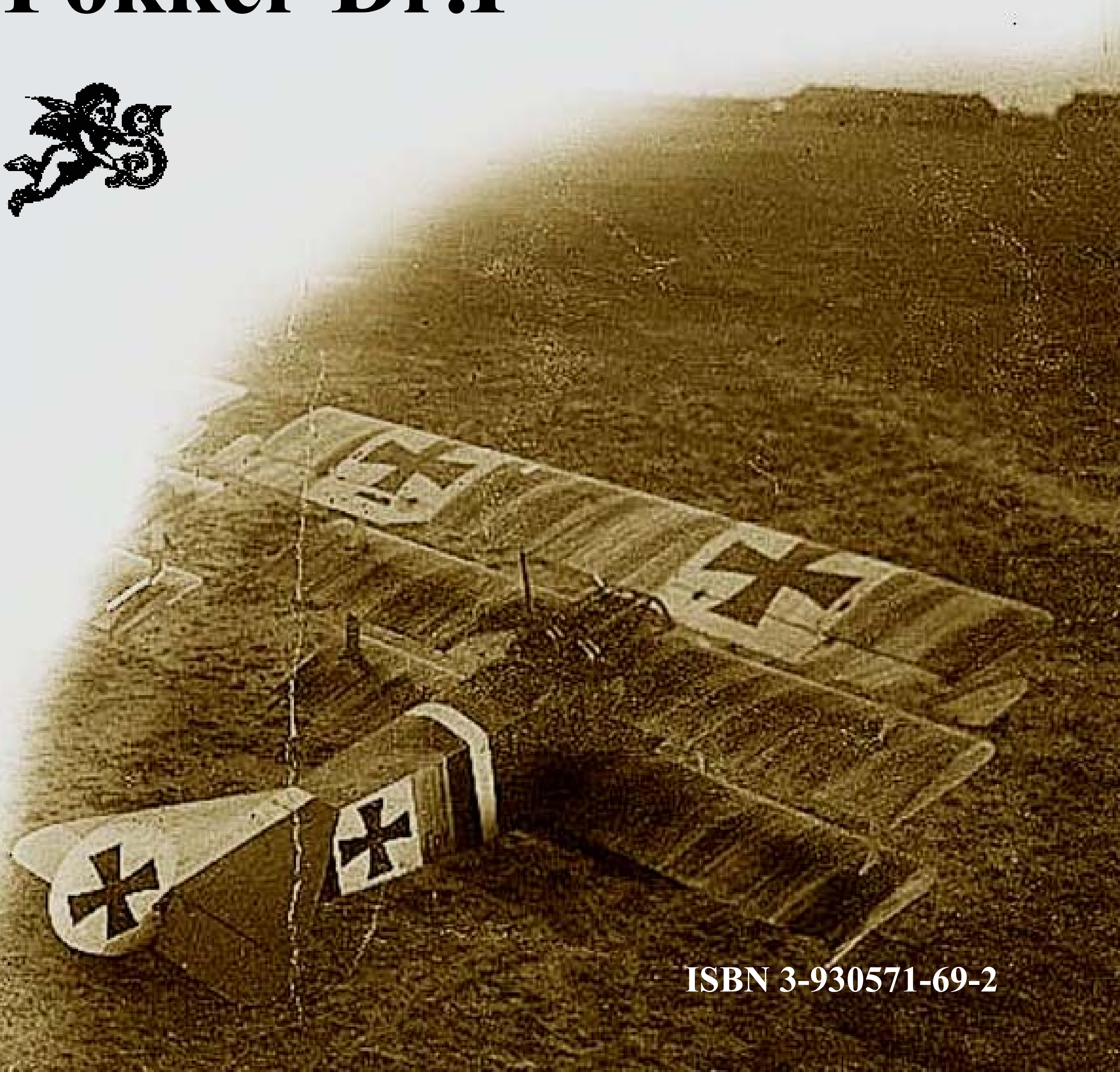
DEUTSCHE FLUGZEUGTECHNIK 1900 – 1920

Achim Sven Engels

Treatise on the aerodynamics of the Fokker Dr.I



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Treatise on the aerodynamics of the

FOKKER DR.I

of the year of war 1917

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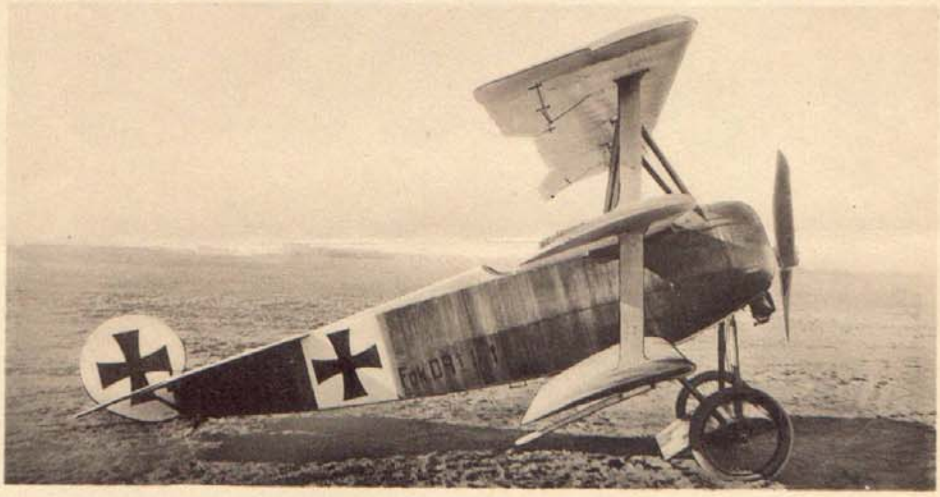

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Introduction to commence

The Fokker-Team-Schorndorf will produce a new series entitled

'GERMAN AIRCRAFT TECHNOLOGY 1900-1920'

intended to make the results of their research available to all interested groups. The primary focus of this series will be technical aspects of German aeronautics.

There will be both books that deal exclusively with technical descriptions of airplane structures and books that deal with other technical aspects of aircraft or aspects that were used in the operation of the aircraft. While the historical development of German aeronautics is not of major interest here, it is not completely ignored.

We very much hope that this series of booklets will be of interest to readers and that it will eventually come to be found in all libraries interested in aeronautical technology. In this meaning we wish these little deeds much success.

To be able to understand the topic which is to be discussed here a certain understanding of basic information is necessary. Since we cannot assume that all of our readers have an understanding of the basics of aerodynamics, we must start with a simple introduction to them. Where needed, our sample calculations will be related to the Fokker Dr.I.

However, many of our readers will already be familiar with the science of fluid mechanics (mechanics of flow) so, in order to retain their interest, we will use a little trick.

Since the Second World War there has been a great deal of development in the understanding of fluid mechanics and, in particular, in the design of the formulæ used in the calculation of different forces acting on bodies under the influence of flow. At the beginning, the designers at the aircraft manufacturing companies as well as the scientists at the evaluation Centers in England, France, Germany and other nations did the work themselves and used many different formulae and different literal notations to describe such simple conditions like average air density or the coefficient of drag. However, they have come together more closely after the Second World War and developed more regulated and standardized literal notations to be used by all. For sure the basic calculations did not experience such a great amount of change, however there have been added many more helpful calculations since then.

So that it will not get too boring for those of our readers who are experienced in this field of calculations we will go and strictly use those formulae that has been common in those days during the First World War among German aircraft designers. This way, not only does the layman learn the basic knowledge of aerodynamics, but the expert still learns at the same time some little historical facts about how these calculations had been executed during and after the First World War. As previously stated, sample calculations shall be related to the triplane in particular.

This treatise shall not represent any comprehensive calculation of the triplane aerodynamics, but should enable the interested reader after its study rather to carry out the necessary calculations for most different flight situations in which he is particularly interested and to create the required diagrams himself.

Author´s Acknowledgements

The Author – that's me – wants to keep this one brief. There are only a few people whom I wish to thank for their help with the development of the English edition of this book. First of all, my good friend Bil Hardenberger who is closely working with me on many of the illustrations given here. The other ones are Bill Broussard, Brad Smith, Darryl Hackett, Paul S. Leaman, Lloyd Leichentritt and Rockland F Russo. These have been so kind to provide their service of proof reading that book or parts of it to make it even more enjoyable by you – the reader.

1. The Forces of the Air and the Air Resistance

1.1. The Air Pressure

Castelli Evangelista Torricelles (*15.10.1608 +25.10.1647) befitted on recommendation of his teacher to *Galilei* in 1641 and eventually became his successor as a court mathematician of the grand duke of Tuscany.

During this time *Torricelles* occupied himself with studying the behaviour of different substances and investigated what happened if they were exposed each on one another to mutual pressures. He found that a piston filled with mercury could run dry only to a certain degree, if it is put into a vessel upside down, as long as no air was allowed to flow into the piston, even if he lifted the piston from the bottom of the vessel as long as the piston edge was in the mercury still. He inferred from this that the surrounding air applied a pressure to the mercury remaining in the piston. He also noticed that over time the height of the mercury varied slowly in the piston. Therefore he assumed that the surrounding air pressure must have been changing. All other liquids also exhibited the same behaviour. He called his instrument the barometer.

One therefore understands the pressure by the name air pressure, which the atmospheric air exerts on a certain area. Under normal conditions the air pressure is 1.036 kg/cm² at sea level. You can best explain this to yourself by imagining a hollow body pumped out to reach vacuum. A pressure of 1.036 kg/cm² is exerted on the outer surface under these circumstances. The expression "**at**" became an abbreviation for the measurement unit of kg/cm² or "atmosphere" imported written out. The normal average air pressure therefore amounts to 1.036 at.

The common measure for the measuring of the air pressure is the height of the column of mercury in the barometer. Torricelles made up his mind for the following reason to use the medium mercury. Since the specific weight of the liquid metal mercury is 13.60 kg/l or 13.60 kg/dm^3, consequently the total weight of a column of a cross section 1 cm² and a height of 762mm is exactly 0.01 · 7.62 · 13.60 = 1.036 kg. This in turn is exactly the air pressure, which acts on 1cm² of an arbitrary area. So the barometer reading lies with 1 at surrounding pressure at 762 mm. If the air pressure relieves, which has an effect on the mercury, the reading changes in the column accordingly.

Since the density of the air is of special significance for flying we do come to mention the three major laws of the air density for calm or evenly busy air here.

1. The density of the air always is of equal value in every layer of air, although this must lie spatially for places far separated from each other.

2. With increasing height of the layers of air the air pressure decreases almost evenly.

3. The decrease of the air density is immediately connected with the respective ground lever temperature and the decrease of the temperature with increasing height.

The amount with which the temperature at increasing height falls is called "gradient of temperature". His quantity is 0.5 degrees Celsius at 100 m each approx., but lies with a considerable certainty between 0 degrees Celsius and 1 degrees Celsius.

It still is remarked here that the decrease of the air density grows with the quantity of the gradient of temperature and is also all the bigger the less the ground level temperature is accepted.

Of course it is not to be assumed that the barometer reading will be 762 mm in the column on the ground. It varies from time to time and from place to place in considerable measure. The influence of the barometer reading at ground level is of rather subordinate significance to the decrease of the air density with increasing height however.

Under the premise that the air is an "ideal gas" having the gas constants R = 29.24 (this calculates by the quotient of the pressure by the volume and the absolute temperature) there have been calculated theoretical tables which indicate the air pressure in mm of column of mercury for different ground level temperatures and gradients of temperature. See table No.1.

Using these purely theoretical calculations it is possible to use the decrease of the air pressure for the measuring of the altitude by reading a calibrated barometric scale. Since the air density however – as already mentioned above - depends on several factors and anyway very much fluctuates, the specification of the barometric height scale is based on relatively unsafe assumptions of the gradient of temperature, the ground level temperature etc. Therefore these “measurements” can be considered to merely be sufficiently exact estimations.

The density of the air has an immediate influence on its specific weight. One also talks about the volume of the air. We understand here the weight of a defined unit of the gas "air" by it. As a rule, the unit of the volume, which is used for calculations, is m^3 accompanied by the weight unit of kg. As a common expression for the volume of a substance is the Greek character of “*γ*“ (Gamma.)

Table No.1

Air pressure in mm of column of mercury for heights of 0 to 8000 m at different ground level temperatures and gradients of temperature

Altitude in Meters	Temperature at Ground Level 0ºC			Temperature at Ground Level 10ºC			Temperature at Ground Level 20ºC		
	Temperature at every 100m:			Temperature at every 100m:			Temperature at every 100m:		
	0ºC	0,5ºC	1ºC	0ºC	0,5ºC	1ºC	0ºC	0,5ºC	1ºC
0	762	762	762	762	762	762	762	762	762
1000	671	671	671	675	675	674	678	677	677
2000	593	590	587	598	596	593	603	601	598
3000	523	517	512	530	825	519	537	532	527
4000	462	453	443	470	462	452	478	470	461
5000	407	395	381	416	405	392	425	414	402
6000	359	344	326	369	354	387	378	364	348
7000	317	298	277	327	309	288	337	319	300
8000	280	258	233	290	269	245	300	279	256

The specific weight of the air at a surrounding temperature of 10 degrees Celsius and a barometer reading of 762 mm is exactly 1.252 kg/m^3. The volume of the air can be seen in immediate dependence with the temperature and the air pressure.

A.) Change of the Atmospheric Pressure

If the atmospheric pressure changes, then the volume of the air changes itself also proportionally to this. If the volume of the air is 1.252 kg/m^3 under the conditions just mentioned above, then the volume of the air decreases as soon as the pressure falls. So, what is the volume of the air at a temperature of 10 degrees Celsius and an atmospheric pressure of 567 mm of column of mercury? This simply can be calculated. One must multiply merely 1.252 by the ratio 567:762. Therefore 1.252 · 567:762 = 0.932 kg/m3. From this we also can derive the first formula for the calculation of the volume of the air by using the variable "***b***" for barometer reading (column height of mercury). We have the following equation with that:

$$\tau = \tau_1 \cdot (b : 762)$$

Here τ_1 describes the specific weight of the air at 10 degrees Celsius and 762 mm height of column of mercury.

B.) Change of the Temperature

As soon as the temperature changes, the volume of every substance, as the air, also changes itself inevitably. We can explain this as: expansion is caused by the increasing oscillation of the single atoms with increasing temperature and therefore less of the substance will fit into one m^3 as the fixed unit. The so-called expansion coefficient of the air for 0 degrees Celsius lies around 1/273. Any air volume therefore enlarges at the heating of 0 degrees Celsius to 1 degrees Celsius at 1/273 portion of the former volume.

The volume of the air is τ_1 at +10 degrees Celsius.

How does the volume change at the same barometer reading and an increase of temperature on 20 degrees Celsius? An air quantity that has the volume of $1m^3$ at 0 degrees Celsius will change the volume at 10 degrees Celsius to 283/273 m^3 = 1+10/273 and 293/273 m^3 and at 20 degrees Celsius accordingly to 1+20/273. In the same term the volume of the air at different temperatures changes, the weight changes, too. If is assumed that τ_1 is the value at 10°C, then it is for 20 degrees Celsius the following:

$$\tau = \tau_1 \cdot (283 : 273) = 0.966\ \tau_1$$

This would be in general for the temperature:

$$\tau = \tau_1 \cdot (283 : (273+t))$$

The two orders just listed can also without further ado be summarized in a formula:

$$\tau = \tau_1 \cdot (b : 762) \cdot (283 : (273+t))$$

The volume of the air for every arbitrary height and the individual gradients of temperature and ground level temperatures finds its respective volume of the air under consultation of the values given in table No.1 and can be calculated with this formula.

However, one must keep in mind, that the data that were charged to table No.1 merely have been calculated theoretically. These, as said, have therefore not to be inevitably correct at 100 percent. For the gradient of temperature of 0.5 degrees Celsius per 100 m of increasing height the results are represented in table No.2.

One understands the density of the air is the quotient of its volume by the gravity g = 9.81 m/sec². Under the prerequisite that the temperature is 10 degrees Celsius and the barometer reading amounts to 762 mm the density of the air is $\tau_0 : g$ = 1.252 : 9.81 = 0.128, that is 1/8. The value 1/8 is the mean average value set for the density of the air on ground level. The density of the air relieves to almost about the half in larger heights. The letter "*m*" will be set for the quotient $\tau : g$ in the following calculations. For the aerodynamics and its calculations the variability of the composition of density of the air always is of outstanding importance.

Table No.2

Volume τ in kg/m³ and the density $m = \tau : g$ for heights to 8000 m at a ground level pressure of 762 mm of column of mercury and a gradient of temperature of 0.5 degrees Celsius per 100 m

Altitude in Meters	Temperature at Ground Level 0ºC			Temperature at Ground Level 10ºC			Temperature at Ground Level 20ºC		
	Tempe-rature	τ	$\tau{:}g{=}m$	Tempe-rature	τ	$\tau{:}g{=}m$	Tempe-rature	τ	$\tau{:}g{=}m$
0	0°C	1,298	132	10°C	1,252	128	20°C	1,210	123
1000	-5°C	1,165	119	5°C	1,129	115	15°C	1,094	112
2000	-10°C	1,044	106	0°C	1,015	104	10°C	988	101
3000	-15°C	933	95	-5°C	911	93	5°C	890	91
4000	-20°C	833	85	-10°C	816	83	-0°C	800	82
5000	-25°C	741	76	-15°C	730	74	-5°C	719	73
6000	-30°C	658	67	-20°C	651	66	-10°C	644	66
7000	-35°C	583	59	-25°C	579	29	-15°C	575	59
8000	-40°C	515	53	-30°C	514	52	-20°C	513	52

Related to a ground level temperature of 10°C and a gradient of temperature of 0.5° per 100 m of increasing height we are able now to establish the following average values to appear for heights to 8000 m as rough guidelines:

Height in Meters	1000	2000	3000	4000	5000	6000	7000	8000
Density in %	90	81	73	65	58	52	46	41

1.2. The Impact Pressure

The orders listed in section 1 for the variability of the atmospheric pressure in different heights apply to both resting and monotonously busy air. For our work here other than steady motions of the air are not to be considered. It should be mentioned here that there are also nonuniform motions, which of course also have influence on the aerodynamic qualities of an object. One also talks about turbulences. These nonuniform motions of the air appear in the immediate proximity of objects, which are moved through the air. This can be explained by the fact that the particles of the air that waft over the objects surface have to follow the surface at full speed or have to avoid the objects. This subsequent movement disappears with increasing distance from the objects because of the friction between the individual atoms in the air. For this reason there appear turbulences (nonuniform motions) in the air next to the object moved through it.

Hand in hand with this uneven speed distribution between the air particles at increasing distance from the object goes a change of the atmospheric pressure. A constitution of the mechanics forms the connection between these pressure and differences in speed:

$$\textbf{\textit{Force = Mass · Acceleration.}}$$

How this all is linked we will take a look at in the following formula?

If one imagines for example a uniform flow of several air particles succeeding one another at an even acceleration passing the path $AB = l$, one can calculate the force, the mass and the acceleration of the air particles.

The pressure in point A is $\boldsymbol{p_1}$ the pressure in B is $\boldsymbol{p_2}$. The speed of the air particles is $\boldsymbol{v_1}$ in A and $\boldsymbol{v_2}$ in B. We describe the average cross-section of the airflow as an $\boldsymbol{f}$.

The force $\boldsymbol{p_1 \cdot f}$ acts into the direction of motion and the force $\boldsymbol{p_2 \cdot f}$ works contrary to the direction of motion. From this results that the **force** of the air particles looked at has to be calculated from $\boldsymbol{(p1 - p2)\cdot f}$.

The **mass** of the air particles of the airflow can be derived from $\boldsymbol{m \cdot f \cdot l}$, $\boldsymbol{m}$ just because this describes the air density of the unit.

We describe the increase of the speed as an **acceleration** in the time unit. We equate the average speed for $(v_1 + v_2):2$, now results from this the time out of the quotient path/speed = $l:([v_1 + v_2]:2) = 2l:(v_1 + v_2)$ and the acceleration therefore is:

$$\boldsymbol{(v_2 - v_1) : (2l : [v_1 + v_2]) = (v_2^2 - v_1^2) : 2l .}$$

We multiply this expression by the mass of the air flow $m \cdot f \cdot l$ then we get the form $m \cdot f \cdot ([v2^2 - v1^2]:2)$. Now, if we equate $(p1-p2) \cdot f$ this product from mass · acceleration of the resulting force, then the cross section *f* of the air flow falls out of the equation and we have:

$$p_1 - p_2 = m \cdot ([v_2^2 - v_1^2]:2) = m \cdot (v_2^2:2) - m \cdot (v_1^2:2) .$$

From the derivation of this formula we see that the difference in pressure between two points is as large as the difference of the product of density and half speed square. With this order the speed also can be measured relative to the "resting" air by a so-called concentration device. The force of pressure of the incident air is measured compared to the surrounding pressure. By:

$$p2 - p1 = m \cdot (v1^2:2),$$

can be charged the sought-after speed v_1 now. This equation is correct under the condition that before for $v_2 = 0$ was put, assuming that the air rests in point B.

For the product very frequently appearing in the aerodynamics from the air density and half the speed square one has already soon introduced a name of its own. One calls it the impact pressure and abbreviates it into calculations with the letter ***q***. Therefore be always valid:

$$q = m \cdot (v^2:2).$$

Since ***m*** is the mass of the unit one also can describe the impact pressure as the "live" force of the "unit" air. As the atmospheric pressure is measured in kg/m^2 the impact pressure is correspondingly measured in weight per area unit, in kg/m^2.

It perhaps still should be said as an additional remark here that the impact pressure q is at a speed of 40 m/Sec. (144 km/h.) and a normal air density of 1/8, (1 : 8) · (1600 : 2) = 100kg/m^2, for example.

The impact pressure can also ascertainably be explained by a graphic consideration. One imagines only an object that is moved by the air. Will there be a point at which the speed of the air particles is 0 and these are divided and orbit the object at his front. This one on this point arising overpressure is the impact pressure being part of the speed of the object, *q*.

We can now go on and include ***q*** into the equation $p_1 - p_2$ for the calculation of the differences in pressure. In this case we will get;

$$p_1 - p_2 = q_1 - q_2$$

or

$$p_1 + q_1 = p_2 + q_2.$$

In turn this means that the sum of atmospheric pressure and impact pressure is the same at any old place of the air flow we imagined before. One can speak of a constants as a sum of impact pressure and atmospheric pressure generally because:

The bigger - at any place - the speed is and with that the impact pressure increases, the lower the atmospheric pressure gets. The same order is valid in the opposite direction.

(This is also the reason for the formation of a negative pressure at the top side of the cambered wing and an overpressure at her underside.)

1.3. The Air Resistance

As soon as an object is moved through the air, everybody can notice easily by himself that a force that is judged contrary to the direction of motion gets noticeable. This phenomenon very simply can be explained.

On the surface of the object that is facing towards the direction of motion, the particles, which are flowing around the object, get “jammed”. This jamming results in an increase of drag, which wants to reject the direction of motion. This is an enlargement of the impact pressure, which is one overpressure. A negative pressure forms on the back of the object.

A force results from these two different quantities oppositely to the direction of motion, the so-called "air resistance". The air resistance is marked by the letter *"W"* and also measured in kg/m ^{2}.

For the calculation of the air resistance ***W*** that has an effect on a busy wing the following equation comes to the application:

$$\text{a.)}\quad W = z \cdot m \cdot F \cdot v^2$$

The respective letters stand for the following conditions in this calculation:

W = air resistance in kg/m ^{2},

z = coefficient of drag (so-called abstract number or coefficient),

m = average value of the air density (normally 1/8),

F = front surface of the object,

V^2 = speed in the square.

We would like to discuss the individual constituents of this formula and explain their consequences hereinafter.

The coefficient of drag ***z***

The coefficient of drag ***z*** is an unnamed quantity of the air resistance, which is only dependent of the shape of the object that is moved through the air, and of its section and the composition of its surface.

For it the question how far it has to be looked at in dependence of air density, the front view of the object and the speed of the air particles wafting over arises.

Change of the air density

The coefficient of drag does not change if only the density of the air changes and or else all other values remain the same.

Change of the front view

The shape of the object remains unchanged and its size is reduced, the value *z* of it remains untouched so if the speed increases in the relations upside down to the reduction of the object (rule of similarity). One can make use of a simple example to clarify around this circumstance. One takes a ball of 10 cm of diameters and moves it with a defined speed through the air, this has a certain coefficient of drag so. It has the same coefficient of drag as the large ball if one makes this ball half size, therefore 5 cm in diameter, if so the speed is extended in the ratio upside down therefore is twice as high.

The structure of the surface of the object does not change at the reduction, though, the coefficients of small models always turn out so a little more unfavourable than at the actual wings since a rough surface falls of course less into the weight at larger objects if reduced as at the models.

Change of the speed

If only the speed is changed, with which the object moves due to the air, *z* changes to the effect so that, the speed from zero gains gradually, it at first reduces in itself, then gains again to decrease first slow then faster, to keep a roughly constant quantity then again and soon he approximately keeps this one to approximately 100m/Sec. and which noticeably grows only after this to approx. 300m/Sec. again. Cf. point 1.5. Drag and Other Forces of the Air.

The average air density ***m***

It should be clear for everybody that the respectively ruling air density also has an influence on the size of the air resistance. The greater the density of the air, the higher the resistance that it brings to an object that is moved through it. This value is – as has already been said - depending on both, the immediate section of the object and its speed.

Restricted validity only has the equation of drag under a.), since it presupposes that the coefficient *z* of an object has a constant quantity. We can see that this is not at all so just said from this. If z is not constant but grows proportionally to the speed, for example on, results from this that *W* does not raise to the square of the speed but to the third power.

Since the coefficient of drag *z*, however, remains roughly constant in the speed ranges between 20 m/Sec. (72 km/h.) to 100 m/Sec. (360 km/h.), the formula a.) permits itself to be used in aerodynamics practically. Speed ranges about this are considered anyway only for the modern aerodynamics or ballistics.

The drag coefficient ***C***

Instead of the coefficient of drag *z* is often used the so-called drag coefficient *C* used for calculation formulas. What the drag coefficient *C* is, which advantages it brings to us and how it is used we want to make clear to us now.

If we liked to put the impact pressure *q* into our formula a.), then we can surround the formula as follows: $W = 2z \cdot q \cdot F$. Or we write:

b.) $$W = C \cdot (q:100) \cdot F.$$

The capital letter *C* means nothing else but *200 z*. Now one employs formula b.) instead of a.) for two reasons.

We have seen on one hand, that at tests the speed *v* is never measured but merely the impact pressure *q.* If one wants now to get the speed *v*, one first have to find out the air density *m* so to calculate the desired speed *v* from *m* and *q* after that. If a test only was made to figure out the size of the coefficient of drag *z* now, however, or what is the same, the drag coefficient *C=200z,* it is superfluously to calculate *v* first. It suffices to take the size of the resistance as measured during the test and to divide this one by the 100th portion of the impact pressure and the size of the front view of the examined object. According to the formula b.) the quotient provides the size of the sought-after quantity of *C*.

On the other hand, the drag coefficient C also can be awarded a plastic meaning. In section 2 of this book we have fitted in as a remark that the impact pressure q for the speed of 40 m/Sec. has exactly the value 100 at 1/8 air density. The drag coefficient C is therefore the air resistance being allotted to the area unit at the speed 40 m/Sec. = 144km/h. and normal air density. The quantity of the air resistance ever generally gives area unit *to* C in percent of the impact pressure. For example: $z = 0.3$, $C = 60$ means that the air resistance of the object at $m = 1/8$ and $v = 40$ *m/Sec.* is 60% of the impact pressure. One also can derive from the said that C, like also z are dimensionless quantities and are therefore independent of the chosen measurement unit used to carry out the measures. They are therefore also described as unnamed quantities. With these we get to work here will not result in C higher than 100 in most cases.

The harmful area of an object

The idea of the harmful areas shall manage to achieve a greater vividness of the air resistance of the different objects.

An object which is streamlined formed or covered has a considerably more favourable coefficient of drag z, than a flat plate which is moved through the air of course. However, one can go and calculate the size of the so-called “harmful area” of any object of any shape that is moved through the air. This “harmful area” means nothing else but the area of a flat plate that is moved through the air at an angle of attack of 90° that produces the same amount of drag as the actual body moved through the air. Not presupposed for such a disk its form does differ from that one of a circle or square considerably, the value z amounts to a quantity between 0.6 and 0.7, what results in an average value of 0.65. The actual air resistance of every object can be explained by that one of such a plate now. For its determination one introduces an imaginary area with the coefficient 0.65 to the equation of drag a.) instead of the front view of the object with the coefficient z. If we call f the size of the harmful area we will have the following formula: $0.65\, f = z \cdot F$ or $f = (z \cdot F):0.65.$

Example: Has a cylindrical bar with the diameter 2 cm and the length of 1 m an actual front view of $0.02 \cdot 1.0 = 0.02$ m² and a coefficient of $z = 0.5$. What size in this case is his harmful area? So one puts:

$$f = (z \cdot F):0.65 = (0.5 \cdot 0.02):0.65 = 0.015\ m^2.$$

The equation of drag a.) so can be remodelled once more now and is under consideration of the harmful area f now:

$$W = 0.65 \cdot m \cdot f \cdot v^2.$$

If we now include the average air density $m = 1/8$ in this formula, we will get as a final result:

$$\text{c.)}\quad \boldsymbol{W = 0.08 \cdot f \cdot v^2.}$$

To find the size of the harmful area *f* of an object, it is absolutely required to know the coefficient *z.*

1.4. The Air Resistance of Different Body Shapes

Differently arranged objects have different aerodynamic coefficients. How immensely significant the aerodynamic quality of single body shapes for the aerodynamics is can best be explained with a simple example.

We compare the qualities of cylindrical interplane struts with these of aerodynamically better struts of a drop shaped crosscut here now.

For this instance we make use of a two bay double-decker. This aeroplane has altogether 8 equal struts between his two main planes. We imagine these struts with a length of 1.5 m and a thickness of 5 cm. The front view of each of these struts is 1.5 · 0.05 = 0.075 m². With that we want the speed of the aeroplane to accept with 40 m/Sec. (144 km/h.).

A.) Qualities of Cylindrical Struts

For long circular cylinders was in extensive series of experiments (Eiffel, Prandtl) the coefficient of drag *z* = 0.5 and the drag coefficient *C* = 100 certainly. So the air resistance of one of our imaginary struts can be calculated as follows according to the formula a.): . for *W = 0.5* · 1/8 · 0.075 · 40 · 40 = 7.5kg this means gathered up *W = 8 · 7.5 = 60kg* for all 8 struts.

One still can calculate quite simply, how many hp of the engine output is necessary to overcome this resistance at v = 40 m/sec. The performance is 60kg · 40m/Sec. = 2400kgm/Sec. We know that 1PS = 75kgm/Sec. The necessary propeller thrust is 2400 : 75 = 32PS to overcome the resistance. Since about 30% of the engine output in the propeller are, however, lost and only 70% of the engine output are available therefore, the actual necessary engine output to the overcoming of this resistance is 32 · 0,7 = 45,7PS. Which influence this would exert on the efficiency of the aeroplane is clear. This makes little that way if at all no sense.

B.) Qualities of Drop Shaped Struts

The aerodynamically most favourable form for the cross-section of a strut lies with a ratio length/width of between 3:1 and 2:1. The tubular steel struts used at the Fokker Flugzeugwerke G.m.b.H. for the production of the cabane struts and undercarriage struts had a length/width ratio of 54 mm: 22 mm = 2.45:1. With these we also want to carry out our sample calculation. Series of experiments were also with struts carried out of drop shaped crosscut. For the ratios 2:1 coefficients were investigated of *z* = 0.08 to *z* = 0.05. Therefore *z* is valid on average 0.065. Since our struts do not have the ratio 2:1 but a little more favourable ratio of 2.45:1, we can ponder well at 0.5 and calculate *z* also with that.

So we take our two bay double-decker again and replace the cylindrical struts by the new ones with drop shape. We can save us a renewed arithmetic and assume that, 10 times, the final result is less than in the previous case, especially since the coefficient of the objects lies 10 times smaller than the one of the perfectly circular shaped. The required performance effort does not amount to 45.7 hp but only still to 4.57 hp now any more either and remains within the bounds of the acceptable thus well with that.

Everybody can comprehend as it is importantly to take care at the conception of an aeroplane that all surfaces lying on the outside are formed as favourably as possible. The efficiency of the aeroplane can be optimised only in such a way. Much otherwise is given to the engine output available.

With the help of the details on the cross-sections of the tubular steels made above one can charge the efforts consumed by the air resistance of the cabane struts and the undercarriage struts of the Fokker Dr.I at different airspeeds now.

Cabane struts:

Every cabane struts of the triplane consists of two braces of drop shaped tubular steel. They go from the top edge of the upper fuselage longeron to only just under the underside of the upper wing. This corresponds to a construction height of approx. 870 mm. The cabane struts in addition are moved by 450 mm to the outside at the top so that the strut length can be calculated to $870\ mm^2 + 450\ mm^2 = 978\ mm^2$. The length of the brace that is exposed to the stream of air therefore is 978 mm. Its front view area is $0.022 \cdot 0.978 = 0.0215\ m^2$. The total front view area of the braces is therefore $4 \cdot 0.0215 = 0.086\ m^2$.

The harmful area of the Center cabane struts calculates as follows: $f = (0{,}05 \cdot 0{,}086){:}0{,}65 = 0{,}0066 m^2$. This one arises under use of the equation of drag c.), at v = 40 m/sec., air resistance with the following quantity to be overcome:

$$W = 0.08 \cdot 0.0066 \cdot 40 \cdot 40 = \underline{0.845 kg}.$$

Therefore is a resistance of 845 g of the Center cabane struts to overcome. We calculate the required engine output the way we did in our example.

Performance:	0.845 · 40 =/33.79 kgm sec..
Required propeller thrust:	33.79 : 75 = 0.45 hp.
required engine output:	0.45 : 0.7 = <u>0.644 hp</u>

Undercarriage:

The braces of the undercarriage go from the bottom edge of the lower fuselage longerons down to the so-called undercarriage knies. Since the undercarriage fairing covers the lower part of the tubes, a construction height of 750 mm results from this. The braces are moved also here to the outside, by 220 mm in this case. The length of the brace in the wind therefore is 750 mm of ²+ 220 mm ² = 782 mm ².

The harmful area for a brace:

$$f = (0{,}05 \cdot 0{,}017):0{,}65 = 0{,}00132m^2.$$

For all 4 undercarriage legs 0.00132 · 4 = 0.00529 m ². Air resistance at 40 m/sec.:

$$W = 0{,}08 \cdot 0{,}00529 \cdot 40 \cdot 40 = \underline{0{,}677kg}.$$

Performance:	0.677 · 40 =/27.08 kgm sec.
Propeller thrust:	27.08: 75 = 0.36 hp.
Engine output:	0.36: 0.7 = <u>0.514</u> <u>hp.</u>

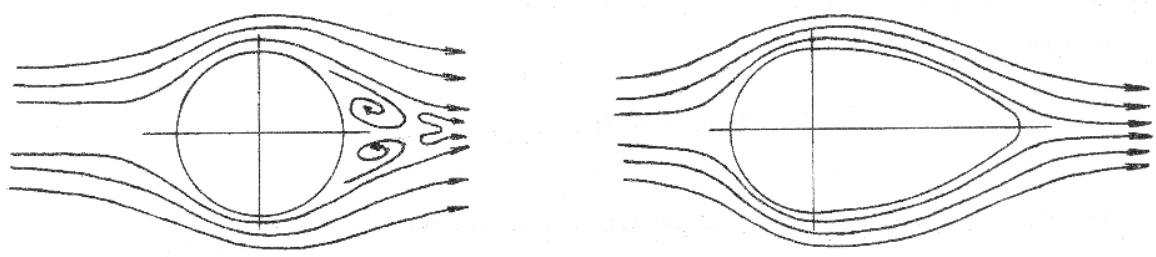
These two short sample calculations are only inserted to repeat here what was said previously. Later, we will get to know still more exactly that the results only are relatively "exact" approximation values. However, it should be mentioned first of all that the two model calculations are inaccurate in two points.

At first it is disregarded completely that the braces do not stand by the longitudinal axis of the aeroplane vertically, but rather the front pair of struts inclined to rearwards and the back pair of struts forwards in the stream of air. We will discuss in the following, how this influences the coefficient *z* of the tubes.

Secondly, the mounting, like the attachment points of the tubes and their disturbing influence on the flow of the air, was neglected completely.

The most important body shapes (of greatest interest to us) are given in the following table No.3. All coefficients *z* were stated in the early research institutes of France, England and Germany. It was primarily Mr Prandtl in Germany who carried out large-scale series of experiments in the Göttingen wind tunnel to the observation of the coefficients and aerodynamic orders.

Those body shaped which are the most favourable ones are those, which enable the particles of the air to keep in touch with the surface of the body as long as possible without forcing them to stall. The back part is the most important one for the design of the object since favourable drain ratios must be available for the air here. The contouring of the forward body portion is of more minor importance. It mainly depends that the individual air flows do not take themselves off behind the greatest section of body of the surface. A dead man space would arise through this in whose area a lower pressure and turbulences appear (see figure 1)



Figgure-1 Different conditions of flow

Table No.3

Important body shapes and their coefficients of drag *z* and the drag coefficients C being part of it

Description of Body	Coefficient	Coefficient of Drag C
A flat thin plat approximately the same length and width dimensions vertically moved.	0.60 - 0.70	120 - 140
Long circular cylinders moved vertically to the axle	0.40 - 0.50	80 - 100
Long circular cylinders moved in the direction of the axle	0.48 - 0.54	96 -108
A drop shaped in a ratio of 2:1 vertically moved	0.04 - 0.08	10 - 16
Ball	0.10 - 0.12	20 - 24
Cables, ropes and thin tubes.	0.60	120
Aircraft wheels Covered Uncovered	 0.25 - 0.30 0.50 - 0.60	 50 - 60 100 - 120
Fuselage of a single seat fighter plane depending on execution.	0.05 - 0.30	10 - 60

If the coefficient of drag z of an object is known, then can be calculated the harmful area any time straight away, too. The ratio of the wing f to the front view F is always the same, namely $z: 0.65$. For an object of z = 0.5 (circle tube) so is valid $f = 0.5 : 0.65 = 0.77\ F$. So this means that 77% of the front view of the tube is the harmful area.

We can do this in this place for these, object listed in the above table No.3.

For the flat plate the calculation yields:

$$z = 0.60 \text{ to } 0.70 \text{ is } f = 0.92\ F \text{ to } 1.08\ F$$

for the drop shaped tube:

$$z = 0.04 \text{ to } 0.08 \text{ is } f = 0.062\ F \text{ to } 0.12\ F$$

for the horizontal circular cylinder:

$$z = 0.48 \text{ to } 0.54 \text{ is } f = 0.74\ F \text{ to } 0.83\ F$$

for the ball:

$$z = 0.10 \text{ to } 0.12 \text{ is } f = 0.15\ F \text{ to } 0.18\ F$$

for cables and thin tubes:

$$z = 0.6 \text{ is } f = 0.92\ F$$

for covered aircraft wheels:

$$z = 0.25 \text{ to } 0.30 \text{ is } f = 0.38\ F \text{ to } 0.46\ F$$

for uncovered aircraft wheels:

$$z = 0.50 \text{ to } 0.60 \text{ is } f = 0.77\ F \text{ to } 0.92\ F$$

for fuselages:

$$z = 0.05 \text{ to } 0.30 \text{ is } f = 0{,}077\ F \text{ to } 0.46\ F$$

Depending on aeroplane the complete harmful area is different and varies. For the time at 1920 between 2 m ² at great types and 0.4 m ² at small fighter planes. One can say as a clue that the harmful area of the fuselage is a little less than the half of the complete harmful area. One takes the greatest fuselage cross section of the aeroplane and multiplies it by about 0.4, one gets 40% of the complete harmful area for a first rough estimate. For the Fokker Dr.I this would be:

$$0.75 \cdot 0.4 = \underline{0.3\ m^2}$$

1.5. Air Resistance and other Forces of the Air

We have explained in section 1.3. that the quantity of the coefficient *z* of an object is dependent of the speed *v* of his motion through the air. We would like to go into this circumstance more nearly now once again.

According to the wind tunnel investigations by the Frenchman Eiffel the coefficient *z* of a ball of 33 cm of diameters behaves so as we have described this already under 1-3 briefly. The smallest speed Eiffel could make an observation was *v* = 2 m/sec. He noticed that *z* rose till about 4 m/sec. and then found a topmost limit. With the increase of the speed *z* sank till about 10 m/sec. and held on then until the completion of the test to 30 m/sec. almost constantly at *z* = 0.09, *C* = 18 (see figure 2). We also reckon with this value if we liked to charge the resistance of a ball.

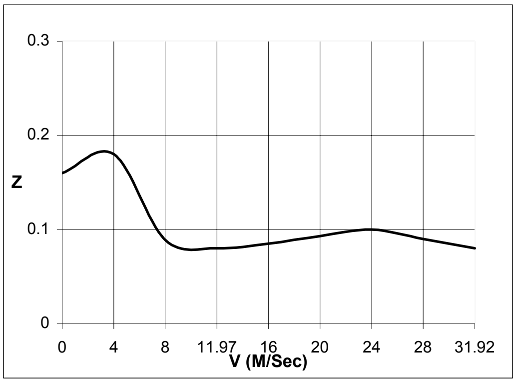


Figure- 2 Sizes of the resistance of a ball as observed by Eiffel.

z does not behave with all objects as represented in figure No.2, though. In our table No.3 we give for cables and thin tubes *z* = *0.6*, *C* = 120. This value does not correspond to an approximate constant of z after a scrap entered at increasing speed, but much more the maximum measured at Eiffel's ball at approx. 4 m/sec. A scrap of *z* did not have to be watched any more in the at that time usual speed ranges.

A tear drop shaped arranged test piece will have the reduction of *z* and the reach of an approximate constant size of it could be observed already at considerably lower speeds. Decisive is not the length width ratio alone for the behaviour of z, but also the exact contour dimensions of the crosscut. We already mentioned the idea of the "rule of similarity". According to this rule *z* behaves identical at geometrically similar sections in case the product of speed and linear object dimensions is identical. Example: A cable of 4 mm of diameters at 30 m/sec. has the same *z* as that one of a cable of 3 mm of strength if the speed amounts to 40 m/sec.

It is clear that all these details can have only the purpose to make a clear judgement on the reliability of details on drag coefficients. As one sees, it is not feasible to describe the behaviour of an object in the stream of air with one single number.

The following point also impairs the serviceableness of results of experiments strongly. Unlike the actual conditions at which the air rests and the object moves exactly the opposite omens apply to tests in the wind tunnel. The object rests here and the air is supplied with the respective speed v. It is very hard now to calm the individual air flows correspondingly so that no disturbances arise in the airflow, however. These turbulences if they are not eliminated adequately, are the reason that the coefficients of drag of the objects to be examined turn out smaller therefore more favourable than they are in the reality.

Furthermore in the name of the "air resistance" the acceptance is still tied, the force which impedes the motion would act exact contrary to the direction of the speed. As we, however, know, the power of resistance puts itself together from differences of the pressure. However, we also know that the dynamic effect which the atmospheric pressure exerts on a particle of the surface is always turned towards it almost vertically. The resultant of these many single pressure does not have to run inevitably exactly contrary to the direction of motion.

We get to speak flat hereinafter quite especially on these indicated interrelation of forces.

2. The Airfoils

2.1. Basic Principles Dynamic Lift, Drag and Glide Ratio.

The effect of a wing is mainly depending of its crosscut, the airfoil section (figure 3).

For all following explanations we make a direct reference to the airfoil section for the Fokker Dr.I.

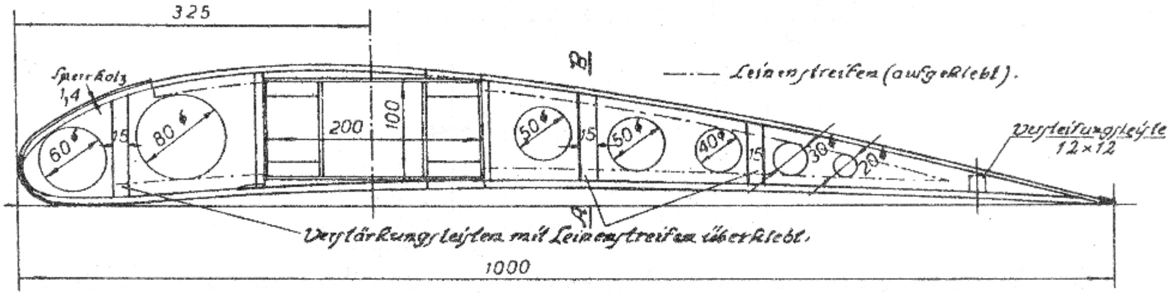


Figure-3 The crosscut through the wing of the Fokker Dr.I

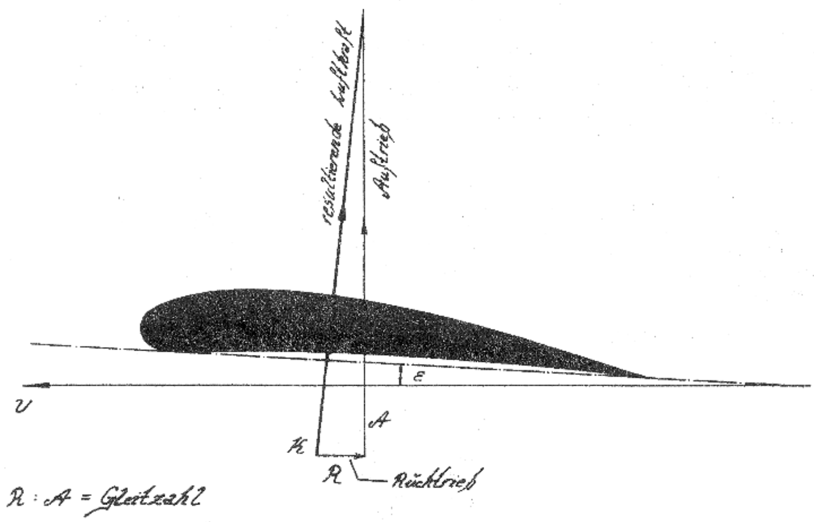
The angle of attack of a wing is the joint which the profile tendon takes in relation to the direction of motion of the aeroplane. The angle of attack is variable with the direction of motion, that is the increase, sink and the horizontal flight.

The angle of attack decides on the effectiveness of the profile as, later, we will see more exactly.

By the angle of attack of the profile to the air appears a rise of the pressure at its bottom edge in front and at the top side a pressure humiliation. Since the pressure effect seems almost vertical to the particles of the surface and this does not differ from a flat plate very much at a wing, the resulting force works almost vertically to the wing. *Dynamic lift* arises. it is and judged contrary to the gravity to overcome these.

After the leap of the parallelogram of forces such a force can be taken to pieces into a horizontal and a plumb component (figure 4). The plumb component is the dynamic lift mentioned already, directed up in this case. The considerably smaller horizontal component works contrary to the direction of motion and therefore is called the resistance of the wing or the *drag* of the wing.

Figure- 4
Lift, Drag and Glide Ratio



The reason for the possibility of flying lies into this that not only an inconvenient resistance just is arising at the motion of a suitable wing but a suitable force which is able to overcome the gravity is also woken.

The quotient drag/lift is called *glide ratio*. Why this is so we study at a later instant. The size of the glide ratio gives information about the quality of the wing. The smaller the glide ratio, all the better the wing. Furthermore a variable quantity is this one to the operating state of the aeroplane in direct dependence the glide ratio stands, i.e. whether it sinks, straight ahead flies or increases.

2.2. The dependence of the dynamic lift *A* and the drag *R* of the of the angle of attack α

Both the dynamic lift and the drag are components of a force of the air. The same applies to the two values as described under 1.3. Similar laws are valid here as for the air resistance of an object. These forces are proportional and determined by a similar number as the coefficient *z* of the air resistance is as long as we keep the same ratios of the density of the air, the wing area as well as the square of the speed. We call these numbers *coefficient of lift* and *coefficient of drag.* Both values, the dynamic lift and the drag are measured in kg per area unit like the air resistance.

Since the same orders are valid, we can now for the calculation of the dynamic lift *A* and the drag *R*, surround the equation of drag a.) correspondingly. We mark the coefficients for *A* and *R* by z_a or z_r. The area of the wing in m² with *F*. This time, the front view is not according to with *F* of section 1.3. meant but rather the total area of the wing ground plan. So we get the formulae now:

$$a_1.)\quad A = z_a \cdot m \cdot F \cdot v^2 \qquad R = z_r \cdot m \cdot F \cdot v^2.$$

For the values *z* of these formulae know for the section 1.3. analogously, these are described to behaviours as follows at changes of the conditions:

<u>Change of the air density</u>

The proportionality of the values z_a and z_r with the air density has 100 per cent validity.

<u>Change of the area</u>

This proportionality of the values makes not quite exact. With tests the drag was stated that small at original wings and the dynamic lift turned out greater opposite the model arrangements. This means that the glide ratio has always to be classified by about 10% more favourably in the original.

<u>Change of the speed</u>

The proportionality with the speed has a substantially better agreement than at the aerodynamic coefficient.

One also can take this formula a_1.) to the same shape which has the formula b.) for the air resistance. To this we reintroduce the impact pressure *q* and put $200\ z_a = C_a$ and $200\ z_r = C_r$ now is valid:

$$b_1.)\quad A = C_a \cdot (q:100) \cdot F \qquad R = C_r \cdot (q:100) \cdot F.$$

So as we *C* (as of now C_w) mention the drag number of the coefficient of drag *z* (*as of now to* z_w), we call C_a or C_r the *dynamic lift number* or *drag number* from this time on so.

The meaning of the dynamic lift number and the drag number C_a and C_r is the same one like this one of C_w. The values of C_a and C_r read directly give the buoyancy and force of drag in kg/m² at *v* = 40 m/sec.

The coefficients *z* of dynamic lift and drag change at the same wing with the angle of attack. The course of the values being able to be written down on right-angled coordinate systems (figure 5+6) as lines (ordinates). This course of the values for different angles of attack indicating the airfoil section of a wing.

The quotient of drag / lift = glide ratio also can be written down on such a coordinate system (figure 7). The glide ratio is represented as for the rest in calculations and representations as ε.

$$Glide\ Ratio = \varepsilon = R{:}A = z_r{:}z_a.$$

The ordinates are found out by practical tests in the wind tunnel. Reduced models of the wings to be examined are hung under different angles of attack into the stream of air and these are measured by pondering the appearing forces. By the wing area of the model and the 100th part divide of the impact pressure q with the stated values for A and R be the numbers C_a and C_r calculated. As results the coefficients z_a and z_r are then available.

By means of the graphic representations the dynamic lift and the drag can easily be determined for different angles of attack.

Example: We would like to know, which dynamic lift and which drag the airfoils of the triplane produce at a speed of V = 27.78 m/sec. (100 km/hour) at an angle of attack of 3°. The weight of the Dr.I is 571 kg. The total wing area (without undercarriage fairing) amounts to 17.48 m ². The dynamic lift which the three wings under these prerequisites produce therefore charges to:

$$A = 0.375 \cdot 17.48 \cdot (1{:}8) \cdot 771.73 = \underline{632.34kg}.$$

The Drag:

$$R = 0.026 \cdot 17.48 \cdot (1{:}8) \cdot 771.73 = \underline{43.84kg}.$$

We read the values z_a and z_r from the diagrams figure 5+6 comfortably and put them into the calculations.

It appears clear that a horizontal flying only is possible as long as the lift produced by the main planes is equal to the weight of the aircraft. The triplane therefore is in our bogus case in a climbing flight since the dynamic lift is greater than the weight. With such simple calculations, also e.g. it can be noticed at which speed the Fokker Dr.I is able to come from the ground. Of course the other values like the resistance of the fuselage or the tail unit and the braces also must be taken into consideration with that the results turn out realistic. However, we want to go into it more specifically only later.

2.3. Crosscut and Ground Plan of the Wing

Crosscut

The efficiency of an aerofoil is the largest portion of the design of the airfoil section therefore its profile depending to this. Other factors, such as the ground plan form of the wing, also play a role. However, these are of subordinate importance.

For the graphic representation of dynamic lift and drag of a crosscut a form which is due to the father of the aviation Otto Lilienthal and his experiments has become naturalized. We represent this into figure 8. At this form of the presentation the dynamic lift numbers, the drag numbers and the glide ratio are not represented one by one as ordinates. The points of the angles of attack rather are assigned to the respective abscissa of the drag number C_r and the ordinate of the dynamic lift number C_a after every test.

The angle of attack of the profile at which the glide ratio is the most favourable can be found out very easily with such a *polar diagram of the wing* by laying out a ruler so that it forms a line which comes from the origin of the axle cross and touches the line there which connects the individual angles of attack with each other where it furthest goes on the left.

We want to go into the meaning of the dotted line in such a polar diagram only later. It refers to the moving of the center of pressure of the wing.

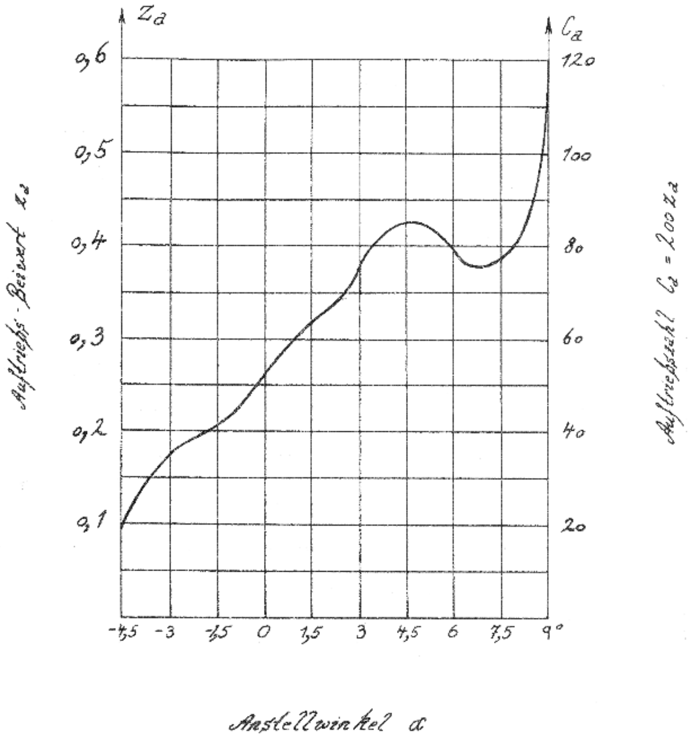


Figure-5 The lift produced by the Fokker Dr.I wing at different angles of attack.

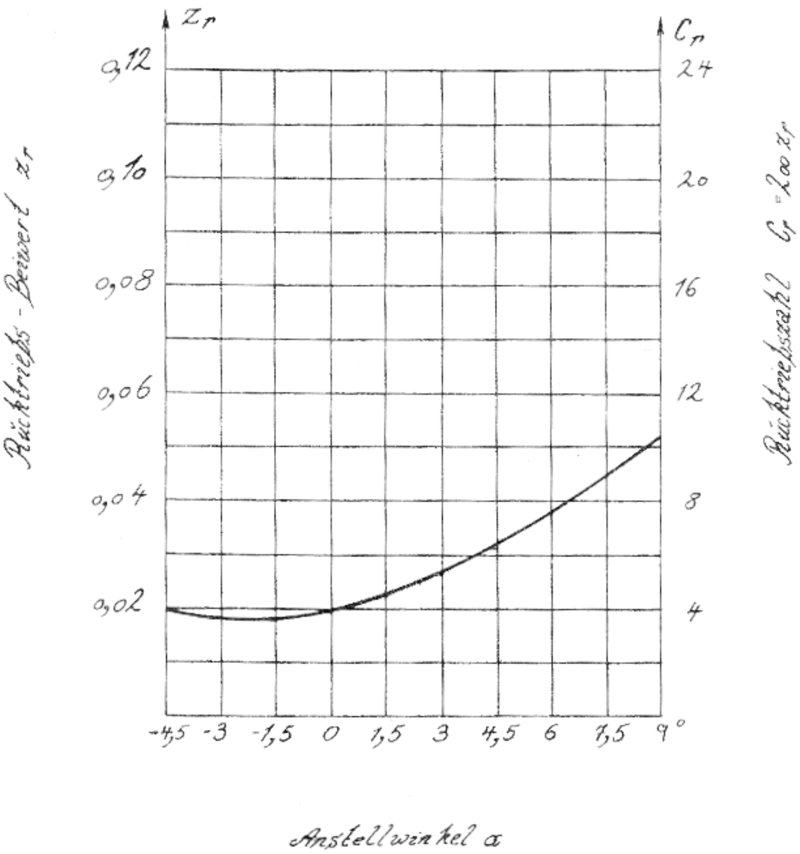


Figure-6 Drag of the Fokker Dr.I wing at different angles of attack.

For the making of a wing they must pay attention particularly that the profile designed originally is realized as exactly as possible. The style brings a certain incompleteness at fabric-covered airfoils with it since the substance uses to be incident between the ribs by the tension.

Ground plan

The ground plan form of a wing does not have great influence on the aerodynamic ratios. Within the years to 1920 all possible ground plan forms were examined roughly and produced the same success without exception. The only feature which considerably influences the values *za* and *zr* is the ratio of depth *L* to wingspan *B.* The glide ratio changes only insignificantly and has the most favourable value at *L / B* = 1/6 to 1/8. The coefficient of lift za grows into considerably if the ratio *for L / B* decreases. If a wing has a variable depth, what is not correct at the Fokker Dr.I, one uses the quotient wing area / span width for *L* in all calculations.

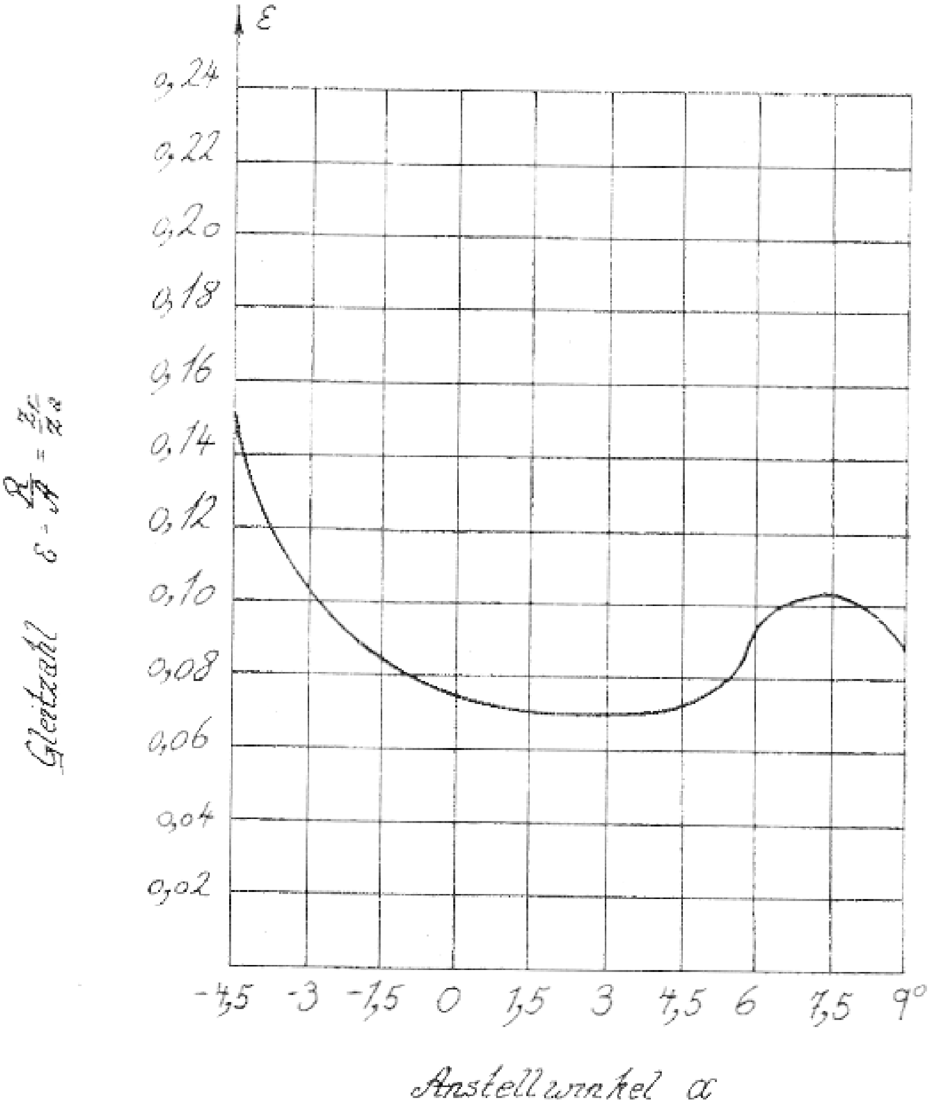


Figure-7 Glide ratios of the Fokker Dr.I wing at different angles of attack.

2.4. Distribution of Pressure, Wing Load and Constructive Remarks

<u>The distribution of pressure</u>

Already in an earlier section we had consulted that a profile form in the stream of air at its top side creates a pressure humiliation while at the under side a increase of pressure comes into existence. A suction effect which the wing draws up (sucks) arises at the top side with that. An effect of pressure which for its part pushes the wing up arises at the underside.

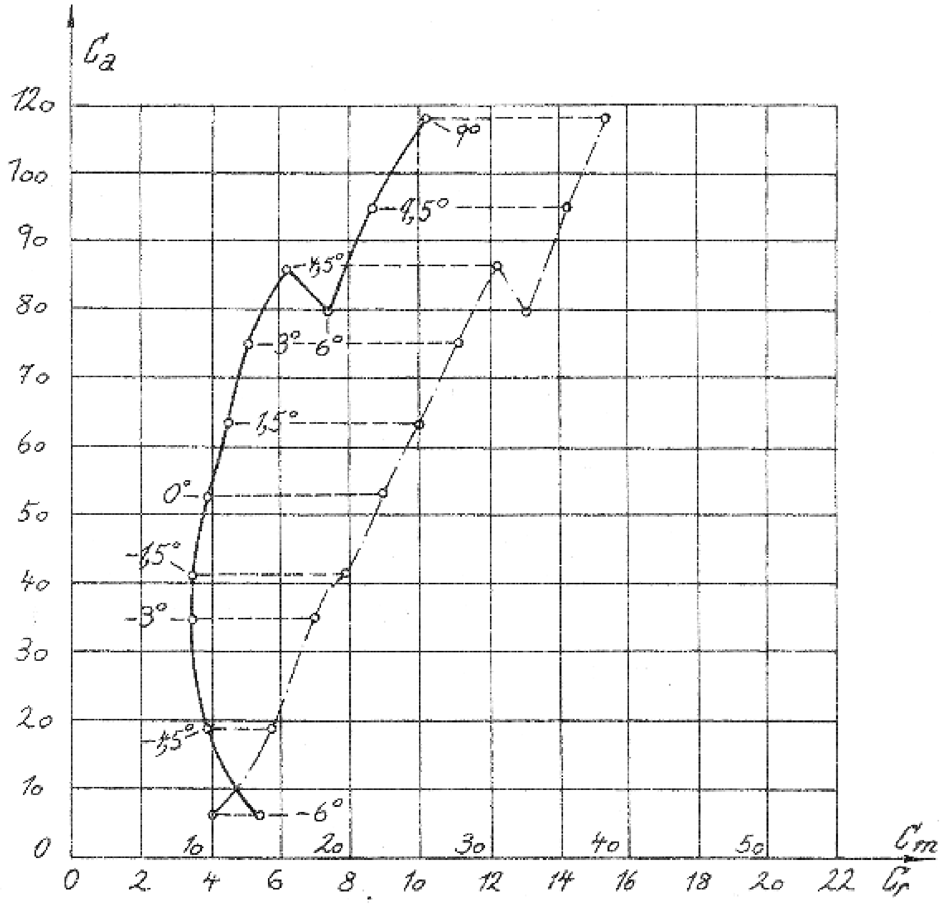


Figure-8 The polar diagram of the Fokker Dr.I wing
(Göttinger Profil Nr.298)

There are the same pressure ratios not in every place of the crosscut. Figure-9 shows the distribution of pressure above and below a fictitious wing crosscut. One can recognize also considerably that the average suction effect is as the average effect of pressure at the profile underside almost twice as big at the profile top side by this illustration. The suction effect of the profile at about 2/3 therefore contributes to the dynamic lift while the underside only contributes about 1/3 to it. One can infer from it that the greatest attention must already be put on the form of the profile top side at the profile outline. The design of the underside does not play a very considerable role.

It would lead here too far, to compare the Fokker Dr.Is airfoil section (Göttingen profile no. 298) with other, thinner profiles with regard to its qualities now. However, it is mentioned that the top side rounded well in connection with the high shape of the crosscut produces a relatively low drag at a high distribution of good dynamic lift with an increasing angle of attack.

If one loads the whole aerofoil, the load of crosscut to crosscut changes only very insignificantly. As in the case of the Fokker Dr.I the aerofoil is interpreted completely symmetrically then the outer crosscuts have a lower resulting pressure than the one inside into fuselage proximity lying. In most falls the angle of attack of the wing is reduced to the outside. One still strengthens the decrease of the pressure in addition through this and reaches both an improvement on the handling characteristics and constructively more favorable ratios with that since the resulting buoyancy then attacks with every side at the smaller lever.

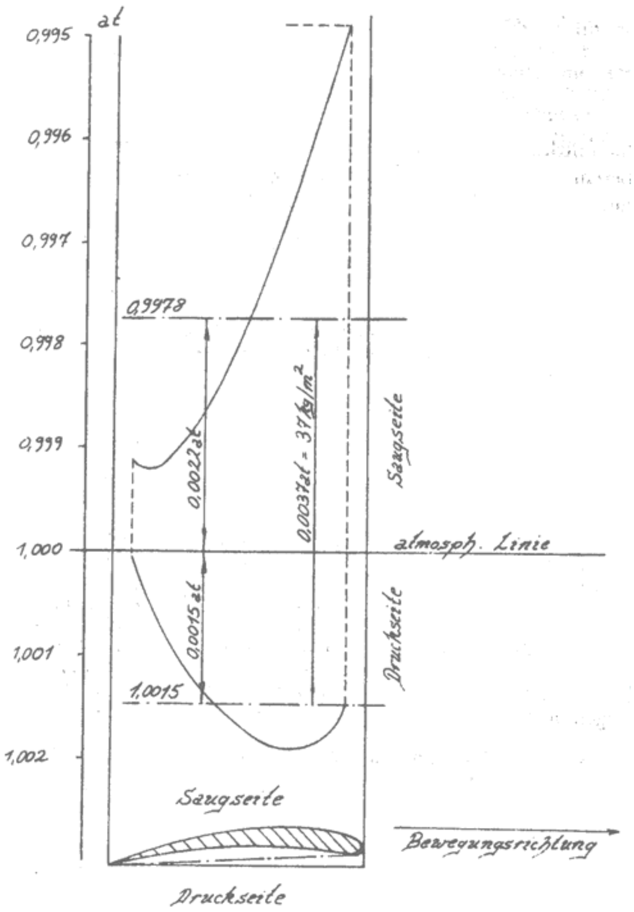


Figure-9

The area load

One gets the area load of an aeroplane (that is the total aircraft weight being allotted to 1 m ² wing area) if one divides his total weight *G* by the total size of the load-bearing wing *F*. This (without undercarriage fairing) is at the Fokker Dr.I:

$$G:F = 571:17,48 = 32.67 kg/m^2$$

The average area load must agree with the average suck effect and effect of pressure for the horizontal flight. Later, we will talk about the significance of the area load for the handling characteristics in detail.

The constructive things

A wing looked at as a component of an aeroplane forms a structural assembly like the foundations of a bridge. The weight of the wing assembly of the triplane arises from the quotient **total weight of the wings / total wing area**, so:

$$90 : 17.48 = 5.15 kg/m^2$$

After the above execution the area load is 32.67 kg/m². As load which has to be taken by the wing assembly actually in the flight charges itself to 32.67 - 5.15 = 27.52 kg/m². This fall occurs since at first the unloaded weight of the wing construction must be carried. If one wants to check the stability of the executed wing construction during the strength tests now, then one turns over the aeroplane, supports the points of the largest load, cab, engine, tank plant and others and distribute a sand load evenly on the wing underside. It must be taken into account that the load must decrease to the outside, though. If we distribute the load in a way that we will have a load of 27.52 - 5.15 = 22.37 kg/m^2 lying on the underside of the wings, the total wing assembly is under the load of 22.37 + 5.15 = 27.52 kg/m^2. This is the case since the unloaded weight and the sand load work in the same direction now. We have checked the wing construction for its "simple safety" with that.

During the type test in Adlershof the prototype had to cope with the "fivefold safety" as a minimum. This is:

$$22.37 + (4 \cdot 27.52) = 132.45 kg/m^2.$$

At the following break test, on the whole the weight was increased till the aerofoil construction was not able definite to withstand the load any more and collapsed. This happened at a reached safety number of S = 7.92. Expressed in kg/m² this yields to:

$$2.37 + (6.92 \cdot 27.52) = 212.80 kg/m^2.$$

In turn this corresponds to a complete sand load on all three wings of:

$$212.80 \cdot 17.48 = 3719 kg.$$

This is related to the total weight of the aeroplane:

$$3719 : 571 = 6.51.$$

This means, the wing assembly of the triplane was in its original form able to stand a load factor of 6.51-fold the total aircraft weight.

In this place of the treatise a remark still is for the very interested one about the areas regarding the used data *17.48 m ² = F* made.

This detail on the total area dates the Idflieg for the Fokker Dr.I. from the official making description (figure-11). The preparation of these documents is based on the wing depth of 1000 mm. However, the break test was carried out in Adlershof with the test series triplane 101/17. The documents which are still available give a wing depth for this aeroplane from only 980 mm and the area was 16.684 m ². The wing weight was established with 84.5 kg. Therefore the unladed weight charges itself by that to 5.06 kg/m2. The area load 34.22 kg/m ². The 5-fold safety of this aeroplane arises from this:

$$\boldsymbol{24.1 + (4 \cdot 29.16) = 140.74 kg/m^2.}$$

The safety number S = 7.92 expressed in numbers:

$$\boldsymbol{24.1 + (6.92 \cdot 29.16) = 225.89 kg/m^2.}$$

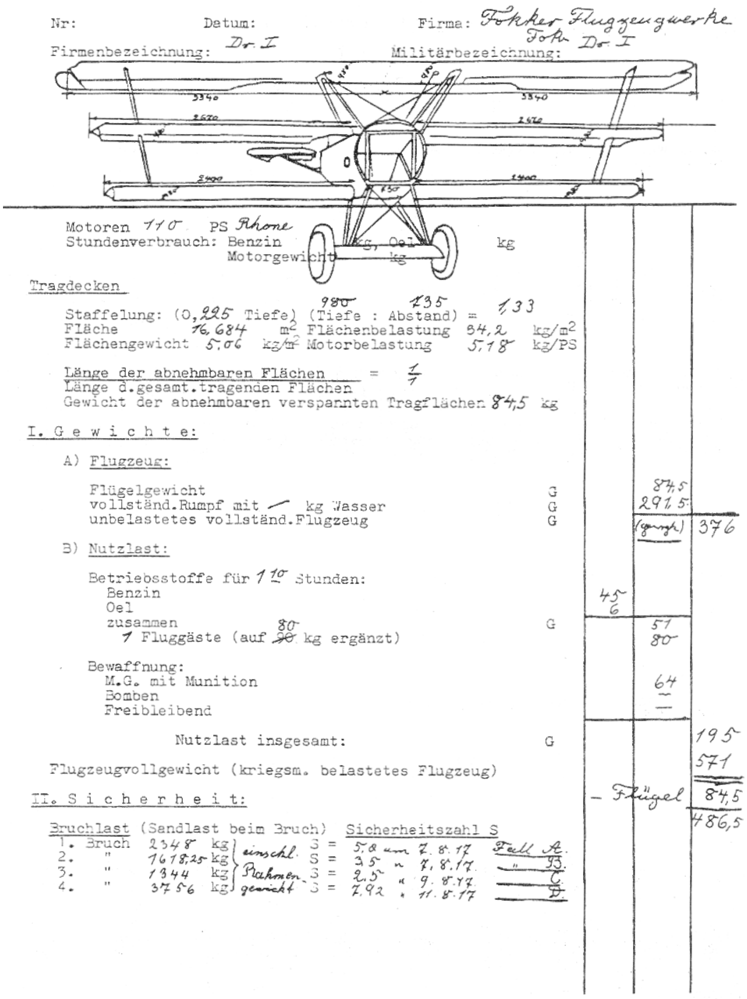
The complete sand load ought to have been therefore:

$$\boldsymbol{225.89 \cdot 16.684 = 3768.75 kg.}$$

One shows to figure-10 for a facsimile account of the notes of the break test of 101/17.

It will not escape the attentive observer that the data given in this document do not agree with the results of our model calculation. After our results the capacity should around the difference 3768.75 - 3756 = 12.75 kg lie more highly than the actual tests yielded in August 1917. Somebody must have made a small mistake well in Adlershof here. If we let the measured weight at the break be regarded quoted as right the fault can only be looked for in the safety number of S = 7.92.

We make the pleasure to us for fun and reckon with the value at the break (3756 kg) back, so we get as a result a safety factor of S = 7.9105859. So it seems reasonable that the wrong safety factor is S = 7.92 actually is duly to a fault in the curve of the second place behind the comma.



Nr: Datum: Firma: Fokker Flugzeugwerke
Firmenbezeichnung: Dr. I Militärbezeichnung: Fokk. Dr. I

Motoren 110 PS Rhone
Stundenverbrauch: Benzin kg, Oel kg
Motorgewicht kg

Tragdecken

Staffelung: (0,225 Tiefe) (Tiefe : Abstand) = 980 : 735 = 1,33
Fläche 16,684 m² Flächenbelastung 34,2 kg/m²
Flächengewicht 5,06 kg/m² Motorbelastung 5,18 kg/PS

Länge der abnehmbaren Flächen / Länge d.gesamt.tragenden Flächen = 1/1
Gewicht der abnehmbaren verspannten Tragflächen 84,5 kg

I. Gewichte:

A) Flugzeug:

Flügelgewicht	G		84,5	
vollständ.Rumpf mit — kg Wasser	G		291,5	
unbelastetes vollständ.Flugzeug	G		(gewogen)	376

B) Nutzlast:

Betriebsstoffe für 1 1/10 Stunden:				
Benzin		45		
Oel		6		
zusammen	G		51	
1 Fluggäste (auf ~~90~~ 80 kg ergänzt)			80	
Bewaffnung:				
M.G. mit Munition			64	
Bomben			–	
Freibleibend			–	
Nutzlast insgesamt:	G			195
Flugzeugvollgewicht (kriegsm. belastetes Flugzeug)				571
		– Flügel		84,5
				486,5

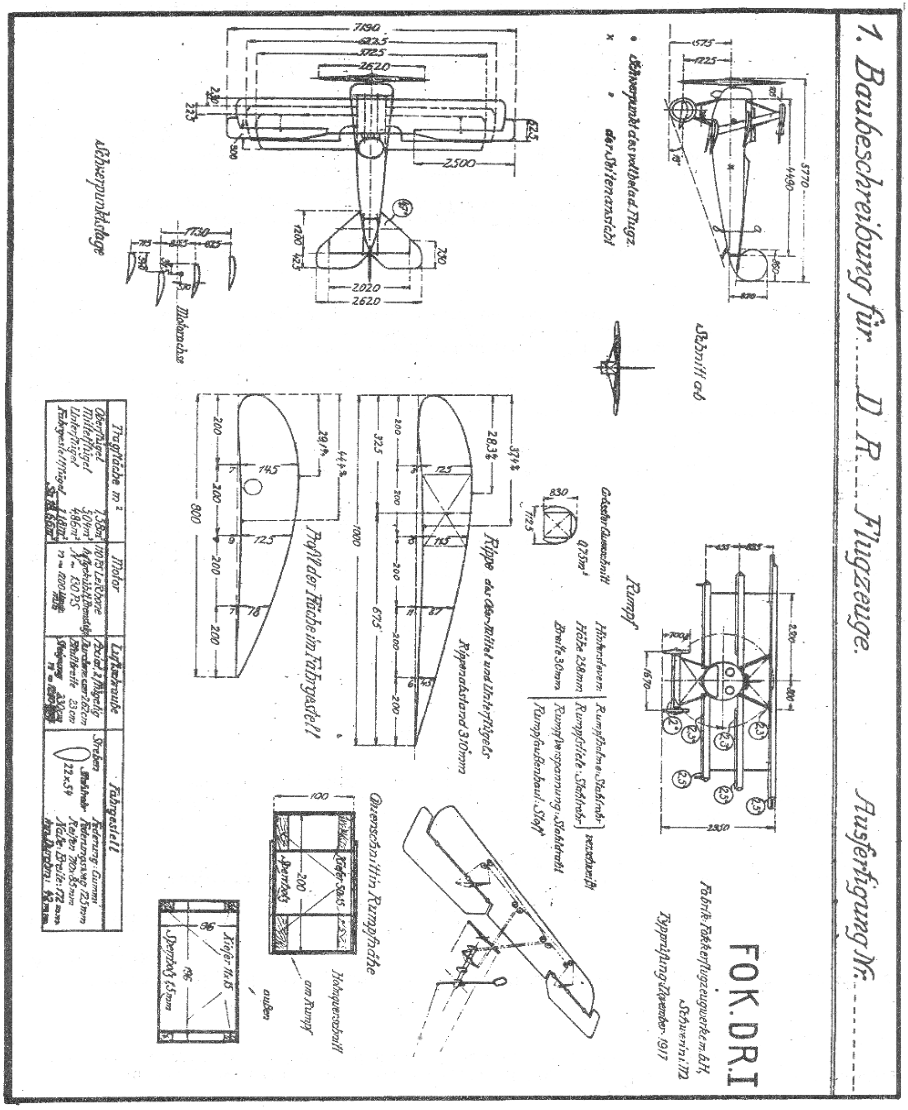
II. Sicherheit:

Bruchlast (Sandlast beim Bruch)			Sicherheitszahl S		
1. Bruch	2348 kg	einschl.	S = 5,8 am 7.8.17	Fall A.
2. "	1618,25 kg	Rahmen-	S = 3,5 " 7.8.17	" B.
3. "	1344 kg	gewicht	S = 2,5 " 9.8.17	C.
4. "	3756 kg		S = 7,92 " 11.8.17	D.

The capacity of the construction achieved at the 7.91-fold safety corresponds to 160% of the demanded 5-fold safety of 140.74 kg/m².

The figure-11 shows the Baubeschreibung (assembly description) of the triplane on whose details our first model calculations were based.

We still must investigate the occurrences of October 1917, which led to the prohibition of flight of the triplane by the collapse of the wing structure at a different place.



2.5. Speed for the Horizontal Flight and Tractive Power at given Angle of Attack

The Speed

The sections dealt with till now make it possible for us to determine the speed for the horizontal flight if we know the angle of attack, the total area, the total aircraft weight and the coefficient of drag of the profile.

For the horizontal flight the weight of the aeroplane G must be as great as the dynamic lift which the airfoils deliver. If a surplus or a lack of dynamic lift were existing, then the aeroplane would climb or go down. So we have the following equation for the horizontal flight:

$$\mathbf{G = A = z_a \cdot m \cdot F \cdot v^2.}$$

If we want to dissolve this equation after the speed *v*, then we receive the relation:

$$v = \sqrt{G : (z_a \cdot 1/8 \cdot F)}.$$

We can take the coefficient z_a from our Illustration No.5. We see from the Baubeschreibung of the Fokker Dr.I the angle of attack of the aeroplanes main wings. It is indicated there with 2.3° into fuselage proximity and 2.5° of the cell braces. We will calculate 2.4° with the mean average value. For this angle of attack we see the value z_a given with the dynamic lift line in figure No.5 as being 0.344. So we put:

$$v = \sqrt{571 : 0.344 \cdot 1/8 \cdot 17.48} = 27.56 m/Sec.$$

We succeeded with this calculation to notice that so the series triplane is in the horizontal flight at an angle of attack of 2.4°, a normal air density as well as a speed of 27.56 m/sec. (27.56 · 3.6 = 99.22 km/hours). Therefore it is neither in the climbing nor in a sinking.

Since both the dynamic lift and the drag increase with an increasing angle of attack, the speed necessary for horizontal flight becomes less. This can be pursued up to a certain point at which a demolition of the flow then arises and the dynamic lift falls relatively to the weight on zero.

<u>The tractive power</u>

Furthermore we can build up and notice on the previous calculations which tractive power the engine must produce by the propeller if it wants to keep the aeroplane in the horizontal flight.

Up till now we have got to know two different resistances which appear at a moving aeroplane. We have the resistance for the airfoil itself and on the other hand the harmful resistance for the other aeroplane parts with the exception of the airfoils once there. Exactly as in the case of the dynamic lift the tractive power must correspond to the complete resistance to be overcome also here. We can therefore draw a conclusion:

Z = drag of the wing + harmful resistance.

We can therefore build the equation for the calculation of the tractive power *Z:*

$$Z = (z_r \cdot m \cdot F \cdot v^2) + (0.65 \cdot m \cdot f \cdot v^2).$$

The first summand of this calculation refers to the drag of the wing, the second on the resistance of the other aeroplane parts. So we investigate to the triplane for an angle of attack of 2.4° by the data known to us:

$$Z = (0.025 \cdot 1/8 \cdot 17.48 \cdot 27.56^2) + (0.65 \cdot 1/8 \cdot 0.40 \cdot 27.56^2) = 66.18 kg.$$

According to section 1.4. the performance expects from this to 66.18 · 27.56 = 1823.92kgm/sec., the propeller thrust to 1823.92 : 75 = 24.32 hp, and the engine output to 24.32: 0.7 = 34.74 hp.

However, we still want to make two small remarks here. With these calculations we have already anticipated a little. Up till now this was not a complete calculation of tractive power and speed yet since we do not know yet which tractive power the engine is actually able to perform by the propeller. We will investigate this only in the coming sections. The harmful area of 0.40 m ² adopted in the above calculation to the required tractive power is only based on a temporary rough estimate. We will make out an exact calculation about the complete harmful area of the Dr.I only later, if we also are able to draw the influences of the control surfaces into consideration. This result as an approximation value shall be enough for us however now.

3. Of the Propeller

1.3. Form and Effect of an Airscrew Segment

The task of a propeller consists in converting the torque of an engine to a tractive power. The propeller achieves his effect by the form of the individual propeller elements. One can imagine such an element through this easily if you intellectually thinks of the propeller in the top view (front view) and with a pair of compasses exactly stings into the spin axis of the propeller hub and draws on a propeller blade in any distance of the middle two narrowly at each other lying circular arcs. One makes along these two lines vertically to the propeller unites a cut now, so one gets a small piece of the propeller which one corresponds in its cross cut very much to the carrying airfoil section. By this analogy to the wing we also can explain the operation of a propeller.

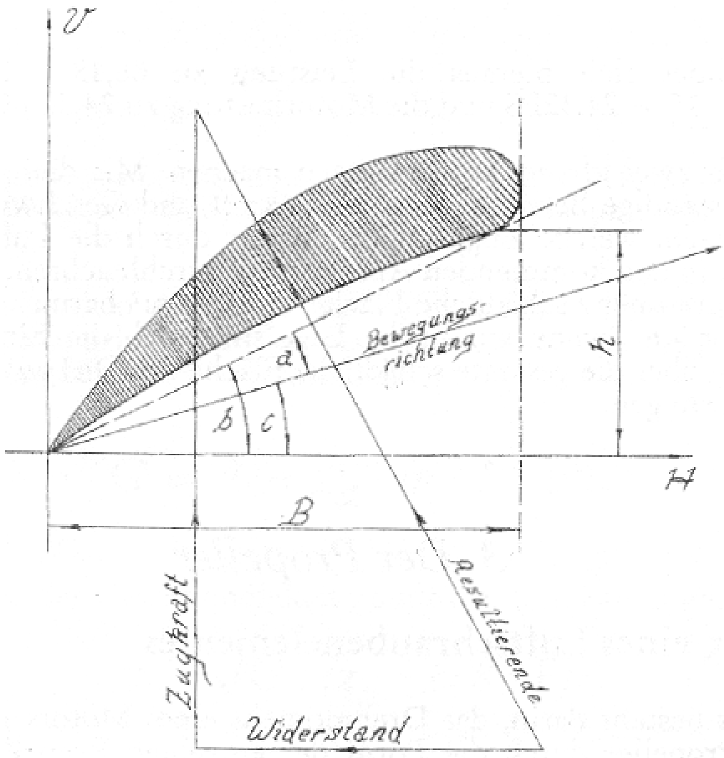


Figure-12. A Segment of the propeller blade.

The forces are represented clearly in the figure-12 this one at a single propeller element take effect. Before we go into it more nearly, at first we must discuss an essential concept which has to work with the propeller. It is here the idea of the "pitch".

One describes the increasing height as a pitch which a helix learns at a single turn around of a circular cylinder. The pitch **S** is calculated by the formula *tgb = S : (2r · π).* If we want to know the size the helix rises, if it does not cover the complete way of the cylinder extent, but merely circle unite part ***B*** of it, then we find the proportion *h : S = B : (2r · π)* for the increase ***h****.* In turn from this the form lets be derived *h = (B · S) : (2r · π) = B · tgb* .

Every element of a propeller corresponds to a short piece of such a helix in which the part *B* of the helix passed through corresponds to the width of the propeller blade in the respective place.

As explained already, the cross-section of a propeller element looks whole like that one of the carrying airfoil section. The propeller owes his effect to this design of the profile.

His task consists in changing the rotary movement of the engine in a translation of the aeroplane and the torque performed by the engine into a tractive power. By the twist of the propeller and by the forwards motion of the aeroplane every single element of the propeller learns a certain speed. One of these elements is represented the vector for in figure-13.

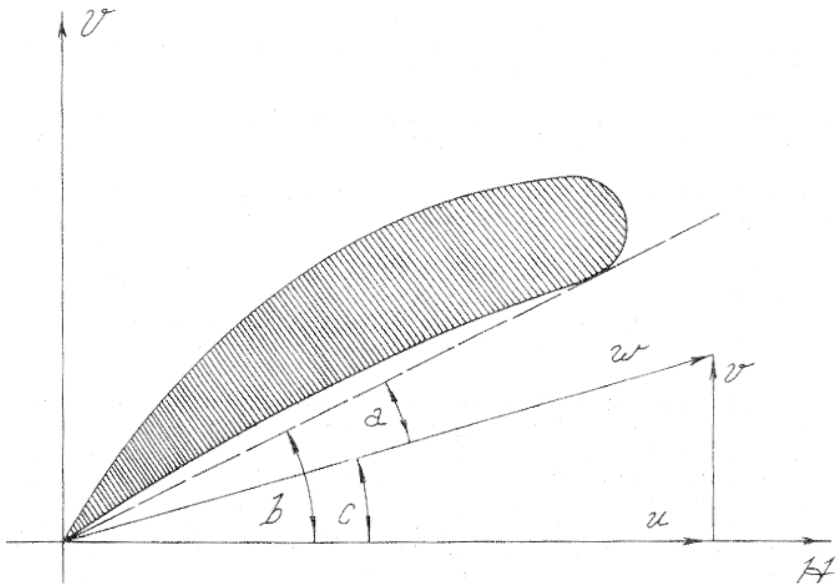


Figure No. 13

The speed of the elements is the resultant of the revolution speed of the propeller in the direction *H* and of the speed of the forwards motion of the aeroplane itself in the direction of the *V*. Exactly as in the case of the aerofoil a negative pressure forms by the motion through the air at the top side of the element and an overpressure at the underside. Through this a resulting force of the air (figure-12) seems on the level of the elements and with that up (or in front) almost vertical. This resultant is described as a tractive power of the propeller. A daring right force component which counteracts the twist of the propeller is also found in figure-12. This force will be differently great of all single elements of the propeller and they are gathered up described as the momentum of drag of the propeller. If the propeller shall be turned by the engine, then the engine permanently must overcome this momentum of drag.

During the forward motion of the aircraft, the motion of the airscrew segments sets itself together from two components forwards. On the one hand, we have motion of the propeller turning this one here with the circulation speed ***u*** in the direction ***H***. On the other hand, we have the forwards directional motion of the aeroplane in the direction of the ***V*** with the speed ***v***. From these constituents for the propeller the speed vector ***w*** represented in the figure-13.

The angle between the tendons of the individual elements and the resultants ***w*** is called the angle of attack of the propeller element. One recognizes from this easily, into how far the angle of attack of the propeller elements of the flight speed ***v*** and the circulation speed *u* depends. At the stand the angle of attack coincides with the helix angle ***B*** and is the greatest with that. If the speed of the forwards vector of the aeroplane enlarges, then the angle of attack ***a*** of the airscrew segments reduces itself.

As we have seen at the wing the coefficients z_a and z_r they change with the angle of attack of the wing. The same is valid for the single segments of the airscrew here. What does this mean for the dependence of the angle of attack of the propeller elements of the quantity of the speed *v* of the aeroplane actually now?

The tractive power (or say lift) of the individual propeller elements decreases, the smaller their angle of attack at increasing *v* of the aeroplane becomes.

From this sentence can be concluded that the tractive power of a propeller is the greatest at the stand and decreases with increasing flight speed.

Not only the tractive power of a propeller rotating at the stand is greater than that one of one in the flight moving forwards. The resistance is also the greatest here.

We mark the angles of the vector which is defined by *v* and *u* by *c* in figure-13. It calculates by $tgc = b - a$. It will be obvious from the drawings that this is the difference between the helix angle *b* and the angle of attack *a*. *c* is therefore $b - a$. The angle *c* changes from propeller element to propeller element. The reason for the forming of the propeller blades in this way means much in the fact justified that the circulation speed *u* is proportional directly to the distance *r* from the spin axis. One makes the circumstance that the best efficiency of a propeller can be reached only in a restricted area of angles of attack reason for the helix angle *b* relieving to the tips. It is ensured that the angle of attack of all propeller elements remains constant at their motion by the air with different speeds. The inner, slow shifting elements got through this unite a steep angle of attack, the element of the propeller turning faster at the outer, got therefore a flatter angle of attack.

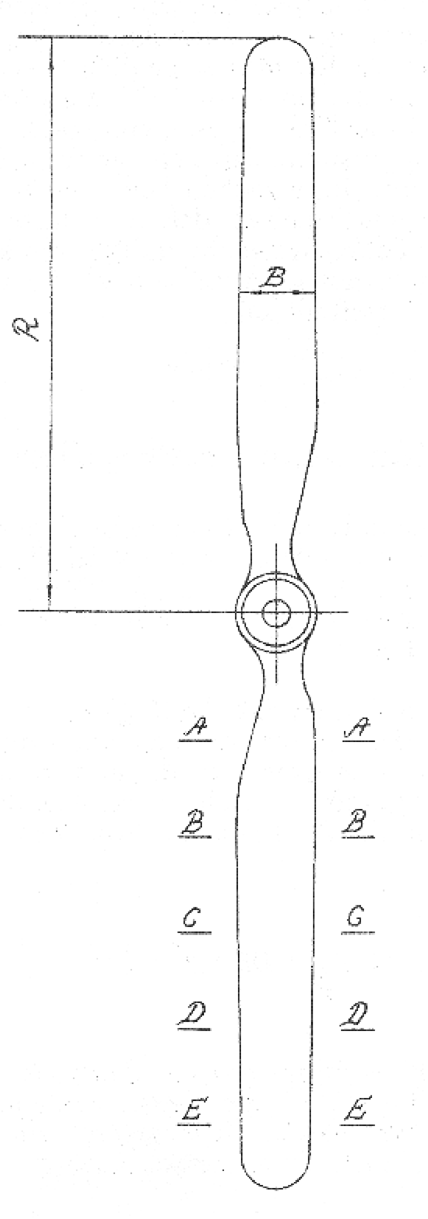
3.2. Tractive power and momentum of drag of the propeller

Both, the tractive power as well as also the momentum of drag of a propeller are, analogous the dynamic lift and the drag of the airfoils, integral constituents of a force of the air. For the calculation of the dynamic lift and the drag of the airfoils we could already build quite generally valid orders in section 2.2. of this chapter. For the specification of the tractive power of a propeller we can undoubtedly use the same laws here now, too.

We can do this out of a simple reason. We may assume that the tractive power is exactly (like the dynamic lift of the airfoils) proportional to the air density *m* to the area *F* of the propeller and to the square of the extent speed *U*. Furthermore it is determined by a coefficient which depends on the shape of the propeller and is marked by z_p. This is called the "coefficient of the propeller tractive power". From these connections we can build a formula which makes it possible for us to find the tractive power of the propeller out. This formula must look as follows:

$$Z = z_p \cdot m \cdot F \cdot U^2.$$

By this formula list we can calculate only the tractive power of the screw, though, as long as it actually runs at the stand. The speeds of the individual elements of the propeller are then only proportional under each other. The extent speed *U* grows then the speeds of the other elements of the airscrew also increase in the same measure.



A completely different fall occurs if the aeroplane of the place moves. The speeds of the elements are not alone determined by *U* any more. They are determined by the ratio of extent speed *U* to the flight speed *v*. If *U* is extended around the double one, for example, while the aeroplane is in a forwards motion, then the speed of the elements increases very differently. This one will hardly change fundamentally the inner in while this will double the outer soon.

However, one provides that the quotient *v : U* the same remains, the speeds of the elements can all be increased or lowered correspondingly in the same ratio so. All motion ratios at the propeller then remain the old ones.

It gets understandable with the just said, that we can also use the same formula introduced above for the calculation of the tractive power of the screw at the stand if the aeroplane moves.

One then must take into account that for the motion in flight the coefficient z_p does not depend alone on the design of the propeller, though but in the same measure of the ratio *v : U* which also is called *the progress degree of the propeller*. At the run at the stand the progress degree amounts logically to the quantity for zero.

It is around necessary to know the change of the coefficient *zp* with increasing progress degree to carry out sensible model calculations with a propeller. These data only can be found out by tests with the propeller in the wind tunnel. Unfortunately, these data which were used in the Dr.I are with us for none of the propellers yet. For all further model calculations we will therefore refer to a airscrew in this first support, there are all necessary values for which and this one furthermore still in form of and quantity resembles the propeller of the company AXIAL very much, which manufactured the propeller which was most frequently used in the triplane. The propeller in question is represented in figure no. 14.

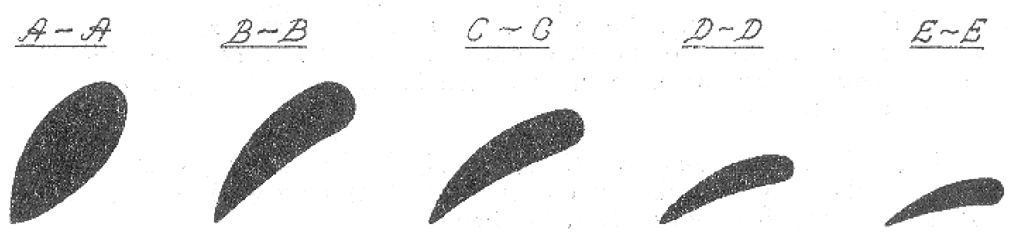


Figure 14 Representation of the propeller

Of this propeller the tractive power coefficient, the coefficient of drag and the efficiency of the airscrew are given in the representations 15, 16 and 17.We want to talk about the meaning of these three things now.

Figure no. 15 shows the coefficient of the propeller tractive power for into dependence to the progress degree v *: U* of the propeller. One can read from the graphic that the tractive power decreases at the same circulation number *U* of the propeller with increasing progress degree. With the coefficients in this diagram, of course this process can be comprehended also arithmetically. The propeller in our example has a diameter D = 2r = 2.70m and a blade width of 0.17 m. The area of the top view *F* arises from this to 0.41 m ² (we must take into account at the calculation of the front view of the propeller that we may not use the full product from D · B since the hub and the transition into the twist still come off it).

At a revolution number of 1200 U/min. the extent speed calculates to: *U = 2.70π · (1200 : 60)* = 169.64m/Sec.. We set the flight speed *v* of the aeroplane to 44 m/sec. now then the quotient amounts *v : U* , therefore the value of the progress degree of the propeller is 44 : 169.64 = 0.26. For this progress degree we gather the coefficient z_p *to 0.06* from figure no. 15. We can with that calculate the tractive power for the flight speed *v*= 44 m/sec. (158.4 km/hour) according to our formula. So we have:

$$Z = 0.06 \cdot 1/8 \cdot 0.41 \cdot 169.64^2 = 88.49kg.$$

The same propeller would deliver a tractive power of at the stand:

$$Z = 0.2 \cdot 1/8 \cdot 0.41 \cdot 169.64^2 = 294.97kg$$

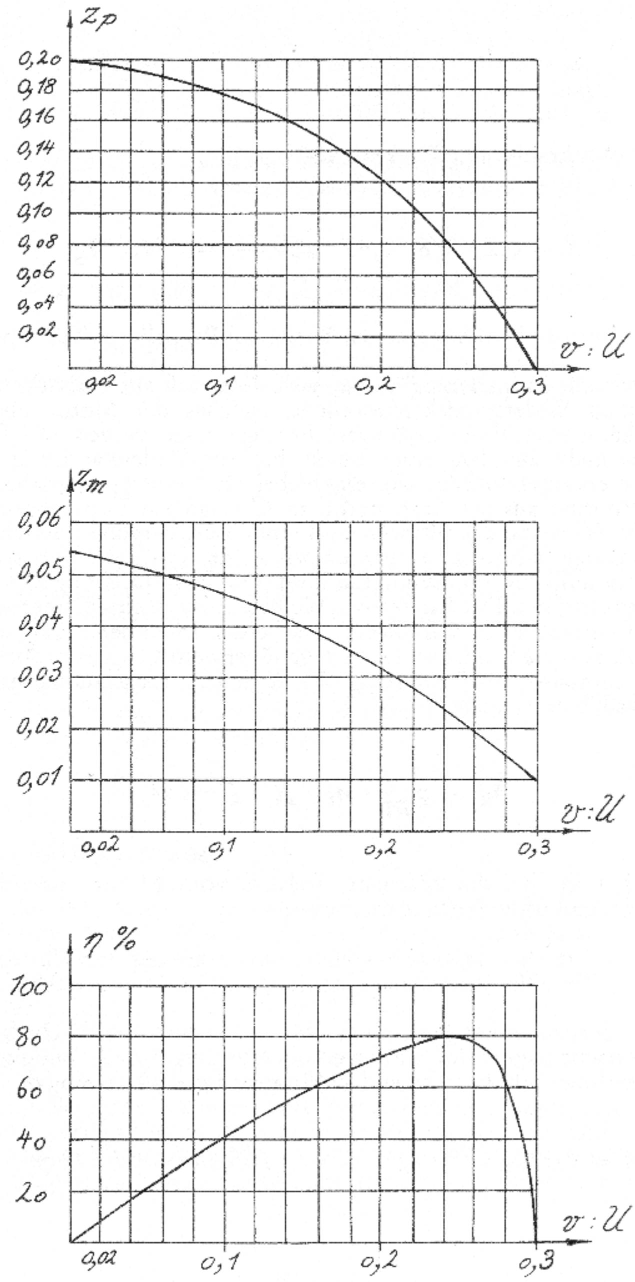


Figure 15, 16 and 17 The propeller coefficients tractive power, resistance and efficiency

We have made the first component of the forces professed and conceivable at the propeller with that.

It similarly behaves like with the coefficient of the propeller tractive power z_p also with the second component of the forces of the air at the propeller, the momentum of drag which the engine must overcome. For the calculation of this quantity, a similar formula can be consulted as for that one of the coefficient z_p. One mustn't have from the eye, that these attach powers of resistance to the propeller hub like a lever which counteracts the motion of the individual propeller elements and therefore have an effect on it with its force moment, the product from the force and the distance to the spin axis of the propeller, though. We mark the coefficient of the momentum of drag of a propeller by z_m. Since z_m cannot have the dimension of a length, we must include the half measuring instrument of the propeller R in the formula for the calculation of the necessary moment the engine must develop therefore to move propeller in rotation. The coefficient z_m remains through this a dimensionless quantity which makes it possible for us also to work with model airscrews in the wind tunnel. In the other case, every time, z_m would get smaller around exactly the amount around which the model airscrew is reduced opposite the original propeller. So we can calculate the coefficient z_m of the momentum of drag of the propeller under use of the following formula with this knowledge now.

$$M = z_m \cdot m \cdot R \cdot F \cdot U^2$$

The *M* in this calculation stands for the moment, that must be performed by the engine to turn the propeller around against its own resistance.

z_m exactly like z_p also is so in direct dependence to the quantity of the progress degree of the propeller. Figure no. 16 shows the z_m line for our adopted propeller from fig. 14.

For an adopted flight speed of 44 m/sec and an extent speed of 169.64 m/sec therefore a progress degree of the screw of 0.26 figure no.16 shows us the accompanying z_m value to 0.021. The necessary moment for the twist of the propeller expects with that:

$$M = 0.021 \cdot 1/8 \cdot 1.35 \cdot 0.41 \cdot 169.64^2 = 41.81 \text{kgm.}$$

That is at the stand:

$$M = 0.054 \cdot 1/8 \cdot 1.35 \cdot 0.41 \cdot 169.64^2 = 107.51 \text{kgm.}$$

One recognizes by this that the rotational speed of the airscrew is necessarily smaller than in the flight at the stand at a given engine, if the torque remains unchanged, since the effort is the greatest then to the overcoming of the propeller resistance.

3.3. Performance and Efficiency of the Propeller

Since every force moment acting on the airscrew must be looked at as being a quantity of the force attaching to the lever arm the performance which is taken by the propeller has to be equal to the product of torque and circulation speed in the distance 1 to the axle of rotation. The speed in the distance 1 of the Center of the spin axis has the value for $U : R$ The taken performance therefore is $M \cdot U : R$. For our last example of the triplane in the flight we got the values M = 41.81 kgm, U = 169.64 and R = 1.35. The taken performance of 41.81 · 169.64 : 1.35 = 5253.81 kgm/sec. can be determined from these values. The hp number which the engine must make available to rotate the airscrew at 1200 RPM in flight at a speed of v = 44m/sec. amounts to 5253.81: 75 = 70.05 hp. Performance giving of the propeller in this flight state charges itself from the product of $Z \cdot v$. = 88.49 · 44 = 3893.56 kgm/sec. or 3893.56: 75 = 51.91 hp.

One describes the ratio between performance of a propeller taken and handed in as its efficiency. The efficiency is marked by the Greek character ***n*** (eta.) It arises from the formula:

$$n = Z \cdot v \cdot (M \cdot U : R) = Z : (M : R) \cdot (v : U).$$

One also can derive a simplified form from it and then gets the formula:

$$n = (z_p \cdot z_m) \cdot (v : U).$$

So that a similar analogy is existing also between the efficiency *n* of the propeller and the glide ratio ε of the aerofoil notices now, too, how the coefficients z_p and z_m are analogous to the aerofoil coefficients z_a *and* z_r. The line of the efficiency is found in figure no.17 for the propeller of the figure no.14.

An arithmetical observation of the efficiency is superfluous for the stand run since this must obviously be 0 also at *v* = zero. In this case work is taken but not passed on to the triplane by the propeller.

3.4. The "Slip" of the Propeller

From the last sentences of the section 3.3. we have learned that the efficiency of the propeller is zero at the progress degree of zero, since no work is handed in. In figure no.17 the efficiency decreases to zero another second time at a progress degree of the propeller of *v : U* = 0.3. One can explain this behaviour easily, if one gets clear about it again what we said in section 3.1. about the motion of the single segments of the airscrew. We have seen there that the angle *c* of the speed vector *w* is formed by the quantity of the circulation speed and the forwards speed. Sometime, so a point at which the angle *c* collapses with the angle of attack *a* of the propeller elements must be reached at growing progress degree. We already have seen, too, the forces of the air get lower as in the case of relieving angle of attack. So it is absolutely plausible if at one determined quantity of the ratio *v : U* the propeller can perform a tractive power no more. At this point the aeroplane also reaches its maximum speed, too. But this we will discuss later.

4. The Interplay of the Wing with Propeller and Engine

4.1. The Propeller and the Engine

We have learned in the earlier sections that, all other things provided remains unchanged, the momentum of drag of the propeller proportionally stands by the rotational speed **n**. One can type the rotational speeds in as an abscissa in an axle cross and as an ordinate to this the momentum of drag, building on this observation. One can mark ordinary parables into this axle cross and read the momentums of drag of the individual engine speed ranges from these lines for firm quantities of different *zm* coefficients. We already know, too, how a change of the progress degree of the propeller has an effect on the quantity of the coefficient *zm* of our propeller. It is the smallest at the stand and at the greatest at the horizontal straight flight. It finally will become a little more greatly than in the horizontal flight at the climbing. We have marked three parables of the type just discussed into an axle cross in our figure no.18.

In chapter no. 10 of the book "FOKKER DR.I / Drei Flächen - Eine Legende" we have listed the braking lines in figure no. 28 for the Oberursel Ur.II rotary engine.

How the performance measurement of an engine at the brake works can be looked up in every good book over aircraft engines. We need the figure no. 28 (not contained in this book) mentioned above for the further reflections on how the propeller and engine act in combination .

The braking line of the engine which concerns the torque can directly be copied out into our figure no. 18 which the parables represent for the connection of torque and circulation numbers at different z_m coefficients. We have prepared a diagram in which the parables of the momentums of drag of our propeller cross with the line of the deliverable torque of the Oberursel engine with that. The interfaces of the lines give us information about the rotational speeds which the engine can reach with our propeller from figure no. 14 in the three flight states.

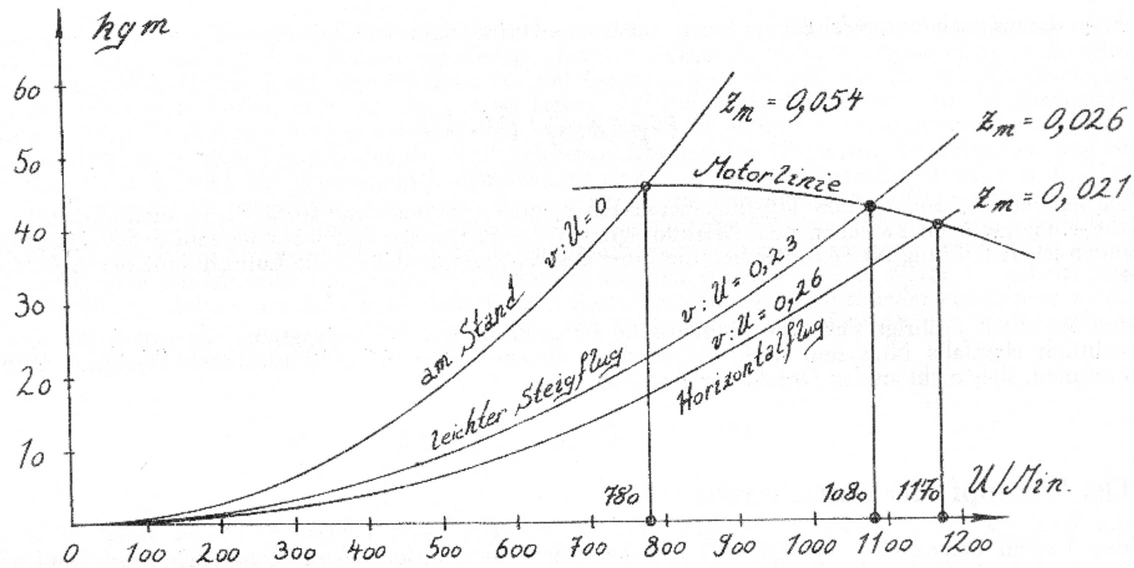


Figure 18
Read: am Stand = at the stand, leichter Steigflug = slight climbing, Horizontalflug = horizontal flight.

In case somebody should have difficulties to get clear about the connection, himself only needs to imagine how the engine must at first use its force to move the propeller in rotation after starting up. This goes as long as, as the engine is able to overcome the momentum of drag which the propeller objects to its twist. Sometime, the power of resistance of the propeller is then just as big as the force of the engine. Both forces therefore get like each other and the propeller shifts with a roughly constant rotational speed. So the number of revolutions of a propeller increases obviously with increasing forwards speed of the aeroplane.

We want to examine now, which tractive power our propeller can deliver at different flight speeds in connection with the Ur.II rotary engine. To this end, at first we must find even further revolutions per minute of the propeller out at different progress degrees. We have done this in figure no. 19 in the way just described for the progress degrees 0.082, 0.115, 0.15, 0.18, 0.213 and 0.246. These with this diagram found revolutions per minute of the engine are 835, 865, 900, 965, 1060 and 1140. First it is necessary for different speeds at the search for the propeller tractive power to produce a cover between the circulation numbers just found and the flight speeds in question. We get the flight speed from the quotient progress degree/Extent speed. We get the extent speeds for the rotational speeds of the two diagrams figures no. 18 and no. 19 by the calculation U = **n** : 60 · 2π · R **=** **n** · (2π : 60) · 1.35 = **n** : 7.08. So we have at a number of engine revolution of 835 RPM a extent speed of U = 835 : 7.08 = 117.94m/Sec. And therewith a flight speed of v = 0.082 · 117.94 = 9.67m/Sec. = 34.82km/Std.. We have assigned the flight speed v of the aeroplane to the respective propeller rotational speed in figure no. 20 in this way.

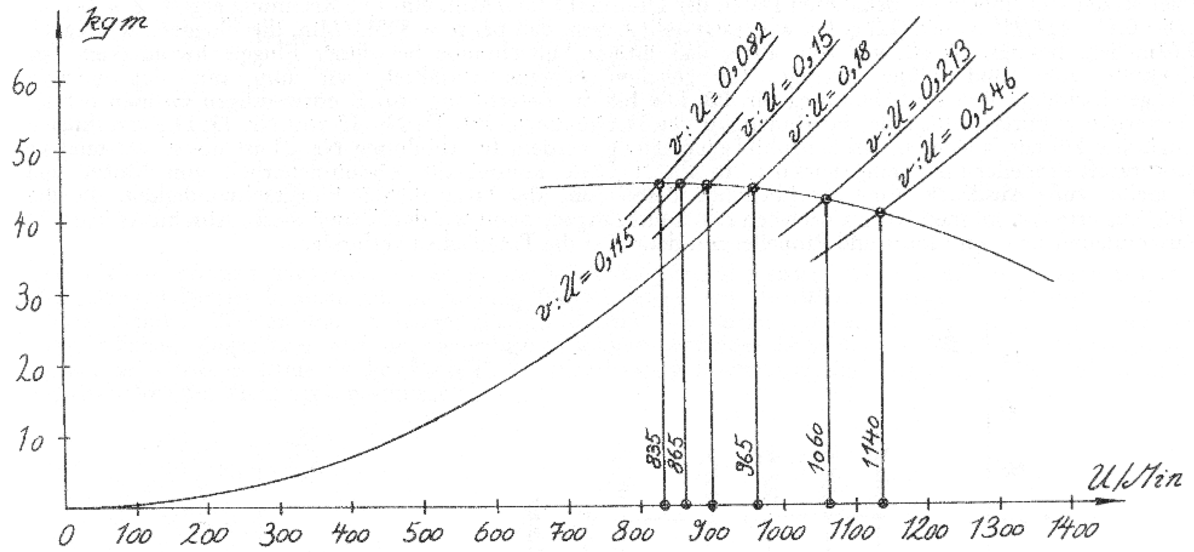


Figure 19

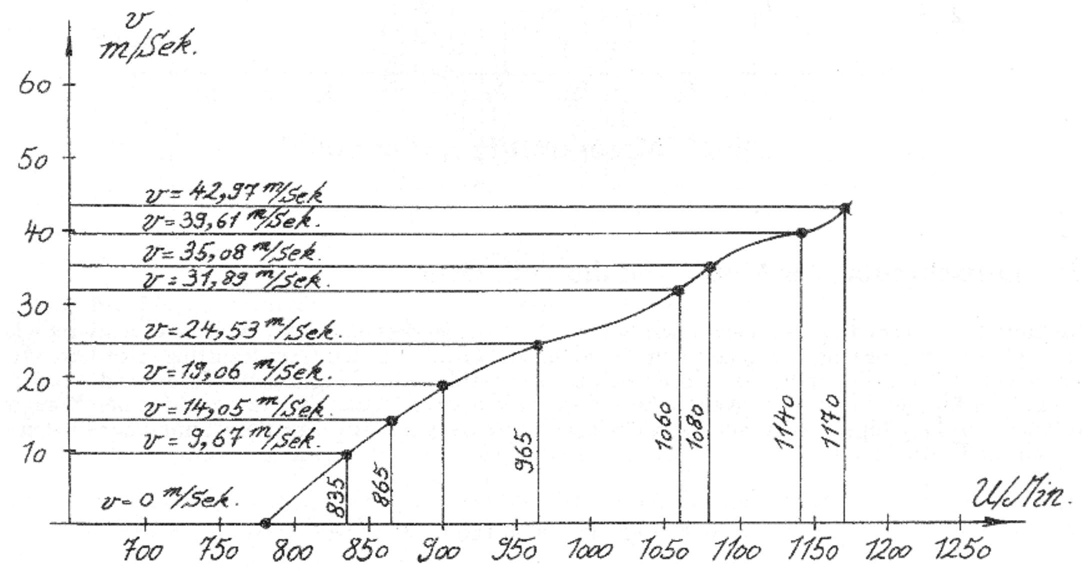


Figure 20

After we have made a connection between the rotational speeds and the flight speeds reached by these, it is not further hard to find out the tractive power of the propeller for the speeds of the aeroplane found in figure 20.

For the specification of the flight speed we have just calculated the extent speed for all revolutions per minute concerned. If we now want to know what tractive power is produced by the airscrew at 835 RPM, that is an extent speed of 9.67m/sec, we will learn this by employing the formula introduced in section 3.2.

$$Z = z_p \cdot 1/8 \cdot F \cdot U^2.$$

We simply use the known data of the rotational speed 835 RPM here. The calculation yields $Z = 0.182 \cdot 1/8 \cdot 0.41 \cdot 117.94^2 = 129.722$ kg. Since we have noted the extent speed at n = 835 RPM amounts to 9.67 m/sec., we know now, too, that our propeller produces a tractive power of about 130 kg at this flight speed have we stated. We deal with the other flight speeds of the figure no. 20. in the same scheme now. We take the quantities necessary for the calculation of *Z* of the *zp* coefficients and progress degrees from the representations no. 15, no. 18 and no. 19. The calculated tractive powers can be written down on a diagram again. The "engine force-propeller line" is arisen so in figure no. 21. The cooperation gets from engine and propeller to the expression in this line. We can conclude a final calculation of the actual flight speed which catches the aeroplane in the next section if we connect the knowledge of this section about the interaction of engine and propeller with it about the wings.

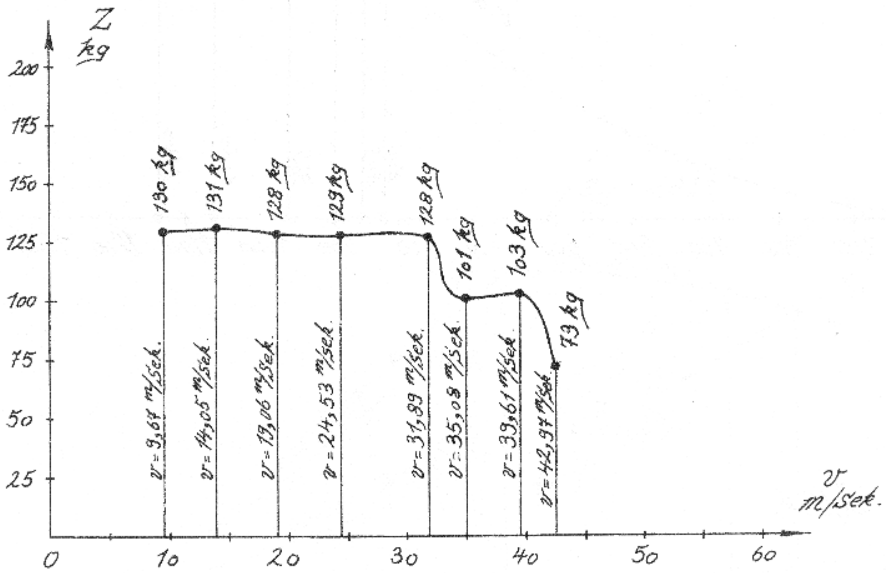


Figure 21 "Engine-force-propeller-line"

4.2. The Propeller, the Engine and the Wing

In section 2.5. of this chapter have we made thoughts, which speed and which tractive power is required for an aeroplane of given weight and quantity for the horizontal flight. We had fixed there that the tractive power which is required must be a match for the quantity of wing resistance + harmful resistance of the other aeroplane parts. We as well stated that the dynamic lift of the airfoils must equal up with the weight of the aeroplane for the horizontal flight. For the calculation of the two quantities we built the formulae:

$$Z = z_r \cdot m \cdot F \cdot v^2 + 0{,}65 \cdot m \cdot f \cdot v^2$$

and

$$G = A = z_a \cdot m \cdot F \cdot v^2.$$

Since the aerofoil coefficients z_a and z_r are dependent of the respective angle of attack, we have chosen the angle of attack of the wings in section 2.5. as provided to us by the Adlershof Baubeschreibung (riging instruction) of the Fokker Dr.I and calculate the following values of v and Z from which:

$\alpha = 2.4°$ $v = 27.56$m/Sec. $Z = 66.18$kg.

In the same approach we will state the necessary tractive power and the speed for different angles of attack for the horizontal flight now. The calculations yield:

for $\alpha = -2°$	$v = 36.84$m/sec.	$Z = 95.26$kg
" $\alpha = 0°$	$v = 34.26$m/sec.	$Z = 91.33$kg
" $\alpha = +2°$	$v = 28.14$m/sec.	$Z = 67.26$kg
" $\alpha = +4°$	$v = 24.65$m/sec.	$Z = 60.90$kg
" $\alpha = +6°$	$v = 25.89$m/sec.	$Z = 77.44$kg
" $\alpha = +8°$	$v = 25.56$m/sec.	$Z = 88.32$kg
" $\alpha = +12°$	$v = 19.82$m/sec.	$Z = 123.92$kg

In turn these values can be written down on an axle cross as we already know it from our earlier figures. In representation no. 22 we have represented the values of Z as ordinates to the corresponding values of v. Such a cover could be produced between the required tractive powers and the respective speeds in this diagram. We describe this line as the "line I" into this following. It is determined mainly by the total aircraft weight and by the qualities of the aerofoil.

We have designed the engine force propeller line in figure no. 21. The form of this line remains completely independent of weight and aerofoil and is only defined by the interaction of propeller and engine.

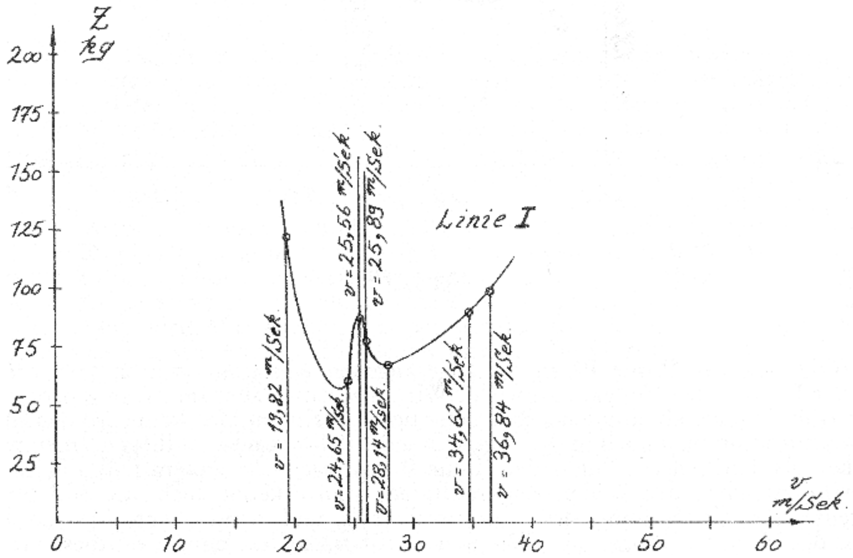


Figure 22

If we describe this line as the "line II" now and together with the "line I" is brought together in the same diagram, we receive the diagram in figure no. 23. This picture is showing us the available and the required tractive power for the flight of the triplane now at the same time.

We have already been proper before that an even horizontal flight of the triplane is possible, only when the required tractive power agrees with the available tractive power.

So only the two points *A* and *B* of the figure no. 23 are considered horizontal flights of the Dr.I. The "line I" which shows the required tractive power and the "line II" which represents the available tractive power intersect namely on these two points. Eliminates the smaller speed for quite certain reasons in the point *B* and point A only has it left for the horizontal flight. Later, we want to discuss more exactly why this is so.

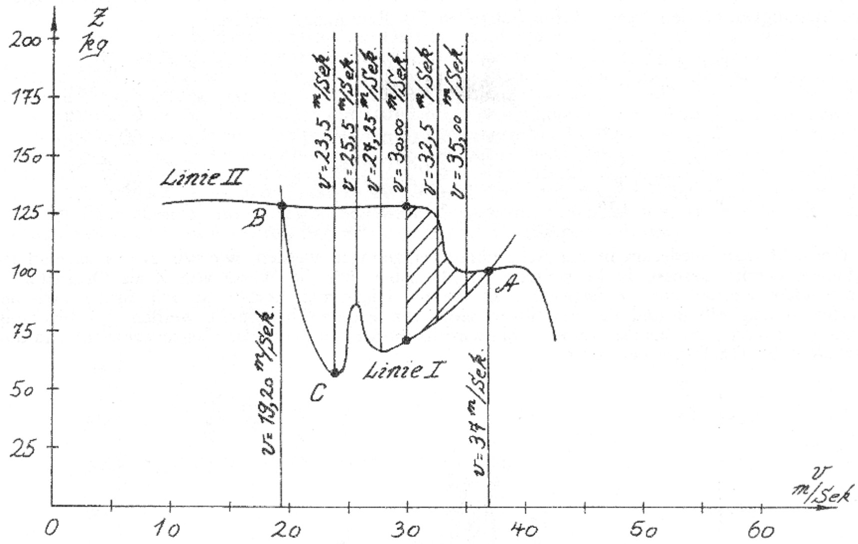


Figure 23

Since the "line I" is determined by the angle of attack of the wing, the representation no. 23 represents us also exactly, which angle of attack enters if the aeroplane flies daring straight. One needs to read only the speed of the intersection point *A* and to look for the angle of attack belonging to *v* in the above table to it. In our example the point A sits at *v* = 37 m/sec.. This corresponds to rather exactly one angle of attack of -2 °. Also on this we want to speak in another connection later once again.

Due to the derivation of the "line II" in the previous section we know that the engine force- propeller line corresponds to the performance at full throttle. If the engine, however is choked in the flight a very similar but more deep-seated curve will find its place instead of "line II" in figure no. 23. So one cannot shut down the engine arbitrarily far if one would still like to be able to fly horizontally. Sometime, the "line II" has sunk corresponds more deeply than the deepest point of the "line I". In this case there is no more intersection point between the two lines of traction force at all. Figure no. 23 also discerns from picture that there is a fixed limit for the position of the gas thrush lever and thus also for the smallest possible speed of the horizontal flight for one. This speed is only insignificantly below the speed at full throttle how one can see easily. So region in which the airspeed of the Fokker Dr.I can be set arbitrarily by using the throttle is very small.

4.3. The Climbing and Sinking

A horizontal flight of the triplane can take place only as we have explained already repeatedly when the required tractive power has the same quantity like the available tractive power. As of now we mark the required tractive power (line I) with Z_1 and the available tractive power (line II) by Z_2.

A climbing of the aeroplane only can be carried out when Z_1 is smaller than Z_2. Only in this case is a surplus of tractive power available which can be put into to raise the aircraft. We mark *v'* the speed which stands up in figure no. 23 in the point *C*, therefore 23.5 m/sec., arises from $Z_1 \cdot v'$ the job performance which is used up by the aeroplane resistance and from $Z_2 \cdot v'$ the performance which the engine by the propeller is able to hand in.

We receive the performance which is allotted to the climbing if we name the total aircraft weight, like already earlier, with G and the climb rate by *w* and then calculate the product of G · W. So we see that:

$$G \cdot w = Z_2 \cdot v' - Z_1 \cdot v' = (Z_2 - Z_1) \cdot v'$$

Must be. From this formula we can derive a formula which makes it possible for us to calculate the climb rate *w*. This formula is:

$$w = ([Z_2 - Z_1] : G) \cdot v'.$$

For the speed in point *C* of the figure no. 23 we get for *v'* = 23.5m/sec. and read in the same representation for Z_1 to 56.25 kg and Z_2 to 127.8 kg. From this a climb rate of 71.25 : 571 · 23.5 = 2.93 m/sec. calculates at a total aircraft weight of 571 kg. All the more strongly the surplus of Z_2 is about Z_1, all the bigger the climb rate of the Dr.I. also is. We however also want to know the climb rates at the remaining airspeeds we have put in figure no. 23. To get to know these we simply calculate them the same way we did above. For the chosen speeds this yields to:

v = 23.50	Z_2 = 127.8	Z_1 = 56.25	w = 2.93m/sec.
v = 25.50	Z_2 = 128.0	Z_1 = 85.00	w = 1.92m/sec.
v = 27.25	Z_2 = 129.0	Z_1 = 66.25	w = 2.99m/sec.
v = 30.00	Z_2 = 130.0	Z_1 = 70.00	w = 3.15m/sec.
v = 32.50	Z_2 = 125.0	Z_1 = 78.75	w = 2.63m/sec.
v = 35.00	Z_2 = 101.0	Z_1 = 90.00	w = 0.68m/sec.

We have executed in section 4.2. that the point *B* in figure no. 23 eliminates for a horizontal flight state. We are now able to understand why this is so. The matter is connected with the fact, that the course of the "line I" corresponds to different angles of attack of the wing. Smaller speeds apply to greater angles of attack and for smaller angles of attack larger speeds. If one wants to link the aeroplane up to a climbing flight from the horizontal flight, then one must extend the angle of attack, that is, put the aeroplane up. By this enlargement of the angle of attack, of course the flight speed drops by waxing the coefficient z_r. With a relieving forward speed we come into an area on the left the point *A* and with that according to figure no. 23 into a state in which Z_2 lies above Z_1 and a surplus of tractive power is available with that. If the nose of the triplane is further taken up, then the difference between Z_2 and Z_1 enlarges still further at first. At a further approach towards the point B the difference reduces, again zero finally is in point *B*. One gets himself clear about it from this that one cannot extend the climb rate *w* arbitrarily by pulling up the aeroplane. On the contrary if the angle of attack is extended too far, the climb rate sinks to zero at a point.

The pilots had to know exactly in the air fight therefore how they had to treat the aeroplane if they wanted to get an advantage out of the good climb capability of the triplane. Putting one up too intensely leads to a reduction of the climb rate.

One sees quite considerably at the above explanations once, too, that the flight speed is always smaller during a climb than at the horizontal flight since only points can be considered for a climbing on the left of A. However, one has speeds with full throttle when sinking unlike this also on the right of *A* which can be far over that one of the horizontal flight. Because if in our formula for the calculation of *w* the Z1 gets greater than the Z2, then the difference Z2 - Z1 and thus also *w* becomes negative. However, the area in which this can happen is on the right of our point *A* and with that located in a part of the axle cross in which the flight speed *v* grows. In the air fight such circumstances in which an opponent was chased with full throttle into the depth or the pilot might escape a dangerous situation by a dive himself, often happened.

However, the sinking flight can already be introduced at smaller flight speeds in this the engine is throttled, too. By this approach one gets a value of *w* which also is a negative one.

A certain area has been represented in hatched, between "line I" and "line II" in figure no. 23. This area reaches from intersection *A* of the two lines to that point in which, according to the above given explanation, the climb rate reached its highest value. At a further approach towards *B* *w* must continuously get smaller and reach a value of zero finally in point *B*. We assume now once our triplane would be in the horizontal flight and would have the flight speed which enters point *B*. In this case the "line I" and the "line II" would cut each other and a horizontal flight actually would be possible after this. The situation will get difficult for the pilot, however, when he likes to still climb now. He will try to reach his goal raising the nose of his aeroplane. However, an immediate reduction of the flight speed arises by the enlargement of the angle of attack. This is the reason that the aeroplane gets into a speed range on the left the point B. No more surplus of Z_2 is here left, however, so that the aeroplane will immediately start with a sinking motion at nose put up. Or formulates differently "it falls down". The pilot can counteract a complete falling through of the aeroplane only by making use of the so-called "reversal of control" which happens in the very moment of stalling. He pushes the control column forwards just so as if he wants to start a downtrend. However, in any falls stalling is, therefore the transition to the not hatched area of the representation in figure no. 23, harmful.

We have mentioned already briefly, that by a throttling of the engine the situation of the "line II" moves down. Of course through this the hatched marked field is always more smaller and more smaller, to the end no more interface of the two curves exists. In this case a flying horizontal or a climbing are no longer feasibly at all. The reason for it is clear. If Z_2 sinks under Z_1, only a negative value can be possible for *w*.

Z_2 falls at engine completely switched off on zero. From our formula for the calculation of *w* we can draw a conclusion that the sinking speed is now:

$$w = Z_1 : G \cdot v'$$

The angle in which the aeroplane goes down is defined by the ratio of sinking speed *w* to flight speed *v*. We get the flattest gliding trajectory when the flight speed is *v* of at once the speed which corresponds to the deepest point of the "line I". The more deeply this point lies, all the more flatly the aeroplane can slip at engine switched off. In our case this corresponds to $w = 56.25 : 571 \cdot 23.5 = 2.32$ m/sec.. It became figure no. 24 to form more clearly around the connection of path and sinking speed designed. For this picture the values Z_1 and Z_2 got multiplied by the speeds *v* so that a diagram which shows the necessary and the available traction performance to the respective flight speeds at the propeller arose. The same considerations as for the figure no. 23. apply to this representation. One can recognize some essential conditions at this form of the presentation better, though. So three points are marked whose meaning we would just like to explain. The intersection point of the two lines which we have already marked by *A* in figure no. 23 is quite on the right. The speed of the horizontal flight is found on this point at engine running at full speed. On the left of point *A* another point approximately at v = 30 m/sec.. In our example two things meet here. On the one hand, engine choked correspondingly is the smallest possible speed of the horizontal flight. This is the last intersection point between the "line I" and the "line II" pressed by the engine reduction. On the other hand, this point also describes the speed at which the climb rate is the largest. The lines "I" and "II" are located in this place furthest from each other. A third point which we have already marked by *C* still further is of these on the left. The smallest possible sinking speed has to be looked at engine turned off at this point. The most deep-seated point of the "line I" is it also. There is point *B* quite on the left which we already know from figure no. 23.

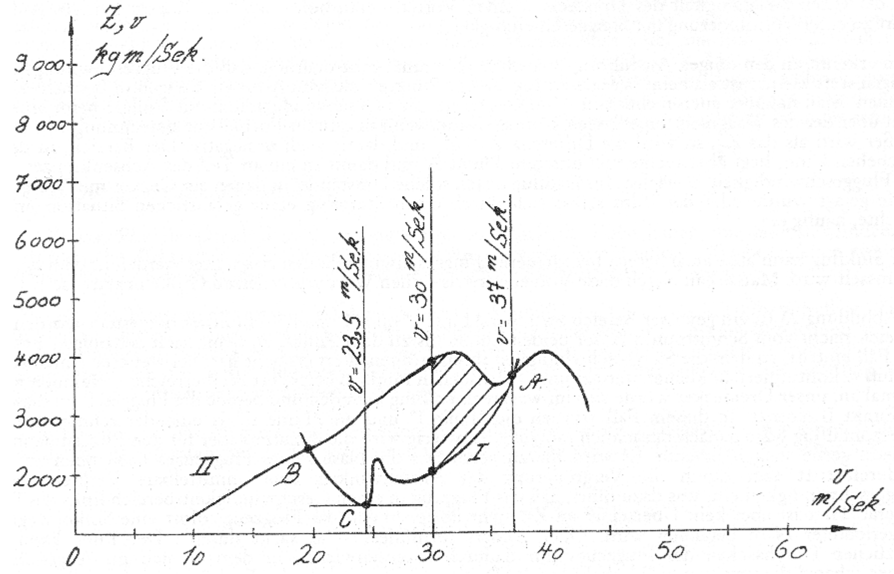


Figure no. 24

4.4. The Flight in the Height

We want to have a try in this section, with the cognitions attained till now about the aerodynamic ratios at the Fokker Dr.I to form a judgement on it in which measure the altitude in which the triplane is has an effect on the possible flight speed and climb ability of the aircraft.

As is well known, it behaves so that the climb rate of an aeroplane further always decreases at increasing height till the aeroplane has reached its "top ceiling" and therefore does not increase any more at all. Therefore the climb rate falls on zero. Of course the reason for it finds itself at increasing height in the relieving air density.

We are interested the flight performances for the Fokker Dr.I in large heights now. To the ascertainment we can proceed just the same as we have explained this in connection with figure no. 23. We need to approach here merely and design the lines "I" and "II" under consideration of the value of the air density for a chosen height newly.

So we further assume our triplane is in a height of 5,000 m. And this at a ground level temperature of 10 degrees Celsius and a gradient of temperature of 0.5 degrees Celsius as well as a barometer reading on the ground of 762 mm of column of mercury. We then state with the table No.2, that under these prerequisites the air density is = m 0.074. This corresponds to 59% of the average value considered normal of 1/8 = 0.125. At first we will design the "line I" just like we know it from section 4.3.

According to section 2.5. we can in accordance with the formula:

$$v = \sqrt{(G : [z_a \cdot m \cdot F])}$$

determining the speed *v* for certain angles of attack. The flight speed is immediately dependent on the air density how we can see at the formula design.

The quantity of the tractive power required for it is according to the second formula of 2.5. touched on:

$$Z = (G : z_a \cdot [z_r + 0{,}65 \cdot f : F])$$

completely independent of the composition of density of the air. While so the values of *v* for the chosen angles of attack of the values from *m* are proportional turned over, from what results that if m becomes smaller in the ratio of 59 : 100, for the values of *v* at the same angles of attack must grow in the ratio 10 : √59 = 1.30, the values of Z remain the same for the individual angles of attack.

We get the points which correspond to the "line I" at 5,000 m of height when we multiply the values of *v* in the average column of the table of section 4.2. by 1.3. The table for the new "line I" looks thus as follows:

for α = -2°	v = 47.89m/sec.	Z = 95.26kg
" α = 0°	v = 44.54m/sec.	Z = 91.33kg
" α = +2°	v = 36.58m/sec.	Z = 67.26kg
" α = +4°	v = 32.05m/sec.	Z = 60.90kg
" α = +6°	v = 33.66m/sec.	Z = 77.44kg
" α = +8°	v = 33.23m/sec.	Z = 88.32kg
" α = +12°	v = 25.77m/sec.	Z = 123.92kg

In figure no. 25 the new points of the "line I" were typed in so for the high-altitude flight at 5,000 m.

The "line II" also was designed newly. A graphical here conduction of the "line II" exactly like in the previous section was carried out (cf. fig. 26 and 27).

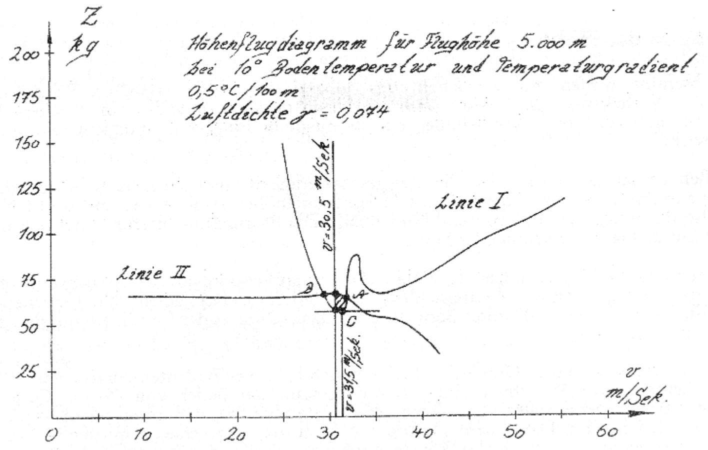


Figure no. 25

In figure no. 26 the engine performance line was marked by 50% reduced.

Such a reduction of the engine output is caused by the decrease of the air density inevitably. In our case of the Ur.II rotary engine we started out from a performance decrease of 10% per km of altitude. This is with a considerable safety very overvalued so that the flight performances of the triplane are represented a little more favourably here as at the use of the propeller corresponded from fig. 14 in reality. Unfortunately, documents are missing about this as how much per cent of its performance really lost the engine in 5,000 m of height. figure 26 has therefore arisen just the same like the diagrams no. 18 and 19. The representation 27 finally corresponds to fig. 20 in its emergence.

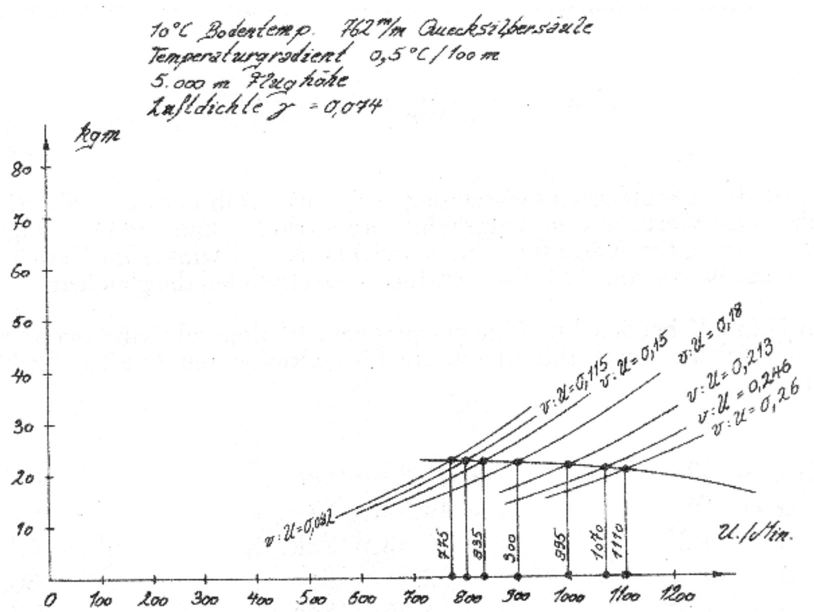


Figure no.26

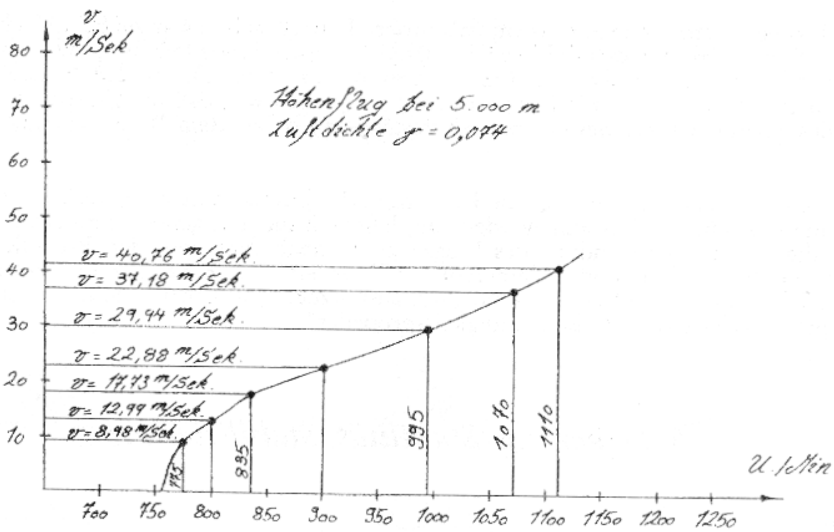


Figure no.27

We can make the same considerations in connection with fig. 25 like to fig. 23 and 24. We have the intersection points of the lines "I" and "II", the points *A* and B as well as the point C here again, too. The same applies also to these points as in the case of the earlier representations.

The climb rate *w* charges according to section 4.3. to the formula

$$w = ([Z_2 - Z_1] : G) \cdot v`.$$

We see from figure no. 25 at a speed of *v'* = 30m/sec. the tractive power *Z2* at 67.5 kg and *Z1* to 58.75. The difference between the two tractive powers amounts to 8.85 kg. And we therefore get at an altitude of 5,000 m *w* = (8.85 : 571) · 30.5 = 0.47 m/sec. The greatest possible *w* is 0.47 m/sec in this height only. One can recognize considerably that the climb rate falls off strongly at an increasing altitude by this. The highest flight speed of the horizontal flight in point *A* amounts to almost 32 m/sec in 5,000 m only, too.

The "line II" sinks logically still further at an even further decrease of the air density by change of the weather or by a further climbing of the triplane. Till no more intersection point of the lines "I" and "II" exists sometime at all. The Fokker Dr.I cannot increase further then any more.

4.5. The Significance of the Propeller for the Flight Performance

The flight performances of an aeroplane, like we have examined them previously with the diagrams in the last sections, such like flight speed, climbing and sinking rate, service peak height and that forth can be influenced by the choice of the propeller decisively. As we have seen, the "engine performance/propeller-line" is formed by the interaction of engine and propeller forces at different rotational speeds. The engine of the aeroplane remains the same while the airscrew gets changed, the "engine performance/propeller-line" will move itself according to the qualities of the propeller so of course.

The positions of the intersection points *A* & *B* change at the same time with that, however, too. This accordingly changes the quantity of the largest climb rate, the greatest possible flight speed at horizontal flight as well as the smallest possible speed of course through this. Depending on this as every propeller is very different from another one (even if of the same type in those days) these performance differences turn out greater or smaller.

One will always endeavour to choose a propeller with a greatest possible efficiency. We have already seen, though, that the efficiency of the propeller is in direct dependence of the respective away step degree *v : U* of the airscrew concerned.

We want to clarify the discrepancy of different airscrews at the example of the flight of the Fokker Dr.I in the height of 5,000 m. We see in figure no. 25 that the point of the horizontal flight is at point *A* at about 32 m/sec.. The progress degree that corresponds to this speed is 32: 142.72 = 0.224. In the representation no.17 we see the efficiency of the propeller being at this progress degree at approx. 75%. The point which corresponds to the speed at which the climb rate is the greatest in figure no. 25 sits at 30.5 m/sec. The progress degree here is 30.5 : 141.37 = 0.215. Therefore the efficiency of the propeller also is here approx. 75%. One sees that our propeller of figure no. 14

loses nothing in this case of the engine output if a climbing flight is introduced in an altitude of 5.000 m.

It behaves at our example in the figures 23 and 24. differently. The point of the horizontal flight at 37 m/sec. lies what corresponds to a progress degree of 37 : 156.92 = 0.236. The propeller reaches an efficiency of approx. 78% here. The point of the greatest climb rate is 30 m/sec.. The progress degree is 30 : 148.44 = 0.202. The efficiency of the airscrew at that progress degree is just 70%. So it is a difference of 8% which is so to speak lost of the engine output. At these explanations one can recognize that our propeller is not chosen badly but the best choice nevertheless does not represent for the Fokker Dr.I. Then it reaches its highest efficiency at a progress degree of about 0.25 and is enclosed at approx. 80%. Since the efficiency could be reached only between 70% and 78% in the two instances, we see that its most favourable efficiency, which is of 80%, is outside the complete area of the operating states between the horizontal flight and the strongest climbing.

Another propeller can therefore still improve the performances of the triplane. Providing the answer to the question as of what propeller shall be chosen, can not be a general thing. A certain liberty also is the use of the aeroplane here. One chooses the propeller for a larger or smaller efficiency depending on the size of v : U. This means that one can make use of the engine output either to use the airscrew to obtain a higher climbing performance or to obtain a higher cruise speed. And one just the same talks about a "climb rate-airscrew" or a "high-speed airscrew" depending on this.

5. Control, Stability, Stabilization

5.1. General Notes

We have always only talked about flight situations, which can be described as constant or stationary operating states in all previous explanations. The triplane, as well as every other usable aeroplane also must dispose of such facilities, however, that make it possible for it to change from a permanent condition a different one. In addition, these facilities must enable the pilot to counteract perturbations of a stationary state.

The mode of action of such controls or stabilization organs is carried out by the fact that by their motion arising forces of the air are transferred to the aeroplane in a suitable way. The components of an aeroplane which takes these forces of the air are called depending on this control surface or fins, which task they have to accomplish (control, stability).

The perturbation motions which can appear during a stationary and straight flight are divided up into two categories generally. Firstly, one talks about longitudinal motions of the aeroplane and secondly about its transverse motions.

At first we imagine the triplane in a straight horizontal flight. Rejects into the direction of motion, called the aeroplane axle or also propellers or longitudinal axis. This is crossed vertically by the so called Center plane or longitudinal plane. A perturbation motion on the Center or longitudinal plane belongs to the longitudinal motions. Such a perturbation can show itself by the fact that the Center or longitudinal plane differs from the normal direction of motion without moving off from its original situation. The aeroplane can show a course deviation in the vertical one (nose sinks or lifts).

The transverse motion stands opposite to the longitudinal motion of the aeroplane. One understands by this a shifting of the aeroplane along its roll axis and therewith vertically to the longitudinal axis. This means a revolution around first of all the longitudinal axis and secondly around the vertical axis. (Aeroplane "banks" to the left or the right or aeroplane turns its nose to the left or to the right).

The respective facilities consist of three groups. We will try to get a clear idea about the different purposes of the respective aeroplane organs now first. The first group is those which are to achieve an arbitrary change of the speed vector, which means to change the course of the aeroplane, or the direction it goes to. Its is achieved by twisting the aeroplane correspondingly once for such a change of course. It must be able to be swung around both axis, its vertical one and its traverse axis. After everything we know till now the first of these two changes belongs to the transverse motions and the second to the longitudinal motions.

The rudder serving for the sideways control is a flat area which is attached relatable in a suitable distance to the Center of gravity at the tail end of the aeroplane. Its angle of attack in the stream of air can be settled by the pilot. Accordingly to the direction the rudder is swung to, the control surface area learns an atmospheric pressure of the left or the right and pushes the tail of the aeroplane in the appropriate direction with that according to the direction of the rudder movement. The lengthways control by the elevator quite similarly also works. This control surface is an also flat area which is attached rateably and also can be adjusted by the pilot around an axle which is going horizontal and crossways to the direction of flight. Forces of the air which push the tail end up or down arise at a rash also here.

It will a little more complicatedly become now if we want to have a try to understand what one understands by the stability or the organs for the obtainment of the stability. Formulated quite generally one can say that a motion or also a resting condition one describes stably, if it has the peculiarity to return to a stable condition without additional help from the outside after an outer perturbation occurred. This short paraphrase shall suffice here at first. More exact information can be looked up in every physics book under the heading "statics". We only enclose the fig. 28 to the better clarification here.

Figure 28: Different stages of equilibrium

Up till now we have examined merely the conditions with our model calculations under which the aeroplane is in the equilibrium. With this we did always only assume that the forces of the air which have an effect on the individual parts of the aeroplane as well as on the wing and the airscrew segments are in equilibrium opposite to the total aircraft weight and the engine power. Whether last end of it these calculation results have practical value or not depends off, whether the state of the equilibrium is of stable nature or not. The circumstance actually lies so with an aeroplane, however, that a system arises which well is in a calculated equilibrium, if wing, engine, propeller and larger parts of the aeroplane are united with each other, but a completely unstable one as a matter of fact. If an aeroplane has no facilities which provides it that from this unstable system it can come back to at least a stable system at some certain degree, then it is just as impossible to fly with it then it is to put an undamaged egg on the top.

The facility which one is to act against any perturbation force in the motion of the aeroplane in the longitudinal motion is generally called the stabilizer and elevator. A similar effect of the stabilization of the longitudinal motion can be reached by it that the wings are drawn arrow-shapely to behind. But like we all know this remedy for the stability attainment was not employed with the Fokker Dr.I. The stabilization is merely attained by the stabilizer at this aeroplane.

It is something more complicated than it is the case at the longitudinal stability to achieve stability in the roll direction. The roll stability can to some extent be achieved by the fact that one gives the wings a V position or been the wing tips bent strongly up at an aeroplane just like the flying seeds of the Zanonia plant. Also here we know that these methods of the stabilization did not come to the application in the roll direction at the triplane. How is the stability achieved in the roll direction at the Dr.I, however? Well, the aeroplane is indeed very unstable in the roll direction at first.

The fact that the triplane only can be described as unstable in the roll direction leads up to the explanation of the group of necessary facilities which is third and mentioned in the heading of this section namely to the organs which serve for the stabilization of the equilibrium state.

Since the aeroplane can only be described as being relatively unstable in both, longitudinal and roll direction (it can be never started out from a 100 per cent stability at appropriately big perturbations), it must dispose of organs which can be used directly by the pilot of organs, too, to enable him to work effectively contrary eventual outer perturbations and.

The stabilization is needed for the roll motion mainly. As said above, the triplane is absolutely unstable in the roll motion, so would be impossible to fly if it would not have the appropriate facilities for the stabilization of this evil at his disposal. The organs which take over this task are called ailerons. Exactly like the elevator and the rudder, the ailerons are, rotated around an axle lengthways at the trailing edge attached flat areas located at the wing tips. The ailerons also are called warp flaps since at the beginning of aeronautics all of the carrying wing tips were still warped (bent completely).

The ailerons are flaps working inversely. This means this flap goes at an aileron rash up while the other one is going down. As we will see later in more detail through this at the wing half at which the flap goes down a rise of the dynamic lift comes to happen. This forces the wing up. The dynamic lift is reduced by the aileron going up at the other aerofoil half. Through this wing half falls. By this process, of course the complete aeroplane concerns his longitudinal axis. The pilot can proceed directly against eventual perturbations and cause the equilibrium state again through this.

By the fact that the triplane is unstable in the transverse motion from the beginning on, by the way also by its short wing span and low wing chord, it of course reacts "poisonously" to the activity of the aileron. This adds perfectly to its manoeuvrability.

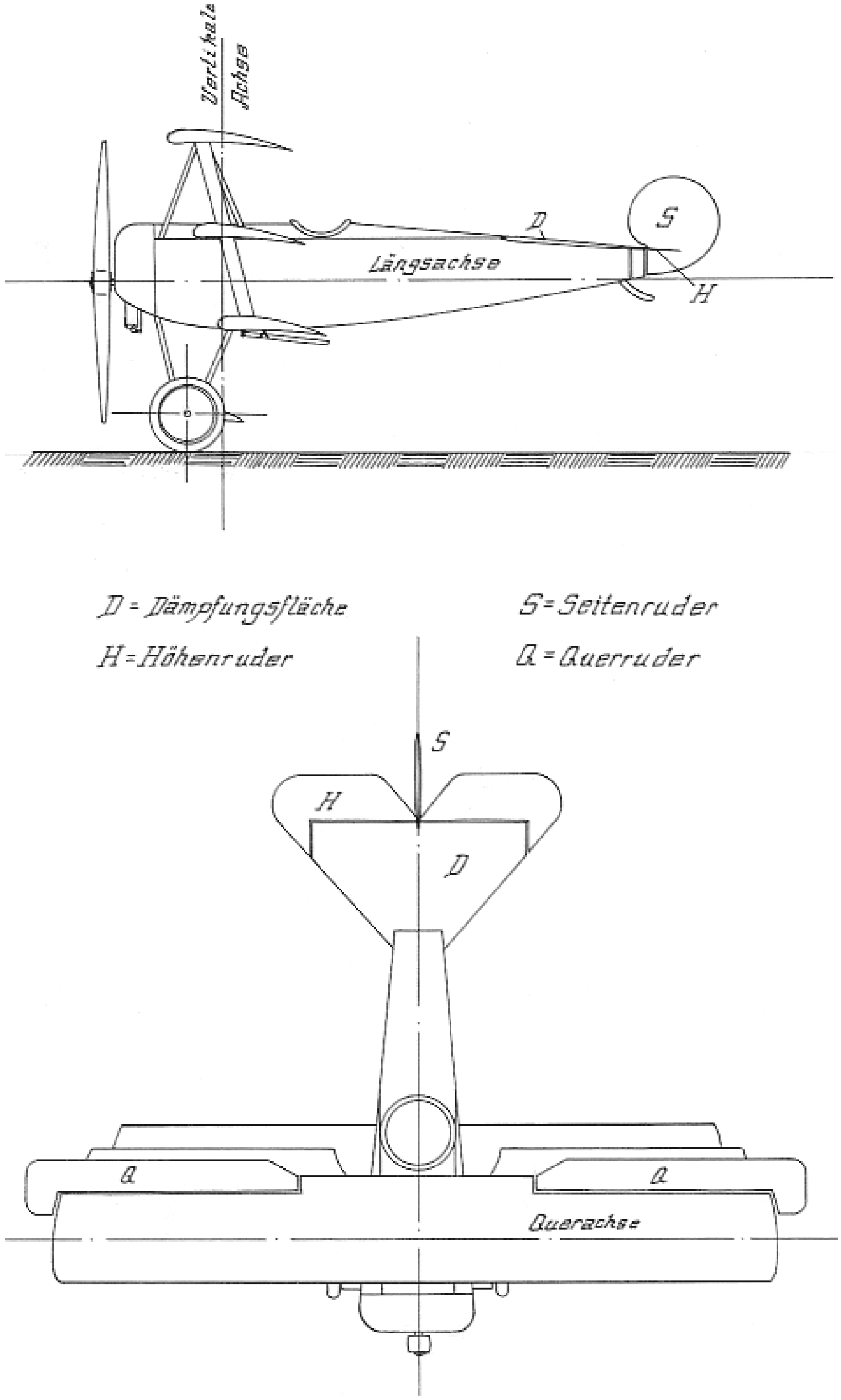


Figure 29 The axis of the aircraft

Perturbations in the longitudinal motion which cannot be compensated by the stabilizer because of their size only can be stabilized by the activity of the elevator.

The situations and names of the axles, fins and control surfaces are given in figure no. 29 once again pictorially.

5.2. The Center of Gravity of the Aeroplane and the Average Pressure Distribution of the Wing

For the equilibrium of an aeroplane it does not suffice alone that the forces equal up: Dynamic lift = weight, resistance = tractive power. As one knows, two pairs of equal forces which are parallel and acting in opposite directions attacking at two different points of an object are described as a pair of forces or trick couple. This means that they would like not to leave the object in the equilibrium but twist it. It does not be enough therefore that the sums of all force components having an effect on an object must be zero in every direction to leave it in the equilibrium but the sums of all "moments" of the forces also must be zero.

We still must add this equilibrium condition to the considerations made in this book till now. We have disregarded it completely till now. However, it is part absolutely of the terms of the equilibrium and with that the stationary horizontal flight.

We still must subject the following forces to a common examination: the gravity, the dynamic lift and drag of the wing, the harmful resistance of the other aeroplane parts as well as the momentum of drag of the propeller and the tractive power. At first we leave the gyroscopic effect appearing by the circulating parts of the engine which also has an effect on the aeroplane beyond the forces just mentioned quite unnoticed. We want to judge this separately later.

If we mention the forces mentioned above, we mustn't overlook one thing clearly at their consideration. It trades itself at the concepts: Dynamic lift, tractive power, momentum of drag and so forth with forces which are only evenly distributed combinations of many moments and are attacking all around at different points of the aeroplane. In turn every single force consists of numerous individual forces.

We want to regard the gravity as the first. The total weight of the aeroplane works at all parts of the plane and what is in it downwards. The resultant of these forces is described as the "gravity". It always goes by a certain point of the aeroplane. This point is called: the "center of gravity". The situation of the center of gravity of the Fokker Dr.I is in figure 30 marked. It is marked with "S".

We have already repeatedly heard that the forces of the air which have an effect on the individual parts of the wing yield a resultant whose vector almost vertically stands by the aerofoil profile tendon, too. The resultants aerofoil forces K of upper, middle and lower wings are in figure 30 marked in their situation (the arrows do set merely the direction and situation of the forces, but not their size in this graphic). Their exact direction are defined by the ratio $z_r : z_a$ therefore by the glide ratio. Their situation is not given with that alone completely yet, however. To be able to determine the situation exactly, its intersection point still must be acquainted with the profile tendon.

In representation 31, once again, we have the profile of the triplane taken off and drawn in. The situation and size of the resulting force is marked for the positive angle of attack of 2.4°. This one is also called the "average pressure distribution". The situation of this average pressure distribution, is investigated at series of experiments in the wind tunnel exactly like the coefficients z_a and z_r of the profile. Because the average pressure distribution moves itself at change of the angle of attack, it is noted down for the examined angles of attack at once, too. The situation of the average pressure distribution is determined in proportion to the wing depth *L*. Its distance of the leading edge of the profile is marked with *e* and of the trailing edge with *e'*. The moving of the center of pressure as a dotted line is in the polar diagram figure 8 marked. This line represents values of the ordinates C_a and the abscissas of C_m belonging together. C_m corresponds in this case nothing else but $e \cdot C_a : L$.

The complete resultant of the individual forces of the air K_O, K_m and K_u is in illustration 30 also marked by *K.* Of course its situation moves by the dissimilar quantity of the wings and the dynamic lift distribution going hand in hand with that forwards in the direction of the greatest carrying wing area. With the figure no. 8 the situation and direction of the resultants of the individual wings can be marked exactly for every arbitrary angle of attack.

As a force to be taken into account further we still have the harmful resistance of the individual aeroplane parts. This force is acting contrary to the direction of motion of the aeroplane. The resultant of the harmful resistance can be calculated only with difficulty. However, its situation can be assessed more or less well. In figure 30 we have marked the resultant by *W* and suspected its situation below the longitudinal axis of the triplane a little. If one prolongs this line so far forwards till it cuts all of the resultants *K* of the three wings, then one can put together these two forces *K+W* according to the parallelogram law for a new resultants. The resultant arisen so was marked K`. It is well-disposed towards the plumb aeroplane axle than *K*.

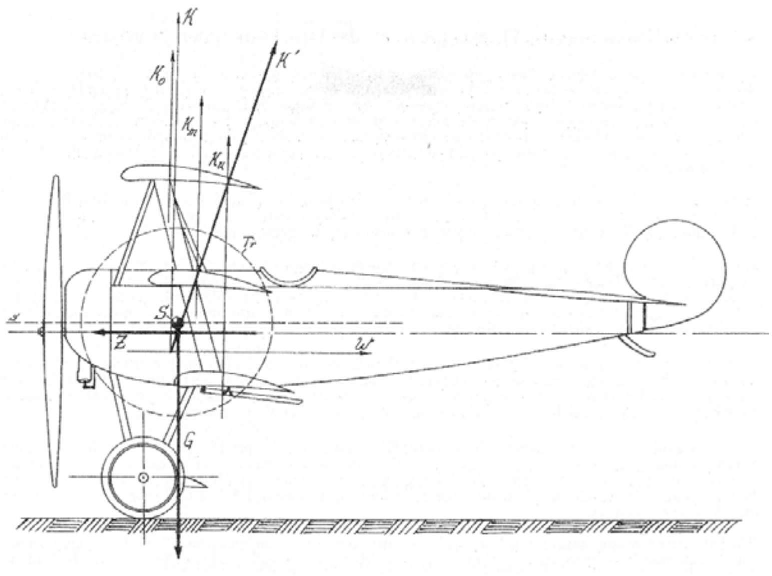


Figure 30 Forces acting on the aircraft

The momentum of drag of the propeller leaves for the lengthways equilibrium. The tractive power of the propeller is, therefore the last force which we still must discuss here. Due to the even form of the two airscrew blades the resultant *Z* of the force of the air fells exactly on the spin axis of the propeller. Mostly, its vector will reject exactly to the direction of flight.

5.3. The Balance of Forces

The forces marked thickly in figure 30: Gravity, resultant *K '* and the tractive power are the three main forces which have an effect on our triplane. From the static's it is known that three different forces can fulfill the requirement of momentums only when their effect lines intersect in a common point. For a stationary horizontal flight it is so absolutely required the effect lines of the three resultants for *G*, *K'* and *Z* meet in a common point. The system only then can be in the equilibrium in the lengthways direction. In figure 30 this prerequisite has been accepted as fulfilled.

One sees also easily from the representation that the intersection point of the three forces lies below the center of gravity. This also has his reason because, if the propeller axle, as shown, is going through under the center of gravity, the forwards directional traction of the propeller endeavors to turn around the aircraft about the center of gravity so that the aeroplane nose lifts up and the tail sinks down. The opposite torque of the force of the air *K'* counteracts this force, so that in the horizontal flight both torques cancel each other out and the aeroplane keeps its situation in the lengthways direction. A good transition into a glide is also provided by that arrangement. When the engine is throttled down the momentum of K' dominates and turns the nose of the aircraft down.

We enclose the illustration 31 to the better clarification of these connections here which explains the situation of the forces around the center of gravity once again. The agreement of *Z* with the horizontal and of G with the vertical partial force of the resultants *K'* also is well explained in that illustration. We have talked about the necessity of this agreement in the greatest detail in section 4 of this chapter.

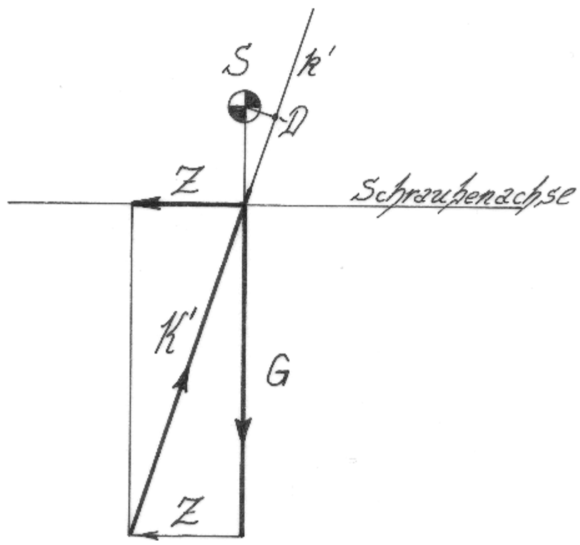


Figure no. 31: Situation of forces around the Center of gravity

In the above picture we have marked the distance of the resultants for K' from the center of gravity with k′ while we marked the distance of *Z* from the center of gravity with *z.* This way two right-angled triangles, *ABC* and *ADS*, arose with the angle in *A* have in common. Through this these triangles are similar to each other and we can by this create the following relations:

$$z : k' = K' : Z \quad \text{or} \quad z \cdot Z = k' \cdot K'$$

The product $z \cdot Z$ is the quantity of the moment with which the propeller tractive power tries to turn up the aeroplane nose around the center of gravity. The product $k' \cdot K'$, however, is the moment which endeavors to force the tail of the triplane around the center of gravity up. Out of the above relation we can see that both products are at once and cancel each other out thus mutually. With that the condition of moments mentioned before is fulfilled and therefore the stationary horizontal flight also is practically possible.

In connection with this, we still want to explain the two concepts "tail-heavy" and "nose-heavy" quick. The two distances of the center of gravity k' and z correspond to the lever arms, at which the forces K' and Z attack. If now the lever arm k' is smaller than $z \cdot Z = k' \cdot K'$, the torque $z \cdot Z$ predominates in the consequence which raises the aeroplane nose -- the aeroplane is tail-heavy. The torque $k' \cdot K'$ which is the reason that the aeroplane nose is pushed around the center of gravity to below predominates in the other fall of a too big lever arm *k ', the aeroplane is nose-heavy*.

It enters different possibilities, to balance an aeroplane which has proved as a head or tail-heavily, afterwards. One can move the order of the loads, for example, so that the situation of the center of gravity is changed. Or one changes the position of the airfoils. Of course the situation of the resultants *K′* moves mainly and primarily in this case. The fuselage can just as well be prolonged or shortened. The most simply carry out but will be to give the stabilizer a corresponding angle of attack? It is clear that a harmful resistance arises at the very most at a stabilizer that has put its angle of attack to 0° in the horizontal flight. If one, however, gives a stabilizer a positive angle of attack, then it learns an additional dynamic lift. If the aeroplane was tail-heavy, then this defect can be cleared easily by a turning on the stabilizer positively. Turned over of course the same result can be obtained by a negative adjusting of the stabilizer at a nose-heavy aeroplane. The Fokker Dr.I had a positive angle of attack of 4.7° for the stabilizer. But later more to this.

It can be thought easily that an aeroplane may be also so carefully adjusted and nevertheless can never be full in the equilibrium. One only thinks of the shift of the weight by fuel consumption, ammunition consumption or motions of the pilot as well as sudden perturbations of the outside (e.g. gusts of wind.).The pilot must counteract such perturbations of the equilibrium by the activity of the control surface already mentioned just now.

It remains still to examine what is the influence which the momentum of drag *M* of the propeller exerts on the equilibrium of the aeroplane. While all forces (*G,K',Z)* discussed before had an effect exclusively on the longitudinal motion of the aeroplane, is a little different at the force M of the propeller. This force tries to turn around the aircraft along axle that is parallel to the propeller axle in the contrary sense to the trick of the propeller. As we have already heard, such a rolling motion falls into the area of the transverse motions of the aeroplane. Of *M* the size is for at once the driving torque of the engine and we are able employ a formula of which the conduction we can get in every good book over engines for its calculation. This formula is:

$$M = 716 \cdot (L : n)$$

In this *L* stands for the hp performance of the engine in question and *n* for the number of the revolutions per minute. In our case of the triplane the momentum of drag is $M = 716 \cdot (110 : 1200) = 66kgm$. With this moment the propeller endeavors to twist the triplane at about the axle of its center of gravity in a way that the right wing lifts and the left sinks. Half the total weight of the aeroplane, that is 285.5 kg, weighs on the two wing halves. The wing span of the middle wing is 6.225mm. The distance of the aerofoil middles on the left and on the right of the fuselage at which one can imagine attacking the 285.5 kg is 6.225 : 2 = 3.11 m. One imagines now the dynamic lift of the left wing around 66 : 3.11 = 21.22kg extends and opposite around just as much reduced, still yields 571 kg the grand total so. However, the torques do not cancel each other out, but 1.56 (571 + 21.22) surrender in the direction of rotation of the propeller and the trick sense set to 1.56 (571 – 21.22) so that 3.11 · 21.22 = 66kgm set are left counteracting to the torque *M* of the propeller.

After the above calculation the moving torque of the propeller can be compensated for as follows. One provides that the other aerofoil side which delivers by 13.84% more dynamic lift is pushed to below. This looks in the practice so that the ailerons of the triplane already have a corresponding rash as long as the control column is in "neutral position." Furthermore a slight adjusting of the rudder also can support this effect at the triplane. This since its largest portion lies above the center of gravity axle sS (Figure no..30). A force of the air attacking to this causes not only a twist of the aeroplane around its vertical axle but also a twist around the center of gravity axle which leads to a rolling motion of the aeroplane then. To this consideration we still want to tie quite separately at the end of this exercise book if this goes to discuss the bent down top fuselage longeron behind the cockpit at about 1° downwards.

5.4. The forces appearing at the control surfaces and the stabilizer of the triplane and the moment of inertia of the aeroplane.

All forces which appear at the aileron surfaces, the rudder, the elevator as well as at the stabilizer can be calculated according to exactly the same orders which we have found in this chapter for all forces of the air till now. For all control surfaces as well as also the stabilizer of the triplane can be valid, that these are almost flat areas. The control surfaces are attached in hinges so that the angle in which they are exposed to the stream of air can be adjusted arbitrarily by the pilot about rope tractions and appropriate facilities in the cockpit. The stabilizer is tightly (not adjustably) connected to the fuselage and has a positive angle of attack of 4.7°.

The power play at flat wings which are moved with different angles of attack through the air already got examined in detail by the father of flight, Otto Lilienthal. The forces which act on such a flat plate can be easily calculated if we set the letter *P* for the force in kg, the letter *v* for the speed, for the area in square meters of the surface *F*, for the density of the air *m* and last but not least if we name a coefficient of the area called z_e.

With to everything explained till now we can derive the following formula from the above details for the calculation:

$$P = z_e \cdot m \cdot F \cdot v^2.$$

Exactly as in the case of the calculation of the coefficient of lift *za* the coefficient of a control surface immediately also depends on the angle of attack and on the design of the control surface in question, on the one hand. If the control surface is a rectangle, then particularly the ratio of the lengths plays a large role. The results of tests with rectangular plates are in the following figure no. 32 represented at angles of attack of 0° to 90° and aspect ratios of the width to the depth of 3, 1.5, 1 and 0.5.

If one watches the course of the coefficient z_e of the plate with the ratio width : depth = 3 : 1, one may note one interesting thing. At first it grows proportionally up to an angle of attack of about 12°. But then, it stops completely growing and even falls again a little bit. Only with larger angles of attack it starts to climb again. One can draw the right conclusion from it that an adjusting of

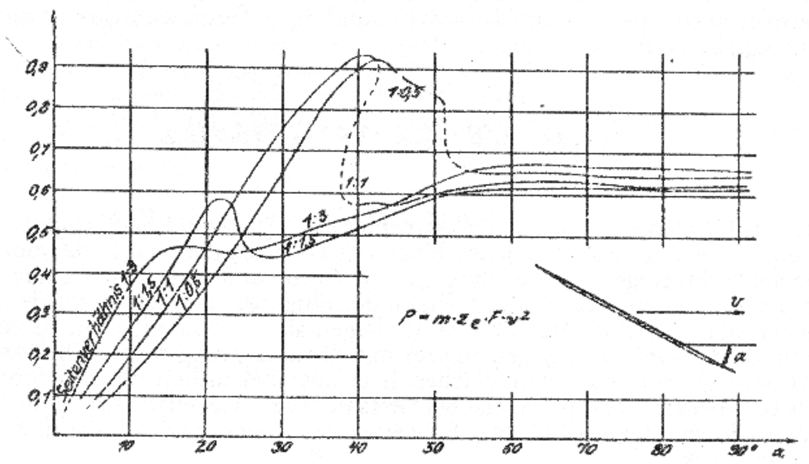


Figure.32 coefficients of right-angled plates of different aspect ratios.

elevator and aileron control surfaces of the Fokker Dr.I - which are substantially wider than deep - of more than 12° 15 ° is of little sense. Through this, obviously no rise of the effect is reached. For such a elevator or aileron with an aspect ratio of 1:3, we can assume the ze according to figure no.32 at an angle of attack of 12° with 0.4. By this we can set the coefficient ze for a calculation of P of such a rudder set at 12°, what is the maximum number of a useful flap, to 0.4 and we will get the following result at an airspeed of 44m/sec. for an area of 1 square meter of the rudder:

$$P = 0.4 \cdot 1/8 \cdot 1 \cdot 44^2 = 96.8\text{kg/m}^2.$$

The ailerons of the triplane have a ratio width : depth = 1 : 8. Unfortunately, no notes of the coefficient z_e are available for such aspect ratios. The FOKKER-TEAM-SCHORNDORF is working on the preparations to corresponding tests presently, too, but the results will not be available so early that they still can be brought in here. In a later support, however, this defect will be cleared. Till there we will assume, that the most effective control surface rash is about 10° and the at this one attainable value of z_e reaches not more than 0.3. We want with these -- for the time being fictitious -- values calculate the forces having an effect on the ailerons at an airspeed of v = 44m/sec. The total area of an aileron amounts to 0.78 m ². We arrive at the conclusion with that:

$$P = 0.3 \cdot 1/8 \cdot 0.78 \cdot 44^2 = 56.63\text{kg}.$$

Also for the elevator such a calculation can be carried out. At the elevator we have the case that it is two areas, of which both have the ratio for width : depth = 3 :1. So we can carry out a calculation in the way described first and to be more precise in the way, that at first a page is examined and the result is multiplied by 2. Also here shall the speed V = 44 m/sec. be assumed. The area of an elevator side is 0.56 m ². We get as a result for P with that:

$$P = 0.4 \cdot 1/8 \cdot 0.56 \cdot 44^2 = 54.2\text{kg}.$$

We multiply this result by two, so we get as total control pressure which can be achieved with the elevator 54.2 · 2 = 108.4kg.

It behaves a little bit different with the Fokker Dr.I rudder. As we can see in the illustration 32 the coefficient curve goes for plates with the ratio width : depth = 1:1 what approximately corresponds to the triplane rudder a little different from the one of a plate with an aspect ratio of 1:3.The difference consists that the quantity of z_e is half so large at 12° only approximately but still rises for this to about 40° and reaches a maximum value of 0.92 at that angle of attack. With that said it lies around a little more than twice so high as in the case of a plate with the ratio 1:3.The effect which produces the rudder at a maximum swing of 40° and a speed of 44 m/sec. at a total area of 0.66 m ² is:

$$P = 0.92 \cdot 1/8 \cdot 0.66 \cdot 44^2 = 146.94\text{kg}.$$

It may not be overlooked at the quantities of the control forces of heights, cross and rudder calculated here that it can only be fairly exact approximation values. We have started out from flat rectangular plates namely in the choice of the coefficients, on the one hand. On the other hand, we have just dealt with the control surfaces and not looked at the control surfaces in connection with the other parts of the aeroplane. Control affectivity of the elevator should actually lie more highly than this, for example, what we have just calculated. This can be explained by it since the elevator forms a system of a cambered wing together with the stabilizer (at rash). However, the taken force of the air lies with cambered wings in higher areas than at flat plates which are exposed to the stream of air at different angles of attack, as is well known. More exact tests to the observation of the coefficient of the control surfaces, are still due in connection with the other aeroplane parts, too.

The decision on the necessary dimensions of the control surfaces and their distance of the center of gravity of the aeroplane takes off also particularly of this as the individual weights of the aeroplane are distributed. If the load is ordered around the center of gravity very near, then this speaks in a less complete sluggishness of the aeroplane. In turn this leads to a greater agility. It also allows the size of the control surface at the same time to be laid out smaller. By which the sluggishness of an aeroplane certainly is, for the size one calls the sluggishness radius or the moment of inertia of the aeroplane.

For every arbitrary axle which is going through the center of gravity the sluggishness radius can be found out arithmetically as soon as one knows the weights of the individual aeroplane parts and their situation in the reference to the center of gravity. One then marks the weights of the single loads and aeroplane parts with *A,B,C,D,E,...* and simultaneously the distances of these parts of the axle which is in question and going through the center of gravity by *a,b,c,d,e,...* and forms the expression $A \cdot a^2 + B \cdot b^2 + C \cdot c^2 + D \cdot d^2 + E \cdot e^2 + ...$ and the sum then divides by the total weight G, one only needs to take that result and to pull the square root out of it to get the sought-after sluggishness radius *r*. One also calls this *r* the sluggishness radius of the aeroplane of the axle concerned.

We want to carry out this calculation now, too and select the most important quantities, their weights and distances of the center of gravity for this.

A	=	propeller + hub	a	=	1,030m
B	=	110 Hp Le Rhône	b	=	0,768m
C	=	undercarriage	c	=	0,240m
D	=	full fuel tank	d	=	0,192m
E	=	complete upper wing	e	=	0,120m
F	=	middle wing	f	=	0,120m
G	=	lower wing	g	=	0,240m
H	=	seat and bearing	h	=	0,960m
I	=	pilot	i	=	0,720m
J	=	elevator and stabilizer	j	=	3,480m
K	=	tail skid	k	=	3,720m
L	=	waepons and ammo	l	=	0,288m
M	=	rudder	m	=	4,152m
N	=	fuselage	n	=	0,600m

From this this one the calculation looks as follows:

$$r = \sqrt{(18 + 87{,}3 + 1{,}98 + 2{,}58 + 0{,}58 + 0{,}39 + 1{,}32 + 4{,}60 + 41{,}5 + 96{,}88 + 13{,}8 + 3{,}9 + 77{,}6 + 19{,}2) : 571} = \underline{0{,}8m}$$

The multiplication $X \cdot x^2$ *was* executed already in this calculation. The individual weights of the quantities *A,B,C,D,E,... are* found in the book "FOKKER DR.I / Drei Flächen - Eine Legende" in another place. (The english Edition of this book will soon become available under the title "The Complete Fokker Dr.I" ISBN 3-930571-68-4)

So the sluggishness radius of the Fokker Dr.I is 0.8 m. We have marked it dotted in illustration no.30 and marked it by *Tr.* It is this one the sluggishness radius of the axle of the machine that goes through the center of gravity parallel to the traverse axis of the aeroplane. This axle is considered for the effect of the elevator. The control force moment of the elevator shall be under otherwise the same conditions at least proportionally to the total weight in the square of the sluggishness radius ($G \cdot r^2$) . In the other case the control would react very clumsily since its momentum is not able to overcome the sluggishness of the aeroplane around the corresponding axle.

The following fall stands up for the triplane and his elevator:

$$G \cdot r^2 = 571 \cdot 0{,}8^2 = 365{,}44$$

This is opposit to:

Control force moment = P · lever arm (control surface canter of gravity of the) = 108.4 · 3,96 = 429.26kgm.

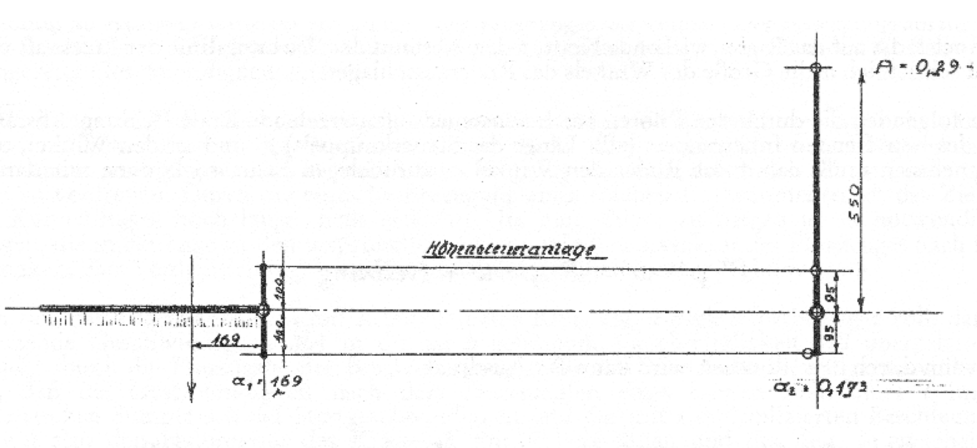
We now clearly see that:

$$356{,}44 < 429{,}26$$

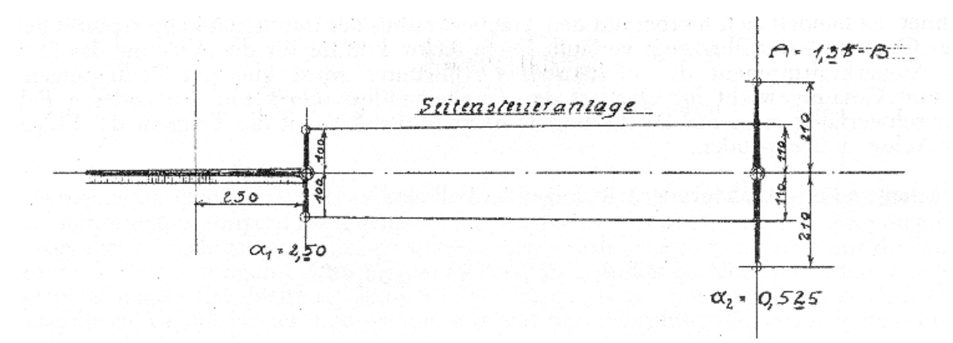
and therewith that condition is fulfilled.

Of course it is possible to do the same calculations to charge the sluggishness radii for the vertical axle (rudder effect) going through the center of gravity and for the longitudinal axis (aileron effect) going through the center of gravity. We want to not show these calculations also since these are not from the one just carried out above. Who is interested in it can carry out the calculation according to the above example himself.

5.5. The control of the surfaces and forces required by the pilot to bring up for their activation.



33. Elevator Control.



34. Rudder Control.

One mustn't pass over another important factor during the design of the control surfaces. The talk is of this by expenditure of work at the commissioning of the control surfaces in the flight to be produced by the pilot. The mechanical connection between the control elements and the control surfaces is represented in figures 33 and 34. The control of the rudder is, reached by rope tractions which is fastened to a treadle in the cockpit and by this one treads one end of the rudder horn forward while the other is left loose. Through this the rudder is turned around its bar which represents its spin axis at the same time. The motion sequence of operations is activated by the leg force of the pilot.

The control of ailerons and elevator is carried out via the control column. The elevator control ropes run to points above and below of the control columns spin axis and from there all through the cockpit to connection points at the lower and upper rudder horns of the elevator. The pilot can activate the rope tractions and cause the control surface rash through this by consulting and pushing away the control column of his body.

The ailerons are taken to the left or to the right in action by a tilting of the control column. By this motion the torque tube is moved in twist. On this torque tube two lever arms are placed at these the control ropes are fastened. By the twist of the torque tube one of the lever arms pulls the rope to it while the other one let´s it loose.

The forces having an effect on the control surfaces are transferred by the control ropes to the corresponding components of the control elements in the cockpit. The effort that must be produced by the pilot corresponds to the control surface forces plus the friction work which is consumed in the pulleys and conduction bearings. The appearing friction is always held to an understandable way as little as possible to minimize the necessary effort. This is said the work, which one does, charges himself at twist around a certain joint at a control surface in activity:

$$P \cdot p \cdot w$$

With this P describes the force having an effect on the control surface, while p describes he distance of the effect line of the resultant of the air power from the axle of the rudder and last but not lest w describes the angle of attack of the rudder surface.

If we in the following we mark the force to be provided by the pilot at the inner control organs P', its distance from the axis of rotation of the inner organ concerned (for instance the length of the control stick) p' and with w' the way the inner control organ has to go to let the outer control organ reach the angle of attack w, then we can establish the following formula:

$$P' \cdot p' \cdot w' = P \cdot p \cdot w + friction$$

Or, if we divide by $p' \cdot w'$ we can form the expression:

$$P' = P \cdot ([\, p \cdot w \,] : [\, p' \cdot w' \,] + friction : [\, p' \cdot w' \,])$$

The ratio $p \cdot w : p' \cdot w'$ also is called the gear ratio of the control. The gear ratio of the control must be carefully chosen for two reasons. Due to the physical efficiency of the pilot only a quite certain maximum value can be possible for the size of P'. Secondly because if P' turns out too low, the control would be too sensitive secondly.

Now the question arises which dimension can be changed to achieve to achieve a suitable size for P'. The value of p' can be changed only insignificantly since the dimensions of the control organs are put into certain limits due to the anatomical physique of man. On the other hand some can be changed also the ratio $w:w'$, since the quantity of the control surface rash W by the requirements of the aeroplane on the one hand and the quantity of the freedom of movement $'$ for it internal controls by the possibilities of movement of the pilot be restricted for W. This because the size of the control surface rash w is limited by the givings provided by the aircraft on the one hand and by the limited dimension of movements that can be done due to the limitations of space for the movements w' available whithin the cockpit on the other hand. What can be consulted for the change of the effort to be produced by the pilot at the activity of the control surface remains the distance *p* of the effect line of the force of the air *P* at the control surface of the spin axis with that. The effect line *p* can be given a shorter distance to the spin axis of the control surface better by an aerodynamic compensation. Aerodynamic compensation, this is if a part of the control surface area is attached in front of the fulcrum. The pressure which has an effect on this part of the control surface endeavors to turn the control surface around the spin axis contrary to the sense which the rest of the control surface area causes. Through this a certain part of the work is taken for the pilot. This type of the regulation was of *P ′* was used with all control surfaces of the Fokker Dr.I. All control surfaces of the triplane are called control surfaces "partly relieved." At a complete relief of the control surfaces *P* would become 0. Control surfaces relieved completely cannot be recommended since the control would react to an unintentional activity too sensitively in such a fall as mentioned already.

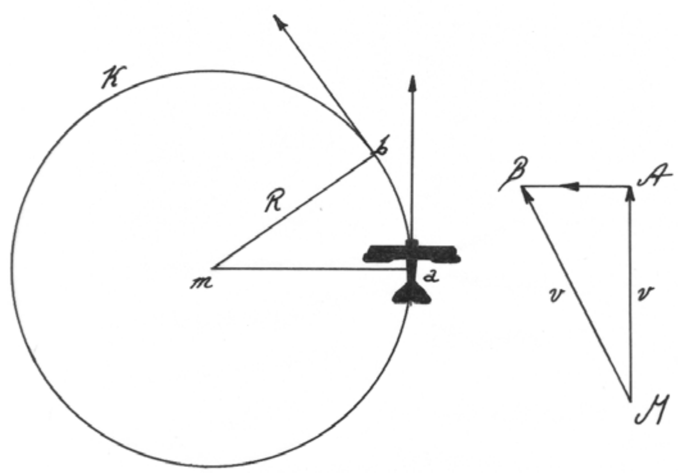
The maximum upper limit of forces to be provided by the pilot over a longer period of time are considered the following:

25 kg of traction or pressure of the arms on the control stick,

45 kg of pressure with the foot on the rudder pedals.

5.6. The Operation of the Control

The way the elevator effect works can be explained very simply and plausibly. If the aeroplane is in a stationary horizontal flight and the pilot assigns a positive rash to the elevator by consulting the control column up, then this one gets a directional force component to below which leads to a rotation of the aeroplane around the traverse axis going through the center of gravity. Because of this rotation the aeroplane nose straightens up while the tail is going down. This at the same time enlarges the angle of attack of the wings which in turn leads to an enlargement of the drag and the dynamic. At first so the dynamic lift increases since the speed remains the same and declines only gradually because of the inertia of masses. The surplus of dynamic lift appearing at this process is put into a climbing of the aeroplane. The motion sequence of operations continues as long as a new equilibrium state adapts with rising trajectory, extended angle of attack and speed reduced slightly.



35. Forces during a curve flight.

The mode of action of the rudder control, that is the controlled curve flight can not quite so simply be explained. By kicking the rudder bar to the left or to the right, the rudder can produced a torque of course, for which one the aeroplane endeavors to turn around its vertical axle that goes through the center of gravity. By the simple production of such a torque the goal, the introduction of a curve flight, is not accomplished yet for a long time. It is to produce a force necessarily which is able to turn the original speed vector of the aeroplane away to the left or to the right to fly around a curve. Our figure 35. serves for the clarification of this connection.

If the aeroplane shall move to *b* in the circle marked by *K*, then the speed *MA* ruling in *a* must be led up to the speed MB being part *of b*. This happens by adding the bonus of the acceleration quantity *AB.* One can say this generally valid since one knows that the speed after passing through a short period of time *t* is always the geometric sum at the start speed and the acceleration multiplied by *t*. If we now do mark the half measuring instrument of the circle *K by R*, and the time which is necessary to pass the distance *ab* will be marked with t then the expression is *ab* = *vt*. The relation can from the similarity of the two triangles *mab* and *MAB* be with that:

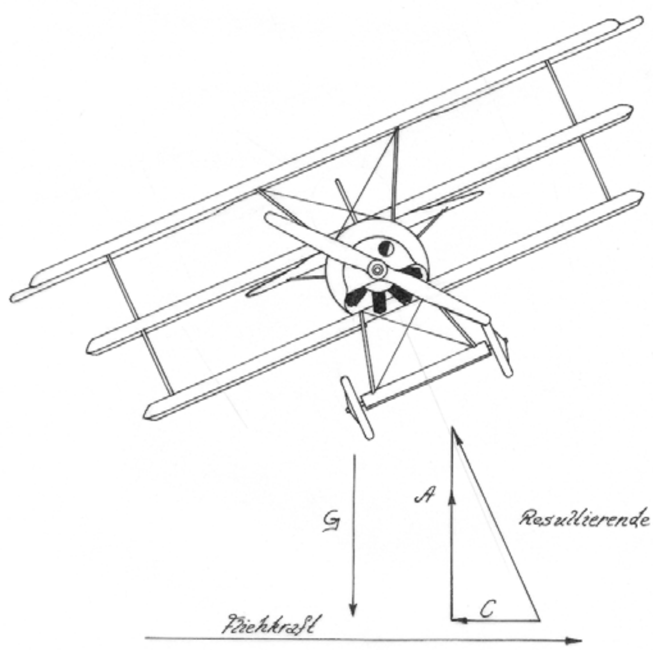
$$R : vt = v : AB, \quad AB = (v^2 : R)\, t$$

This means the required acceleration or speed change is $v^2 : R$ in the time unit. The required force for flying a curve with the radius R with an aircraft of the total weight G, that is the mass G:g is equal to *Mass* · *Acceleration* = $G \cdot v^2 : g \cdot R$. And this in a centripetal direction. We still must come to declare now where such a force, we want to call it *C* shall come from.

$$C = (G : g) \cdot (v^2 : R)$$

The force which counteracts the force C is called centrifugal force.

In a curve every aeroplane takes a certain crooked situation. The forces which have an effect on the aeroplane at that moment are represents the in figure 36. It is getting obvious now, where the force *C*, necessary for a curve flight, comes from. We can explain this phenomenon also very easily. From the earlier sections we know that the forces of the air having an effect on an aerofoil always seem roughly vertical to the wing. This does not change at



36. The play of forces acting on an aircraft in a curve flight

a slant position of the aeroplane either. From the representation can be recognized how the force *C* arises from a new parallelogram of forces. One also can declare out of this phenomenon why an aeroplane must inevitably lose height in the curve flight. By the generation of the sideways directional force *C* a part of the up directional dynamic lift disappears.

So that in a curve flight equilibrium can be, the horizontal force must have the value *C* just calculated. From this the inclination results, that the aeroplane must take this slanted situation in relation to the vertical axle must have the value *C : G* or corresponds to

$$C : G = v^2 : (g \cdot R)$$

according to the above derived formula.

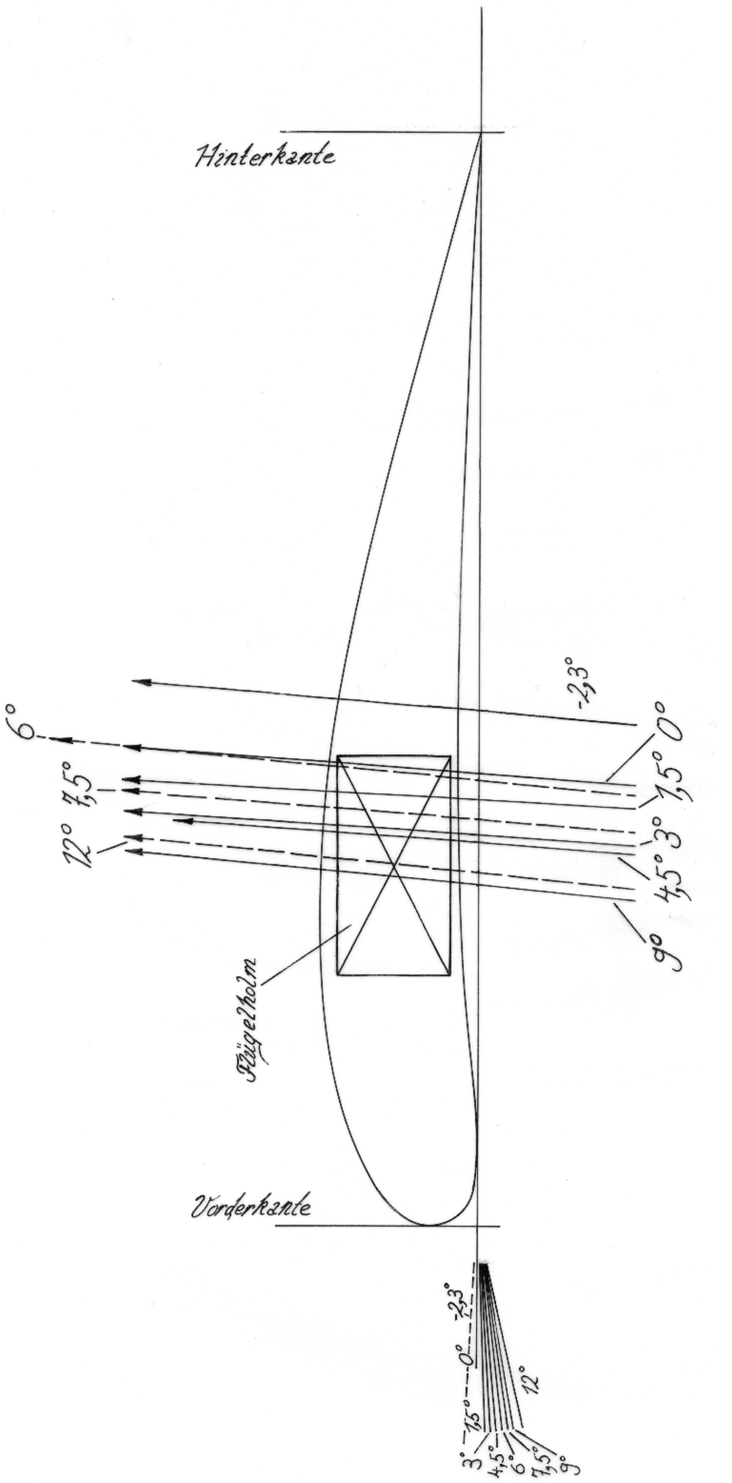
We can draw the cognition from this that the aeroplane must accept a slant position in a curve whose inclination is proportionally to the speed square and reversed proportional to the radius of the curve.

This just explained is also the explanation why a simply treading the rudder is not suitable for the introduction of the curve flight. With the remarks made at the end of section 5.3. the rudder is suitable to cause a slight slant position, but this, however, does not be sufficiently enough to start a fast curve flight. The introduction as fast as possible of a curve flight, what absolutely is required at fight maneuvers, is reached by use of the ailerons at the Fokker Dr.I.

5.7. The Longitudinal Stability of the Triplane

We have already dealt in this exercise book with the meaning of the stabilizer and the elevator for the stability in the lengthways direction. In this section we want to explain why these components are required for the attainment of a serviceable flight behavior of the aircraft and why the aeroplane would be unstable in the lengthways direction without having it.

In section 5.1. we have discussed the meaning of the average pressure distribution in principle. The average pressure distribution describes the situation and direction of the effect line of the force of the air having an effect on the wing. This effect line stands out due to its special behaviour. It changes both its quantity and situation as well as its direction with the adjustment of the angle of attack. One calls this phenomenon the walk of the average pressure distribution. In this walk of the average pressure distribution the explanation for the instability of a wing which is alone looked and charged is found. In figure 37 we have once again here honored the profile of the triplane and typed the walk of the average pressure distribution in for different angles of attack.

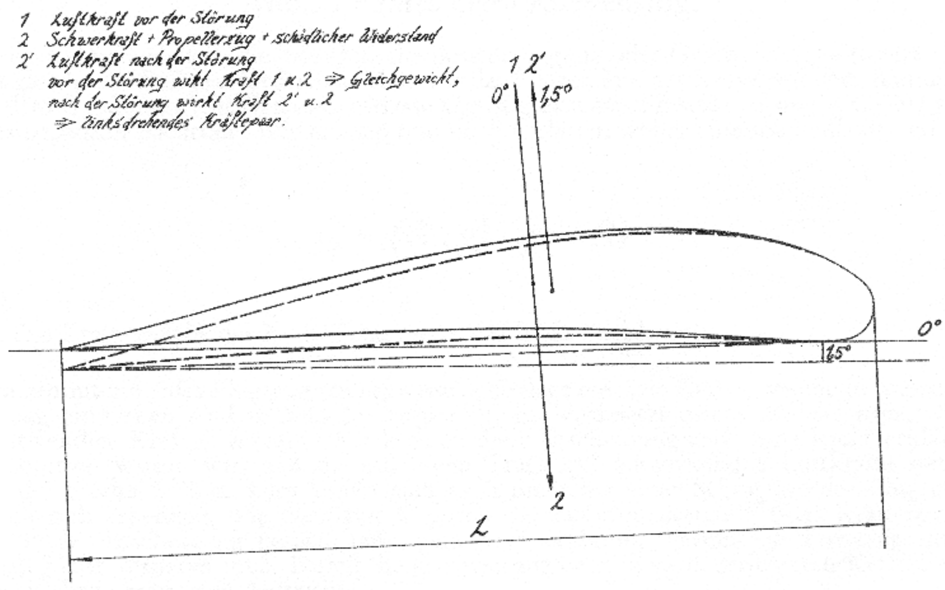


37. The walk of the average pressure distribution at the airfoil of the Fokker Dr.I

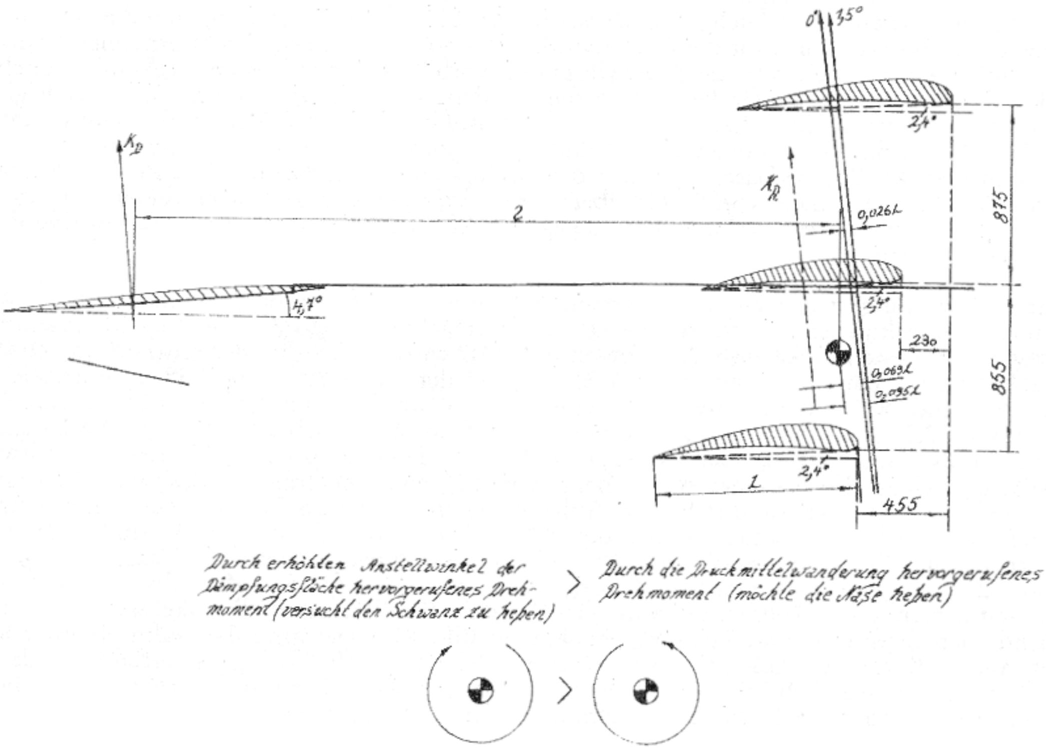
Remark:

The situation of the wing spar was also marked in this graphic. Unfortunately, we are missing the space for an incoming examination of the static's of the triplane here. Only a small remark the one or other is for certain interested in is slid here. All average pressure distributions lie without exception for the angles of attack of 0°-12 ° within the area of the wing spar how one can see. In this the reason is hidden why the engine has "one" spar only. For almost all ordinary aerial maneuvers the support of the wing ribs suffices with one spar. Alone the average pressure distribution for the angle of attack of –2.3 ° (what corresponds as we have already heard to the angle of attack of a stationary horizontal flight at maximum speed) does not lie too far behind the spar so that the crease moment which would like to wind the back rib part round the spar up cannot turn out too big.

We assume now our triplane is in the state of a stationary horizontal flight and the profile has the angle of attack 0° to the direction of flight. Furthermore we assume that an unforeseen perturbation, e.g. an air shock, the aeroplane puts up by 1.5°. However, the case is occurring at this moment that the new average pressure distribution attacks in front by 2.6% of the wing depth further than the average pressure distribution for the angle of attack 0°. What does this mean for the stability of the flight state now? To understand, one only must make clear to himself that the aeroplane was in the equilibrium before the perturbation. According to admission of the perturbation, further works the gravity as well as all other forces in the same place like before. The force of the air which has an effect on the wing, has walked by the perturbation, however, by 2.6 cm further forwards, from what results a torque of the approximate size of lever arm 2.6 cm times total aircraft weight now. This moment tries to extend the angle of attack still further, what leads to the aeroplane lifting its nose further. Illustration no.38 clarifies the process just described graphically once again. One can comprehend easily that the equilibrium of such a system must be disturbed unrestorable by the lowest perturbation.



38. Effect of a sudden perturbation of the system.



39. System of equilibrium

The remedy against the consequences of the moving of the center of pressure is the use of the stabilizer. figure 39 shows the interplay of forces between the three wings of the Fokker Dr.I and the stabilizer. The principle of the mode of action of this order is easily understandably and quickly explained. The aeroplane starts further to take the nose up caused by the perturbation through this walk forwards for the average pressure distribution. The aircraft tail sinks simultaneously, this leads to a compulsory enlargement of the lift produced by the stabilizer. We have marked the situation and approximate direction of this force and marked it by K_D in the drawing. This force results in a momentum of the size of the lever arm *l* and the distance of effect line of the resultant K_D of the force from the center of gravity times its size. If one puts the force having an effect on the stabilizer together with the pressure center line of the angle of attack moved forward, then the resultant *KR* arises which is moved to the left exactly around the amount as the moment of the force *KD* corresponds to. So the size of the stabilizer is determined by it, that the torque produced by it is greater than this by the moving of the center of pressure caused acting opposite. One can express this also in a simple formula:

$$m \cdot z_{aD} \cdot f \cdot v^2 \cdot l > D \cdot L \cdot G.$$

In this z_{aD} mean the coefficient of lift of the stabilizer, *f* for its area, *l* marks the distance of its effect line to the center of gravity and *D* the number, which gives the moving of the center of pressure for the respective case, *G* is for the total weight for the aeroplane as well as *L* means the wing depth. In our special case of a stationary horizontal flight at 0° of angle of attack the required stability equation would look as follows:

$$1/8 \cdot 0{,}04 \cdot 2{,}7 \cdot 29^2 \cdot 3{,}47 = 0{,}069 \cdot 571 \cdot 1$$

and that is:

$$39{,}39kgm = 39{,}39kgm.$$

In this calculation the dimension 0.069 m is the distance of the resultants for 0° of the aeroplanes center of gravity (cf. figure no.39) and the value for *zaD* corresponds to an angle of attack of the stabilizer of 2.3° which it takes at a 0° streaming on of the wings. A stationary horizontal right flight is possible according to this equation at 0° of angles of attack at a speed of 29m/sec. = 104km/h. If we imagine now that the perturbation enters and the average pressure distribution shifts through this by another 2.6 cm forward, then the lever arm "center of gravity / average pressure distribution" grows to a 0,069 + 0,026 = 0,095. The torque that would like to raise the nose will increase by that from former 39.39 kgm to 0,095 · 571 = 54,245kgm. To reproduce the original equilibrium, the torque caused by *KD* must outweight the quantity 54.245 kgm. By the enlargement of the angle of attack of the wing the coefficient *zaD* increased to 0.056. If we carry out the calculation with the new numbers now, then we notice that the condition mentioned above is filled, because:

$$1/8 \cdot 0{,}056 \cdot 2{,}7 \cdot 29^2 \cdot 3{,}47 > 0{,}095 \cdot 571$$

,since

$$55{,}16kgm > 54{,}245kgm.$$

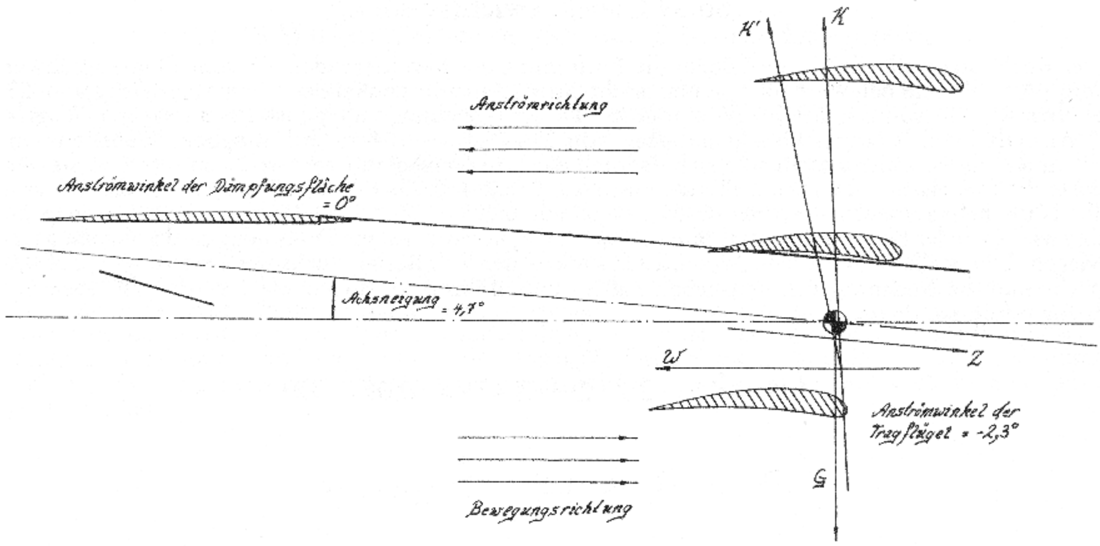
One can use the complete area of stabilizer and elevator, since it is insignificant for the stabilization which part of the elevator unit is mobile and which tightly stands straight away in such a calculation. The size of the moveable and the fixed area depends on the following consideration. The more greatly the movable part is held, all the bigger the controllability of the system is at a simultaneous reduction of the stability.

As we have stressed once again particularly in figure 39, the stabilizer of the aeroplane is designed as a lift producing component from the start and has an angle of attack of +4.7°. In section 5.1. we have in the beginning talked about the meaning of the center of gravity and the average pressure distribution for the first time. The meaning of their interaction results said above also from this well. In connection with this, we have marked and stated the complete resultant *K* of the forces of the air K_O, K_M, and K_U of the individual wings also in figure 30 and we found that this moves forwards towards the upper wing, too[1]. The resultant marked *K'* was also provided in this graphic. The resultant *K'* was, as we have seen, passing behind the center of gravity and formed hereinafter an interplay with the other remaining forces acting on the aircraft which in turn lead to an system of equilibrium. The figure 39 shows us the actual situation and direction for the resulting *K* for the angles of attack 0° and 1.5° now. As we can figure out quite easily all average pressure distributions are passing by in front of the center of gravity. There we know that with an increasing angle of attack

[1] The letter „O", „M" and „U" are common abbreviations describing the German words „Oberflügel" (Upper wing), „Mittelflügel" (Middle wing) and „Unterflügel" (Lower wing).

the average pressure distribution walks forwards constantly, we can see from this that, at the same time, leaves the center of gravity the larger the angle of attack becomes.

Of course with the moving of the center of pressure the resultant *K'* from figure 30 also walks constantly forward and leaves in the same measure the center of gravity. However, this means that the torque which endeavors to raise the nose predominates at least at the angles of attack of 0° to 12 °. So a torque must be produced in settlement of this tail heaviness, which one counteracts here. Just this is reached by the positive adjusting of the stabilizer.

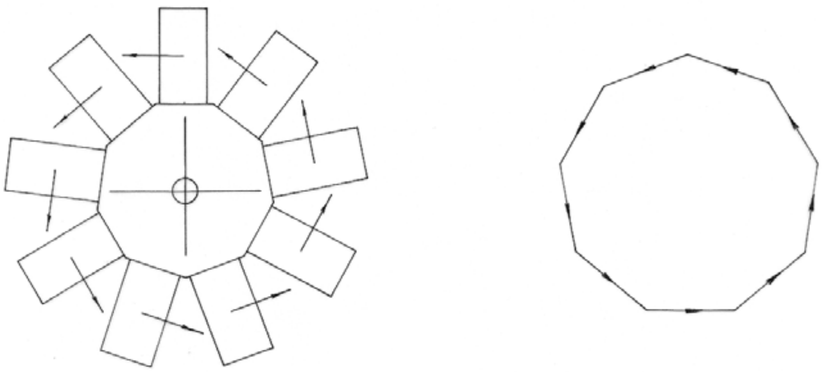


40. The fastest horizontal flight.

In connection with this, a following consideration still is by the way of special interest. We have calculated, that in an earlier section the triplane wings at the greatest possible speed in the horizontal flight take an angle of attack of -2.3°. We also know that the average angle of attack of the airfoils is 2.4°. To get a negative angle of attack of the airfoils of -2.3°, at first the aeroplane nose must be lowered by 2.4° to get an angle of attack of 0°. For an angle of attack of -2.3° the aeroplane nose must become lowered by 2.3° once again. So the longitudinal axis of the aeroplane takes an inclination of 2.4°+ 2.3° = 4.7°. This corresponds exactly to the angle of attack of the stabilizer which so takes a neutral angle of attack at an axle inclination of 4.7° and therefore is not able to counteract a torque produced by the movement of the average pressure distribution by a dynamic lift production any more. In figure no. 40 we have once more put together the interplay of forces at the aeroplane while flying a horizontal flight at the highest possible airspeed at an angle of attack of - 2.3°. The figure 37 shows the average pressure distribution relatively far behind for the angle of attack -2.3°. The resultant *K* of the average pressure distribution for this angle of attack and the resultant from *K +W* also are written down on figure 40 in their situation and direction. At an attentive study of the graphic it stands out that the equilibrium condition discussed in section 5.3. was satisfied and the stabilizer does not have to deliver any dynamic lift. No surplus of forces is available either, which endeavors to raise the aeroplane nose, the engine is in the equilibrium briefly.

5.8. The Influence of the Gyroscopic Effect of the Rotating Parts of the Engine.

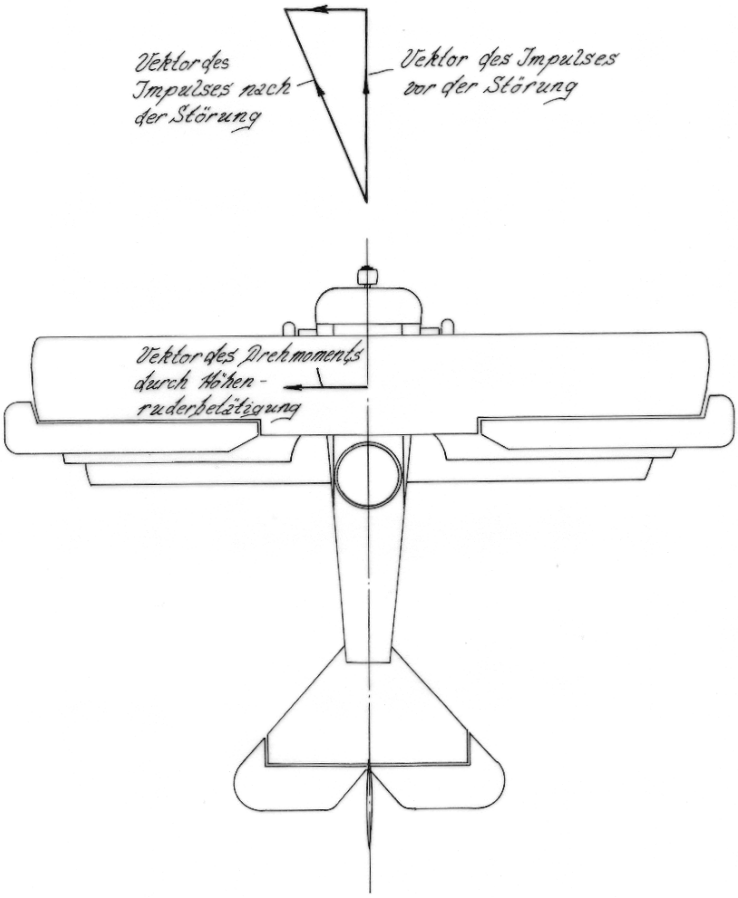
In connection with this we will discuss now the so-called gyroscopic effect of the rotating parts of the engine? A gyroscopic effect of rotating masses takes place practically only at rotary powered aeroplanes like the Fokker Dr.I. Such an effect also causes the propeller alone but despite its high circulation speed this turns out very low due to its low weight opposite the total aircraft weight and therefore can be neglected. The rotary engine, however, absolutely takes the gyroscopic effect to noticeable areas. After all, its weight takes about 26% of the total weight of the fighter plane at the Fokker Dr.I.



41. Vectors of the revolving masses of the rotary engine

The nature of the gyroscopic effect lies justified exactly like also that one of the centrifugal force, in the general law of the mechanics which says that size and direction of the acceleration multiplied with the mass must always coincide with the quantity and direction of the resultants. In this case the same addition law like for forces (parallelogram law or geometric addition) applies to both, speed and acceleration.

The engines of the triplane run all rotate clockwise if viewed from the cockpit. The individual rotating parts of the engine which multiplies by the mass and a closed polygon and with that the resultant compositely yield zero with her beginning and end-points -- we be able to take the nine cylinders of the engine as representatives -- have touching speeds, (see figure 41). Nine forces nevertheless yield in this order not at all an equilibrium system since their moment is not zero with respect to the propeller axle. This moment works in the trick sense around the axle and can be taken to the representation by a vector lying in this axle. This vector delivers the so-called momentum or also angular momentum to the rotating object or still formulates differently the moment of the speeds multiplied by the masses. The momentum always stands vertically by the direction of rotation. One can clarify himself its effect also by turning a gyroscope on the table and observes how it straightens up. The direction of the momentum of the engine is represented in figure 42. All rotating masses have such a momentum.



42. Momentum of the rotating masses related to the axles of the aeroplane

If such a moment is exerted on the aeroplane now that the nose sinks and the tail lifts, such as it happens when the elevator is used, therefore the trick sense from the right wing seen is clockwise, then an angular momentum arises also. This angular momentum orders as we see in figure 42 from the right to the left. Since the force always corresponds to the change of the speed, one must add this angular momentum arisen newly to the angular momentum of the engine to get the new one current momentum vector after the action of the shifting forces. The vector of the momentum which has consisted of the two individual moments lies slightly inclined to the left against the original angular momentum of the engine. The propeller axle looks into this situation to adjust now. Expressed differently: When raising the tail the gyroscopic effect of the rotating masses causes a turning of the aeroplane left around its vertical axle. So the gyroscopic effect also can be investigated for all other control motions. The aeroplane turns left by the rudder effect, the aeroplane nose will lift, it will dive at a right-hand curve so. Of course these peculiarities could exploit the pilots during a battle with a stand engine operated opponent well. It required special attention of the pilot at starts and landings, though. Particularly if to sudden jerky motions by the gyroscopic effect ground unevenness also appeared.

6. The Take-Off of the Triplane

6.1. Undercarriage and Tail Skid

In all previous sections about the aerodynamic events at the Fokker Dr.I we have always looked at the machine only in interaction with the air surrounding it. It remained completely unconsidered how the air moves compared to the ground. The only reference to the ground we had till now was the influences of the gravity which is, however, independent of the situation and motion of the object. The triplane, like also all other aeroplanes, enters into an immediate relation to the earth in triple way, however. Since we cannot simply disregard it, we would like to examine one of these three points at least hereinafter a little more nearly. The talk is of the start process, of the landing and of the navigation. We want the navigation to leave aside here since this finds itself too little triplane specifically and therefore is for us not of interest. We also would like to do without the treatment of the landing.

That we can understand the connection of all the events linked to the take-off, we must look at the parts necessary for the motion on the ground first. The undercarriage and the tail skid.

The order of these parts at the Fokker Dr.I shows us the representation 43 of this exercise book. The undercarriage consists of two at the traversing ends of an axle attached wheels. It offers the aeroplane only one support point which is 0.391 m in front of the center of gravity of the engine, looked in the longitudinal section. As long as the triplane is at the ground, it finds a second support point in the tail skid which is assembled at an elastic connection at the fuselage end. The height of the tail skid was chosen so that the engine axle of the resting aeroplane takes the relatively steep angle of 18°. This angle is between 15° and 20° at most aeroplanes so that the tail skid can no more touch the ground at the moment of take-off.

The aeroplane cannot take the situation represented in figure 43 at engine running at full speed straight away any more if the tail is not pushed by an outer force to the ground. Because as soon as brake chocks are put in front of the wheels the traction of the airscrew tries to turn the aeroplane around the on-bearing point of the wheels with the moment $Z \cdot h$ (figure 43). The torque of the heaviness, which is the product of weight of the aeroplane and the distance S from the center of gravity of the on-bearing point of the wheels, works contrary to this torque. The moment of the heaviness is generally kept smaller than the traction of the airscrew at the stand (section 3.2.). In the case of the Fokker Dr.I the difference of the two moments is:

$$Z \cdot h - G \cdot S = 294.97 \cdot 1.575 - 571 \cdot 0.759 = 31.18 kgm.$$

The propeller traction tries therefore to turn the aeroplane with the moment 31.18 kgm around the on-bearing point of the wheels at locked wheels.

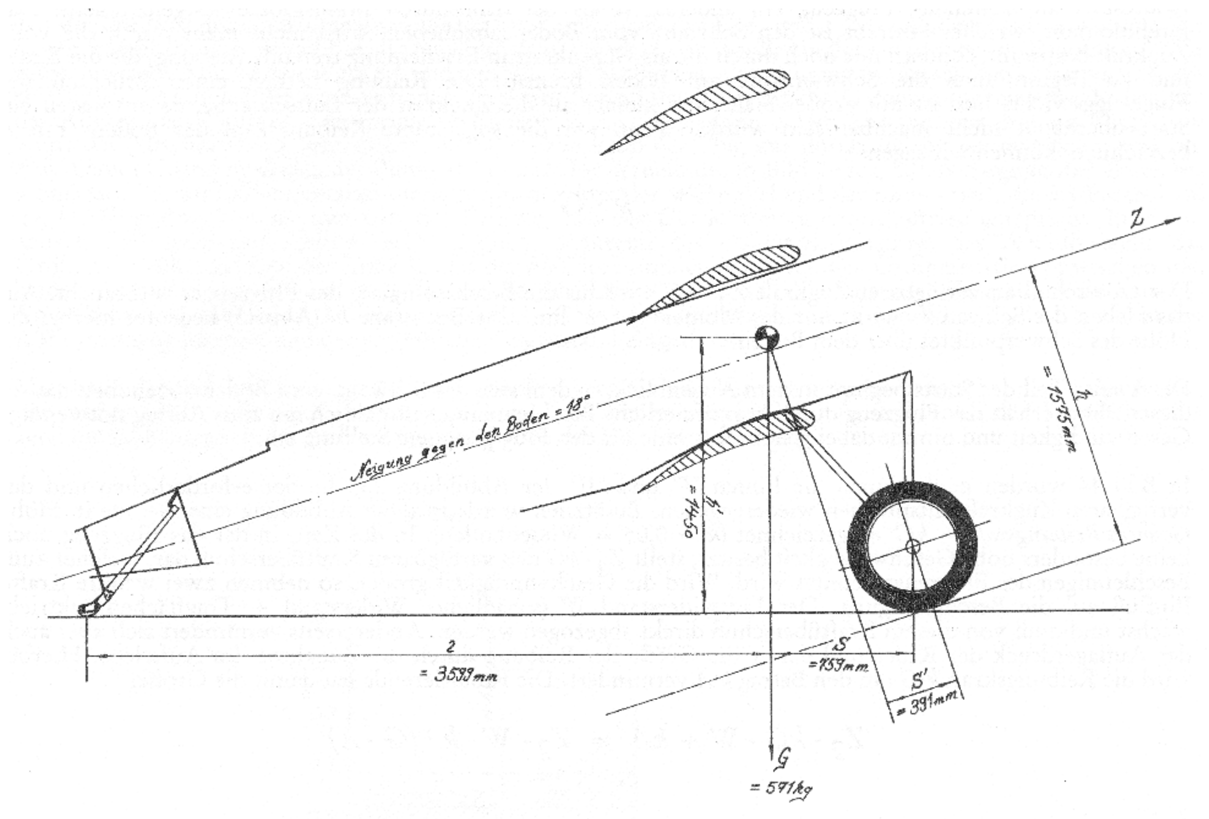
The distance of the center of gravity from the on-bearing point of the main wheels also is responsible for the size of the so called tail skid pressure which is the portion of the total aircraft weight that rests on the tail skid. If the letter *l* describes the distance of the on-bearing point of the tail skid, then S *: (S+l)* is the part of the total aircraft weight which is carried by the tail skid. Here so lay:

$$S : (S+l) = 0.759 : (0.759 + 3.599) = \underline{0.174}$$

And with that:

$$571 \cdot 0.174 = 99.35kg$$

is resting on the tail skid. The rest of the aircraft weight therewith is carried by the main undercarriage. And that is: 571 - 99.35 = 471.65kg



43. Forces acting on the resting aircraft

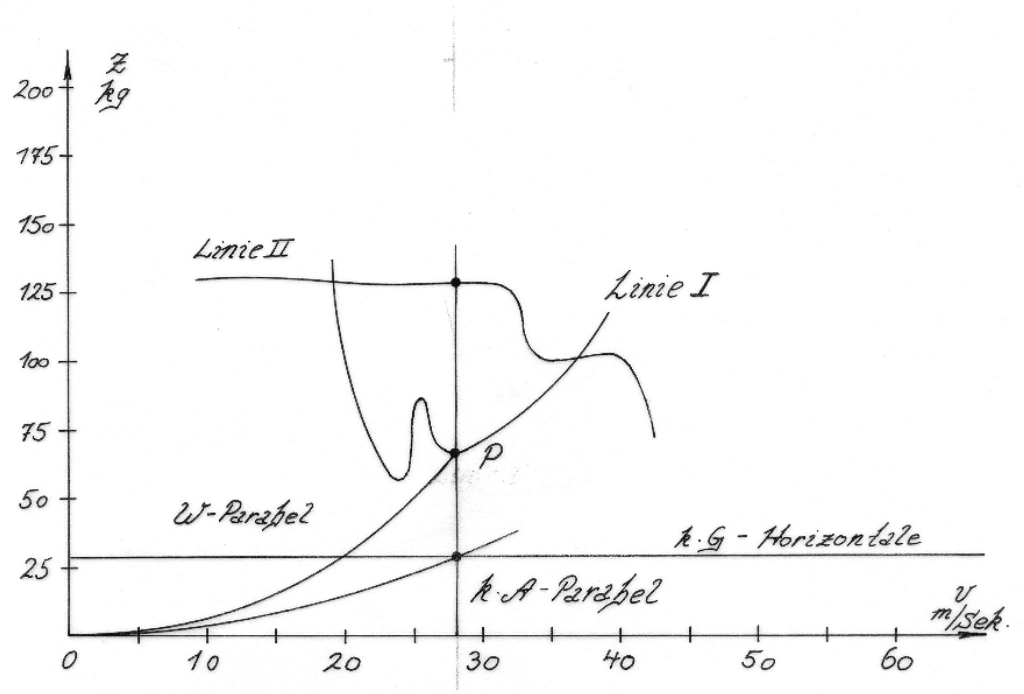
6.2. The Take-Off

To understand the motion sequence of operations and the power play at the Fokker triplane during the take-off, it is to take it to pieces into two parts meaningfully. The first part of the start consists of a gradually setting in motion by rolling with onto the wheels and dragging the tail runner. The tail already stands out from the ground relatively early by the tractive power of the propeller as we have just seen. It is clear, that the power play is another at an taxiing aeroplane that it is at one held tight by brake chocks, though. The torque which endeavors to lift the tail of the ground is not that one determined by full tractive power, but just that one determined by the friction of the wheels on the ground appearing as a counter-force and the tail runner which also brakes at the beginning on the ground. The friction is a fraction of the total aircraft weight and is smaller with a great safety as the tractive power of the propeller since a start otherwise would not be feasible at all. If we mark the so-called friction coefficient of the ground by *k*, we can say:

$$k \cdot G$$

The surplus of an available tractive power *Z2 - kG is* consumed for the acceleration of the aeroplane. Only the moment *k·G·h'* works on raising the tail. The letter *h'* means the height of the center of gravity (figure 43) over the ground for.

The second part of the take-off starts at the moment at which the tail has stood out from the ground. In this phase the aeroplane gets by a continuous acceleration gradually this one for the take-off necessary speed and takes a position suitable for the flight simultaneously.



44. The triplane´s take-off.

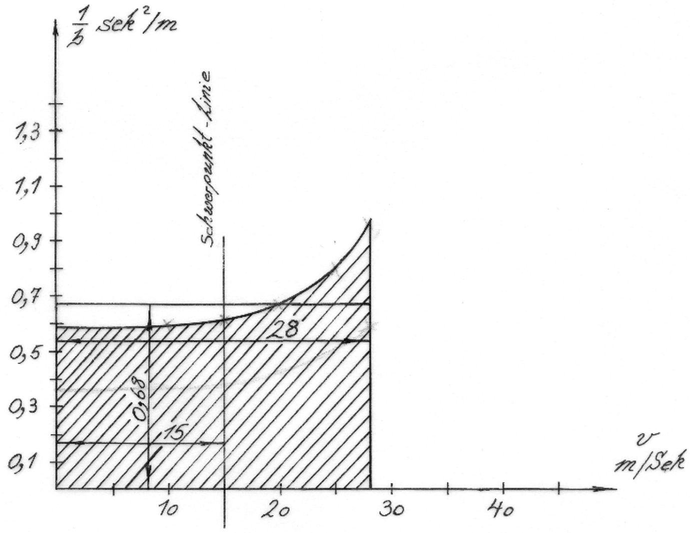
In figure 44 the lines "I" and "II" of the figure 23 were, once again which corresponds to the required and the available tractive power represented. In addition a line was drawn into this illustration in the height of *weight · friction coefficient* = *kG* (*k* = 0.05 meadow ground). At the time at which the aeroplane does not have particularly high speed, yet *Z2 - kG* puts for the available force surplus which is used for accelerating the aeroplane. If the speed gets larger, then another two forces have influence on the acceleration. The air resistance *W* (harmful resistance + wing drag) grows and must be subtracted from this force surplus directly. On the other hand the on-bearing pressure of the wheels and with that the quantity of the friction by the increase of the dynamic lift also reduces itself, however. The friction force $k \cdot G$ is reduced by the amount $k \cdot A$. The resultant has with that the quantity

$$Z_2 - kG - W + kA = Z_2 - W - k \cdot (G - A)$$

Since the dynamic lift and the resistance increase with the speed and we may assume a constant angle of attack the coefficients z_a and z_r remaining unchanged, we may also assume *A* and *W* will grow in the square of the speed. So we must mark the value *kA* and the value *W* in figure 44 as a parable. The *W* parable cuts the line for I of the required tractive power on this point *P*. As soon as the aeroplane has reached the speed which corresponds to the abscissa of the point *P*, the aeroplane is in a state which makes a flying possible according to the section 4.3. In any falls the flight only can be started by a climbing. For this reason, so the point *P* must cut the line for I within the area represented hatched in figure 23. The *kA* parable meets at the same abscissa of this intersection point of the W parable and the line I the *kG* horizontal line because the case occurs now that the weight corresponds to approximately the dynamic lift. In another way a take-off would not be possible at all. During the complete process of the take-off the ordinate piece between the *kG* horizontal line less the ordinate piece between the parables of *kA* and *W* represent the quantity of the surplus of tractive power. At last one gets as a force surplus - due to the fact that $A = G$ and $W = Z_1$ -, merely the value Z_2-Z_1. The take-off process is finished and the real flight state has entered with that.

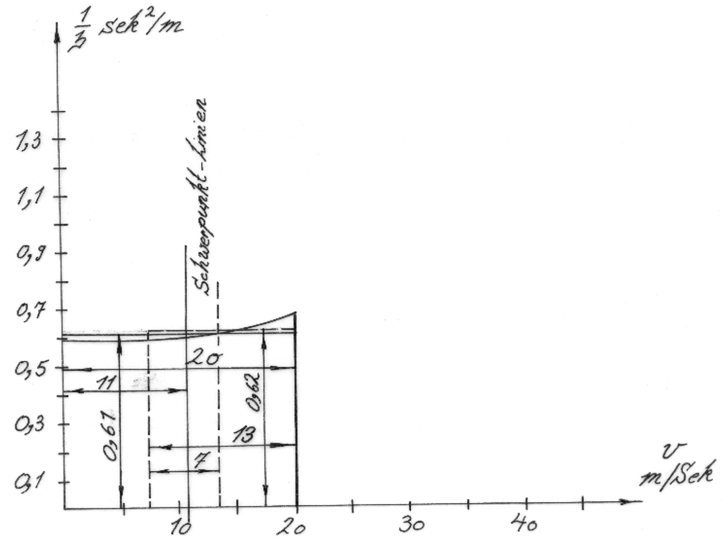
One can examine different circumstances with the thoughts made above at which the take-off shall take place. One can investigate the effect of different angles of attack of the wing or also the dependence of the take-off run of the size of the friction coefficient, for example.

On the results of figure 44 the diagram in figure 45 was built up. With this illustration the take-off time like also the take-off run can both be calculated. The graphic arose in a following way. One gets the curve in figure 45 by measuring the ordinate pieces between Z2 and kG-horizontal and between the W parable and the kA parable in figure 44. These two parts are subtracted from each other. Then the



45. Take-off diagram

acceleration is determined by the division of the aeroplanes mass *G:g* and the reciprocal value drawn in. The hatched area in figure 45 gives an immediate rake measure for the calculation of the take-off time if one drained the baseline of its rectangle equal in area in the scale of the abscissas and its height in the scale of the ordinates and these values multiplies by each other. In the fall of the Fokker Dr.I the total aircraft weight is 571 kg. As a friction coefficient we have accepted 0.05 here again, too. The speed at which the

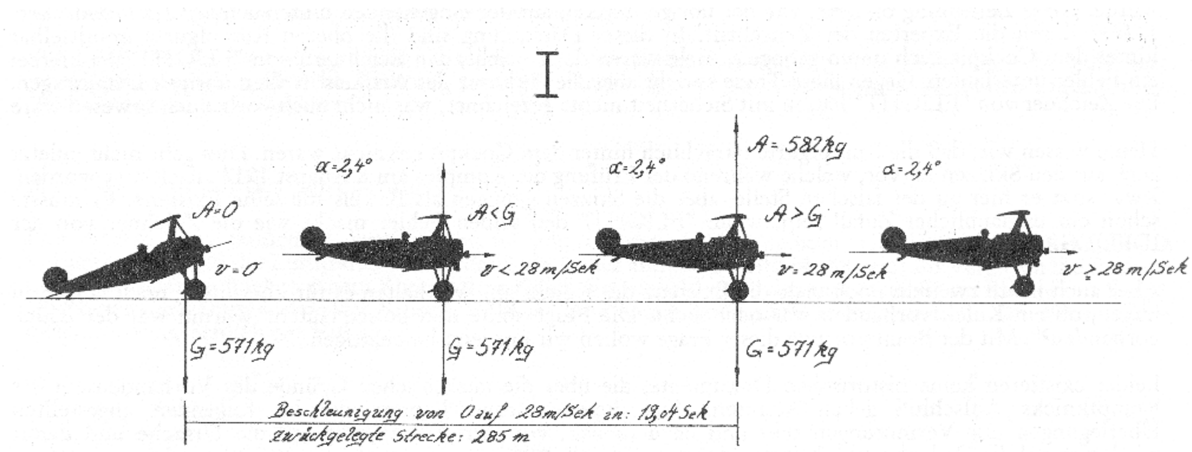


46. Reduction of take-off run

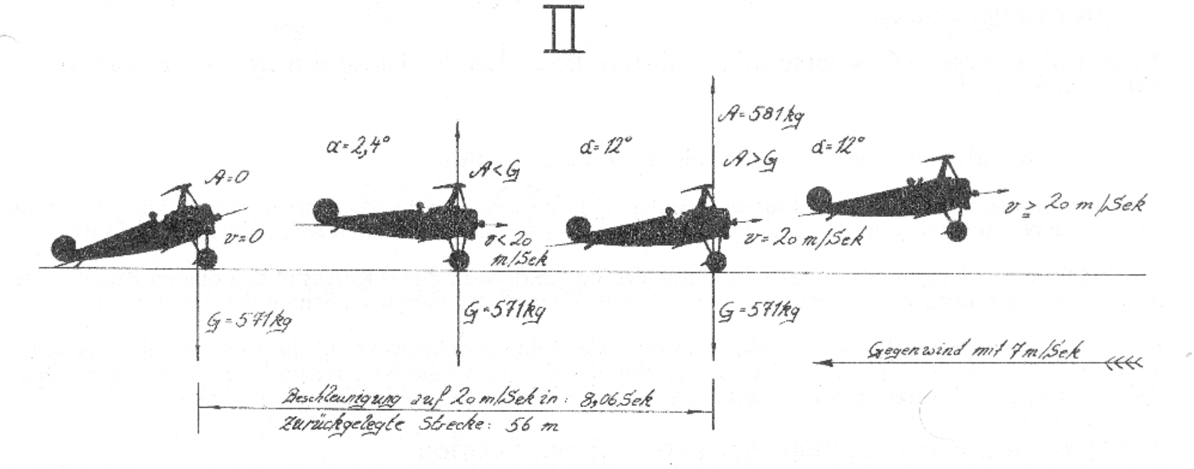
kA parable cuts the k*G* horizontal line amounts to 28 m/sec.. We therefore get the following values: *Z2 - kG = 100kg, W - kA = 39.5kg* , difference *60.5 kg*, acceleration *60.5 : 58.20 (G:g) = 1.0395m/Sec.²,* , reciprocal value *1 : 1.0395 = 0,962*. This value was typed in for the preparation of the diagram in figure 45 at the abscissa height* - which we could see from figure 44 (intersection point of the *W* parable with the line I) therefore at v = 28 m/sec. In the same way the other values of the curve were investigated and applied. From this new graphic the take-off time can be calculated, as mentioned already, by multiplying the baseline of the rectangle equal of the hatched area by its height according to the given scale. We get the following value as a take-off time: 28 · 0.68 = 19,04Sec.. With the illustration the ascertainment of the take-off run is no more great problem either. One must multiply merely the take-off time found out by the average speed to this. The average speed is nothing else but the center of gravity of the hatched wing. The distance of the center of gravity times the field area yields static moment. This means nothing else but a renewed integration and with that area formation. We hereby come from the time/speed curve to the time/distance curve. We get as a result of the calculation represented above the way which is required to reach the necessary speed (dynamic lift > weight) to lift-off. The triplane therefore goes through the distance of 19.04 · 15 = 285.6 m to accelerate to 28m/sec..

This detail of the take-off way will to many readers seem a little strange, since Alfred Weyl in his book "Fokker -The Creative Years" writes of performance tests carried out with 141/17 during which a take-off run of 45 m is recorded. A distance of under 100 m is also given by Alex Imrie in his book "The Fokker Triplane" for the take-off run. The pictures 46 to 47 II which hereby still deal a little more closely are found hereinafter. At the preparation of the graphics 44 + 45 a didactic take-off sequence of operations was started out from. This means, it became a constant angle of attack (2.4°) and absolute calm accepted. Under these prerequisites the triplane needs according to illustration 45 and 47I a time from 19.04 seconds and a take-off run of 285.6 m to reach a take-off speed of 28m/sec. For reason of the coefficients of lift it can be calculated that the dynamic lift at 2.4° of angles of attack yields at a speed of 28 m/sec exactly to 582 kg. However, this means nothing else but that the dynamic lift predominates the weight and the aeroplane is able to come loose of the ground by now.

Of course a good and practiced airman can shorten the take-off time as well as the take-off way through application of some tricks considerably. A trick used mainly consists in reducing the take-off by an early rise of the angle of attack to a minimum. The illustrations 46 + 47 II represent this process clearly.



47/I. Didactic take-off run.



47/II. Reduced take-off run at headwind.

If the angle of attack of the wings increase to lets say 12° by a early consulting of the control column by the pilot, the dynamic lift increases suddenly, too, of course. With the coefficients of lift the speed at which a lift is possible with 12° of angles of attack calculates to 20 m/sec. According to figure 46 becomes the take-off way through this reduced to 134.2 m and the take-off duration was shortened to 12.2 seconds. In addition, another fall is dotted in figure 46 represented. In this case the aeroplane starts against a wing of 7 m/sec. Through this the values are reduced for 8.06 seconds and 56.42 m. In figure 47 II this is also represented.

The take-off also surely can be shortened still further under appropriately favorable ratios, e.g. lower friction by fastened runway, less payload and like that. So a take-off run of 45-50 m actually lies with this triplane in the context of the attainable. We mustn't forget either that the calculations of the take-off run are determined also authoritatively by the form of the line II which is put together for its part from engine and propeller data. In section No.3 of this exercise book, however, we have heard that we have chosen only a propeller whose data relatively approach near to that one of the AXIAL-Propeller.

7. The "crease" in the Fuselage

The question whether the Fokker Dr.I was designed or not with a crease in the upper fuselage longeron is discussed for decades in experts. The most different views were here (and are also today certainly) represented.

The debate started because of a representation of the fuselage framework of the triplane in the British aeronautics periodical "FLIGHT" which also was printed by the German counterpart "FLUGSPORT". This drawing was based on the incoming examination of the triplane 144/17 by the experts of the periodical like the rest of the article. In this representation the upper fuselage longeron have immediately turned behind the cockpit to below. Many were of the opinion the draughtsmen of "FLIGHT" have made a fault. Against this thesis, however, the accuracy of the article speaks in all other questions of detail. The draughtsmen of "FLIGHT" would have drawn nothing certainly which would not have been available either.

We know today that the fuselage longeron were actually folded behind the cockpit. This also results from the outlines which were done during the check of the fuselage on August 8th, 1917 not least. Although it sits here in the wrong place, the outlines suffice as a proof of its existence. It should already be an unbelievable chance if the "FLIGHT" made the same mistake like the draughtsmen at IDFLIEG.

Many doubt the existence of the crease certainly today however still. We think it is superfluous to longer ask whether a crease was there or not. The question should be now better: "Why was the crease there?". We want to deal with the answer to this question now.

Unfortunately, no historical documents exist, that provide the actual reasons for the existence of the fuselage crease. The considerations made in the following can be only assumptions and serve to infer from this reason of the effect on the cause and thus in turn on the thoughts of the designer.

In our considerations we want to proceed systematically and at first wonder which sense a bend of the upper fuselage longeron could have.

1.) It could have been the test to improve the optical impression of the triplane.

2.) The crease was included in its plans from static basic considerations to optimise the strength of the structure.

3.) Aerodynamic points of view were the reason that the fuselage crease of the designer was designed.

We can meet the following statements to the first two points:

To 1.) The optical impression of the aeroplane changes only very insignificantly if the crease causes that, for an inclination of about 1° (according to the late Charles Bourgets) for the back upper fuselage longeron one takes care.

To 2.) The static's of the fuselage framework is not improved by the existence of this crease fundamentally in the upper fuselage longeron (one notices the remark to this at the end of the section).

We therefore have it left on the search for a satisfactory answer to the question why the crease existed only the point No.3, that is the influence of the crease on the aerodynamics of the triplane. Then the crease affects only and alone the aerodynamics. The immediate consequences are:

3-1 The elevator unit takes a position lain more deeply.

3-2 The rudder takes a position lain more deeply.

What gives up through this for the elevator unit and the rudder?

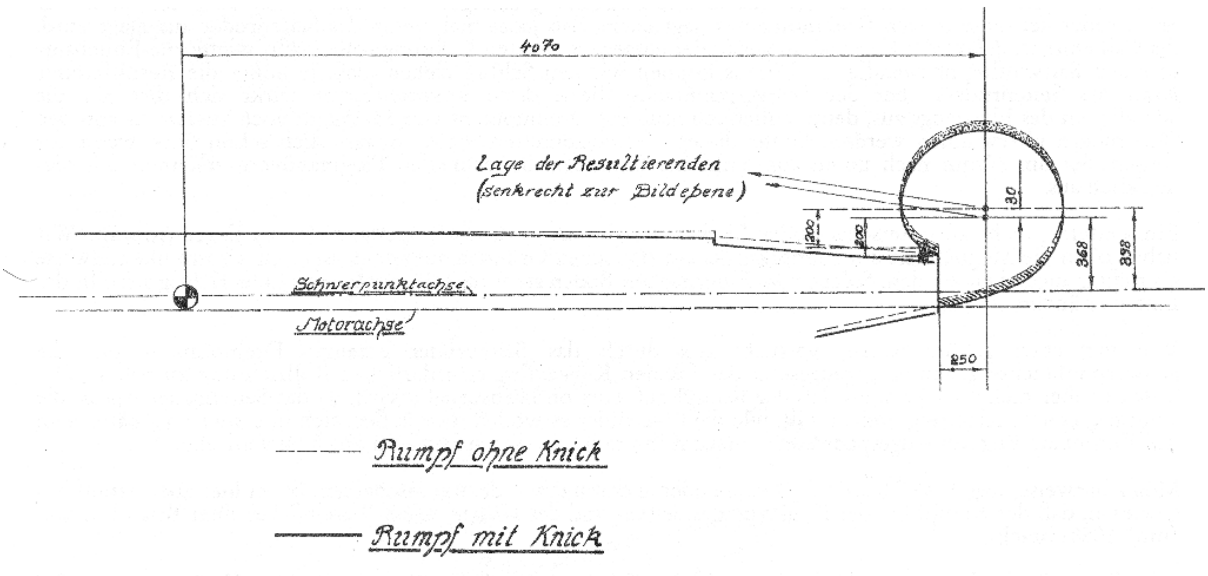
To 3.1. the position of the elevator unit.

The top edge of the fuselage longeron sinks by the crease in the upper fuselage longeron up to the inset of the stabilizer by about 30 mm. Through this the complete elevator unit also comes down (figure 48) by 30 mm. One could speculate and say now that by this lowering of the elevator unit this is taken out of the lee of the middle wing and a better streaming on of the component is also the consequence by which. This conclusion does not seem very convincing, though, since the elevator unit immediately sits behind the middle wing most time, if we look at the figures 39 and 40 once again. In figure 40 can be seen even that the elevator unit is in this position above the middle wing. Without fuselage crease it even would lie 30 mm more highly still. At these explanations can be recognized that so it can have been hardly the sense to get the elevator unit from the lee of the middle wing. Against this thesis, also talks about the fact that the upper fuselage longeron of the types Fokker D.VI and D.VII show a similar crease. However, the two types are double-deckers without middle wing "disturbing".

The function of the stabilizer as such also is not influenced by the change of its height situation since neither the direction nor the quantity of the vertical force of the air kD (figure 39) will be changed through this.

3.2. The Position of the Rudder

What actually is changeable and can be measured as soon as the fuselage crease is taken into account is the forces of the air which the rudder takes. Figure 48 shows the position of the rudder in the comparison at a fuselage without crease (sketched in) and to the different one at a fuselage with crease in the top fuselage longeron. As already mentioned, the fuselage would without the down bent fuselage longeron lay some 30mm higher than it actually does.



48. Comparison of rudder position

At hand of the documents recorded during the type evaluation test of the aircraft by the Inspectorate of the German Army Air Service at that time, the center of gravity of the forces acting on the rudder was located some 200mm above the elevator spar and 250mm behind the rudder spar. The upper point drawn in the rudder describes the situation of the resultants at a fuselage without crease. The resultant is 398 mm above the center of gravity axle of the aircraft.

We have already spoken in an earlier section, too, that at a rudder rash a rolling motion is caused not only a around the vertical axle of the aeroplane, but also, caused by the situation of the resultant of the rudder above the center of gravity axle of the aeroplane also a torque around this axle happens at the same time. Of course this torque also can be calculated. We need the control pressure for it first which is taken by the rudder. For our example we calculate with a total rash at v = 36 m/sec. According to section 5.4. the control pressure *P* is:

$$P = 1/8 \cdot 0.92 \cdot 0.601 \cdot 36^2 = 89.57kg.$$

The torque that tries to roll the aircraft at such a rudder rash around the axle that goes parallel to the longitudinal axle of the center of gravity calculates from the size of the control pressure P times the lever arm, that is the distance of the resultant from the longitudinal axle of center of gravity. Herewith we have:

$$89{,}57 \cdot 0.398 = 35.65kgm.$$

We know now with that that in this case 35.65 kgm is for the torque around the longitudinal center of gravity axle at a fuselage interpretation without fuselage crease.

How does it behave now, however, if the rudder and thus also the resultant force of the air of the rudder gets lowered at around 30 mm? Well, the lever arm goes down by these 30 mm since the resultant pulls up more nearly to the center of gravity axle. So the lever has the quantity 0.398m - 0.030m = 0.368m. The quantity of the torque notices through it:

$$89.57 \cdot 0.368 = 32.96kgm.$$

The difference between these two numbers is 2.69kgm.

What does this torque mean for the use of the triplane in the practice? On the one hand, one can use that effect to compensate the torque of the propeller to some degree. This can be made by a slight adjusting. Another peculiarity of the torque caused by the rudder lies into this that the case stands every time up, when the rudder is interpreted, that it has the aeroplane rolled in exactly the opposite direction, how is necessary for the introduction in a curve flight. We can from it draw the conclusion that this has an effect on the agility of the aeroplane the higher the resultant force of the rudder is over the center of gravity axle the more disadvantageous, because the torque of 35.65 kgm finally still must in addition be overcome by the aileron control surfaces. Of course under these points of view it already copies sense if the rudder is lowered by 30 mm. This stands out noticeably particularly at fast aerial maneuvers.

Another effect to be not underestimated arises if the rudder comes to lie more deeply. We have ruled out the possibility of the fuselage crease for static reasons above. This can be only partly considered right.

This may be right also completely as long as the aeroplane is at the ground. In the air, however, this changes.

As we have just heard, the torque produced by the rudder tries to roll the aircraft around in the opposite direction that is required for the introduction of a curve flight. However, this means nothing else but that the fuselage is used on torsion since the rudder wants to turn it in the opposite direction as the ailerons want it. This speaks approximately as one would have the fuselage fixed at the tail and tries to twist it like a spindle at the nose.

This theory may possibly seem a little miserable to the one or other. It is rejected here but at this, that the fuselage broke "already" at a break load of "only" 108% at the load of the rudder and the elevator.

With these observations we have found two plausible and possible reasons for the existence of the fuselage crease.

A.) At interpretation of the rudder the rolling moment results is a moment that is at 2.69 kgm lower than it would be if the fuselage would not have that bent down longeron.

B.) The use of the fuselage structure on torsion is reduced by the fuselage crease. At co directional activity of cross and rudder very big torsion forces can have an effect on the fuselage. By the fuselage crease the danger is lowered from fuselage breaks by over-use at unusual and sudden control surface rashes at high speeds.

At the conclusion of this treatise we would like to point out once again that the complete area of the aerodynamics was not treated here. Merely those of all most interesting points were picked out and treated more or less superficially here. The sense shall be to also make the bases of aerodynamics understandable to newcomers and to put the possibility to your hand to carry out further model calculations on your own, if this or that problem still should be of special interest.

We want to mention particularly once again that we have not built up this work with a full intention so that modern formula signs and calculation methods were used. At the results, however, this changes nothing.

In case the English translation is somewhat “funny” at some points, we also beg for your understanding. Our proofreaders invested a lot of time going through and over it, but they for sure could not pick out every mistake I made during the translation of this German article.

Anyway, I hope you enjoyed it and in case you have learned something the work invested just paid off to us.

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