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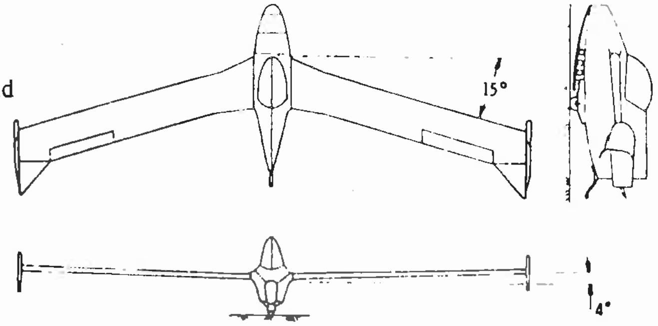
VORTEX GENERATED LIFT is not a new theory. It is a fact (Fig. 1). The first Kasper "lifting vortex" was generated accidentally while testing the stall characteristics of the first Kasper tailless glider. A row of tufts was placed at about 70% chord and 70% span and was observed as speed was slowly reduced ready for the stall. At 40 mph the wing tufts curled up and the sink rate increased to 600 ft/min. The stick was still in a forward position, but when pulled gently back, an amazing thing happened. The sink rate decreased!



SPAN	49 FEET	EMPTY WEIGHT	450 LB.
WING AREA	164 SQ. FT.	FLYING WEIGHT	650 LB.
CHORD	38. 4 INCHES	WING LOADING	3. 96 LB/SQ. FT.
LENGTH	12 FT. 6 IN.		

Fig. 1 – Kasper glider

The variometer (glider pilot's word for rate of climb indicator) indicated 200 ft/min while the speed dropped to 30 mph. Stability increased and control was as good as before. The tufts curled forward and remained stretched forward, indicating a strong flow opposite to the direction of flight. This was repeated several times, and the same thing happened. In order to get more information, four rows of tufts were glued from the center of the wing to the wing tip, and three variometers and an angle of attack indicator were fitted. At 40 mph the aft row of tufts started curling up, showing the first signs of separation. The sink rate increased to 600 ft/min as before.

As the stick was pulled further back, the aft row, followed by the second row, followed by the third row, all reversed and pointed in a forward direction. The front row, which was positioned at 25% chord, remained in the flight direction, but moved up tangentially to the leading edge curvature. The speed dropped to 20 mph. The angle of attack indicator showed 35 deg; but the most astonishing thing was shown on the variometers—the sink rate dropped to 100 ft/min, which was only half the sink rate in normal flight. All three of the instruments indicated the same. When tried again, exactly the same thing happened. The time and the loss of height during this maneuver corresponded with the low sink rate.

There could be no doubt that an unknown phenomenon was keeping the glider afloat at half the sink rate and half the stalling speed.

After puzzling over this it was realized that after the stall, a huge vortex was forming over the wing and that the presence of this vortex was the reason for the additional lift at high angles of attack and low speeds (see Fig. 2). Here, perhaps, was the phenomenon we were looking for to improve the slow speed characteristics of our airplanes.

ABSTRACT

In tests on a glider designed for experimenting with vortex generated lift, the author experienced an unknown phenomenon which kept the glider afloat at half the usual sink rate and stalling speed. After study it was realized that a huge vortex had been forming after the stall which explained the presence of additional lift at high angles of attack and low speeds. The implications that this discovery has in terms of improving the slow speed characteristics of airplanes are explained in the paper in addition to a detailed study of the characteristics of this vortex.

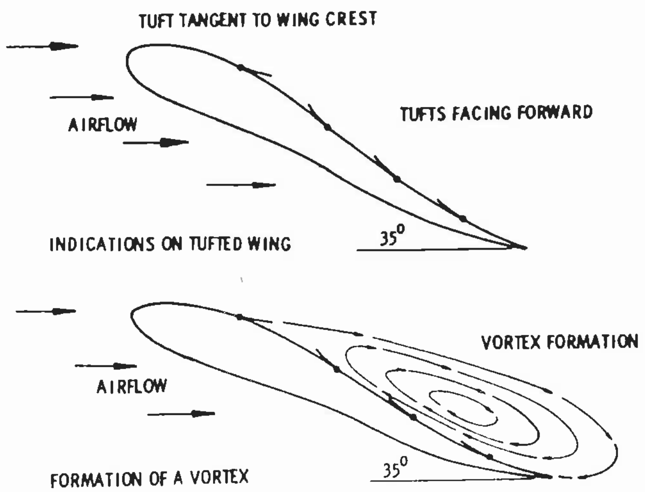


Fig. 2 – Formation of a vortex

The middle speed ranges had been pretty well explored over the past years, the high speed ranges were now being explored, but the missing area of aircraft study was in the ultra slow speed range.

Now, having produced the vortex in flight, it was necessary to study the properties of a vortex so that it could be used to the best advantage.

A multitude of books and reports on the various aspects of the vortex dealt mainly with particular phases and applications in some particular situation; the literature was too fragmented and it was necessary to compile a theoretical background for this study entitled "Vortex Motion and Its Application to Aircraft," indicating the behavior and characteristics that can be found and controlled within a vortex.

A vortex can be pictured by visualizing a spiral spring being fed tangentially into a corner with velocity, V_t, and being pulled out axially with a velocity, V_a (Fig. 3).

It can be seen that this vortex can be initiated from either end, the axial force or the tangential force being sufficient to set in motion the whole chain of effects, ending, after a suitable period of time, with a fully developed vortex.

A fully developed vortex has to obey several rules:

1. The rate of fed must equal the rate of bleed. This is called the "entrainment/detrainment" rule.
2. The tangential speed component, V_t, is proportional to the outer radius divided by the inner radius, r_o/r_i, in the outer annular part of the vortex, and obeys the law of constant angular momentum.
3. The diameter of the core is established when the momentum of the radial flow component, due to the pressure drop, is in equilibrium with the momentum of the centrifugal forces, due to the tangential feed component.
4. It has to begin with a tangential flow and end with an axial flow, or vice versa.
5. Increase or decrease of the flow at either end of the vortex causes an increase or decrease of the inner tangential speed component.
6. Any interruption of flow at any point will cause the decay of the vortex downstream of the disturbance.

In a vortex, pressure is decreasing from the outer radius to the increasing tangential speed component. This approximates to addiabatic expansion, which causes heat transfer from the inner radius to the outer radius. The air cools as it approaches the core, and the heat remaining in the vortex expands the air volume. This causes an unconfined vortex to swell and a confined vortex to accelerate tangentially. It is this aspect that produces the driving power in a tornado or a dust devil.

It has also been used to cool gases by blowing gas tangentially into the closed end of a tube. A closed vortex system is set up within the tube. Two outlets at the far end of the tube exhaust heated gas at the outer rim and cooled gas at the center.

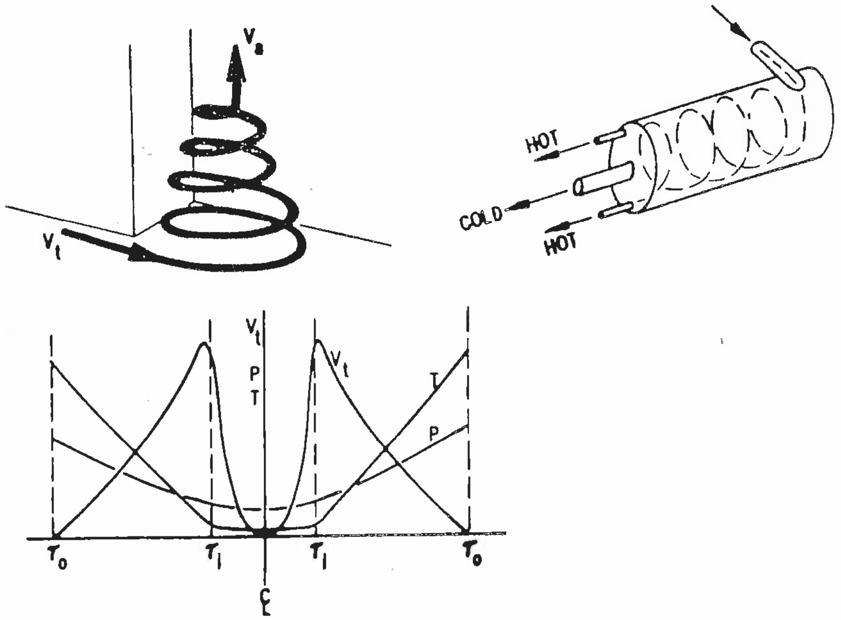


Fig. 3 – A vortex

On Delta wing aircraft, at high angles of attack, a vortex is formed along the leading edge of the wing, causing a spanwise flow which is faster than the forward speed of the plane. Total lift is about 100% higher than the total lift at the maximum angle of attack, and furthermore, no stall occurs as the angle of attack is increased.

On straight or swept wing aircraft, at high angles of attack, at least 30-35 deg, a sharp flow separation occurs at the crest of the airfoil upper surface (Fig. 4). The airfoil is now acting as an obstruction in the free airstream; a vortex is formed along the upper surface. It forms a regular flattened vortex along the top of the wing with these benefits:

1. It maintains lift at angles of attack well beyond the stall angles for potential flow.

2. Because the forward flow of the air on the upper wing skin is in the same direction as the direction of flight, the direction of the drag is reversed and is now assisting forward motion.

3. Wing stability is increased because the aft movement of the center of lift generates a counteracting nose down about the center of gravity.

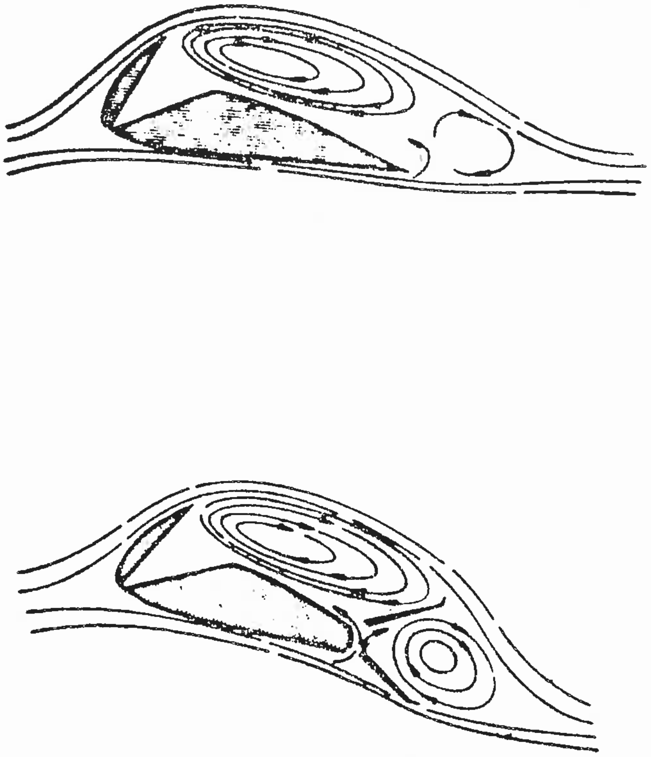


Fig. 4 – Sharp flow separation at crest of airfoil in straight or swept wing aircraft

In order to generate the vortex, the most important condition is the separation of the flow at the crest of the leading edge. A high angle of attack will cause this separation, but there are other methods which may be used to advantage.

A baffle may be used at the leading edge to produce a deeper leading edge curve and to provide a sharp edge from which the vortex may be generated.

However this vortex will vary in size, due to gusts and variations in airspeed, affecting the airflow over the wing. It can be stabilized by the use of various flap configurations along the trailing edge, which will limit the size of the vortex and trim off the outer periphery. This leaves a stable, slightly smaller, vortex, circulating along the top surface of the wing with minimum variation in strength. The size of the vortex and the lift that it can generate is thus limited to some value less than the possible maximum, but the vortex is of constant size and is very stable.

A further increase in lift can be obtained by transferring moving air from the bottom of the wing to the top, by means of slots which direct the high pressure air from the underside, in a forward direction, along the upper skin, increasing the mass and velocity of the air flowing in the vortex between the wing top surface and the external potential flow.

This self-regulating arrangement will automatically increase the vorticity according to the pressure and flow along the wing bottom surface.

At the same time the speed of the airflow on the underside of the wing will decrease. A portion of the airflow on the underside will be transferred to the upper side, leaving a smaller, and therefore slower, mass of air to pass beneath the remainder of the underside. With this reduced velocity, the air will generate more positive pressure on the undersurface and thereby increase the lift.

By interpolating measurements made with gliders, it is possible to forecast that the new powered flying wing at slow speed in the vortex generating configuration, will produce ten times the lift that it would in the "clean" configuration (Fig. 5).

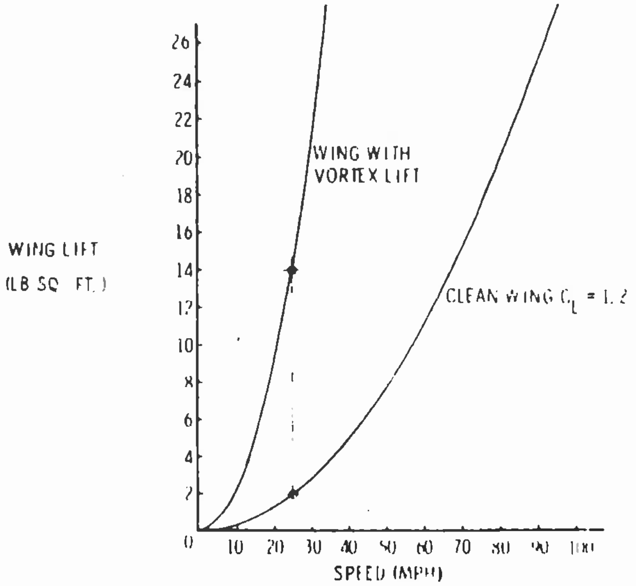


Fig. 5 – Forecast of lift in Kasper new powered flying wing

So, if vortex lift is so marvelous, why has it not been used in nature?

Well, it has. The birds, who depend for their very existence on controlled flight, are well aware of the value of vortex lift and they use it to achieve high lift and low speed at the moment of landing.

The bird assumes a special configuration for landing which differs very much from our airplanes (Fig. 6). Instead of increasing curvature of the profile by means of flaps, as we do, a bird changes the profile to a high reflex trailing edge and curves the wing tip upward. Additionally the wing tip ceases to be a solid profile and looks like a venetian blind, with the feathers separated and arranged in an "up" cascade contrary to the "down" cascade of our flaps.

According to the potential flow theory, the bird is not producing higher lift, but is destroying any trace of lift by blowing through the slots against the outside airflow.

Assuming a normal flow of air over the top of the wing, the bird's arrangement is wrong, but this is contradicted by the results.

The wing of the bird, in this "wrong" configuration, produces great lift—so great, that it permits a decrease in forward speed to zero.

The conclusion must be that the bird is using a different aerodynamic phenomenon.

Analyzing the configuration of the bird's wing tips, we find that the airflow on the top of the wing is reversed. It blows from the trailing edge forward, then it curves upward, and at a distance from the wing, reverses again in the direction of flight, joining the outside airflow.

This phenomenon was observed by aerodynamycists in the middle twenties but was not understood.

In pictures of a landing bird we can see ruffled feathers on the back of the wing due to the reversed flow. However, we also notice that this occurs at very high angles of attack, well above the so-called stall angle. Unfortunately conventional airplanes can never attain angles of attack higher than the stall—about 20 deg.

Therefore they cannot produce a vortex along the wing; but the bird, by controlling his pitch by an appropriate shift of lift, is not limited to the stalling angle and can use the vortex generated lift for his point landing.

The landing pattern of a bird goes like this:

1. The bird selects the landing spot.
2. It dives toward it.
3. It flares out to an angle of attack of about 70 deg.
4. It hovers for a moment and settles gently at the selected spot.

The first phase is nothing new; any airplane can do it. The second phase also. The third phase is impossible and consequently, phase 4, as a follow up to phase 3, is also impossible.

Now, why is this?

In phase 3 the forward speed is near zero. It is the so-called "deep stall" condition where airplanes have no control whatsoever over the pitch, roll, or yaw condition. The bird, by moving its wings forward, obtains so much pitch-up moment, that it can overcome the pitch-down moment from the spread and downwardly inclined tail. Wing tip feathers are spread and bent up to generate the vortex and improve lateral stability.

Due to the property of a vortex that if no additional energy is supplied, the vortex will gradually decay, the lift generated by the vortex will slowly decline, and the fourth phase, the settling down, will take place.

Because the decay time is a function of the size of the vortex, small birds have to settle down in a fraction of a second, while larger birds can hover for several seconds.

So now that we know the mechanism of a bird's landing, the question is, how can this be duplicated with our airplanes?

We can't use wing-tip feathers to generate a vortex, neither can we bend the tips up to increase our roll stability at low speed.

We have, with our sweptback wings and our wing-tip control surfaces the capability to shift our c.p. forward, which could enable us to fly at practically any angle, without stalling, if only we could get rid of our tails.

We need to be able to generate a vortex at the top of the wing, keeping the plane level (Fig. 7). The first requirement is to break up the potential flow at high angles of attack. This can be done by changing the profile by use of a nose flap opening upward. The next step is to create high pressure differences between the bottom and top surfaces of the wing to feed the vortex at the trailing edge.

This is done by means of a split flap with a slot at the hinge line. This slot will feed the vortex, even at zero forward speed, by shooting the high pressure air forward along the top surface.

Having examined some of the properties of a vortex and some of the methods by which a vortex can be generated on top of a wing, we now have to address ourselves to the problem of airplane configuration.

No bird in the universe has a cross tail. Some have no tails at all, like ducks and geese, others have tails of varying sizes which are folded during gliding flight. It seems it is possible to glide in a stable condition without a tail. Without a tail a lot of weight would be saved in the structure, the fuselage would be lightly loaded, and the airplane would produce less drag and so require less power to drive it through the air.

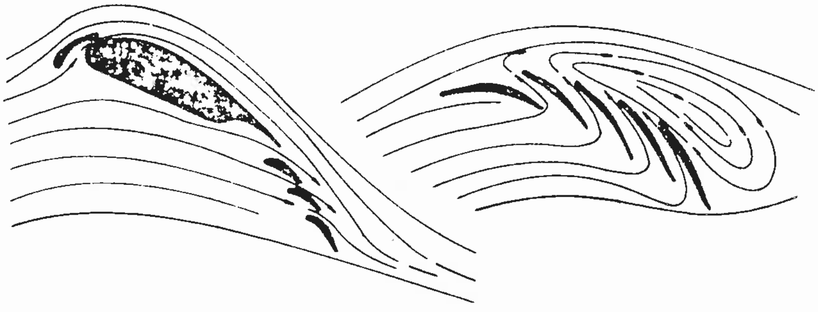


Fig. 6 – Configuration of a bird's wing for landing

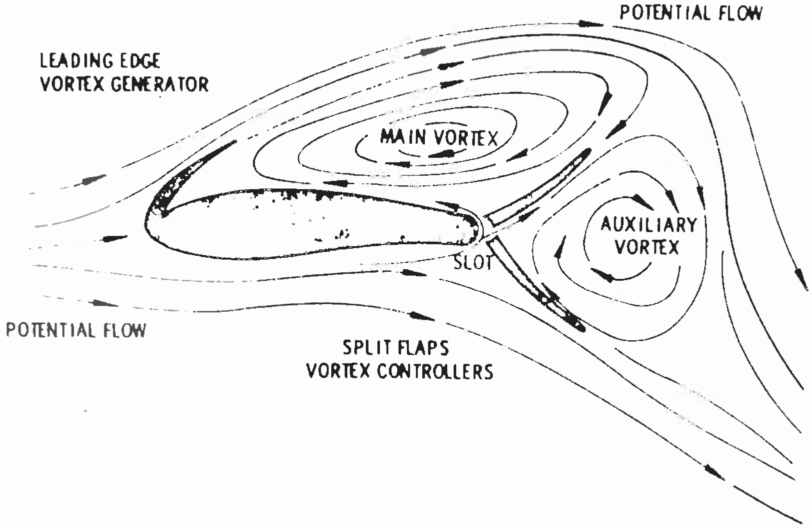


Fig. 7 – Kasper flaps

This seemed a very logical line of approach for a more efficient glider. Over the years a series of designs of flying wings was arrived at and in 1958 the first Kasper flying wing glider was built with a second improved version following a few years later.

These flying wings fly well and maneuver well. They are stable and at the same time very maneuverable and led directly into vortex lift. Here is a machine to which flight comes naturally and to which vortex lift comes naturally, and to which no stability problems, during either of these two phases of flight, were encountered.

Some of the thoughts, principles, and mechanisms which have gone into the building of these flying wings are a big advance on the conventional layouts and a direct step toward a family of aircraft which are fitted to both high, medium, and low speed flight, and should be able to land at much lower speeds and with far more safety than anything we have today.

When we start the actual design we must consider four major factors: stability, controllability, lift, and speed.

The first two aspects are really contradictory. Stability is necessary to relieve the pilot and the control system of the necessity of making constant corrective movements to maintain a desired flight path and controllability is necessary to divert the aircraft from its stable flight to another and to provide the necessary agility at all speeds.

Stability can be defined as the property of a system in which a body, when disturbed from a condition of equilibrium, generates forces or moments which act to restore it to the original position without the help of external forces, and that the sum of the forces acting upon it, in all three planes, must be zero.

In order to achieve not only equilibrium but stability, those forces and moments around the possible center of movement must be finite forces and not just zeros. That is, the sum of all the "x" plane forces must be zero, the "y" plane forces zero, and the "z" plane forces zero, also all the "x" moments, "y" moments, and "z" moments must be zero.

People often say a pendulum is an example of a stable system. This system does not produce a return of the disturbed body to its original position without external forces. The body when released from a displaced position passes through the null position at high speed and moves to an opposite displaced position; then, after a momentary rest, the cycle is reversed. Also, in the case of a pendulum, only the vertical forces, the weight, and the reaction in the string are real, and all the other forces are zero. Thus it does not comply with the requirement that forces in the XYZ planes must all be real constraints and not just zero.

However, if we add two more strings to a pendulum, the ball would immediately become part of a stable system. As soon as the ball was displaced it would return to the position in which the forces in each string were balanced, and it would remain there in equilibrium henceforth.

We must not continue to make the same mistake of using oscillating systems and then build in artificial damping, yaw damper, and stability augmentation systems to keep the machine on an even keel.

Rather we must seek the stability of, say, a flight refueling drogue for flight along a constant path and must seek to modify the "stability datum" by means of our flight controls in order to divert our machine into another equally stable mode of motion.

In this way stability and controllability can be made to complement each other rather than being contradictory to each other.

The stability systems of the Kasper Wing are based on a "V" pattern, with real and positive forces acting on either side of the "V", and the control system providing an unbalance of the "V" forces to displace the whole "V" pattern in a stable and constant mode to one side.

The wing sweepback and dihedral, the stabilizer surface angle, the rudder toe-in, and the rudder dihedral are all examples on which will be elaborated in a moment.

When we recognize the fact that a system is not stable, we should not try to deceive ourselves by renaming it "dynamically stable," using external forces to make it acceptable, but we should develop a truly stable system. Unfortunately airplane designers do not feel this need, for seldom are they professional pilots who have to act as stabilizing agents for those "wandering" airplanes. It was only when heavy airplanes were built and after the pilots and passengers seated in the tail complained, that the designers were forced to stop the oscillations. However, instead of using a positively stable system they replaced the tired pilot with the "yaw damper" and automatic pilot–like giving an aspirin for a toothache, removing the symptom without the cure.

PITCH STABILITY

The same story exists with the pitch stability. The system used is an oscillating system and speed is used to obtain "dynamic stability." The wing profiles commonly used on aircraft due to their positive Cm factor are the major source of pitch instability. There is a type of profile available with, so-to-speak, "intrinsic" pitch stability having a negative Cm. This is the reflex profile commonly used on helicopter blades; these cannot rely on a crosstail for "dynamic stability." Why the reflex profile is not used on fixed wing aircraft is a mystery. The reflex profile is suitable for low and high speeds, has a larger laminar dwell, has a much better L/D ratio, and is stable. The birds use them exclusively.

Flying wing airplanes which use reflex profiles have adequate pitch stability without a tail. The stabilizing moment is provided by the total lift of the wing itself which is many times greater than the downforce on the tail in a normal aircraft. Furthermore, an additional benefit from using a stable profile is increased lift with less drag. The downforces on the conventional stabilizer load the wing additionally and produce torsional stress, decreasing payload and forcing us to use higher lift profiles, with corresponding higher drag coefficients. Talking about drag, don't overlook the high crosstail drag.

The downforce on the horizontal stabilizer and elevator is only generated when the airplane is maintaining a forward speed; when the airplane speed decreases, it loses stability and controllability, pithes down, and at low altitude frequently becomes a coffin for the occupants. Now is it just that the pilot, merely for loss of speed, should be penalized with the death penalty? It would seem that the aircraft designers approve it.

Let's see how the bird designer solved this problem. For pitch stability the bird uses the reflex profile with fixed center of pressure, sweep back, and washout. The stabilizing force is the lift. This lift does not depend on forward speed, even at 90 deg angle of attack (vertical descent) lift is generated and is used to stabilize and control the bird.

Should the gust raise the nose of the profile, lift increase is generated at the tip, due to the washout, causing the center of pressure of the wing to move outboard, resulting, due to the sweep back, in a rearward displacement causing the bird to nose down thus restoring it to the initial position. In the case of a down gust the opposite takes place, causing a pitch up reaction.

THE BIRD'S LONGITUDINAL PITCH/CONTROL

Let's find out now how the bird controls pitch (Fig. 8). The tail is folded so it has to be discounted. We have also to eliminate any control relying on muscles, because this would limit its flying time. Taking a closer look at the forces acting upon the bird in flight we can see that all the forces and moments are in equilibrium at a certain angle of attack. As soon as the position of the forces changes in relation to others, a new angle of attack is attained where again perfect equilibrium exists. The center of lift is above the center of gravity and is in line vertically. The best way to illustrate this, is having a picture hanging in level position. In order to change the inclination of the picture we can proceed in three ways:

1. Push with the finger on one end of the picture.
2. Hang weight on one end.
3. Shift the position of the support.

Airplane designers use solution 1, pushing the tail down; parachute jumpers use solution 2, shifting the weight; birds use the third solution. They move their wings forward, shifting the center of lift ahead of the center of gravity and assume a new higher angle of attack position where again the lift and gravity are in line. If you recall, a slow flying bird keeps the wings forward and a fast flying bird keeps them back.

This way the bird maintains a desired angle of attack without any effort and without relying on forward speed, because even in vertical mush, lift is produced and by shifting it, full pitch control can be maintained. This pitch control, not being limited by forward speed, enables the bird to fly at far greater angles of attack than our usual 20 deg stall angle. It seems that this system using the total lift as control force would be over sensitive and would require very precise movements of the wings, but this is taken care of by the bird in a very simple and elegant way. The wing is heavier at the root than at the tip, but the lift is greater at the tip due to the negative taper ration of the bird's wing. Moving the wings forward or back, the lift center moves ahead of the center of gravity which is following the movement of the wings at a slower rate. This way the high sensitivity is attenuated, and the pitch response is smooth.

LATERAL STABILITY AND CONTROL

The lateral or roll stability on an airplane is obtained by the use of dihedral. For airplanes with a straight (not sweptback) wing it is a stable system which does not need any artificial means to improve it. However, this changes for sweptback wing airplanes. For them the dihedral is not sufficient, because it changes with the angle of attack; at low angles the dihedral increases and so does the stability, but at high angles it decreases and eventually becomes negative. This way when we need the lateral stability most, at landing or take-off, it vanishes.

The bird overcomes this by spreading the wing tips and, due to the lift distribution moving outboard, the tip feathers bend upward increasing the dihedral; at the same time, as it was

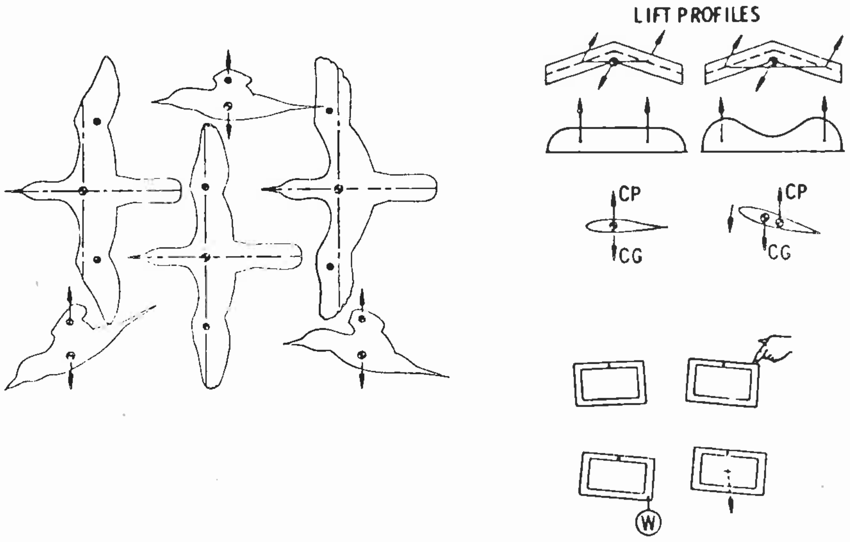


Fig. 8 – How a bird controls pitch

mentioned earlier, in order to pitch up, the wings move forward, which increases the dihedral additionally. This way the bird's lateral stability not only does not decrease at high angles but it increases.

LATERAL CONTROL

The bird exercises lateral control by twisting the wing tip in the direction of the desired bank. This is similar to the movement of the aileron up, by the airplane. (Sometimes, especially at low speeds, birds with tails twist these too.) Due to the fact that only one wing tip is twisted, the bird has no adverse yaw, which is sometimes a problem with airplanes at high angles of attack. By twisting the wing tip, the bird also produces greater drag at the inside wing tip, causing it to turn in the direction of roll. This way the bird does not need a vertical tail to turn. Every turn is very well coordinated with one single control surface which, when not needed, is an integral part of the wing without producing additional drag, as is the case with a vertical tail.

The above discussed principles of bird stability and control have been used on the Kasper wing. However, because a movable wing would be too complicated, different means were used to obtain the same results.

PITCH STABILITY AND CONTROL OF THE KASPER WING

Selecting as the profile a reflex shape, we are assured that the center of pressure (c.p.) does not shift cordwise with a change of the angle of attack. Sweeping the wings back and applying a moderate washout assured an adequate pitch stability. Adding a triangular stabilizer at the wing tips controllable from the cockpit assured a compensation for c.g. shift and increased additionally the pitch stability. Placing the elevators at the wingtip increased the washout at high angles of attack, increasing the pitch stability at low speeds. When not used, the elevators are also part of the wing and do not produce additional drag when not in use.

The pitch control is obtained by moving the elevators up and down (Fig. 9). Their action is twofold. They generate forces behind the c.g. like an ordinary elevator, but this is only part of their action. Changing the profile of the wing tip, they change also the lift distribution over the wing, shifting the c.p. inboard and outboard and, due to the sweep back, forward and rearward. This action is much more powerful than the pitching action due to the deflection and it imitates the movement of the c.p. that birds obtain by moving the wings back or forward. Especially important is the fact that this pitching moment created by the shift of c.p. is independent of the forward speed. This way the wing maintains full pitch control at zero forward speed (vertical mush). The loss of control at the so-called "stalling speed" is completely eliminated.

ROLL STABILITY AND CONTROL OF KASPER WING

Having placed the elevators close to the wing tip, a new problem arose: how to control the roll? The simplest solution appears the use of the elevators as ailerons. These kinds of controls are known as elevons. However, when deflected as ailerons they produce a yaw opposite to the desired roll direction. This phenomenon is known as "adverse yaw." Airplanes with a tail oppose this yaw with the vertical stabilizer, so it is not much pronounced, but a flying wing without this "tail damping" fully submits to this yaw. This is the reason why normal ailerons are not used for roll control on flying wings. Instead we use tip spoilers or split flaps. Thus, however, precludes the placement of the elevators at the wingtips, which is vital for the pitch control independent of forward speed. Something had to be done which had never been done before.

First let's analyze the causes of the "adverse yaw." The down aileron, especially at high angles of attack causes about three times as much drag as the "up" aileron for the same deflection angle. A partial cure in common practice is to make the movement differential, but in the case of a tailless plane

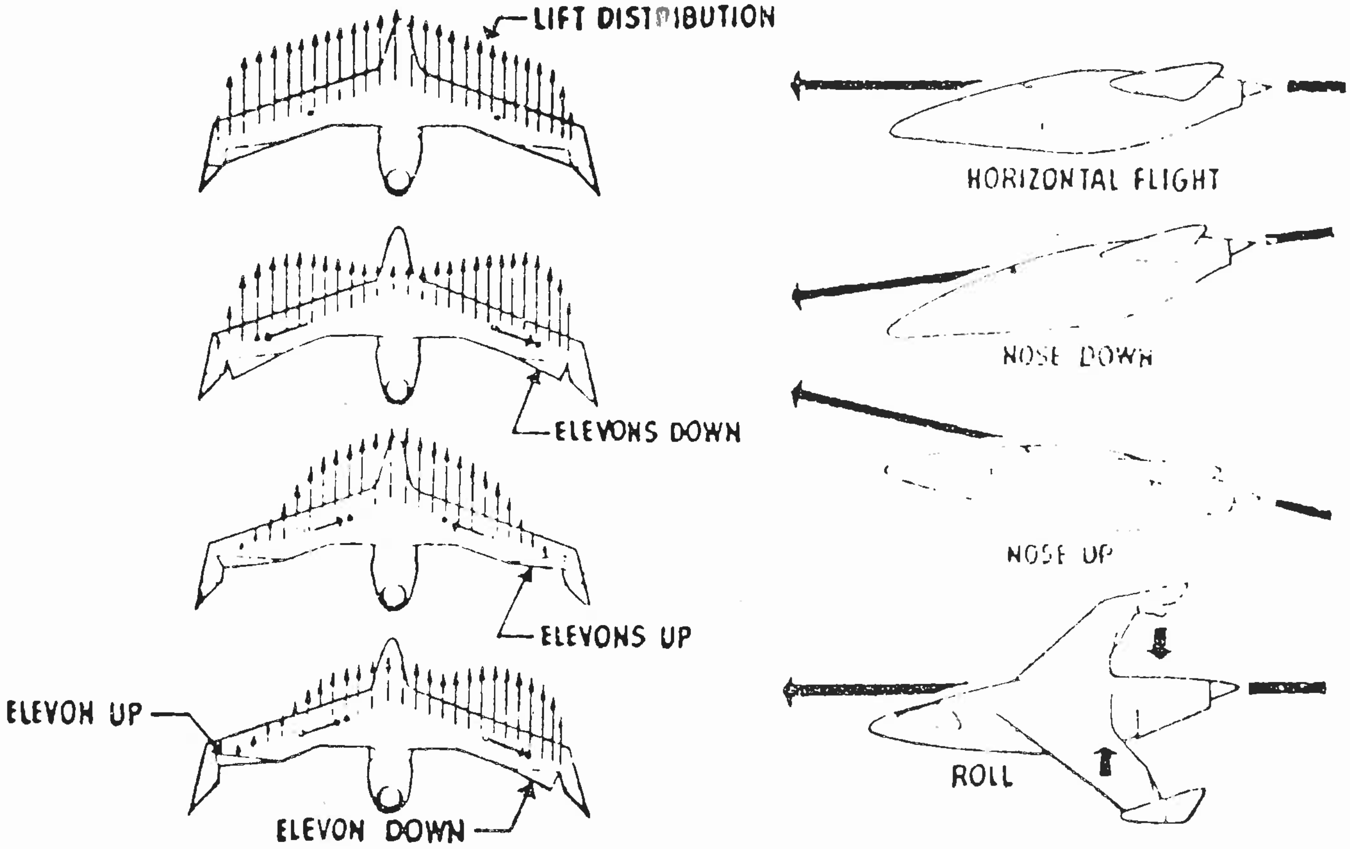


Fig. 9 – Pitch and roll control

this is not sufficient. We have to substantially decrease the drag on the "down" aileron and increase it on the "up" aileron. One way to decrease the drag on the "down" aileron is to install at the trailing edge a flap which will move "up" when the aileron moves down. but the same flap has to increase the drag on the "up" aileron which can be done when the flap would also move up on the "up" aileron.

All that remains is to find a suitable mechanism which will do the work. The simplest geometrical solution would be two tangential circles with different radii.

When the hinge line of the aileron is the center of the bigger radius and the lever actuating the flap is shorter, it will always pull the flap "in" regardless of the movement up or down of the aileron. This kind of flap has another advantage: In the case when we are using the elevons as elevator, it increases the response in the "up" low speed position and decreases in the "down" position, equalizing the pitch sensitivity regardless of speed.

Now, any control arrangement on an aircraft has a primary purpose with a specific beneficial effect wanted by the designer, but it also causes secondary and tertiary effects, which can be beneficial or detrimental. In the last case the designer has to evaluate whether the "cost" is acceptable for the desired primary effect. Because the pitch control is of greatest importance let us check the secondary and other effects of the elevator on ordinary tail planes and compare them with similar effects on the Kasper wing.

1. In the standard airplane: produced drag is all the time, whether used or not; the force produced is a function of speed and fails when speed drops below minimum control speed thus limiting the minimum speed of the airplane; the forces on the elevator are loading the airplane when actuated, causing additional bending and torsional moments in the wings and at landing increasing the airplane's weight.

2. In the Kasper wing: being part of the wing, no drag is produced when not in use; an additional effect is produced–the shift of the center of lift is not a function of speed, which at low-low speeds permits full control of the wing; because of the location of the elevators at the wing tips, the forces generated by maneuvering are opposite to the "G" forces, this means they are relieving the bending moment.

As we can see, the bending moment of the wing with elevators on the tip is only 1/4 of the bending moment without the tip elevators. This means we have to pull four times the G forces to generate the same bending moment as a standard airplane's wing. This relief does not exist in normal cantilever wings, and the high bending moment generated by a rectangular wing was one of the main reasons why the rectangular wing was abandoned as soon as the cantilever wing was adopted. The height of the spar being limited by the profile could simply not take the bending stresses multiplied by the "G" factor which was, in cases of acrobatic planes, as high as 12.

In the case of a wing with the elevators at the tips, the lift distribution corresponding to the rectangular shape of the wing is present only as long as the elevators are flush with the profile (Fig. 10). As soon as they are deflected upward the lift distribution changes to a triangular form very similar to the one of a tapered wing, decreasing additionally the bending stresses. This relief added to the relieving forces of the elevator, reduces the bending moment to about 1/6-1/8 of the bending moment of the standard cantilever rectangular wing. This means that when we build a wing with the elevators at the tip for gust loads of 3½ G, this wing can withstand as much as 25 G, as a maneuvering load. Because of the vulnerability of the human body to G-loads, it would be of little value to design a wing with tip elevators for more than 3½ G, as this strength would more than satisfy any acrobatic load requirement.

Another beneficial effect is that the wing in a pullout does not develop any torsion. The load is pure handling. Both those effects permit building a much lighter and stronger wing than the standard airplane wing which has to take the maximum bending and torsion at the pullout.

Summing up all those effects we arrive at those final conclusions; It is well known that for the classic "crosstail" airplanes, the effectiveness of the elevators decreases with speed decrease. This is because the forces on the tail are a function of speed.

Now, how is it on a sweptback wing with tip elevators? As we have seen before, the pitch-up moment is the sum of two moments; one is the elevator pitch-up moment due to down forces on the elevator which is a function of speed and the pitch-up moment due to the inboard shift of the center of lift and consequently, because of the swept back, the forward movement of the c.p. This is not a function of speed, because a wing mushing vertically down with zero forward speed produces lift, or is it drag, at 90 deg angle of attack? When this lift can be shifted forward or back we are maintaining full pitch control at zero forward speed. This then leads to another question: What happens to the so-called "stalling" speed? Very simple: there is no such thing. The "stalling" speed is "man made." Nature does not have it. The birds never stall and our planes with elevators on the wings land at angles of attack of the order of 45 deg. in the Delta configuration. A Delta is nothing more than a wing with a greater sweepback angle, thus the behavior is similar to a flying wing.

DIRECTIONAL STABILITY AND CONTROL OF BIRDS AND THE KASPER WING

The directional stability of the classic "crosstail" airplanes is obtained with a vertical stabilizer placed at the end of the

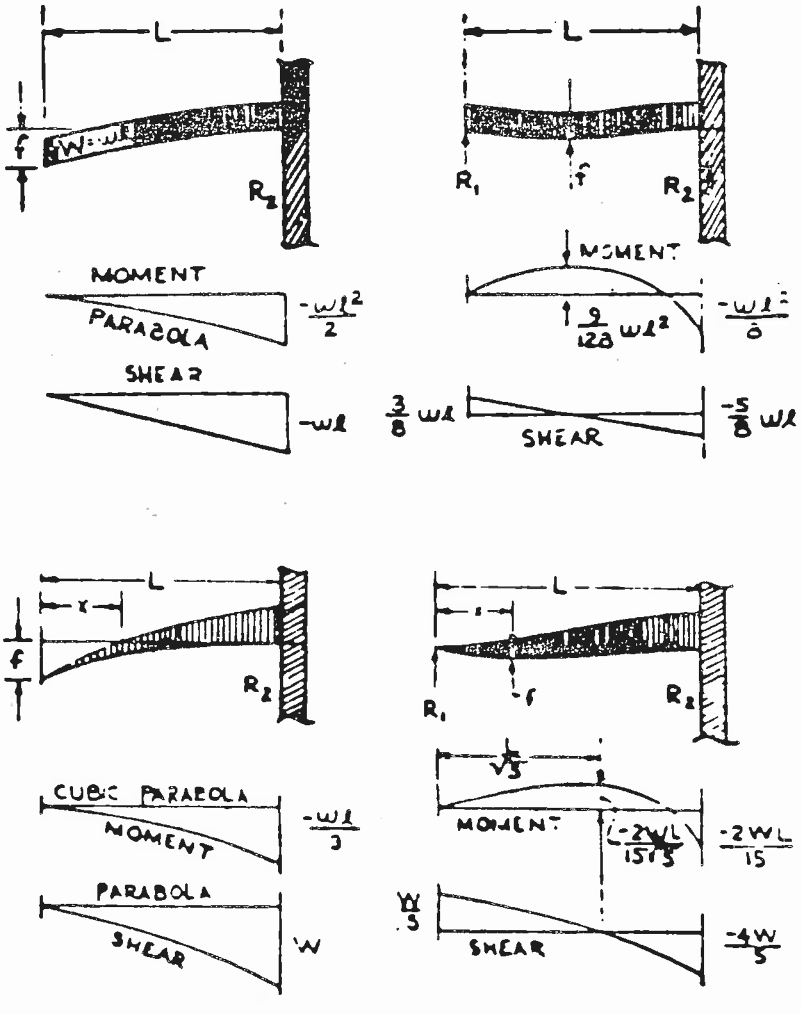


Fig. 10 – Lift distribution in wing with elevators at tips

fuselage called the tail. This is similar to a weathervane with a flat plate at the end. As we have previously seen, this is not a stable system but an oscillating one. The only true stabilizing factor is the pilot wiggling the rudder continuously in gusty weather. That this is true is proven by the fact that on big, heavy transport planes, the pilots could not take it any more acting as a dampening device and forced the designers to do something about it. They, in turn, came up with a yaw dampener which is another rudder wiggler, but this time a mechanical one. The birds use the sweep of the wing to obtain directional stability. However, this applies only to high speed flight configurations, where the low angle of attack increases the dihedral, which increases the roll stability and helps also the yaw stability. But how about the low speed flight when the wings have a forward sweep and the system becomes unstable? First, the wing tips spread automatically and bend up, increasing the dihedral improving the roll stability; the first longest feather bends most, each following less, forming an end plate with toe in. Additionally the tail is spread and assumes a "V" configuration. All those changes in the bird's shape provide sufficient roll and yaw stability because they are based on the "V" shape, which as we have seen before is a stable system and not an oscillating one. In order to execute a turn, the bird twists the inner wing tip which is first acting like an aileron decreasing lift on that wing, and secondly as a tip rudder which is very effective due to the long arm from the center of gravity. As we see, with one movement the bird accomplishes a true co-ordinated turn, for which we have to use two control surfaces, the aileron and the rudder.

As we now realize, the bird's designer provided for a very sophisticated system which simplifies greatly the maneuvering and is failproof. Then how can we obtain the optimum flight characteristics in the rigid man-made plane? The simplest measure would be to use a split stabilizer in a "V" form. But this would cause a continuous drag increase, and we would have difficulties in placing the rudder. So, let's borrow as much as possible from the bird. When we place our stabilizer at the wing tip in the form of an endplate, the drag penalty is offset by the decrease in induced drag and improvement of the lift. A toe-in of about 4 deg will provide the needed yaw stability forming a "V" system (Fig. 11). Now, we can place the rudder at the trailing edge of the stabilizer, and providing it with an aerodynamic balance in front, we obtain all the advantages of the bird's steering system. The rudders move independently, outboard only, providing the yaw moment for the turn. At the same time the aerodynamic balance in front of the rudder, which was hidden in the recess of the stabilizer, moves over the wing acting as a spoiler, providing the needed roll moment. There are additional advantages of this system. The rudders, being independent, can be used both at the same time to act as airbrakes and spoilers. When we need to increase the directional stability in especially rough air, stepping slightly on both rudder pedals will do the trick. By deflecting the rudders at different angles we can offset any crosswind effects without having to crab or side slip.

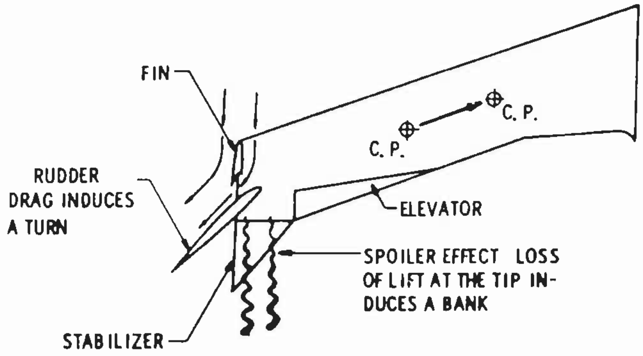


Fig. 11 – Rudder action

This is not all. The vertical stabilizers together with the rudders are in size only 1/3–1/4 of the area of the crosstail surfaces. The reason for this is that the tip controls operate in undisturbed airflow, even outside of the wing, while the crosstail is subjected to the combined turbulence from the fuselage-wing joint disturbance and in the case of engines in the nose, to the propeller turbulence. The wing-tip rudders are also extremely effective in the spin, contrary to the tail rudder, because they react against undisturbed airflow; the wing tip still "flies" in a spin. The wing-tip rudder can never be in the "shadow" of the elevator, nor can it cancel out the elevator action, as is often the case with crosstail airplanes. Still another benefit from using the tip rudder is the stabilizing action in the turn, especially at high angles of attack. The peculiar behavior of sweptback wings during a turn at low speed is the so-called "dutch roll." In a turn, the drag of the outer sweptback wing increases considerably in relation to the inner wing, causing a strong opposite yaw moment around the vertical axis of the plane. With the tip rudder open on the inner wing, the increased drag moment of the outer wing is counterbalanced by the relatively small drag of the deflected rudder multiplied by the half span of the plane. Their opposite moments are in equilibrium only at one inclination angle. When the plane inclines more due to a gust, the drag at the outer wing increases and yaws the plane back to the equilibrium inclination. When the inclination is decreased due to gust, the inner wing drag increases and the wing rolls in again to the initial inclination set by the deflection of the rudder, without any corrective action of the pilot. So, as you can see, we are using the natural phenomenon of the "dutch roll" to stabilize the plane in a turn, instead of fighting it.

The last problem is roll and yaw stability at near zero forward speed. This is done in a very simple way. As shown before, the Kasper wing is provided with vertical endplates and rudders. Inclining the endplates about 45 deg to the vertical increases the roll stability. However, in order to maintain the same movement of the aerodynamic balance of the rudder over the wing; the hinge line must be slanted by the same amount. Analyzing the secondary effect of this modification we find that the rudder in the deflected position, being inclined to the airstream, produces a down component tending to incline the wing in the proper direction; this component is about 25% of the total drag of the rudder.

Let's now check the secondary effects of the tip rudders. Being inclined 45 deg to the vertical and with 4 deg toe-in, they are at a positive angle of attack to the airstream, consequently producing an aerodynamic force perpendicular to the surface; of this force 0.7 is lift which is added to the lift of the wing. The inclined rudder and the adjoining horizontal stabilizer are forming a funnel which is acting like a venturi tube, increasing the speed of the air leaving the wing's tip. This action is one of the conditions preventing the formation of the tip vortices. At high angles of attack when a sweptback wing loses roll stability the inclined endplates are still stabilizing the airplane in roll. When the rudder is deflected, the angle to the airstream changes from positive to negative, producing a downward force which is added to the downforce generated by the spoiling action of the rudders' aerodynamic balance which moves on top of the wing, acting as a spoiler. This way, besides the action as a rudder, we are obtaining a very powerful roll action, which makes the use of the ailerons for roll unnecessary. The rudders, being independent, can be opened both at the same time, then they act as very powerful spoilers, eliminating the need of sideslipping the plane when we have to lose altitude fast. As we can see, all the secondary and tertiary effects are beneficial and we do not pay any drag penalty.

SUMMARY

Summarizing all the analyzed properties of the flying wing built on the bird-flight principle, we are getting an airplane which has the following advantages as compared to a conventional crosstail airplane:

1. The useful load of the wing has increased from 60 to 100% of the empty weight as a result of the loss of the tail section excess weight and downward forces.
2. The total drag of the plane has decreased about 30%, resulting in a considerable increase in cruising speed or decrease in fuel required.
3. Utilizing the stable system for pitch and yaw, the pilot's task is greatly eased, especially under IFR flight conditions.
4. The pitch control being independent of forward speed of the plane permits the maintaining of full pitch control at any low speed, thus eliminating the falling off to the side and uncontrolled diving, which at low altitude inevitably leads to a fatal crash. The wing can be mushed to a landing with very little forward speed in a level or slightly nose-up attitude. Thus, in addition, 180 deg turns can be safely made in the flight position, greatly reducing the fatal "engine failure at take off" crashes.
5. The end-loading action of the wing-tip elevators permits the limitation of the safety load factor to 3.5 G (the gust load factor), resulting in great weight savings, increasing at the same time the maneuvering strength of the wing.
6. The absence of the tail, eliminates the torsional forces on the wing at pull-out. The wing has to be calculated only for bending 3.5 G. The obtained weight economy can be converted into additional playload.
7. The absence of the crosstail eliminates all bending and torsional forces on the fuselage, making it a nonstressed member in flight, like the fuselage of a helicopter. This allows for lighter structure, another weight saving.

In short, by applying the flight principles of the bird, we could build an airplane superior in all respects to those in which we all travel today; an airplane with special emphasis on safety, stability, and economy and with the STOL capability that we are all searching for.

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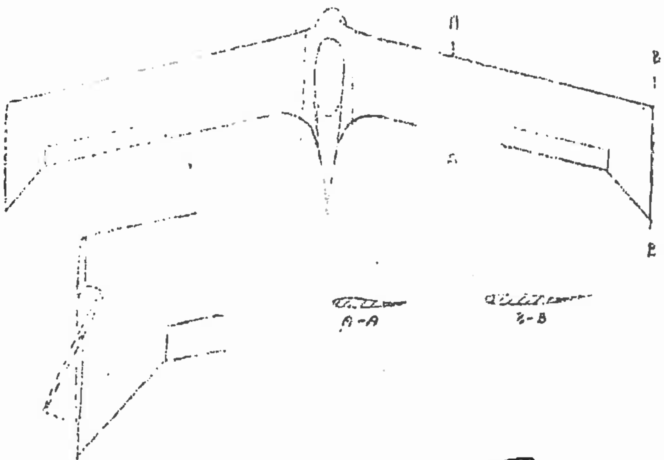
Kasper Aircraft, Inc

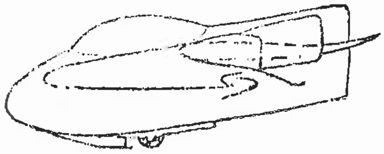
Experimentflygplan : data och prestanda, projekt

Segelflygplan BKB-1

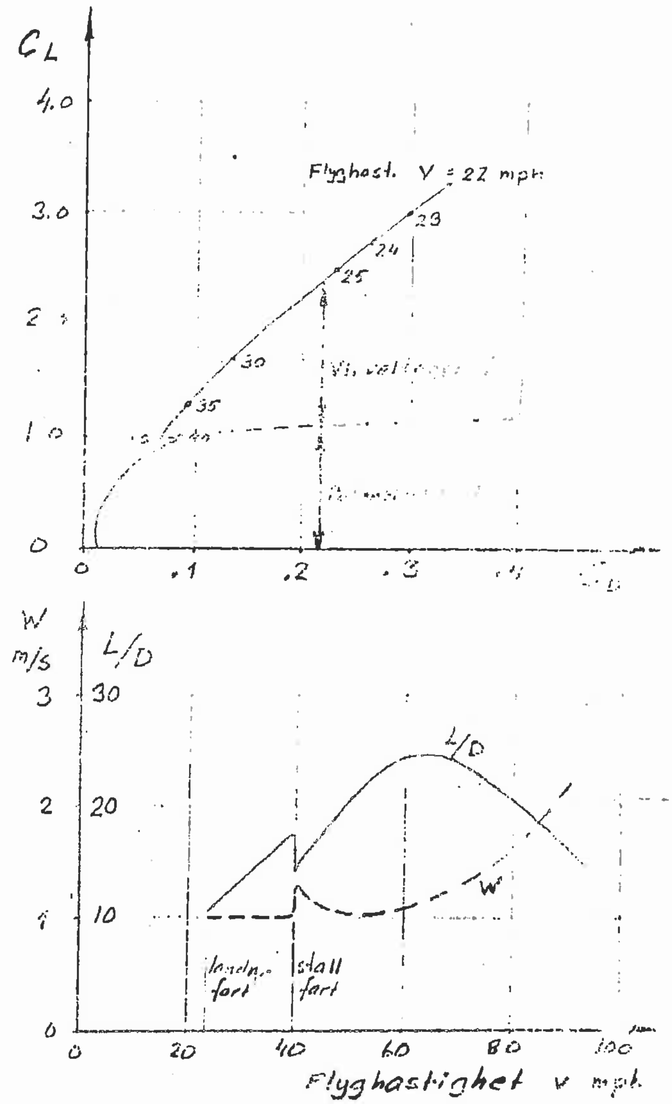
Byggt 1966

Spännvidd ... 11,9 m
Pilvinkel ... 13°
V-form ... 1°
NACA-profil ... 18 H 12C
Flygvikt ... 260 kg

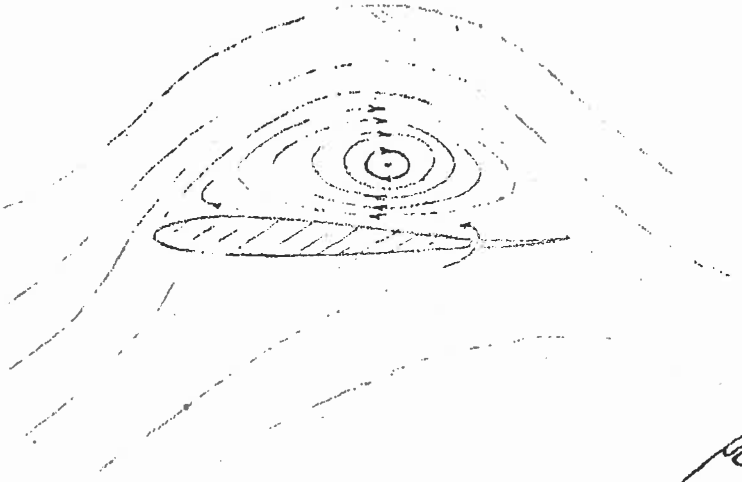




Prestanda BKB-1



Strömningsbild



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