THE STRETCHED-MEMBRANE SAILWING

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INTRODUCTION

In recent years a special interest has been displayed in ultra-lightweight lifting surfaces for slow-flying gliders, short-haul all-cargo aircraft (Ref. 1), recovery systems of meteorological rockets or satellite vehicles and even military aircraft pilots (Ref. 2 and 3). The lightest are the single-membrane synthetic fabric sailwings of cambered airfoil, having a specific weight of about 1 kg/sq.m. (0.2 lb/sq. ft.)

The greatest interest so far has been roused by the Rogallo wing shown in practical application in Fig. 1. The wing was extensively tested at NASA (Ref. 4 to 9 et al) and entailed about 100 proposals for patents filed in the U.S.A., West Germany, Great Britain and France. As illustrated, in this simple structure the fabric is loosely fastened to three struts meeting at one point on the nose and joined by a cross spar. This wing, referred to as parawing, has the planform and some aerodynamic qualities of the delta wing (Ref. 10 and 11). A basic feature of the Rogallo wing is a quite appreciable

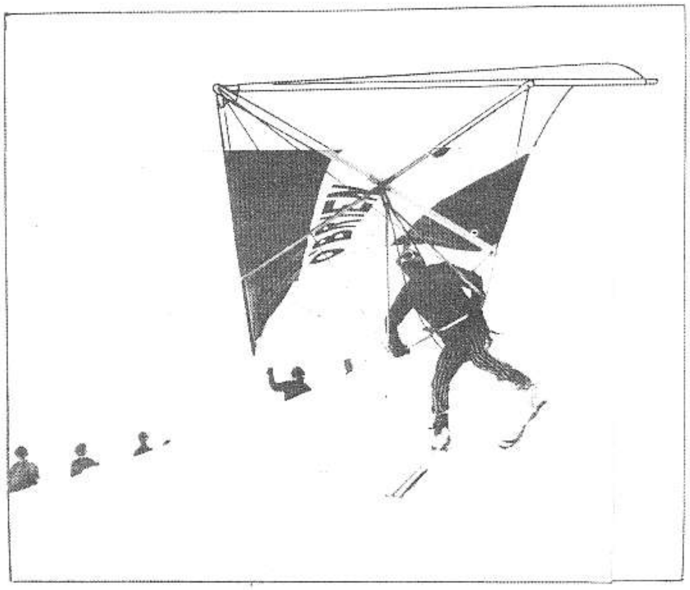


FIG. 1. STRUCTURE OF THE ROGALLO WING FOR A HANG GLIDER

geometrical and aerodynamic twist of the canopy filled out into two half cones, one on each side of common generators. Due to the twist and a large flank, the Rogallo wing has directional and longitudinal self-stability that is very advantageous for some applications, because it simplifies the construction of the flying vehicle. On the other hand, the considerable twist decreases the lift/drag ratios, already limited by the low aspect ratio which usually does not exceed 3:1.

The Rogallo wing is characterized by a difficulty at small angles of attack connected with fluttering of the slack trailing edge of the canopy. In the case of the greater wing loadings or of insufficiently rigid frame, the sail is deformed with unfavorable aerodynamic effects. The deformation takes the form of waves and wrinkles. One of the reasons for this is that the struts to which the sail fabric is fastened are subject to bending.

Our Institute, in connection with its research work on equipment to agricultural aircraft, developed an experimental stretched-membrane wing of permanently tight sail fabric capable of considerable elastic deformation but without the unfavorable aerodynamic effects.

CONCEPT OF A STRETCHED-MEMBRANE SAILWING

A stretched-membrane sailwing can be considered as a kind of single-membrane wing, derived from the Rogallo wing by shifting the spar attachment points with the two leading edge struts to the ends of the wing with simultaneous replacement of the struts by tie rods. In this way, we obtain a wing with a leading edge which is not stiff. This is admissible because the leading edge has no tendency to flutter. At the same time, we get a stretching of the trailing edge, which reduces its natural tendency to flutter. This enables us to decrease the sweepback angle of the leading edge and to increase the aspect ratio.

The general concept of a sailwing is surprisingly simple. It is an ultra-lightweight rigid frame to which a permanently tight profiled elastic sail cloth is attached at only four points. The canopy which forms the wing area is shaped and designed according to design rules for modern high-performance sails. However, it differs from the sails in certain ways because it is designed for unidirectional loading while the sails are intended for alternate airfoil loading during change in heading and air stream direction. The canopy of the sailwing has a contour of two sails joined by boom ends in the wing axis of symmetry.

The concept of the sailwing construction is shown in Fig. 2. Generally, it consists in locating four points in space intended for fixing and tautening the sail fabric. These points, that is, the nose and tail point and the two points at the spar ends should, if possible, only slightly change their positions toward one another under aerodynamic loadings. Naturally, to obtain these attachment points, we can use any construction consisting of only two crossed struts. Yet, from the point of view of weight and strength, a more advantageous solution is the framework shown in Fig. 2. This configuration can be regarded as basic. The framework is formed by a very rigid spindle-shaped polyhedron, the two upper lined triangular walls of which form the aerofoils, and edges of inextensible wires. The polyhedron interior contains a three dimensional cross of struts bracing the entire structure. Fig. 3 illustrates one of the simplest and possible forms of a s-m sailwing which can be used, for instance, in a simple lightweight glider with the pilot suspended in a parachute-type harness. Fig. 4 shows a sketch of an experimental stretched-membrane sailwing developed at our Institute. Fig. 5 shows a wing canopy not loaded with aerodynamic forces.

One can easily notice in the latter figure that the sail fabric is quite uniformly stretched along its entire surface in a way very much resembling a membrane. It is taut especially on the periphery, tension on

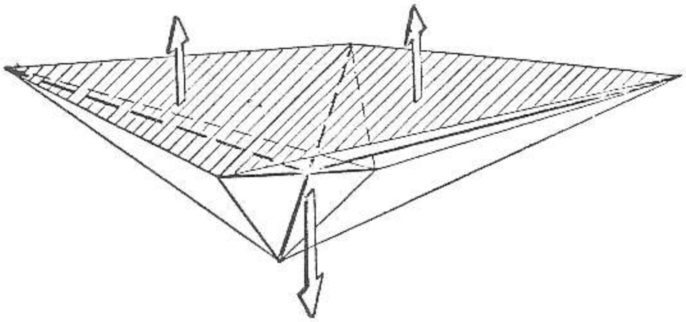


FIG. 2. STRUCTURE PRINCIPLE OF THE STRETCHED MEMBRANE SAILWING

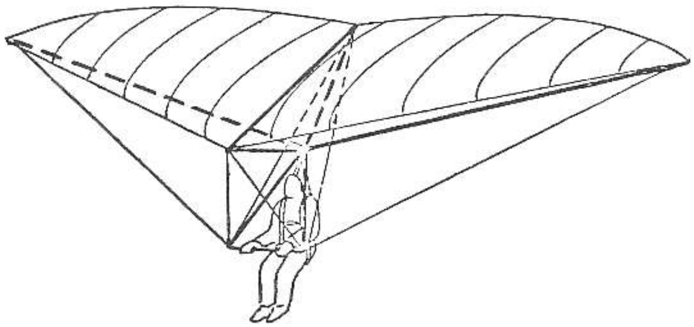


FIG. 3 EXAMPLE OF THE S-M SAILWING STRUCTURE FOR A HANG GLIDER

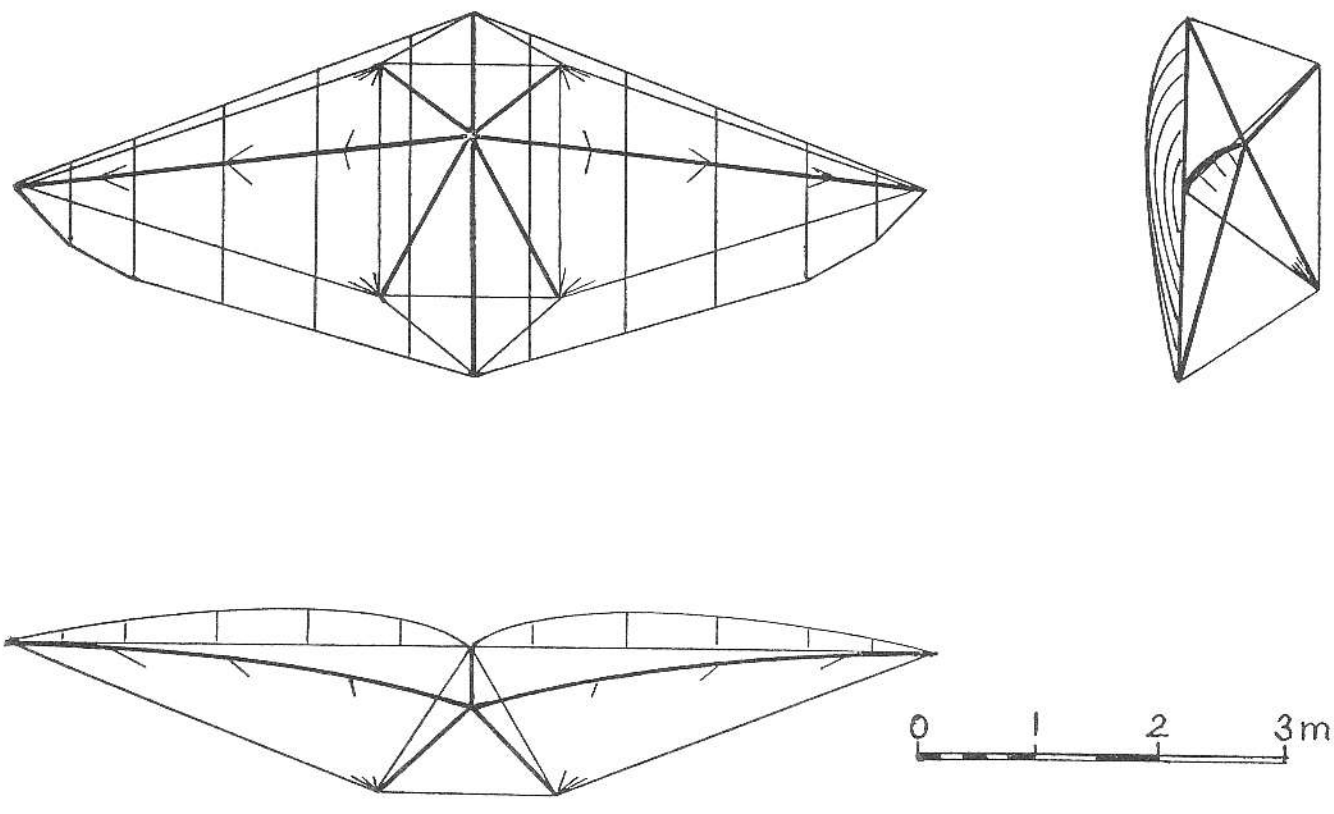


FIG. 4. SCHEME OF THE EXPERIMENTAL S-M SAILWING CONSTRUCTED IN AVIATION INSTITUTE, WARSAW

FIG. 5. CANOPY OF THE EXPERIMENTAL S-M SAILWING

the leading edge being chiefly transmitted by a steel or nylon rope sewn into the sail fabric, while tension at the trailing edge is taken by the wide strip of fabric along its weft which is always less deformed than the warp. This offers a possibility of obtaining an aerodynamically advantageous profile of the canopy with curved leading part and flat trailing part. This profile results from the canopy shape which, as shown in Fig. 5, forms an undeveloped surface, contrary to that of a Rogallo wing, in the form of cones. Fig. 6 shows that the profile geometry stiffness as well as the initial stretching of the sail fabric is maintained by tautening it with force P_w and by using curved ribs to which the canopy bulging is suited. The ribs are in the form of a flat pattern and can be made from thin plywood, dural sheet or glass-fibre reinforced plastic. One of the ribs in enlarged scale is shown in Fig. 6. The ribs are tightly secured in fabric coverings connected by one edge with the bottom (positive pressure) side of the canopy. When tautening the sail fabric, the ribs assume a position perpendicular to the wing surface and their ends rest on the taut leading and trailing edges, exerting on them force P_1 and P_2. Thus they form comb-shaped and curved beams, supporting and stretching the sail fabric in its cantral section between the leading and trailing edge. These beams are protected against buckling or just overturning by the sail fabric tension p_z; the tension distribution in the proximity of rib and sail fabric attachment is shown in the drawing.

Due to such construction of the canopy, the wing geometry in longitudinal section, that is the wing profile, does not change after the wing has been loaded by aerodynamic forces. Fig. 7 illustrates how the canopy is deformed under these forces. The deflection increases with the increase of the wing loading. It has a good effect on stresses in the supporting structure and the canopy, causing the appearance of non-linearity in the relationship between stress and foil loading. This non-linearity, as well as elastic deformability of the canopy, can be further increased by elastic members used to help in fixing the sail fabric ends to the spar. An increase in the canopy elastic deformability has not only a good effect on the wing static strength, but also on its behaviour in turbulent air, reducing vertical accelerations and dynamic loads. This greatly improves flight safety and increases comfort at low speeds in the proximity of the ground compared to rigid-frame wings.

Quite a large bending deflection of the canopy, without deformation worsening the wing aerodynamic qualities, is possible due to the use of a rectilinear central profile forming a sort of long hinge. The hinge gives a freedom of movement for both foils, at the same time not deforming their profiles. For this reason the canopy has a rectilinear stiffening in its axis of symmetry on which is formed a V-shaped longitudinal keel. The keel together with the ribs is responsible for a considerable self-stability of the wing.

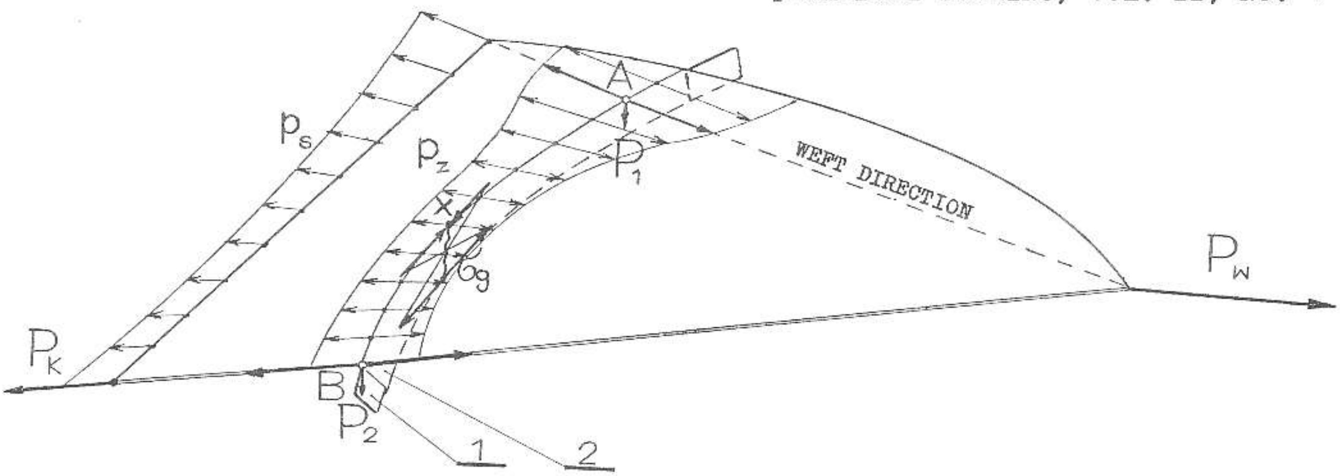


FIG. 6. PRINCIPLE OF INTERACTION BETWEEN CANOPY AND RIBS OF THE S-M SAILWING

FIG. 7. EXPERIMENTAL S-M SAILWING DURING AERODYNAMIC TESTS

The canopy, due to initial circumferential tension, does not show much tendency to vibrations or the trailing edge to flutter. Any such tendencies are further reduced by short battens bracing the fabric at the trailing edge. The battens can be noticed in Fig. 5.

The wing canopy is made from high-strength synthetic sailcloth of high air tightness, known under the trade-mark Dacron or Terylene. As compared with fabrics made from natural fibres, the synthetic materials of the same weight are three times as strong and are neither aging nor rotting. Due to high elasticity, they keep their initial shape exceedingly well, contrary to fabrics from natural fibres which creep and cannot be used in a sailwing. However, synthetic materials, when used for canopies, need to be very carefully formed. Particular attention must be paid to proper direction of warp and weft threads because diagonal direction of main stresses in relation to thread direction results in wrinkles. The canopy design is something special, just like the manufacture of high quality sails, which are usually made by few specialized companies of great experience.

Despite the presence of the ribs, the sail fabric is easily removable and can be rolled up toward the centre after releasing its fastenings at the wing ends. The supporting structure can be quickly disassembled, too.

Free selection of the mutual position of the spar axis and the axes of aerodynamic centers of the foil sections permits the use of high aspect ratios and sweep of the wing and spar, used for example in the experimental sailwing developed at our Institute. It makes it also possible to obtain the desired foil twist. The frontal position of the spar, as seen from the top gives positive twisting, the neutral position gives zero twisting and the rear position of the spar leads to negative twisting of the canopy.

The experimental stretched-membrane sailwing showed during tests very good structural and strength properties and relatively interesting aerodynamic qualities discussed in detail below.

STRUCTURAL PROPERTIES OF A STRETCHED-MEMBRANE SAILWING

The concept of the supporting structure of the experimental sailwing, shown in Fig 4, was based on a value analysis. The chief aim of the structure is to keep the canopy in permanent tension. Therefore, all its tension members are made from high-strength steel of $R_r = 160 \div 180$ kg/m^2 and high ratio of R_r/γ (γ - steel density). Struts which are subject to buckling have been made from thin-walled dural tubes of high strength and high rigidity E/γ (E - modulus of elasticity). The spar struts have been designed with particular care. By using very thin stay wires, they have been divided into short sections of uniform buckling strength. It is worth mentioning that such division of a rectilinear spar into three or four sections results in 30 to 55 times increase in strength as compared with a spar not supported by wires (Ref. 12). In case of a curved spar with an anticipated direction of buckling which was experimentally used in our sailwing, this strength increase is still higher in comparison with an undivided curved spar. The spar beam was elliptically flattened so as to make its compressive strength uniform in all buckling planes. Additionally, this helps to reduce the aerodynamic drag of the wing by decreasing the frontal area as well as the drag coefficient.

The strength properties of the experimental sailwing were tested during static tests including a test to destruction. The wing supporting structure was loaded, as shown in Fig. 8, with the use of a circumferential nylon rope system of elasticity similar to the elasticity of the canopy. During the test, several structural members were replaced and the strength of the supporting structure was increased from 300 kg to P_n = 540 kg at theoretical strength of 900 kg. For example, the central joint shown in Fig. 9 was replaced by that shown in Fig. 10 of more correct geometry. At the same time, it was found that moments in the joints are the chief cause of divergence between the theoretical strength and that obtained by experiment.

The experimental wing of 7.5 m span, area $S = 13$ m^2 and weight G_s = 13 kg had coefficient of destruction relative to the wing weight: $n_s = P_n/G_s = 540/13 = 41.3$ at weight $G_s/S = 1$ kg/m^2.

In order to compare this result with strength properties of conventional types of wings, a statistical graph of dependencies $n_s = f(G_s/s)$ has been plotted and is shown in Fig. 11. The lower curve in the graph represents limit values of wing strength that have been obtained hitherto. This curve discloses a decrease in strength properties of wings with a decrease in specific weight. The nonlinearity of its shape results from the fact that as the weight decreases, strength is affected by buckling and loss of stability of the finer and finer construction of the wing. It can be proved theoretically that, if the wing weight tends to zero, the coefficient n_s also tends to zero.

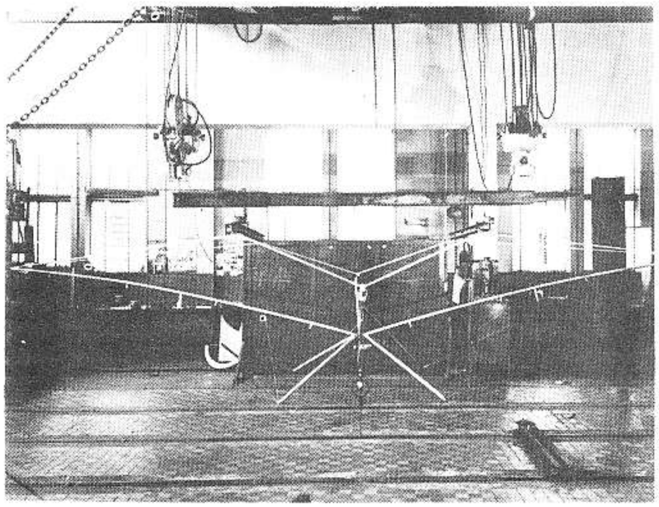


FIG. 8. EXPERIMENTAL S-M SAILWING DURING STRUCTURAL TESTS WITH CANOPY SIMULATING ROPE ARRANGEMENT

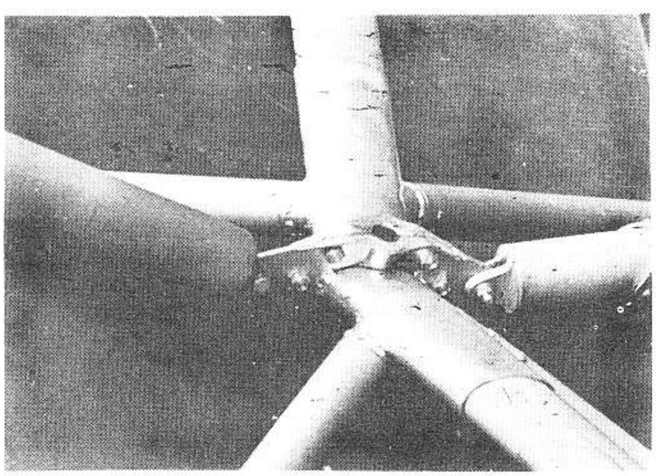


FIG. 9. CENTRAL JOINT OF THE FRAME BEFORE MODIFICATION

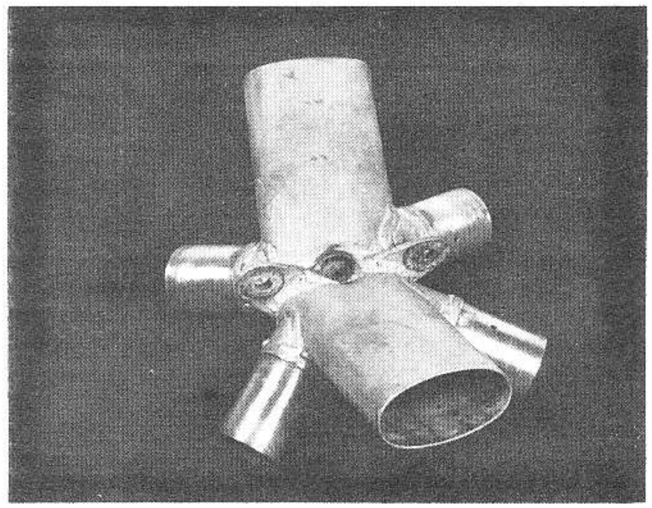
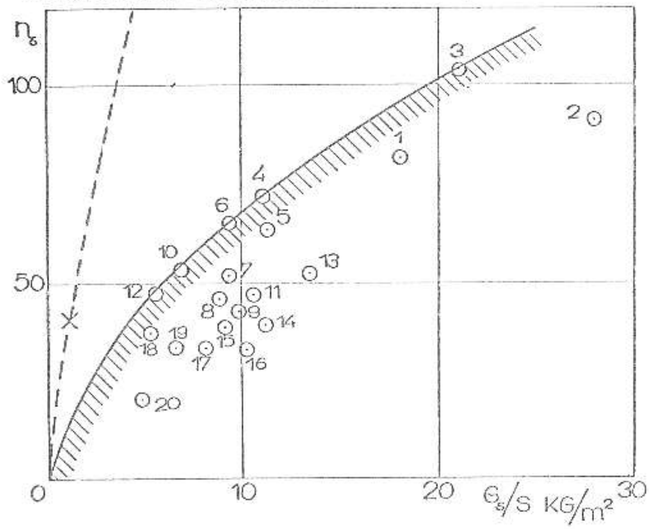


FIG. 10. CENTRAL JOINT OF THE FRAME AFTER MODIFICATION

The cross on Fig. 11 shows that the strength performance of our experimental sailwing is considerably higher than the performance curve of other wings, which results from its very extended construction. The broken line permits values for sailwings of other specific weights than 1 kg/m^2 to be estimated.

The graph in Fig. 11, as well as the aforementioned details concerning the construction and geometry, show that our experimental sailwing, despite its outward appearance, has nothing in common with the early wing constructions "densely quilted" and, therefore, aerodynamically unsatisfactory. On the contrary, it represents another development trend beginning $G_s/S = 4$ kg/m^2 (0.08 lb./sq. ft.) and tending to $G_s/S = 0$ when the first trend represents conventional wings of high G_s/S (greater than 4) and a wing structure enclosed in a profile. So far as the other trend not developed by aviation is concerned, its chief representatives are modern Bermuda sails of aerodynamically clean



1. Spitfire 1940	11. Letov KB-6
2. Focke-Wulf 190	12. Żak 3
3. Me-109F	13. SAAB-91B
4. THK-2	14. PZL-104
5. Nord N-3202	15. MS-880
6. Jak 18P	16. Focke-Wulf BL-500
7. PZL-102B	17. PIEL CP-30
8. AISA J-11B	18. Druine D-3
9. Junak	19. Jodel D-112
10. Meteor FL-53	20. Sailplane ABC

X- Experimental s-m sailwing

FIG. 11. COMPARATIVE DIAGRAM OF THE WING STRENGTH PERFORMANCE DIAGRAM n_s vs G_s/S, where n_s - ULTIMATE LOAD FACTOR IN RELATION TO WING WEIGHT G_s AND WING AREA S

surfaces as if pressed out of one piece of smooth dacron and having $G_s/S = 0.5$ kg/m² (0.1 lb./sq. ft.), including the weight of the rig structure.

AERODYNAMIC QUALITIES OF STRETCHED-MEMBRANE SAILWING

Aerodynamic qualities of a sailwing greatly depend on the canopy geometry. Therefore, according to the value analysis, a canopy, which is to produce aerodynamic lift, can be made only from air tight anisotropic fabric of high modulus of elasticity and low hysteresis of deformation.

The geometry of the experimental wing canopy made from dacron of 220 g/m² weight has been gradually improved during aerodynamic testing of the wing, the optimum camber being 10 per cent and the final shape of the foil being as in Fig. 5. The tests were conducted on the special test vehicle shown in Fig. 7 and provided with a two component aerodynamic balance to determine the wing polar. The polars obtained are presented in Fig. 12. The diagram contains also polar curves obtained at NASA for an ordinary Rogallo wing with conical canopy and for a modified Rogallo wing with curved beams at the leading edge and a cylindrical untwisted canopy (Ref.13). The comparison clearly shows that our sailwing has much better aerodynamic qualities for a very wide range of angles of attack than the Rogallo wing. Our experimental sailwing has very good maximum L/D ration which is 10 : 1 for $C_z = 0.6$ as compared with the 6:1 for the Rogallo wing. This result is quite promising considering the small aspect ratio $\lambda = l^2/S = 4.33$ and simple construction of the wing.

An interesting aerodynamic quality of a sailwing with a few alternative canopies of various aspect ratios and one framework is the existence of an optimum canopy aspect ratio for which a minimum total drag and maximum L/D ratio is obtained. This phenomenon is typical for wings of profile drag independent of the wing area and in the case of a sailwing is caused by the presence of a framework of constant frontal area. This quality results from the fact that the coefficient of induced drag for a given constant C_z diminishes hyperbolically with the increase of the aspect λ of the canopy in accordance with the dependence $C_{xi} = C_z^2/\pi\lambda$ while the coefficient of pro-

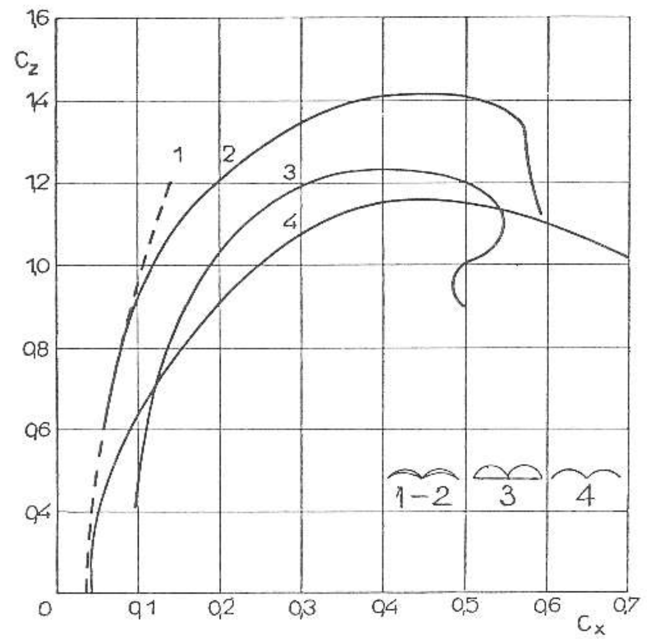


FIG. 12. POLAR COMPARISON: Theoretical /1/ and experimental /2/ polar for the s-m sailwing shown in Fig. 4 having aspect ratio 4.33. Experimental polar /3/ for the conical Rogallo wing having aspect ratio 4. Experimental polar /4/ for the cylindrical Rogallo wing having aspect ratio 4/ according to Ref. 13.

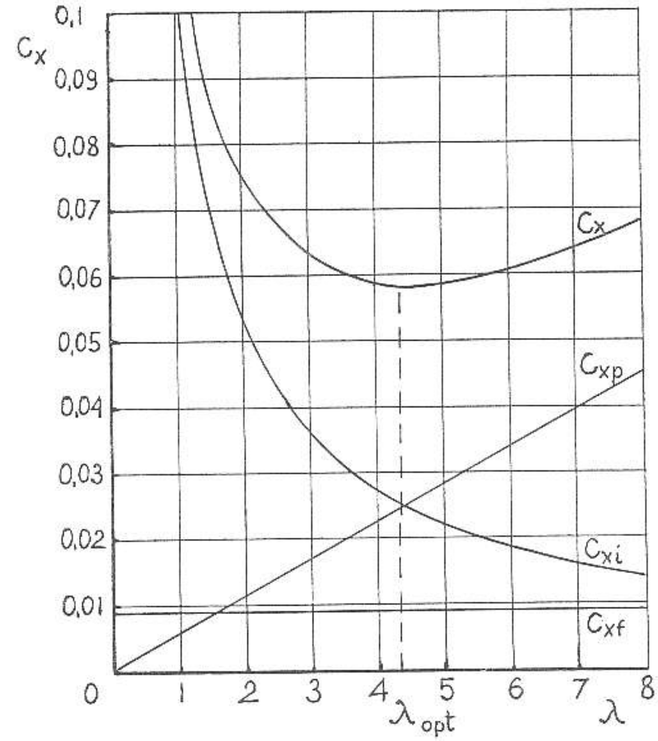


FIG. 13. DRAG COEFFICIENTS IN FUNCTION OF ASPECT RATIO FOR EXPERIMENTAL S-M SAILWING: C_{xf} - COEFFICIENT OF FRICTION DRAG FOR THE CANOPY, C_{xi} - COEFFICIENT OF INDUCED DRAG, C_{xp} - COEFFICIENT OF PROFILE DRAG, C_x - COEFFICIENT OF TOTAL DRAG

file drag C_{xp} of the framework increases linearly with the aspect ratio. The result is a minimum of the coefficient of total drag at the point of intersection of the curve C_{xi} and the line C_{xp} where the profile drag becomes equal to the induced drag. Fig. 13 illustrates this quality of our experimental sailwing (Ref. 12) for $C_z = 0.58$. The diagram also contains beside the two curves of coefficient C_{xi} and C_{xp} a straight line of the constant value of coefficient of the canopy friction drag C_{xf} independent of λ and a curve of the coefficient drag C_x with a minimum for λ opt = 4.33. This has been used in one of the canopies of the experimental sailwing. One can see from the diagram that the extended framework of the experimental sailwing was limiting its λ opt. Undoubtedly, a careful profiling of its structural members would permit obtaining a more horizontal shape of $C_{xp} = f(\lambda)$, and would considerably increase λ opt and the $(C_z/C_x)_{mx}$. The above provides a material indication as regards methods and possibilities of improving the aerodynamics of a sailwing.

It is worthy of notice that our experimental sailwing, in spite of its rather unfavorable, almost rhomboid planform, showed unexpectedly good aerodynamic qualities and quite good conformity between the test results and calculations for an elliptical contour. It seems to me that, in addition to the effect of the previously mentioned small twist, it is connected with the arching of the wing to a shape similar to that of the long wings of some well-soaring birds like sea gulls or sea swallows. It is very likely that the arching of the wing counteracts the loss of stability of the vortex sheet flowing off the arched trailing edge and prevents it from buckling, that is, from rolling up into a horseshoe vortex. Probably, the same effect is achieved by swifts due to their swordlike or boomerang shaped (though flat) wings. It may well be that this type of contour gives an automatic optimum increase of the arching of the vortex sheet for the increasing incidence angle. Evidently, the effect discussed above is essential only for moderate aspect ratios not exceeding 20. The vortex sheet, as shown in Fig. 14, according to the wing vortex theory, behaves like a flexible plate on one side loaded with compressive stresses and on the other with tensile stresses. A properly chosen initial arching of such a plate in the opposite direction to the expected deformation, and in case of a wing the vortex sheet of turbulent air trailing over the wing, increases the stability of this sheet, hindering the formation of a horseshoe vortex and thus decreasing the vortex energy behing the wing and hence, also the induced drag. This phenomenon connected with the three-dimensional airflow around the wing is worth investigating in wind tunnels. It is quite possible that if we get to know this phenomenon better, we will have high-performance sailplanes of arched wings and reduced induced drag. The wide application of plastics in the construction of sailplanes no doubt helps to realize such wing geometry.

APPLICATIONS

Applications of a stretched-membrane sailwing are determined by its qualities. Therefore, the applications may only apply to:

a. flight at low speeds.
b. flight at positive and not too small incidence angles.

The first limitation is a result of the profile camber and the use of external frame structure producing considerable drag and vibration at higher speeds.

The other limitation, resulting from the existence of flutter of the trailing edge and even the fluttering of the entire canopy at small incidence angles, excludes the possibility of allowing such a wing go into a dive.

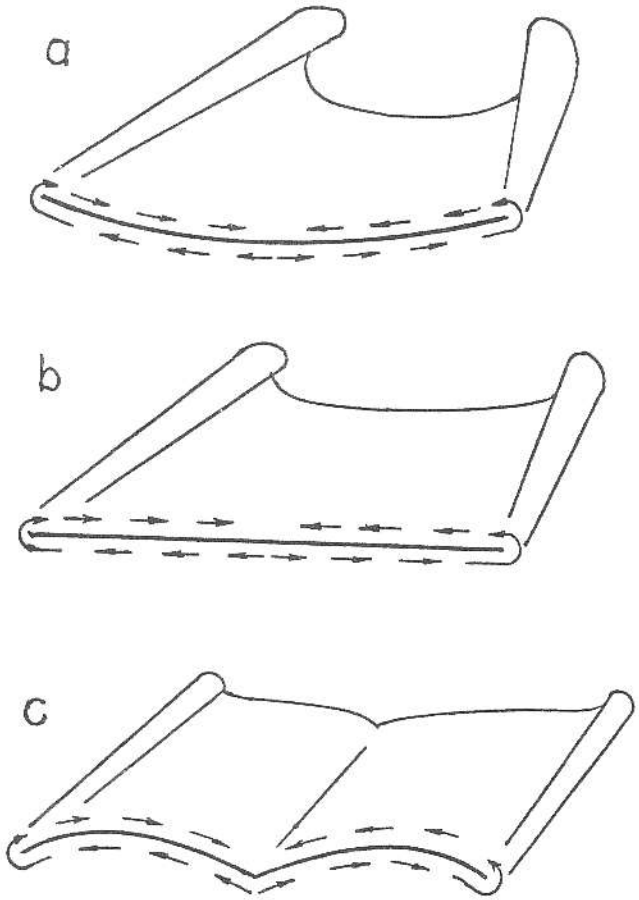


FIG. 14. QUALITATIVE COMPARISON OF THE VORTEX SHEET STABILITY: a - FOR POSITIVE CAMBER OF THE TRAILING EDGE, b - FOR ZERO CAMBER, c - FOR THE NEGATIVE CAMBER

These limitations restrict the scope of a stretched-membrane sailwing to those flying vehicles which require a very low wing loading and a low wing specific weight, resulting in a high ratio of disposable load to take-off weight. Nevertheless, these are several possible applications, and for those of gliding and allied interest a brief discussion follows.

Hang Gliders use simple light and usually folding wings under which a pilot is suspended in a parachute harness. This sort of truly sporting gliding, which can be also practised on snow or water and offers considerable thrill and excitment, is developing spontaneously all over the world (Ref. 14). In this gliding, Rogallo wings are chiefly used, though other solutions can also be found. The other solutions are sometimes an imitation of the early wings and rather far from an optimum ratio of useful effects to expenditures. In this respect, our sailwing appears to be very interesting as its costs are exceptionally low approximating 30 U.S. dollars for unit fineness as compared with the cost of a conventional glider amounting to 150 U.S. dollars for unit of fineness.

A schematic diagram of a hang-glider has already been shown in Fig. 3. One of the best solutions to obtain self-stability without pilot's intervention is the use of a canard-type stabilizer mounted at the extension of the oblique nose beam of the framework. This solution slightly complicates the construction. Moreover, the canard configuration which is characterized by an inability to stall seems very suitable for these applications from the point of view of safety because a man has rather poor perception of flight speed. This handicap has already been the cause of many glider accidents and may also be the cause of accidents on hang-gliders on which all flights are made without instruments.

Variable-Area Sailplanes have been built hitherto with the use of Fowler wing flaps which increase the wing surface. One example is the British SIGMA experimental high-performance sailplane (Ref. 15) with a 35 percent chord flap extension. The application of even 100 percent-extending flap of an unrolled sail fabric is also being considered (Ref. 16). The purpose of the surface increase is to increase the utilization of thermals by a temporary decrease of wing load allowing tight circling at low speed. However, these solutions have the fault that the flaps lead to the decrease in the aspect ratio and L/D ratio, whence the scope of their effectiveness is limited. Besides, these solutions are very difficult from the point of view of designing. Therefore, a promising solution may be a stretched-membrane sailwing unrolling in flight and easy to hide in the fuselage for the flight between thermals. A general concept of such solution is shown in Fig. 15.

Sailing Skimmers are currently developed flying/floating vehicles on the line of yachting and gliding. A sailing skimmer is, on the one hand, a sailcraft with the hull hovered over the water by a sailwing. In this way, the wave drag of the hull, being a main component of the total drag, is eliminated. On the other hand, it may be considered as a kind of hang-glider in direct contact with water through a drop keel and rudder which forms a vertical tandem hydrofoil arrangement.

A sailing skimmer, unlike a glider, is driven by the energy of the relative motion of air and water and this motion from the point of view of mechanics is the motion "squeezing" the craft from between the two media (Ref. 17). Its performance determined by the value of the ratio of speed relative to water V_S to the true wind speed V_T depends on the heading angle γ and the drags of the craft motion in both media, conditioned by the so-called horizontal L/D ratio K_A of the above-the-water half of the craft and a horizontal L/D ratio K_H of the immersed half. Performance for the optimum heading γ is given on a graph in Fig. 16. It indicates that theoretical potentialities of sailing skimmer performance are pretty exciting and they exceed the performance of catamarans and even hydrofoil craft and come very near to the performance of iceboats whose speed record is 230 km/h.

A photo in Fig. 17 shows an experimental sailing skimmer with our experimental stretched-membrane sailwing adapted to sailing application chiefly by the addition of a vertical stabilizer.

The development of sailing skimmers still belongs to the future. The main problems encountered at present are stability and controllability of the sailwing and the whole craft as well as obtaining sufficiently low specific weight of the sailwing.

Man-Powered Aircraft are the domain of amateurs from all over the world. There are groups of specialists as well as individual designers who are working on them and

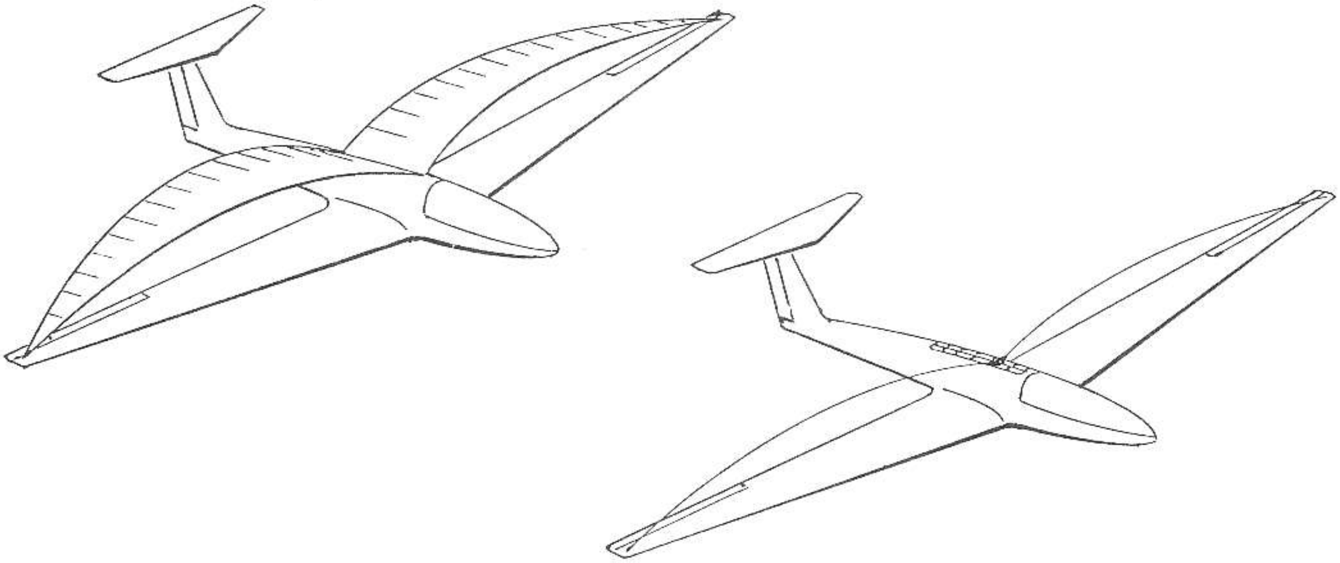


FIG. 15. HIGH-PERFORMANCE SAILPLANE HAVING ROLLED UP S-M SAILWING

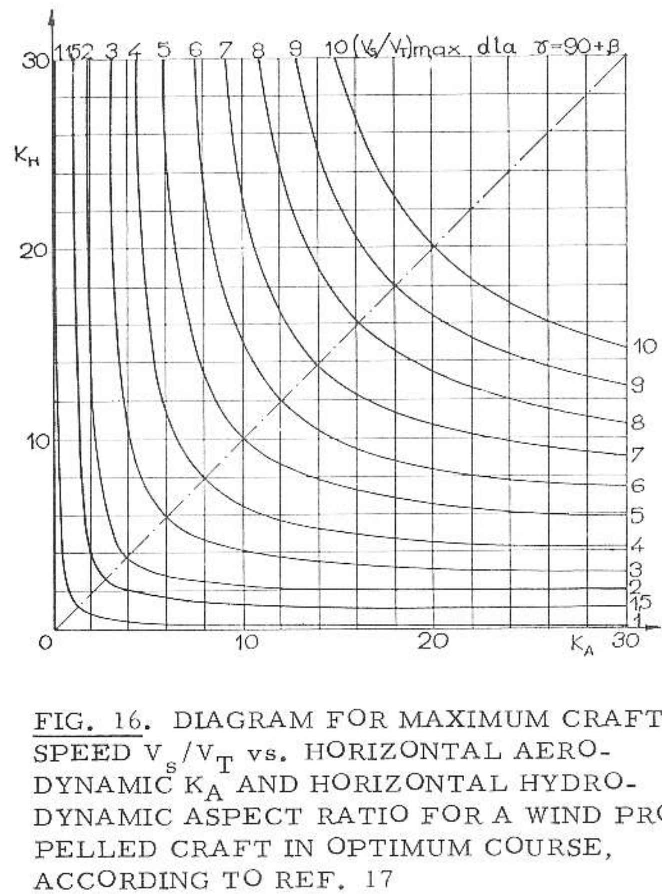


FIG. 16. DIAGRAM FOR MAXIMUM CRAFT SPEED V_s/V_T vs. HORIZONTAL AERO-DYNAMIC K_A AND HORIZONTAL HYDRO-DYNAMIC ASPECT RATIO FOR A WIND PRO PELLED CRAFT IN OPTIMUM COURSE, ACCORDING TO REF. 17

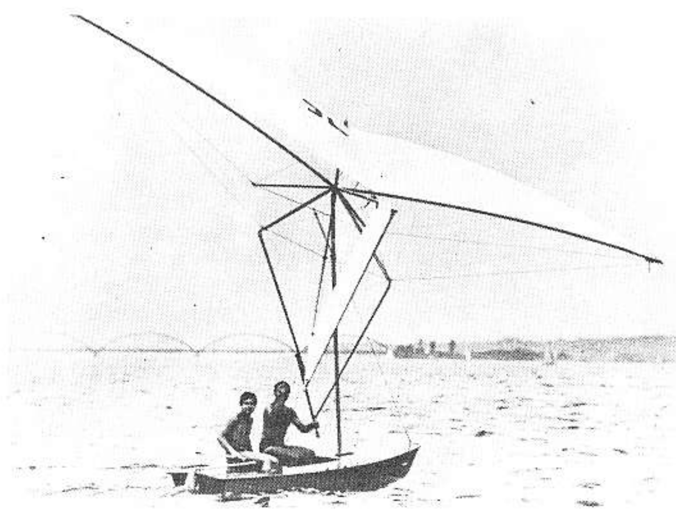


FIG. 17. SAILING AERO-SKIMMER Z-70

they have evolved several new solutions of ultra-lightweight aircraft constructions (Ref. 18). The statistical diagram in Fig. 18 helps to form an idea of the design achievements in this area (Ref. 19). The diagram also shows the possibilities of a sailwing which offers promising prospects for a category of ultralight and very slow-flying man-powered aircraft (about 20 km/h). It seems that this type of a man-powered aircraft has every chance to meet the performance requirements of the Kramer prize. Without any deep studies into the analysis of the optimum arrangement of a man-powered aircraft with a sailwing, the only answer is that it should be a canard arrangement with a pusher propeller.

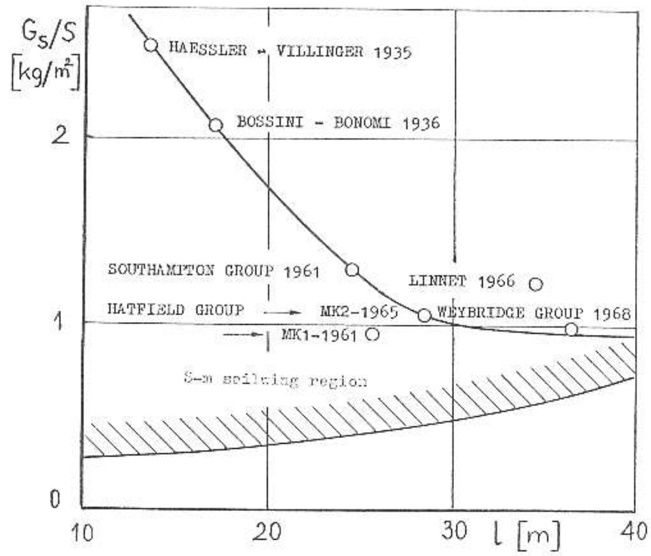


FIG. 18. TREND OF SPECIFIC WING WEIGHT G_s/S VS. WING SPAN l OF MAN-POWERED AIRCRAFT (REF. 19) AND POSSIBLE WEIGHT PERFORMANCE FOR S-M SAILWING

CONCLUSIONS

The above presented basic information on the stretched-membrane sailwing and some possible applications permits us to state that the tendency to reduce the speed of a flying vehicle of fixed wing area without high-lift devices leads at present to the stretched-membrane sailwing concept as the best and unique solution. However, a stretched-membrane sailwing represents a development trend of wing design completely different from the conventional. There is only one danger, that designers, as well as users, accustomed to the traditional wing shapes and design solutions, may feel offended with its rather queer shape and take it for a technical joke! Unfortunately, aviation technology has nothing better to offer at the moment for low flight speeds than this joke.

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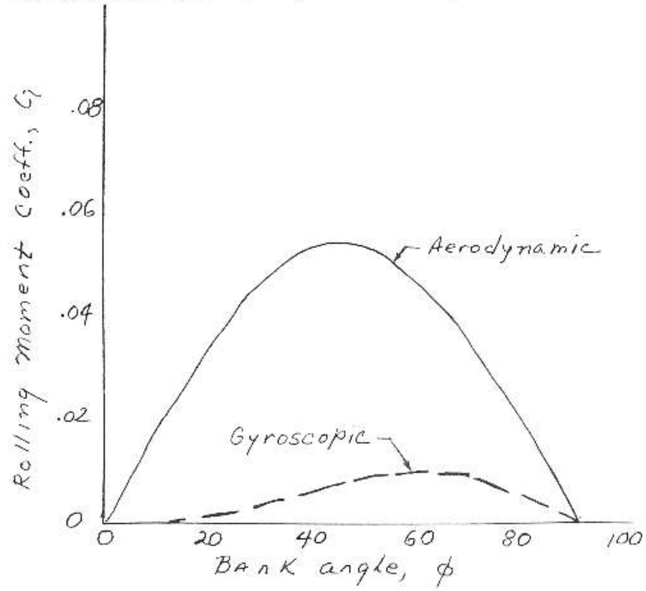

FIG. 4. VARIATIONS WITH BANK ANGLE OF AERODYNAMIC ROLLING-MOMENT COEFFICIENT DUE TO YAWING VELOCITY AND GYROSCOPIC ROLLING-MOMENT COEFFICIENT DUE TO TURNING; $C_L = 1.6$. (MOMENTS HAVE OPPOSITE SIGN)

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