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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 504

MECHANICAL CONTROL OF AIRPLANES

By H. Boykow

From the 1927 Yearbook of the
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 504.

MECHANICAL CONTROL OF AIRCRAFT.*

By H. Boykow.

When I speak of the mechanical control of aircraft, I naturally mean automatic control. Before undertaking a detailed description of the automatic-control mechanism, I will state briefly the fundamental conditions for such devices. These are:

1. The control device must be sensitive at one or more reference values. I advisedly say reference bases (Bezugsgrößen) and not reference attitudes (Bezugslagen);
2. It must stop the angular motions of the airplane which are not purposely produced by the pilot, and it must damp aperiodically as much as possible any oscillations arising;
3. It must be possible to switch it off and on by a simple hand lever and always leave the pilot free to take personal control without first switching off the control device.

On an airplane there are, in principle, three steering axes; on an airship, two. For certain reasons, which I will immediately set forth, the most important axis is the transverse one, which is served by the elevator. The next most important one is the longitudinal one, which is served by the ailerons.

*"Motorische Flugzeugsteuerung" in the 1927 Yearbook of the Wissenschaftliche Gesellschaft für Luftfahrt, pp. 91-98.

If the matter be regarded from a purely technical viewpoint, the latter is the more important of the two; but the automatic control of the elevator is important for other reasons of an aerodynamic nature. As now built, any airplane which has a certain natural stability about its transverse axis, purchased this stability rather dearly. I can imagine, however, that an airplane which is not longitudinally stable can be better built aerodynamically. Hence the automatic control of the elevator is very important, entirely aside from the fact that it removes one dimension of space from the entire control problem, and the airplane can then be flown in the same manner as a motor car is driven. The pilot can have his hands free, since he can balance the airplane with the rudder without using the ailerons. I, at least, had to learn to hold a flying boat on its step with my arms behind my back. The economical operation of the elevator is very important, since it enables the avoidance of detrimental drag during flight.

Previous attempts at automatic control of the elevator have proved unsatisfactory principally for the reason that the basis of reference was incorrectly chosen. All possible bases of reference may be chosen, excepting only the force of gravity. A pendulum, or other object, which is subject to the influence of gravity, is not suited to serve as a basis of reference. An airplane cannot be considered stable merely when its longitudinal axis occupies a certain position in space, but only when it has

sufficient forward speed to render it maneuverable about all its axes. In ideal concurrence with this speed stabilization, we can adopt for the elevator very widely differing reference bases, namely, the maximum speed, the climbing speed, and the diving speed; and lastly, also the vertical acceleration. With the knowledge of the latter, the question can be directly answered as to what safety factor the cell should have, since the airplane can then be automatically so controlled that only a definite and prescribed maximum vertical stress can be developed on the wings. So simple as the conditions for the stability of the elevator position are, the conditions for the ailerons are all the more complex. It is approximately correct to say that the airplane is stable with reference to the ailerons, when the air flow is directly from the front. An automatic control based on this principle alone would not be very practicable. In gusty weather the airplane would be very unstable, which is not only very disturbing but also somewhat dangerous. The lateral component of the air velocity must therefore include another factor, namely, the vertical and, to be very exact, also the angular velocity of the airplane about the vertical axis. All these components of the lateral control must also be determinable with reference to one another.

The relatively least important automatic control is the directional. Its directing instrument must be a compass.

After this brief survey of the problem, I wish to discuss

the model and its fundamental principles. The control mechanism here shown consists of three parts. The first part is the "director" which, in this case, is a negative-pressure indicator, so constructed that the speed pointer can oscillate between two stops, one of which characterizes the admissible maximum speed through the air, and the other the admissible minimum speed, or the corresponding dynamic pressures.

The second part, which is built with the third part, forms a gyroscope consisting of two numerically equal gyroscopic tops coupled together but revolving in opposite directions. I call this mechanism an "inertia frame." Such an inertia frame has various valuable characteristics. In the first place, it has an accurately defined axis of sensitivity, i.e., this inertia frame reacts simply to turns about a definite constructional axis, not being affected by any other turn, but being exceedingly sensitive to turns about the constructional axis.

In order to illustrate the sensitiveness of the reaction, we will take the fundamental equation for the precessional motion of a gyroscope and of an inertia frame:

$$\frac{d\epsilon}{dt} = \frac{Q}{J} .$$

Herein $d\epsilon/dt$ represents the angular speed of the frame about its axis of sensitivity. J is the total momentum of the gyroscopes and Q the precessional resistance, which can be expressed as

$$Q = \theta_1 \frac{d^2\alpha}{dt^2} .$$

In other words, the precessional resistance, in a forced motion of the frame about the axis of sensitivity is equal to the product of the moment of inertia of the gyroscope about the axis of precession and the angular acceleration of the precession, if we disregard the constant mechanical resistances of precession. We thus obtain the angle of inclination

$$\epsilon = \frac{\theta_1}{J} \times \frac{d\alpha}{dt}$$

i.e., the angle of inclination, produced by a forced moment about the sensitivity axis, equals the ratio of the moment of inertia about the precessional axis and the momentum multiplied by the angular velocity of precession.

The ratio θ/J , with rapidly revolving gyroscopes is, however, always around $1/2000$. Hence it is obvious that, even at a very small angle of inclination; a very noticeable angle of precession is produced, which can be utilized to introduce the counter-control force.

The common precessional axis of these two gyroscopes now acts on contacts, which set in operation and direct the third part, which is the real control mechanism. The automatic control comes into action at a definite and very small angular velocity, which is not perceptible to the naked eye. A further result is that the deflection of the controls is proportional

to the angular speed of the airplane, i.e., proportional to the steering force required to offset this angular speed. It thus guarantees the maximum steering economy, which is very important for fuel economy.

This can be illustrated by an example. Every airplane and airship has a considerable moment of inertia about the transverse axis. If the control surface is deflected about this axis when the speed of the aircraft has dropped to ω , the control surface must produce a moment proportional to the product of the moment of inertia times the square of this angular speed. Hence the smaller the angular speed and the more economical the corresponding rudder deflection, just so much smaller is the absolutely necessary expenditure of energy. It follows that the head resistance or drag of an airplane, and still more of an airship, is greatly reduced by keeping the oscillations as small as possible. With an airship this steering economy is very important. On long flights (like the transoceanic ones) the fuel saving may amount to tons.

In order to carry the fuel saving to the limit, all factors affecting the motion of the control surfaces must be regulable within wide limits, since the proportionality factor between the angular speed and the corresponding rudder deflection differs according to the type of the aircraft and possibly also according to the weather conditions.

This is very largely the case with the control mechanism

under consideration. The pilot can regulate this proportionality factor at will from his seat. He can likewise regulate at will the effect of the "director" and hence of the air-speed indicator, the altimeter, the ascending and descending speed meters, etc., as required by the type of aircraft or by the weather conditions. He can therefore regulate within wide limits the rudder deflection corresponding to any given angular speed.

The need of an aperiodic damping of any oscillatory motion has been mentioned. This damping consists in advancing the action of the controls, as illustrated by Figure 1. The airplane, for example, is deflected upward by a gust. The elevator is deflected downward. Thus the speed of the airplane is reduced. Then the elevator does not remain stationary, but moves in the opposite direction. The airplane now attempts to resume its original position. The elevator goes farther back, reaches the midship position and acts against the motion, before the airplane resumes its original position. To a certain degree it therefore asymptotically approaches its original position. This is effected chiefly by giving both gyroscope axes a certain directional force toward the parallel position. Then a certain deflection of the gyroscopes corresponds to a certain angular speed about the axis of sensitivity. As already mentioned, the relation between the deflection of the gyroscope and the angular speed of the airplane can be regulated within

wide limits and indeed as follows.

The inertia frame is free to oscillate about its axis of sensitivity and is connected with the airplane only in a closed circuit, not rigidly. The closed-circuit connection is of two kinds. In one case, the inertia frame in the airplane has a directional force on a definite position of the same, and, in the other case, it is coupled with the angular speed of the airplane through a turbulent-flow brake, which can be regulated. In one case it is therefore affected by the position and in the other case by the angular speed in a way which can be regulated. Since the sign of the angular-speed effect, however, is shifted by phases, it causes a damping of the motion, which can be carried as far as desired. Without sufficient damping, there can be no stability.

The inertia frames and steering devices are all alike for these three axes of control, only the "directors" differing. Naturally the steering apparatus must be so mounted that the sensitivity axis of the inertia frame will be parallel to the steering axis concerned. As already mentioned, the "director" for the aileron machine differs greatly from the one for the elevator machine. In the one case the aircraft flies in a curve, while in all other cases it flies straight ahead. In order to fulfill these conditions strictly once for all, a relatively complex instrument would be required. This instrument would hold the altitude and simultaneously bring the angular speed

of the airplane about the vertical axis to the mechanical representation and indeed as a distance. Thereby the airplane is always laid strongly in the curve and again taken out. The centrifugal acceleration, which determines the attitude of the airplane in the curve, is the product of the angular speed and the air speed. The angular attitude with respect to the vertical can therefore be mechanically presented in quite a simple manner. Nevertheless, strict fulfillment requires a rather complex instrument. It is possible, however, to get along with comparatively simple means, if the actual conditions in a commercial airplane are considered. With a commercial airplane, long stretches are flown without any considerable curves. Such must indeed be the case for the sake of flight economy. When, therefore, no curving flight is contemplated, the control mechanism can be so adjusted that the airplane will be kept on a straight course. However, if curves are to be flown, then the adjustment of the device must be somewhat changed, so that the airplane may lie in the curve and still react in some degree to lateral winds, since these influences are difficult to distinguish with a relatively simple instrument. It can, of course, be done, but it is questionable as to whether the result warrants the cost. In the end it all amounts to the same thing with respect to the further development, if we take the stability of the third steering axis (i.e., the course axis) into consideration. Then a curve must be installed, since it

indicates a change of course and this device can then simultaneously produce even the effect of the aileron machine. In order to avoid possible errors, I will state again that it is never necessary, even with the simple "director" of the aileron machine, to install every curve as such, but only a kind of curve "premonitor." The pilot can, of course, even fly the whole distance in curve preparedness. For the sake of steering economy, however, it is better to reduce the sensitivity on a long straight flight in much the same way as the driver of an automobile, on a straight road, sets the gas lever on the steering wheel.

A p p e n d i x

I will now show you such a control device. For this purpose the device was mounted on an unstable balance beam, which is kept in equilibrium by shifting a weight. The vertical force or gravity was taken as the "director" instead of the dynamic pressure. A sort of steering surface is connected with the weight-shifting as a signal, which shows the rudder deflection produced by the control mechanism thrice enlarged. It is seen that the unstable beam, one end of which rests on the table, is damped aperiodically by switching on the stabilizing device, assumes the horizontal position and remains in it. It can be thrown off the horizontal position by force, e.g., by striking the balance beam with the fist. As you see, it goes, aperiodically damped, back to the position of stability. I now

switch off the "director." You see that the balance beam gradually sags at one end or the other. When the "director" is switched on again, it resumes its normal position. I now switch off the damping device and you see that the balance beam begins to pass through oscillations of constantly increasing amplitude. If I again switch on the damping device, the oscillations are immediately damped and the beam resumes the horizontal position.

C o m m e n t s

Engineer Drexler.- It gave me great pleasure to listen to the arguments of the lecturer. It is certainly a source of satisfaction for one who has devoted himself to the problem of automatic aircraft control for twenty years to know that the circle of its advocates is ever growing wider.

When I published a series of articles on the problem of automatic aircraft control ("Zur Frage der automatischen Flugzeugsteuerung") in Der Motorwagen in 1911-1913, I stood alone in the whole world. I did not let this fact discourage me, but continued to work on this problem for years.

All the work done, which was verified by many experimental results and hundreds of photographs, was not wasted, but formed the basis for such work as the lecturer has been doing. The lecturer has my heartiest thanks for joining me in the effort to overcome the antipathy, which now exists among aircraft pilots, to every kind of automatic control. It is perfectly ob-

vious to me that automatic aircraft control will soon be a matter-of-course and compulsory for every commercial aircraft. The only question now is how to accomplish this. Today's lecture shows that I am no longer alone in working on this problem.

It pleased me that the lecturer, in his prefatory remarks, mentioned three fundamental conditions, although I am not entirely satisfied with them. In the above-mentioned articles in *Der Motorwagen*, I set forth in 1911, ten requirements of automatic control. Any one who has had experience in this field must make much greater requirements of automatic airplane control, than the three fundamental conditions mentioned by the lecturer in his introduction.

The essential principle of automatic control has certainly been comprehended by the lecturer. He naturally based his remarks on the three requisite steering maneuvers. What greatly disappointed me, however, was the lecturer's assumption that the elevator is to a certain degree the limit of automatic control. According to his views, the ailerons play only a subordinate role and the rudder is of no consequence at all. With my many years of experience I cannot accept this view. The rudder is the most important in any system of automatic aircraft control. Far behind it comes the elevator and then, for airplanes (not for airships, as the lecturer correctly maintained), the ailerons.

The automatic control for airplanes must consist essenti-

The first part of the report deals with the general situation in the country. It is noted that the economy is showing signs of recovery, but that the government's policies are still being tested. The report also mentions the importance of maintaining stability and the need for continued efforts to improve the living standards of the population.

In the second part, the focus is on the agricultural sector. It is stated that the harvest has been satisfactory, but that there are still challenges in terms of distribution and access to resources. The report suggests that the government should continue to support the farmers and ensure that they have the necessary tools and information to succeed.

The third part of the report discusses the social and cultural aspects of the country. It is noted that there is a growing awareness of social issues and a desire for reform. The report suggests that the government should take steps to address these concerns and promote social justice.

Finally, the report concludes with a summary of the main findings and recommendations. It is emphasized that the country is on a path of progress, but that there is still a long way to go. The report calls for continued cooperation between the government and the people to achieve the desired goals.

ally of four parts: a releasing device, which switches on a certain auxiliary force; an easily disconnectable coupling between this auxiliary force and the steering controls; the control transmission to the rudder as the principal thing; and, lastly, a safety device, so that the steering machine will never force the controls too far and thus cause a catastrophe.

The chief problem in any automatic aircraft control is the necessary releasing device. I do not agree with the lecturer that a pendulum is unsuited to serve as such a releasing device. It is only necessary for such a pendulum to be correctly constructed and for measures to be taken to prevent it from being affected by acceleration influences, in so far as the latter are not desired.

The lecturer seems to me to be entirely in error, in holding that the releasing of the automatic control can be made to depend on the vertical motions of the aircraft in flight. If an airplane drops, be it for a hundred meters or even more, this can have nothing to do with the automatic control. If care is taken that the releasing device for the elevator control guarantee a given speed, a certain longitudinal attitude of the airplane, a certain flight altitude, and a certain forward driving force of the engine, any up-and-down motion of the aircraft can then be corrected in a much simpler manner.

Judging from the arguments of the lecturer and his showing of the model, he seems to be a firm believer in the gyroscope

for releasing the requisite auxiliary force. Experience has taught me that this cannot be done with the gyroscope alone and especially with two gyroscopes coupled together and rotating in opposite directions. A very complicated device would indeed have to be created to produce any effect in such a case.

The third principal condition specified by the lecturer for an automatic control, namely, simple switching off by a hand lever, is, in my opinion, the principal requirement of mechanical control. Unfortunately, I have been able to learn very little on this point. This last problem has grown me many a gray hair. If we wish ultimately to develop a mechanical control for aircraft, we must not, as the lecturer thinks, simply take away from the pilot the altitude and lateral control, so that he, like the lecturer, can "learn" with his hands tied behind his back, but we must first fix our attention on the directional control. Only then will we have made so much progress that the pilot of a commercial airplane (say with 20 passengers), setting out from Tempelhofer field on a trip to Hamburg, with due allowance for the drift, can, after reaching the proper flight altitude, enter the dining room and be served with a cutlet by the airplane waiter and then, after two hours arise from the table and say "We will be in Fuhlsbüttel in ten minutes." And, behold, it is so!

The other thing with which I am not satisfied is the "Mr. Director," especially if he can be interviewed only when he

The first part of the paper discusses the general theory of the firm, focusing on the role of the entrepreneur and the importance of capital structure. It examines how the entrepreneur's personal characteristics and the firm's financial structure influence its performance and growth. The paper then moves to a detailed analysis of the relationship between the entrepreneur and the firm, exploring the various ways in which the entrepreneur's actions and decisions shape the firm's future.

In the second part, the author discusses the importance of capital structure in the firm's financial management. It explores how the firm's choice of financing affects its risk profile and its ability to invest in growth opportunities. The paper also discusses the implications of capital structure for the firm's valuation and the wealth of its owners.

The third part of the paper focuses on the role of the entrepreneur in the firm's strategic management. It examines how the entrepreneur's vision and leadership influence the firm's strategic direction and its competitive advantage. The paper also discusses the importance of the entrepreneur's personal characteristics, such as risk-taking and innovation, in the firm's success.

Finally, the paper concludes with a discussion of the implications of the findings for policy and practice. It suggests that a better understanding of the relationship between the entrepreneur and the firm can help policymakers and managers make more informed decisions about the firm's financial and strategic management.

stops at one of the two fixed end points. Just on the way it should be preferably possible to interview the "director," whom I would rather call the "outrider," in so far as the mechanical control of the airplane is concerned. It is assumed that every attitude of the aircraft, air speed, altitude, engine speed, etc., is constantly adjusted by the automatic control.

Different opinions can be held regarding the value of the differentials and integrals developed by the lecturer. In this connection, what has become of the experimental coefficients, which are known to be always decisive in practice?

Moreover, I do not believe that any damping can be effected by "advancing the action of the controls." In my opinion, such a method would introduce into the motion of an airplane an inadmissible unsteadiness of several minutes (circular measure), which is entirely inconsistent with the sensitiveness of the control for "extreme steering economy" as mentioned by the lecturer.

In the latter part of his address, the lecturer admits that he could not succeed with over-control, but that "to a certain degree the airplane tends asymptotically to resume its original position." If I understand it correctly, this means a constant oscillation of the airplane, an over-control which is really inadmissible in practice.

As Mr. Boykow says, the "director" for the aileron machine

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is expected to keep the machine in the curve, but to keep the airplane itself in normal flight with respect to all other influences. He then continues: "In order to fulfill these conditions strictly once for all, a relatively complex instrument would be required." Herein lies the difficulty that every automatic control must at all times be regulated for every possible flight attitude. There is really no practical use for an automatic control, with which the aviator is forbidden to fly curves. His concluding sentence, in which he recommends the reduction of the sensitivity for long straight flights, may perhaps cause many of the initiated to shake their heads.

All in all we may judge the lecturer's invention as we wish. The pleasing fact remains that the principle of automatic aircraft control is making progress.

The following photographs will show that others have been working on this problem.

Figure 3 shows such an automatic control installed in an L.V.G. airplane. Even then it was my idea to invent a control, which was operated by a turbine gyroscope driven by the exhaust gases of the engine and which used, as the intermediate force, compressed air generated by a special propeller and rotary pump. This compressed air acted, according to the position of a gyroscopic horizon, on the control cylinders shown in the picture and thus actuated the corresponding controls. The lessons learned with this apparatus showed the need of making the whole

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

In the second section, the author details the various methods used to collect and analyze the data. This includes both manual and automated processes. The manual process involves reviewing each entry individually, while the automated process uses software to identify patterns and anomalies.

The third section describes the results of the analysis. It shows that there are several areas where the data is inconsistent or incomplete. These areas need to be investigated further to determine the cause of the discrepancies.

Finally, the document concludes with a list of recommendations. These include implementing stricter controls over data entry, improving the accuracy of the automated processes, and conducting regular audits to ensure the integrity of the data.

The following table provides a summary of the key findings from the analysis. It shows the number of entries that were found to be incorrect or incomplete in each category.

Category	Number of Entries
Incorrect Data	15
Incomplete Data	25
Missing Receipts	10
Unverified Entries	30

Based on these findings, it is recommended that the following actions be taken:

- Implement a double-check system for all data entries.
- Update the software to better detect and flag anomalies.
- Conduct a comprehensive audit of all existing data records.
- Provide training to staff on the importance of accurate data entry.

These steps are essential for ensuring the reliability and accuracy of the data used in the organization's operations.

steering mechanism as compact as possible.

Progress is shown in this respect in Figure 4, in which the ordinary hand and foot controls are joined with the automatic control, thus realizing an idea which I had had in mind from the beginning.

Figure 5 shows one phase of the development. The first practical flight tests were made with the apparatus here shown. These tests, which were conducted quietly for a year, led to the construction of the automatic apparatus shown in Figure 6.

As a result of the year's experience, I abandoned the hydraulic intermediate force as a means of control. As a turbine constructor, I held too long to the still common prototype of the servo-motors, which are now used to regulate such engines.

Figures 7-8 illustrate our present control apparatus. In this, I have set the chief value on the claim made by the lecturer for quick and unobstructed switching on and off of the automatic control, by simply pressing a button on the hand steering wheel. This is accomplished by switching on entirely independent electromagnet couplings as shown in Figure 7. The construction of the present apparatus is shown in Figures 8, 8a, and 8b. It is characterized by the independence of each individual control. Each control has a separate contact-making and releasing device, whereby a reversible motor rotates either to the right or left and its power is transmitted to the magnet armature. Only when the disk of the magnet armature is at-

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent and reliable data collection processes to support effective decision-making.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and reporting, thereby improving efficiency and accuracy.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies to mitigate these risks and ensure that data is used responsibly and ethically.

5. The fifth part of the document discusses the importance of data governance and the establishment of clear policies and procedures. It stresses that a strong governance framework is essential for maximizing the value of data while minimizing associated risks.

6. The sixth part of the document explores the role of data in strategic planning and performance management. It illustrates how data-driven insights can inform key business decisions and help organizations track their progress against strategic goals.

7. The seventh part of the document discusses the importance of data literacy and training for all employees. It emphasizes that having a data-savvy workforce is critical for organizations to fully leverage their data assets.

8. The eighth part of the document provides a summary of the key findings and recommendations. It reiterates the importance of a holistic approach to data management that encompasses all aspects of the organization's operations.

9. The final part of the document concludes with a call to action, urging all stakeholders to take ownership of their data and work together to create a data-driven culture that drives organizational success.

tracted as a result of the electric current, is automatic control effected. There is a practically very important device, namely, the end contact. This concerns a requirement which was not mentioned by the lecturer and which in practice is as important as the whole steering apparatus itself. The automatic control must never pull the control surfaces beyond their extreme positions, because this would break the control cables, and we can all imagine what the result would be.

The three remaining pictures (Figs. 9-11) show the present form of the automatic control. On the basis of my many years of experience, I have combined the apparatus in a single block (Fig. 9) with the normal foot and hand controls, so that the whole apparatus can be installed in any airplane with four screws and making the proper connections with the controls.

Figure 10 shows the whole assembly. It includes a wind-driven electric generator, a Pitot tube for elevator control, a storage battery, and one or more indicators, so built that the position or deflection of each control surface can be read from any desired point in the airplane.

Figure 11 shows the device installed in a large airplane.

In conclusion, I wish to thank the lecturer again for his address to us on a subject which is bound to have a great future.

Dr. H. G. Bader.— I am very much pleased that the speaker of the day has discussed the question of relieving the airplane pilot from the controls, a problem in which I have long taken a great interest.

I believe that we have found in the "director" described in the lecture the device with which it will be possible to solve the problem. I disagree with the lecturer, however, in the idea of applying the "director" exclusively to the altitude control. Bryan, who was the first one to devote himself successfully to the consideration of the stability of the airplane, distinguishes between inherent and automatic stability, in that the former is obtained by parts rigidly attached to the airplane, while the latter is obtained with the aid of servo-motors. In any case, devices can be employed for longitudinal control, with which an auxiliary wing, correctly located and dimensioned, can increase the inherent longitudinal stability.

Thereby the claim of the lecturer can be confirmed by making the damping so strong with respect to the reacting forces, that a very quick return to the position of equilibrium can be effected without passing through it again, i.e., the return process lies in the region between periodic and aperiodic motion. Therefore the return to the position of equilibrium will not be delayed by excessive overcoming of the damping.

The application of the "director" to the longitudinal stabilization does not therefore seem to be so urgent, since inhe-

rent stability can be easily attained. On the contrary, it seems to be of special importance for overcoming the natural instability about the longitudinal axis. The lateral stabilization through the use of a strong dihedral is impracticable, because of the disadvantages for the piloting.

Since the changing of the course can be most quickly effected by changing the inclination by means of the aileron control, the stabilization of the inclined position would simultaneously mean the steadying of the course, whereby it would not be absolutely necessary, as the lecturer mentioned, to use the compass as in the automatic steering of ships, but the speed difference between the inner and outer wing tips can be advantageously used for influencing the servo-motor.

It follows from the statements of the lecturer that we must in any case provide a return guide to prevent oversteering, as in the revolution-speed governors for engines.

I would therefore suggest the application of the "director" to the control of banked flight, since in this way the pilot can be entirely freed from the three controls and will thus be enabled to give his undivided attention to the problems of navigation and to watching the engines and will also be able to conserve the requisite energy for landing after long flights.

Through the inherent longitudinal stability the damping of the accelerations, which cause air sickness, would thereby be accomplished in the same measure, as through the automatic sta-

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bilization, for in both cases it is impossible to produce a retardation of like magnitude directly through the acceleration itself, but a quick damping of the acceleration can be effected only through the initiated motion.

Engineer F. Diemer.- In the choice of the reference values, the speed is designated as the suitable value for the altitude control. I have my doubts as to whether an automatic altitude control in the form of a speed stabilizer will satisfactorily accomplish the purpose in view.

The angle of attack is the decisive factor for preserving any desired condition of flight. In unaccelerated rectilinear flight a definite speed corresponds to the angle of attack, so that the former can be taken as the reference value for the preservation of the latter. In all accelerated flight conditions, this is not the case, however, wherefore an automatic control adjusted for a certain speed in curvilinear flight under some circumstances would produce angles of attack which are not desired.

In unaccelerated rectilinear flight, the simple speed stabilizer might afford security against undesired or dangerous flight attitudes, but in gusty weather it would allow the airplane to make motions, which would certainly not be agreeable to passengers with any tendency to airsickness. If a Pitot tube or air-speed indicator is used as the "director," the elevator deflection becomes a function of the differential quo-

tient of the speed with respect to the time and the airplane with aperiodically damped rudder motion kept constantly at the speed determined by the pilot. If gusty weather prevails, in which the air layers, traversed by the airplane, have different properties, the airplane will make curves in the vertical plane which will be disagreeable to the occupants of the aircraft, more disagreeable than by the present method of stabilizing, by changing the angle of attack, which is a function of the vertical parallel displacement of the airplane caused by the variations in the dynamic pressure.

A sensitive pilot will proceed as follows for obtaining agreeable motions, when the airplane is not near the critical angle of attack. If the airplane receives a gust from the front, it rises under the action of the increased lift and then drops back to its original relative speed. The pilot will first oppose this motion by pressure and will then return to the original dynamic pressure by very gradual climbing with timely damping of the motion. This process is reversed when the air speed decreases.

In order to ameliorate the motions in the longitudinal direction, the pilot must attempt to offset the disturbance with an elevator deflection in the opposite direction to that of the stabilizer corresponding to the speed change. This circumstance cannot be met by varying the sensitivity of the automatic control.

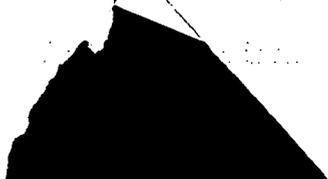
An automatic altitude control of a commercial airplane would therefore not only bring the dynamic pressure to a reference value, but simultaneously also two others, the spatial angle and the altitude, so that the motion of the controls produced by the speed variations will be counteracted as soon as the differential quotient of the spatial angle or the vertical speed exceeds a certain value.

I cannot say as to whether this combined action of three "directors" can be utilized without too greatly complicating the control mechanism. In this connection, I will call attention to the fact that in one case the automatic control, which depends entirely on variations of the dynamic pressure, offers the best solution, when the shortest climbing time is desired.

H. Boykow (concluding remarks).-- Mr. Drexler criticises me for having made too few conditions to be fulfilled by the control machine. In reply, I can only say that, to preserve order in a country, a thousand and one laws can, of course, be made, but that the quintessence of all the thousand and one laws can be condensed into the Ten Commandments, and that these Ten Commandments can be embraced in the one great commandment, "Thou shalt love God above all else and thy neighbor as thyself."

Mr. Drexler also criticises the lack of a limiting position. I expressly stated in my lecture that the connection between the controlling mechanism and the controls must be only provisional, in order to allow the pilot to take personal charge

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of the controls at any moment. The question of the limiting position is fully covered by this provision. I further stated expressly that, along with the speed regulation, any other regulations of the steering machine could be made, which affect the vertical motions and which can be modified to meet the requirements. Mr. Drexler thinks he found proof in my lecture that the device would over-control. You have all seen that it aperiodically damps the oscillations of the balance beam, and I expressly stated that the motions of the indicator were three times as great as the actual motions.

Mr. Drexler also seems to have entirely misunderstood what I said on curvilinear flight, when he comes to the conclusion that curves cannot be flown with this machine. That curves can of course be flown was expressly stated in my lecture.

Mr. Bader thinks the altitude control is not the most important, since there is inherent stability about the transverse and longitudinal axes. This is correct for the present airplane type, but may change, since this inherent aerodynamic stability is obtained at a rather high cost. That the lateral stability can also be combined to a certain extent with the directional stability follows from the control regulations, according to which lateral stability can be obtained both by the rudder and by the ailerons.

Mr. Diemer objects to the reference bases, the one for the altitude control being the air speed. He thinks there is a critical angle of attack, beyond which the stability almost instantly ceases and that, when the airplane is near this critical angle and has its speed increased by a gust, this critical angle would be exceeded by the control machine. In answer to this objection, I would call attention to the fact that this critical angle is prevented in advance, since it is considerably lower than the stabilizing angle of attack. Mr. Diemer also thinks that such a case can occur only just before landing. Here I may remark that any pilot who is not at his post just before landing, but who is perhaps enjoying a cup of coffee in the cabin, is at least very remiss in his duties.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

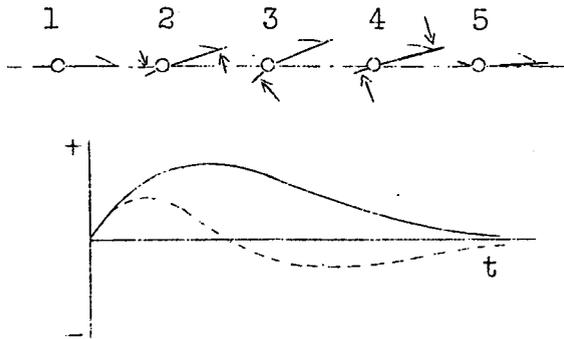


Fig.1

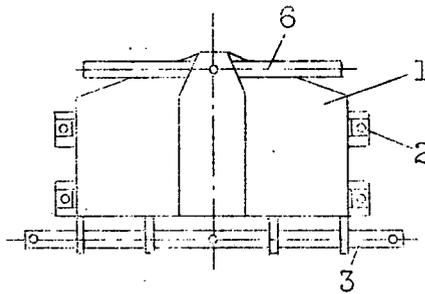


Fig.8a

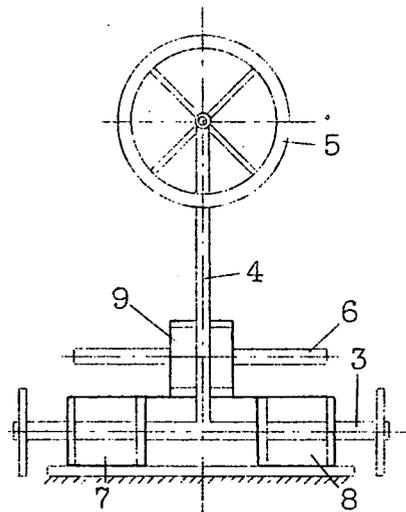


Fig.8

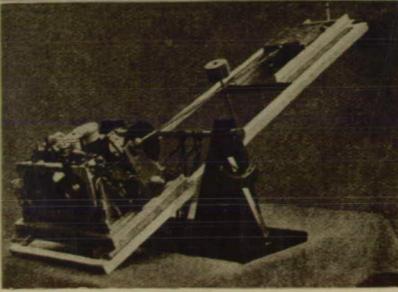


Fig. 2 Control mechanism

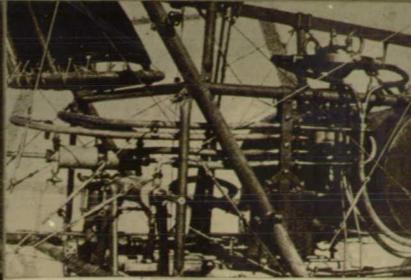


Fig. 3

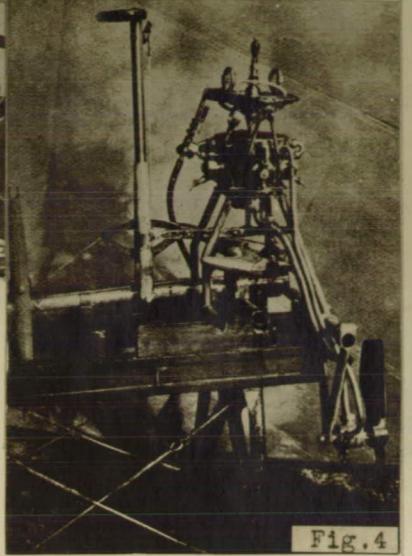


Fig. 4

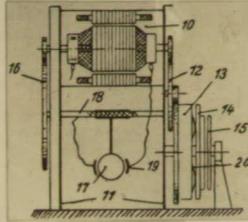


Fig. 8b

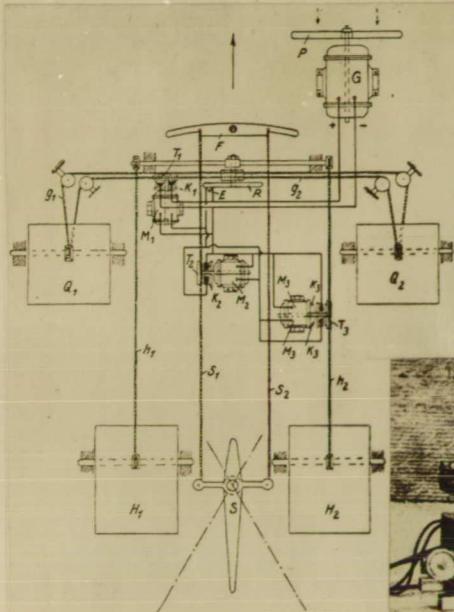


Fig. 7

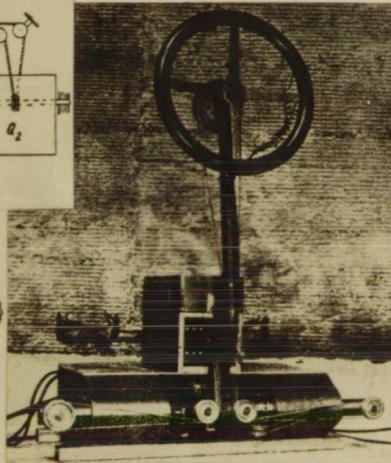


Fig. 9

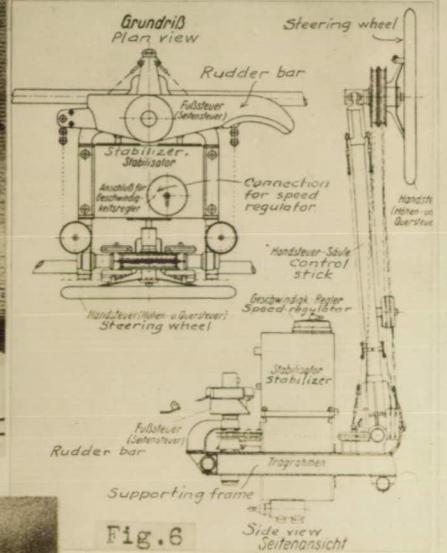


Fig. 6

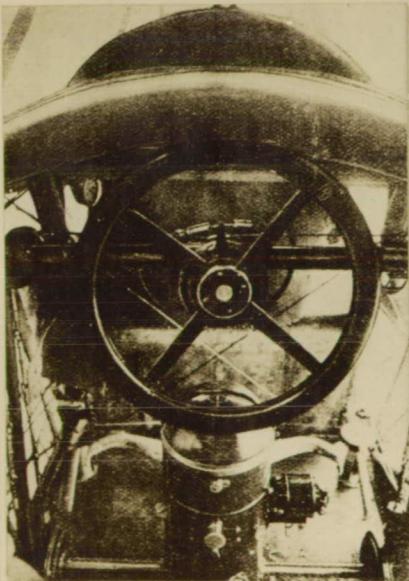


Fig. 5

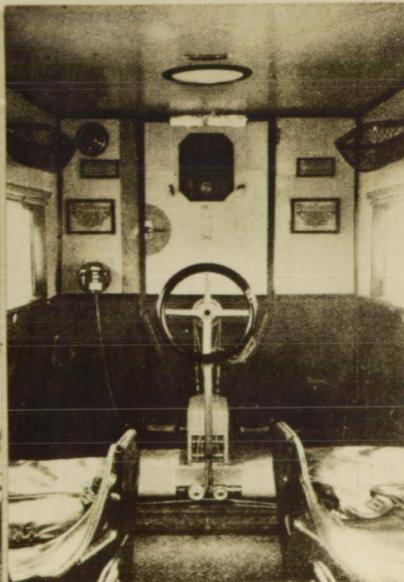


Fig. 11

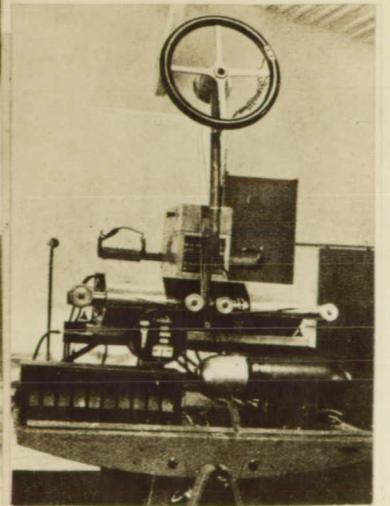


Fig. 10