of Birds" [15]. At the present time, apparently, it is expedient to look at this possibility from the practical point of view keeping it in the arsenal of flying and engineering experience as additional knowledge in order to construct strong, reliable gliders with very good flying data and to master flights on them under new conditions.

Let us suppose that wind velocity changes directly proportionally to altitude--for example, as is often encountered in practical observation. Then, wind velocity at a certain intermediate altitude can be expressed by the following dependence (Figure 6.10):

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$$\omega = \omega_0 + \Gamma h$$

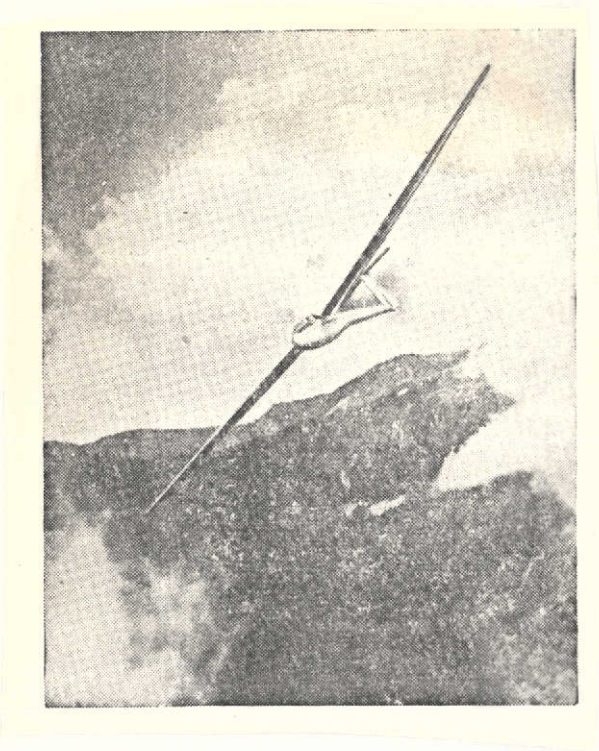

Figure 6.9. Modern Gliding in Mountainous Conditions

Here ω--is the flowing (by altitude) velocity of the wind, ω_o--wind velocity at a certain "zero" altitude H_o, Γ--the change in wind velocity in m/s for each meter of altitude h, h--the flow altitude in m, measured from zero altitude H_o.

The expenditure of glider energy is determined by the velocity of its movement relative to the ambient air and the flight altitude. The velocity of the glider relative to the air can be increased to an equal degree both when glider speed increases in the direction of its movement and in the case of an increase of air velocity in the opposite direction. If the glider climbs when moving against the wind (*a*), then with the accepted law of change of wind velocity according to altitude, the velocity of the glider relative to the air increases and this means the expenditure of energy of the glider increases. When climbing in the direction of the wind (*b*) the glider velocity relative to the air will decrease because of an increase in wind velocity with an increase in altitude. And the energy of the glider also decreases. Sinking of a glider in the direction of the wind (*c*) leads to an increase in the energy of the glider because the glider velocity relative to the lower layers of air is greater than it is relative to the upper layers. Finally, when a glider is descending against the wind (*d*) the energy of the glider decreases because the relative velocity of the glider and the air decreases.

Thus, when the glider is ascending against the wind and descending with the wind the supply of energy of the glider increases.

But maneuvers in a vertical plane following one after the other (zooming and diving) cannot be utilized as a method of maintaining average altitude of flight and thus increasing its distance and length of time. This is because during maneuvers of such a type the increase in energy with altitude climb against the wind (*a*) will equal the loss of energy when descending against

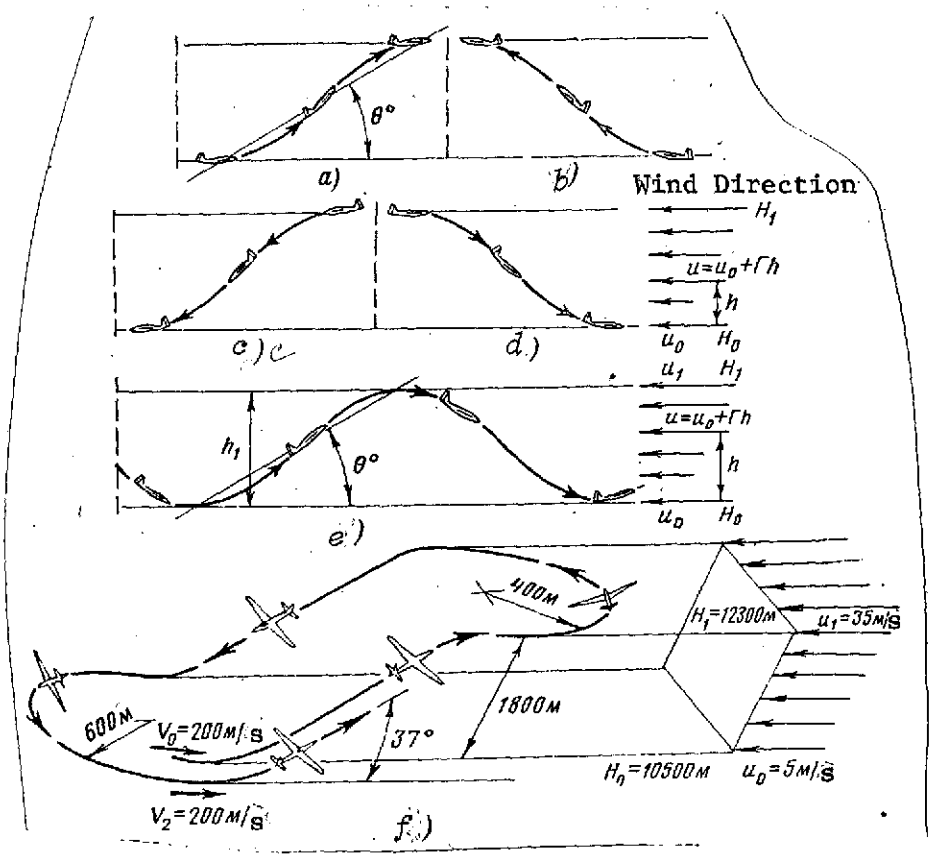

Figure 6.10. Examples of Maneuvers of a Glider in a Horizontal Air Current (For example, in a jet stream) Which Has Movement of the Air Mass Changing Velocity Vertically

a, b, c, d--Ascent and descent of a glider in an air current with changing velocity of wind according to altitude; *e*--Maneuver in a vertical plane without the possibility of utilizing the change in wind velocity according to altidude; *f*--An example of maneuver in a vertical plane utilizing the energy of the wind

the wind (*d*). This is necessary so that the supply of energy increases as a result of both maneuvers--both ascent and descent. Then the entire maneuver will acqure a quantity of energy which is adequate for maintaining average flight altitude at least at the same level.

It is obvious that the type of movement which satisfies the requirements of gaining energy both for ascent and descent of a glider can be its spatial maneuver.

Let the velocity of the glider after a turn at an altitude H_o having completed a spatial maneuver with climb in altitude and descent equal V_2. Then, if V_2 is greater than V_o--the glider increases the supply of its energy which can be utilized for increasing distance and length of time of the flight. In the case of an equality of velocity at the beginning and end of a spatial maneuver ($V_2 = V_o$) there will be no increase in energy but the maneuver all the same can be repeated as long as the characteristics of the jet stream do not change. If this velocity/232 at the end of the spatial maneuver V_2 is smaller than the initial V_o, then this means that the gradient of change according to the altitude of velocity of the air flow is not adequately great and when maneuvering the store of energy of the glider is completely used up. Consequently, to try to use such a jet stream for carrying out soaring flight is unthinkable.

An evaluation of the practical conditions necessary for executing soaring in a jet stream permits one to suppose the reality both in constructing gliders for soaring in jet streams and successfull mastery of this new type of engineless flying.

Besides the type of spatial maneuver of a glider looked at, for soaring in horizontal currents with vertical gradients of change of velocity of the air stream, other maneuvers can be used. In particular, the maneuver of a type of wingover in an inclined plane. It is possible that turbulence in the atmosphere also will be utilized in the future for increasing the distance and length of time of engineless flight. One test of such utilization of turbulence was executed at the end of the 1950's by designer pilot A. Yu. Monatskov who modified an A-9 glider and used fly-wheel movement of the wings for perceiving air movement and transferring the energy of this movement to an accumulator on board the glider. Unfortunately the experiments were not completed at the time of the tragic death of the author of this interesting idea.

Other ideas exist for broadening and perfecting the use of various phenomena of atmospheric energy for the purpose of increasing the distance and length of time of engineless flight.

6.3. On High Altitude Flights on Gliders

Let us agree that high altitudes are considered to be those where the pilot begins to perceive certain specific flight conditions connected with changes in the properties of the atmosphere which are absent when flying in the layers of air near the Earth. Different characteristics of the atmosphere begin to be noticeably

apparent and affect flight at different altitudes. But it is possible to consider an altitude of approximately 5000 m as a conditional boundary above which are what we will call high altitudes. 5000 meters is an altitude where there is an oxygen deficiency (where there is no oxygen on board the glider) and low pressure can cause a decrease in the work capability or cause fainting, and the low temperature of the air requires heating equipment for the pilot and special attention in lubricating the working parts in the control mechanisms of the glider. Lubricants can freeze and make the operation of the control stick difficult. A decrease in the pressure of the air surrounding /233 the glider also begins to be apparent in the character of flight although significant changes in stability, controllability and maneuverability of the glider are noted at altitudes greater than 10,000 m. The initial flight speeds increase and correspondingly the sinking speed because the range of indicator and this means instrument, speeds in glider flight must be retained. An increase in the initial speed of the glider affects its behavior, controllability and stability due to an increase in the Mach number. A decrease in the Re number results in an increase in c_x at certain flight speeds which distorts the polar decreasing the aerodynamic quality. High altitude, and consequently low density of the air noticeably decreases the damping properties of the glider--its wing and tail unit. This is expressed in slower damping of lateral and longitudinal oscillations.

The worsening of damping has a negative effect on controllability of the glider or maneuvers, makes the so-called "seating density" of the glider worse. On the other hand, with an increase in altitude the responsiveness of the glider to the rudder is worse. The glider becomes sluggish and the controls respond to the pilot with more and more noticeable lag. This has a negative effect on the precision of controlling the glider, the glider begins to "respond to the control stick" more poorly. It becomes more difficult for the pilot to maintain the required flight procedure (speed, course, bank).

Thus, an increase in flight altitude makes it necessary to have more frequent interference by the pilot in control of the glider and this means increasing the total work of the pilot (physically and with the nervous system and brain). Shifting the focus of the glider forward results in putting it into a dive which begins to be noticeably perceived even at M = 0.7--0.8. Executing a tow is complicated by the fact that horizontal glider flight at such an indicator speed requires a large angle of attack. And this means a smaller reserve of c_y which is necessary for accomplishing maneuvers and for a glider encountering a vertical air current.

Flight at high altitudes is made difficult by icing up because then observation of external reference points is minimum

or zero and spatial orientation is destroyed. And flying by instrument is a new complexity. Icing up on a glider causes a change in its aerodynamic shapes, especially for the wings and control devices, the leading edges of which ice up first. Because of this the airfoil of the wing and tail are changed. Because of the formation of ice and frost the lubricant can jam the control stick and the ailerons. Ice can cover the air pressure indicator which results in failure of the speed and altitude indicators.

The absence of oxygen in adequate supply in the life support system on board with incorrect calculations of flight time and oxygen reserve causes oxygen deficiency which can end in the pilot fainting and a number of complications connected with this. The most important of these is the possibility of regaining consciousness too late. /234

A low temperature of the outside air has a harmful effect directly on the glider. In connection with the different degree in change of dimensions of the fuselage and wings and parts of the control system due to the low temperature there can be weakening or too great tension on the control wires, especially cables and this can cause an air gap or increase in friction. Either one makes controllability worse.

Finally, at high altitudes the character of operating a parachute changes which requires a change in methods if the glider has to be abandoned and for conditions of opening the parachute.

6.4. Special Cases of Flights on a Glider

Special flight cases usually means those which were not planned for ahead of time in the programmed data of the mission, which occur unexpectedly for the pilot and cause complications which can result in an accident. Thus, special flight cases directly involve, on the one hand, an increase in the volume of work of the pilot which he must expend to complete the operational task. On the other hand, special flight cases naturally require of the pilot the capability to complete this increased volume of work and in a very limited time.

The greatest number and most frequent special cases are encountered in towing and soaring flights for a glider. The first group of flights involves operation of the complex "towing craft--glider" system which can occur under unfavorable meteorological conditions. Free soaring flights themselves by their use and character also presuppose the possibility of encountering various conditions many of which are suitable from the point of view of soaring but which are very frequently difficult for the

pilot.

Let us look at some of these which are the most typical for free flight. When soaring directly under the lower edge of cloud with powerful ascending air currents a glider can quickly by pulled into the cloud and then the pilot suddenly loses external reference points by which he was maintaining required spatial position of the glider before entry into the cloud. Besides, the sudden and unexpected entry of the glider into the cloud can have a strong emotional effect on an inadequately trained pilot. In either case there is a considerable effect on /235 the correctness of controlling glider movement and a complication of flight circumstances.

Encountering a storm or strong rain is also a special case for glider soaring flight. Dropping into a storm cloud threatens almost unavoidable failure of the glider. Then it is very difficult to open a parachute and the process of ejection and landing of a pilot from highly turbulent air in the presence of wind is also difficult.

The necessity for the crew to bail out of a glider is needless to say a special case in soaring. In this case let us stop with a little more detail although parachute jumps are an independent type of control of movement of man in the air and this means a type of flight.

At the present time, most gliders intended for soaring (and this essentially includes all sport craft, beginning with training and ending with record setting sailplanes) plan for life saving parachutes for the crew. An exception are the light single place gliders for beginning training. On these, as a rule, flights are made close to the ground which makes it impossible to use a parachute, but in most cases excludes the possibility of encountering flight conditions which would make it necessary to use life saving equipment. One should keep in mind that the conventional division of gliders used at the present time into those which fly close to the ground and those which ascend into clouds is very conventional. This division does not justify the absence of parachutes on gliders of the first group or their presence on the second. The possibility of soaring at high altitudes involves to a large degree the meteorological and geographical conditions of flight more than the gliders themselves (assuming naturally that glider strength permits making such flights).

One should keep in mind that jumping with a parachute being a complex type of movement of the "pilot--parachute" system, itself can be a special case. However, these special questions of theory, techniques and practice of jumps are looked at in a special section of literature which explain parachuting.

6.5. Flight Instruction on Gliders

At the present time two basic methods of training on gliders exist. The method which arose with the first development of gliding is the so-called "solo" training. The peculiarity of it is that due to the single place on the glider training from the very beginning is done alone in flights and therefore the person must independently act and correct his mistakes although on the basis of instructions (obtained before the flight). This lays /236 a great responsibility on the instructor and requires him to be a good teacher and trainer (see Figure 1.4). Training with this method requires very great discipline and concentration. This is the difficulty of the method. However, these can be overcome especially now where radio communication exists and the instructor can tell the student what to do if any necessary actions are not executed. Before now from earliest times there have existed the simplest training gliders and instruction on balancing in a glider mounted on a pivot blown by the wind, and a system of towing the glider using a truck tow and cables so that the glider cannot go above the prescribed instructor altitude (the V. N. Makarov system, see [26]); this has considerably accelerated the process of mastering the control stick and made it possible for the student to correctly follow all the steps of training.

Another method of training which in recent years has a special place in the schooling system for young pilots is based on the simultaneous flight of the student and the instructor (Figure 6.11).

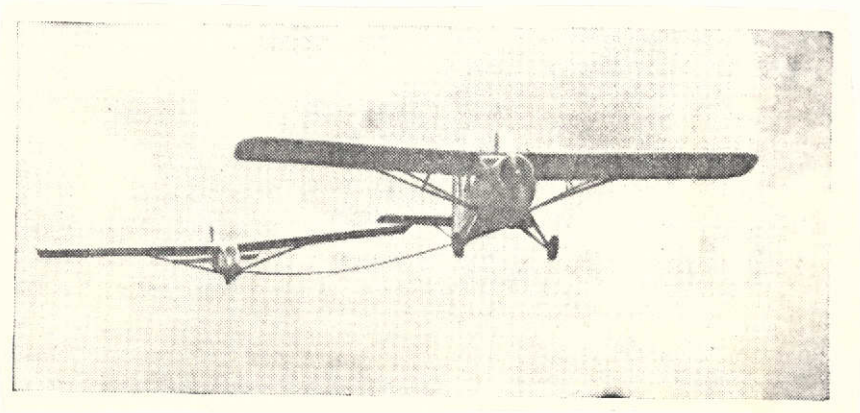

Figure 6.11. Flight of a Student With An Instructor on a Two-Place Glider

The two place glider required for carrying out such a training method is a heavy craft, and more expensive and as a rule cannot be built by a glider society or be launched into the air using a shock cord or light winch. The two place glider makes it

possible for the instructor to intervene in the control of the glider if the student makes a mistake. But because of the things mentioned earlier such custody is not always suitable or necessary although it makes the work of the instructor in training easier. One should add that launching a student on his first independent flight in two place training differs very little from the responsibility and complexity of a first flight on a /237 single place glider. This is because in the latter case the trainee has already tested his strength in completely independent control of the movement of the glider during land runs and others. At the time of a first independent take-off in a two place glider (in spite of preliminary training and of piloting techniques) there is a very complex phychological relationship because the trainee is immediately alone for a comparatively long period of time (on the order of ten minutes) and comparatively high altitude (about 300 m).

However, the combination of both methods of training would apparently be correct--the first as a means of increasing the volume of gliding and improving responsibility and self-knowledge of flight trainees, the second as a method of training in cases where it is impossible without direct instruction on piloting equipment (for example when doing aerobatics including spirals one of the most complex of piloting techniques) and soaring methods (for example when seeking ascending air currents or when solving tactical problems for cross-country flying).

On the basis of actual data on the fleet of sport gliders in a number of countries where gliding has developed and expanded one can compile the following approximate system for make-up of engineless craft necessary for satisfying all of the requirements of gliding.

The gliding fleet of the country must be varied and multiple. The basic type of sport craft are so-called light sailplanes. This is a glider in its aerodynamic perfection side by side with record setting craft but it is simpler, cheaper and consequently available to the main mass of pilots. Here they must mainly be single place because the basic (individual) flying practice of gliding personnel occurs mainly on such gliders.

Two other mass categories of gliders are single and two place training gliders. Their required large quantity is dictated by essential requirements and expense in the process of mastering flights of beginning pilots. Record setting sailplanes, at times unique, are used for championship competition of very high rank and must naturally be fewer.

As to engineless aircraft intended especially for accomplishing high altitude figures, aerobatics, at the present time, it is expedient to use sailplanes for this type of flying which have strength and controllability suitable for such purposes. We note

that the sailplane principally must be a good flying craft because of these basic properties required of it: superior controllability and high strength. /238

6.6. On Planning and Constructing Sport Gliders

The great experience in planning and building gliders accumulated in the past decades shows that the methods developed for aerodynamic calculation, calculation for strength, calculation for controllability, methods of construction and testing (on the ground and in the air)--that all of this and also the presence of the necessary structural materials and production processes at the present time permit making gliders without gross defects and with flying characteristics which as a rule are close to those calculated.

The abundant statistics of various design and aerodynamic solutions for various components, parts and for the gliders as a whole can suggest many reliable steps when creating new aircraft and help the designer avoid expending wasted time and energy.

The modern state of glider construction allows one to construct good gliders with different levels of planning and production beginning with the specialized design bureau and factories and ending with enthusiastic student societies for gliders at aviation institutes and enterprises under the direction of aviation specialists. The problem of creating the glider must always be chosen according to the capabilities of the designers and builders. However, having assigned the actual goal one can attain good results only if all the work is done on an engineering level, that is, under leadership with many-sided consultation and participation in the work of engineers and specialists so that the first condition for creating a new glider will be met for its good controllability and strength with the appropriate selection and precise formulation of the operational task. Providing safety of flight in this way (and this in the final analysis is the most important condition for any glider flight) permits analyzing the factors of aerodynamic perfection of the glider attained (primarily its velocity polar). Such an order in creating a new glider provides final success for participants, planners, builders and pilots who are very often one and the same.

The following approximate diagram for planning, constructing, testing and putting into operation a new glider shown in Figure 6.12 is efficient.

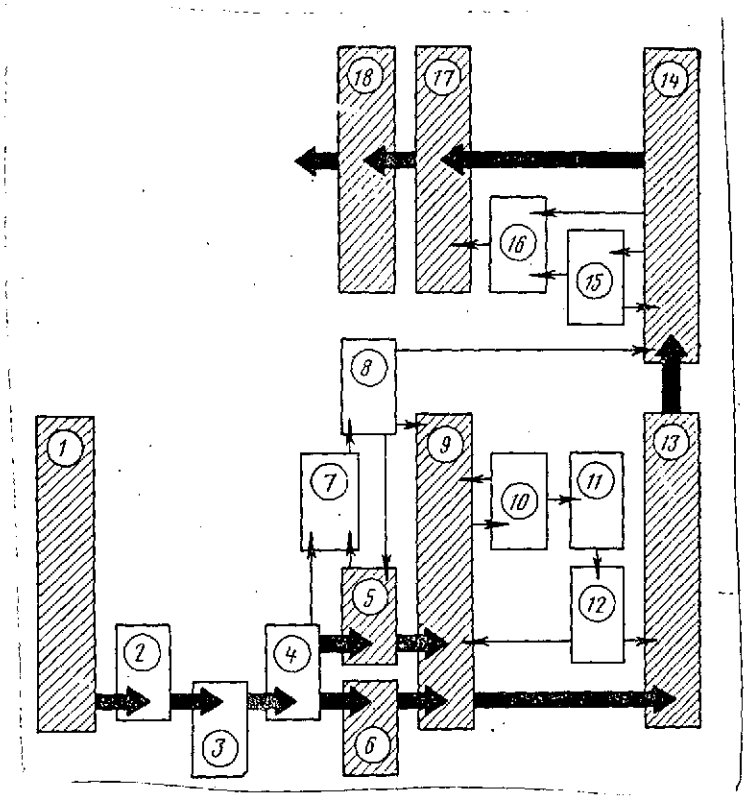

Figure 6.12. An Approximate System of Planning, Building, Testing and Putting a New Glider into Operation:
1--Formulation of the operational task of the glider. Developing its design and structural conception; 2--Selection of statistical and other materials on gliders similar to the use and design solution of the planned glider; 3--Selection of the diagram and basic parameters of the glider; 4--Rough plan and preliminary calculations. Variations of the arrangement solutions; 5--Final selection of the diagram and arrangement--aerodynamic, structural and weight. Full aerodynamic calculation. Polars, controllability, stability, spin, maneuverability; 6--Full calculation for strength, flutter (in accordance with strength standards for gliders in the class to which the planned glider belongs); 7--Construction of a model for aerodynamic testing in wind tunnels (horizontal and vertical); 8--Experiments with the glider model in wind tunnels; 9--Drawing up working drawings; 10--Preparation of the glider mock-up for precise arrangement, convenience of operation (as a minimum, a mock-up of the cabin with equipment and canopy); 11--Construction of a sample glider for static testing (only power

Figure 6.12. continued:
elements); 12--Carrying out static testing of the glider; 13--Constructing the first flying sample of the glider; 14--Flying tests of the glider: testing strength, controllability, aerodynamic perfection and the appropriateness of calculations, evaluation of the glider as a sailplane and flying aircraft (in the limits of the given operational task), general complex evaluation; 15--Carrying out operational testing; 16--Refining work, eliminating defects; 17--Constructing a series of the new gliders; 18--Beginning mass production of the new glider. Refining the support (basic) stages of planning and constructing a glider.

6.7. On Testing Gliders (Methods of Evaluating the Suitability of A Glider for Operation) /240

After the glider is built and before it is flown it must undergo tests. The purpose of these tests consists in the first place of checking the safety of flights on such a glider, that is testing its strength and controllability. In the second place, testing must show how close the flying properties of the constructed glider are to the calculated, that is, to what degree its aerodynamic perfection has been attained. The conduct of tests on the glider before it is put into normal operation is always obligatory because only as a reslut of testing can the actual properties of a glider which determine its real boundaries for safe operation be known.

Testing the glider begins on the ground. When conducting ground tests the glider is subjected to a static load under which the load is gradually increased and the effect of the dynamics of the load factor on the structure can be ignored. These tests are made primarily on the wing, and then on the tail, fuselage, control systems, landing gear and with a combined load factor of certain parts of the glider (Figure 6.13).

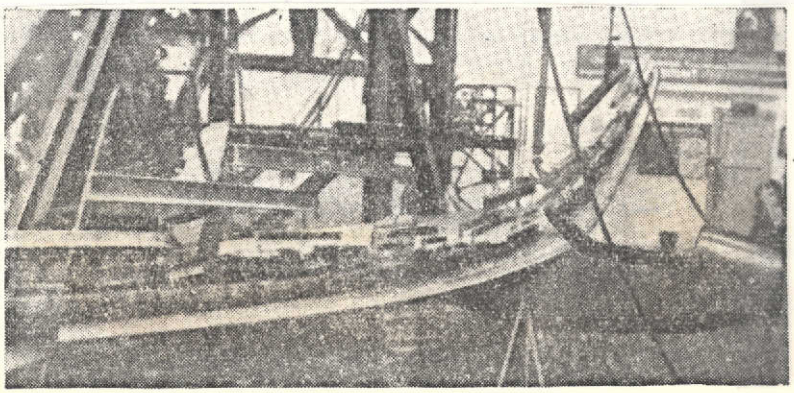

Figure 6.13. A Glider During Static Testing

Then not only strength of these elements of the glider but also their rigidity corresponding to the varying degree and type of load capability of their structure are determined.

The load factor of the main parts of the glider when determining their strength and rigidity are done up to disintegration of the structure. This permits determining the presence and size of the actual strength reserve of the glider in comparison with calculated values and to evaluate the structure from the point of view of its load ratio. If the actual strength /241 reserve is small or completely absent (the design breaks up under loads smaller than that calculated or residual deformations are apparent during smaller load than maximum operational) this means the structure is inadequately strong. If the strength reserve is too great, that is, if the glider shows residual deformation or it breaks up under loads considerably greater than that calculated this means the design is overweighted, that is, it has excess materials in its elements (excessive mass). This is undesirable and in a number of cases not permissible because of weakening of the design.

A very important part of static testing is checking the work capability of the control systems of the glider with deformed wings, fuselage and tail. In connection with the fact that such deformations in flight can be significant (especially of the wings) it is important ahead of time to see that all the control systems with all acceptable deformations of the structure will respond to the pilot with the approximate sizes of effort which he must apply to these conditions to the control stick in the cockpit for overcoming friction forces. The standards of effort, like those of elastic deformations of the glider structure, are fixed when planning a glider originating from the requirements for controllability, rigidity and strength of a glider.

Finally there is still one more type of testing on the ground, not static but vibrational and is the so-called frequency testing of the glider. In these tests, the types and characteristics of special frequency of oscillations of basic parts of the glider are determined--primarily of the wing, ailerons, flaps, tail and rudder. Then, both bending and twisting oscillations are examined. As a result of frequency testing the speed at which flutter will occur on the glider is determined and its specific sections during various flight configurations.

All types of testing on the ground to an equal degree are important and must be made at a high engineering level.

In flying tests on the glider the peculiarities of its controllability are apparent, its strength and appropriate factors of flying data calculated for making such elements of flight which as a total make up its movement in the process of solving the operational tasks are tested. Before beginning

flying tests it is necessary to assemble all the documents on its structure, strength, rigidity, and also the calculations of aerodynamic and strength factors. There is an abundance of documentation because it is essential to know basic data on the glider as completely as possible before test flights: data applicable first of all to flight safety of a given glider, its behavior in the air and those phenomena for which a test pilot must be prepared during experi- /242
ments in the air.

Then, the glider must be equipped although with minimum instruments: visual, self-recorders or sensors and recording devices with the help of which the pilot will be able to fix the specific parameters of movement of the glider. According to these, later on, three basic general characteristics will be evaluated: controllability, strength and flying data on the glider which shows its aerodynamic perfection, most of all the character of the velocity polar (Figure 6.14).

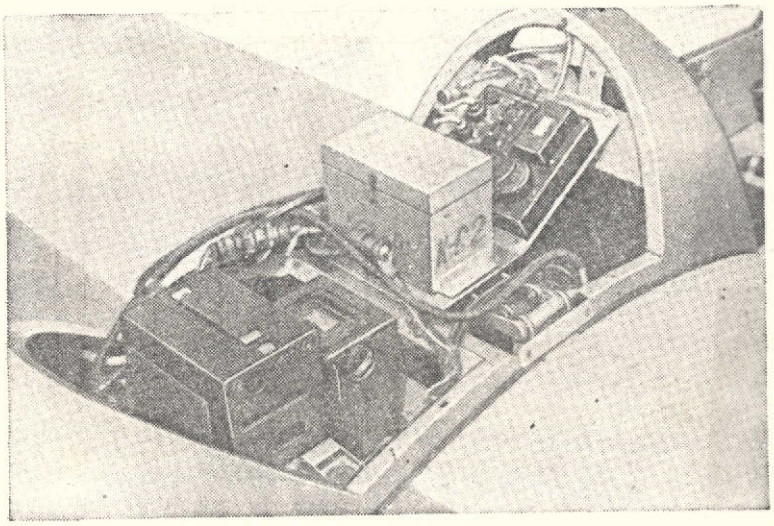

Figure 6.14. Installation of a Test-recording Device on the Glider During Flying Tests

One of the most difficult elements of test flying is determining the vertical speed of descent of the glider which is defined as the change of flight altitude in a certain time interval. And, as is known, the changes in altitude when gliding even at considerable flight path speeds are relatively small in a glider. And to fix them precisely is difficult.

However, from Figure 6.15 it is apparent that the number of points equal to approximately fifty, allow one to successfully construct a velocity polar of the glider fairly accurately.

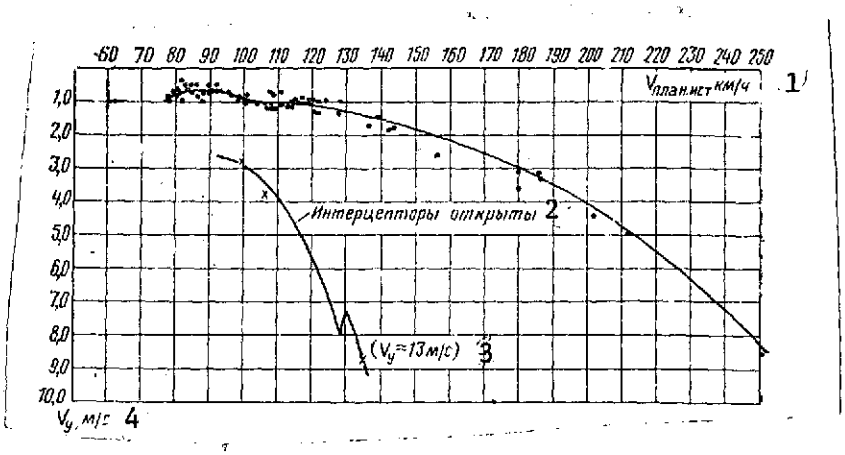

Figure 6.15. The Velocity Polar of a Glider Obtained From a Flight During Tests of the Glider

Key: 1--$V_{\text{test glid.}}$ km/hour; 2--Interceptors open; 3--(V_y = 13 m/s); 4--V_y, m/s.

Testing for the execution of spin and evaluation of strength are very important and complex stages in the flight testing of a glider. The tests in spin, if experiments with a dynamically detailed model of the glider have not preceded this in a wind tunnel, are of especial concern as a test item. During test flights in spin the glider is equipped with an anti-spin parachute which can be opened by the pilot if the need arises, to increase the effect of the rudder when pulling the glider out of a spin. The essence of the effect of the anti-spin parachute includes the fact that the force of its resistance rotates the glider around the center of mass, resulting in small angles of attack. /243

In interpreting the flight recordings of certain characteristics of motion of a glider one can evaluate the changes in the parameters of motion and compare them with the sizes of appropriate criteria.

Of course, testing on the ground and in the air with various gliders can be different in volume depending on the type of glider, that is, on those operational tasks for which they are built. However, when shortening or lengthening the volume of testing of gliders (on the ground and in the air) in all cases one must retain their basic elements which guarantee an objective evaluation of complete safety of flight over the entire range of operational procedures dictated by the operational task, testing for adequate strength and controllability of the gliders tested. From this point of view, determining such a characteristic as,

for example, the aerodynamic quality of the gliders is secondary.

Conclusion

We have looked at the basic questions which concern a glider, engineless aircraft,--its dynamics, peculiarities of control, structure, strength and flight practices. From the materials presented one sees that gliding, an independent field of aviation, /244 is closely connected to other fields and with its help many operational tasks are being solved at present which involve the progress of aviation as a whole and aviation sport in particular. The comparative data on the development of records attained in engineless flight in the last 60 years are evidence of this.

1913

Absolute altitude	30 m
The length of time	5 min

1973

Types of Record Flights	Records on Gliders (1973)			
	Single-place		Two-place	
	Women	Men	Women	Men
Distance covered, km	749	1460	864	921
Distance to the target, km	731	1051	864	714
Absolute altitude, m	12190	14102	9519	13489
Speed on a 100-kilometer route, km/hour	113	155	90	130
Speed on a 500-kilometer route, km/hour	103	135	69	101

The rate of development of glider construction and methods of engineless flight allow one to hope for the mastery of flights in the near future with longer distance, greater altitude and speeds.

REFERENCES

1. Adamovich, N.V., "Control of the angle of pitch on an airplane," In the bk: Lëtchiku o prakticheskoy aerodinamike [Practical Aerodynamics for the Pilot], Moscow, "Voyenizdat" Publishing House, pp. 40-53.

2. Adamovich, N.V., Upravlyayemost' sovremennogo camolëta [Controllability of a Modern Airplane], Moscow, "Oborongiz" Publishing House, 1946, 95 pp.

3. Azarkh, M.M., "One can fly farther on a glider," Kryl'ya Rodiny, 2, 20-22 (1960).

4. Antonov, O.K., Desyat' raz snachala, [Ten Times from the Beginning] "Molodaya gvardiya" Publishing House, 1963, 143 pp.

5. Burdayev, M.N., Teoriya i raschët spiraley dlya planërov [Theory and Calculation of Spirals for Gliders] TsK DOSAAF [Tsentral'nyy komitet Vsesoyuznoye dobrovolnoye obshchestvo sodeystviya armii, aviatsii i flotu SSSR, All-Union Voluntary Society for Assistance to the Army, Air Force and Navy of the USSR] Publishing House, Moscow, 1970, 86 pp.

6. Burdun, G.D., Spravochnik po mezhdunarodnoy sisteme edinits [Handbook on the International System of Units] "Isd-vo standartov" [Standards Publishing House], 1971, 231 pp.

7. Vel'gus, S., Makula, E., Skshydlevskiy, S., Perelëty na planëre (trans. fr. Polish) [Cross-country Flying in a Glider] "DOSAAF" Publishing House, 1963, 146 pp.

8. Vechfinskiy, G., Pervyye pobedy krasnogo planëra [First Victories of a Red Glider] Kharkov, "Ukrvozdukhpur'" Publishing House, 1924, 32 pp.

9. Goncharenko, V., My letayem bez motora [We Fly Without an Engine] "Gidrometerizdat" Publishing House, Leningrad, 1967, 152 pp.

10. Vinogradov, Ye., "Turbulence in the Atmosphere and Soaring," Kryl'ya Rodiny, 12, 29-30, 1969.

11. Gorbatenko, S.A., et al., Mekhanika polëta [The Mechanics of Flight] "Mashinostroyeniye" Publishing House, Moscow, 1969, 420 pp.

12. Grossman, Ye. P., "Flutter" Trudy TsAGI [Proceedings of the Central Aero-Hydrodynamic Institute] [TsAGI" [Tsentral'nyy aerogidrodimanicheskiy institut] Publishing House, 1937, 248 pp.

13. Dvoyenosov, D., Zamyatin, V., Sneshko, Yu., Nagruzki, deystvuyushchiye no planërvv polëte [Loads Affecting a Glider in Flight] "DOSAAF" Publishing House, 1963, 141 pp.

14. Yefimov, A.N., et al., Osnovy teorii polëta samolëta [Bases of the Theory of Airplane Flight] "Voyenizdat" Publishing House, Moscow, 1957, 444 pp.

15. Zhukovskiy, N. Ye., O parenii ptits [On Soaring of Birds] Bureau of Foreign Science and Engineering, Berlin, 1922, 30 pp.

16. Zhukovskiy, N. Ye., O prisoyedinennykh vikhryakh [On Adjoining Vortexes] "Universitet" Publishing House, Moscow, 1906, 14 pp.

17. Illyustrirovannyy aviatsionnyy slovar' dlya molodëzhi [Illustrated Aviation Dictionary for Young People]"TsK DOSAAF" Publishing House, 1964, 455 pp.

18. Kalachev, G.S., Pokazatyeli manevrennosti, upravlyayemosti i ustoychivosti samolëtov [Indices of Maneuverability, Controllability and Stability of Airplanes] "Oborongiz" Publishing House, Moscow, 1958, 131 pp.

19. Kachorovskiy, I.B., Raspredeleniye i pereklyucheniye vnimaniya pri polëtakh po priboram [Distribution and Changes in Attention During Instrument Flights] "Voyenizdat" Publishing House, Moscow, 1972, 104 pp.

20. Kashafutdinov, S.T., Kalikina, R.V., Atlas aerodinmaicheskikh kharakteristik planërnykh krylovykh profiley [An Atlas of Aerodynamic Characteristics of Airfoil Profiles of Gliders] "GKAT" Publishing House, 1962, 44 pp.

21. Kiselev, A.I., Metodika obucheniya buksirovochnym polëtam na planerakh [Methods of Training with Towed Flight on Gliders] "Oborongiz" Publishing House, Moscow, 1952, 94 pp.

22. Kloss, R., Fasi, L., Oblaka (Trans. fr. French) [Clouds] "Gidrometeoizdat" Publishing House, 1970, 120 pp.

23. Kotik, M.G., at al., Lëtnyye ispytaniya samolëtov [Test Flights of Airplanes] "Mashinostroyeniye" Publishing House, 1968, 423 pp.

24. Kravchenko, I.V., Lëtchiku o meteroologii [Meteorology for the Pilot] "Voyenizdat" Publishing House, Moscow, 1962, 313 pp.

25. Marishuk, V.L., Platonov, K.K., Pletnitskiy, Ye. A., Hapryazhennost' v polëte [Tension in Flight] "Voyenizdat" Publishing House, Moscow, 1969, 117 pp.

26. Makarov, V., Metodika obucheniya na odnomestnom planëre [Methods of Training on a Single-place Glider] "DOSAAF" Publishing House, 1957, 96 pp.

27. Markov, G.V., Ostrogskiy, L.A., Spravochnik pilota i shturmana grazhdanskoy aviatsii [Civil Aviation Handbook for Pilot and Navigator] "Transport" Publishing House, 1971, 327 pp.

28. Ostoslavskiy, I.V., Kalachev, G.S., Prodol'naya ustoychivost' i upravlyayemost' samolëta [Longitudinal Stability and Controllability of an Airplane] "Oborongiz" Publishing House, Moscow, 1951, 367 pp.

29. Ostoslavskiy, I.V., Aerodinamika samolëta [Aerodynamics of an Airplane] "Oborongiz" Publishing House, 1957, 560 pp.

30. Pavlov, A.V., Apparatura i metody izmereniy pri lëtnykh ispytaniyakh [Measurement Equipment and Methods During Test Flights] "Mashinostroyeniye" Publishing House, 1967, 2.5 pp.

31. Pashkovskiy, I.M., Osobennosti ustoychivosti i upravlyayemosti skorostnogo samolëta [Peculiarities of Stability and Controllability of a High-speed Airplane] "Voyenizdat" Publishing House, Moscow, 1961, 350 pp.

32. P'etsukh, A.I., Kryl'ya molodëzhi [Wings for the Young] "Oborongiz" Publishing House, 1954, 291 pp.

33. Simonov, N., Shelest, N., Bezmotornyy polët [Engineless Flight] "Redizdat" Publishers, TsS Osoaviakhima SSSR, 1938, 235 pp.

34. "Table of Standard Atmospheres" GOST 4401-64 [Gosudarstvennyy obshchesoyuznyy standart, All-Union State Standard] "Izd-vo standartov" Publishers, 1970, p. 43.

35. Frolov, V.S., Chelovek v sisteme upravleniya samolëtom [Man in the Control System of an Airplane] "Voyenizdat" Publishing House, 1970, 125 pp.

36. Fadeyev, N.N., "The Theory of Soaring Flight" Kryl'ya Rodiny /3, 17-19; Ibid, 14, 25-26 (1963)

37. Chernobrovkin, L.S., Vybor osnovnykh parametrov rekordnykh planërov [Selection of the Basic Parameters of Record-setting Gliders] "Oborongiz" Publishing House, Moscow, 1954, 55 pp.

38. Sheremetev, B.N., Planëry [Gliders] "DOSAAF" Publishing House, Moscow, 1959, 219 pp.

39. Yakubov, V.K., "The Effect of Elastic Twisting of the Wing on Certain Characteristics of Longitudinal Stability and Controllability of a Glider," Izvestiya vuzov. Ser. Aviatsionnaya tekhnika, 14, 84-89 (1965).

40. Albin, K., Szybownictwo na Swiete [Gliding Throughout the World] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1960, 462 pp.

41. Glass, A., Konstrukcje lotnicze Polski ludowej [Polish Aircraft Designs] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1965, 251 pp.

42. Kostka, S., Tracz, W., Trzpil, K., Wyposazenie Szybowcow [Glider Equipment] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1967, 60 pp.

43. Lanecka--Makaruk, W., Mechanika lotu [Flight Mechanics] Wydawinictwa komumikacji i lacznosci" Publishing House, Warsaw, 1969, 112 pp.

44. Nowakowski W., Kaniewska, I., Ablamowicz, A., Bojanowski, J., Zatwarnicki, R., Podrecznik pilota szybowcowego [Glider Pilot's Manual] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1967, 512 pp.

45. Pazio, A., Winczo, J., Zasady pilotazu [Piloting Principles] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1966, 206 pp.

46. Rejniak, T., Historia lotnictwa [History of Aviation] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1966, 60 pp.

47. Schmidt, M., Meteorologia latnicza [Aviation Meteorology] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1967, 106 pp.

48. Sliwak, T., Podstawowe wiadomosci z medycyny lotniczej [Basic Flight Medicine News] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1967, 60 pp.

49. Zielezinski, J., Exploatacja szybowcow [Use of Gliders] "Wydawnictwa komunikacji i lacznosci" Publishing House, Warsaw, 1967, 99 pp.

Periodicals

Soviet

50. Aviatsiya i kosmonavtika

51. Vestnik vozdushnogo flota

52. Izvestiya vysshikh uchebnykh zavedeniy. Aviatsionnaya tekhnika

53. Kryl'ya Rodiny

54. Samölet

55. Sparnai

Foreign

56. Aviatsiya i kosmonavtika (Bulgaria)

57. Flieger Jahrbuch (GDR)

58. Flieger Revue (GDR)

59. Letectvi+cosmonautika (Czechoslovakia)

60. Repülés (Hungary)

61. Skrzydlata Polska (Poland)

62. Sport si tehnica (Rumania)

63. Aero-revue (Switzerland)

64. Aviation Magazine (France)

65. Deutscher aerokurier (FRG)

66. Flight International (England)

67. Interavia (Switzerland)

68. Flug-revue-flugwelt (FRG)

69. Janes's All the World's Aircraft (England)

70. Soaring (USA)

71. The World's Sailplanes (Switzerland)