[1]INTRODUCTION TO AEROFLEXIBILITY

By [2]Francis M. Rogallo

Introduction

Aeroflexibility, as used here, is the study of inelastic flexible aerodynamic surfaces. The parachute and drag chute are well known examples of aeroflexible surfaces designed to produce pure drag. These devices have so many advantages over rigid structures that might be designed for the same functions that comparisons would not be taken seriously, especially, a comparison of rigid and non-rigid parachutes. Although some early attempts were made to use rigid parachutes, none have been in recent years as far as I know.

Several years ago it became evident that if we could discover how to make non-rigid, that is to say, aeroflexible lifting surfaces, such devices would have many uses, not only as improved replacements for some rigid lifting surfaces, but would satisfy needs that cannot be satisfied by rigid surfaces. Although the chances of attaining any degree of success in such an endeavor appeared at the outset to be slight, it was possible to do a lot of exploratory work in the evenings and on weekends at little expense and without any special equipment. Some of the results of that work, done as a hobby during the past six years, are the basis of this discussion.

First Successful Flexible Kites

Probably because our only precedent as to aeroflexible structure was the parachute, our first models were made of cloth and looked something like parachutes because of the number and length of the shroud lines. Although we soon changed to plastic materials, the structure remained the same for several years, and is illustrated by these models of 25- and 50-inch kites. The 25-inch kite has 14 lines and the 50-inch kite, 28 lines. Of course the shape of the lifting surface is not like that of a parachute, but is more nearly that of a highly cambered supersonic wing. Tests of these configurations showed that some form of stabilizer was needed. At first we used long ribbon-like tails such as are commonly used on rigid kites, but later adopted these miniature tow targets that not only serve as stabilizers in flight but also as storage or carrying cases for the kites and flight line when not in use.

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[1]Presented April 21, 1954 to ARDC Reserve Unit at Langley Field, Va.

[2]Head of 7- by 10-Foot Tunnels Branch, NACA Langley Aeronautical Laboratory

These kites can be flown either on a single line like a rigid-frame kite, or on a double line for precise position control and acrobatic maneuvering. I have some still photographs and a movie showing the operation of this configuration of kite. The kite can be taken off the ground or landed very much like an airplane and can be made to dive, loop, do figure eights and other maneuvers. Although it is waterproof and unbreakable, this material will wear out with repeated hard crashes or rough handling. Also, some fliers have objected to the tangling tendencies of the many long shroud lines. These two objections have been overcome in later models that will be discussed.

The Six-String Design

This six-string flexible kite was evolved in an effort to reduce the number and length of shroud lines and to reduce the time required to attach them. These six lines and the tail lines are all of the same length and can be made up independently of the kite body, whereas the previous models required a complicated jig for assembly. Aerodynamically this model is similar to the earlier model, the changes being in the shroud lines and in the material. This material is a new Dupont Polyester film called Mylar which is the strongest plastic film ever made. I have some samples that you may try to tear if you wish. The film itself is transparent, but can be colored or metalized to improve its appearance. A coating could make it an electrical conductor or radar reflector if desirable for special uses. The material could also be coated with phosphorescent paint for night visibility.

The Four-String Tailless Design

This four-string tailless design was evolved in a further effort to reduce the number and length of harness lines and also to eliminate the necessity for the tail. You will notice that the aspect ratio has been reduced by a clipping of the tips. We suspect that this plan-form change is largely responsible for providing the inherent stability that allows the kite to be flown without a tail. Although this design has a higher performance than the previously discussed designs, it has less static and dynamic stability and is therefore more sensitive to construction inaccuracies and to atmospheric disturbances. It has been flown very successfully, however, on either a single or a double line, and the harness or bridle is designed for easy conversion - a single line attached to both loops, or two lines, one to each loop.

Aircraft with Suspended Load

This tailless kite may be converted into a glider if a load is attached to the loops in place of the flight line. Last Monday I had the opportunity to make some brief glide tests of several of these small gliders and of some of these larger ones in the free-flight facility in the old spin-tunnel building. No pictures were taken, but Mr. Zimmerman, Mr. Campbell, and others witnessed the tests and between us we tried to estimate some of the characteristics. The static and dynamic lateral and longitudinal stability appeared to be excellent in the moderate angle-of-attack range. When trimmed to a high angle of attack, the gliders generally experienced a fugoid oscillation and at the highest angles of attack tested, some lateral oscillation was evident, but in no flights did the gliders exhibit any stability characteristics that seemed dangerous or alarming. One of the gliders tangled with a wire, fell off, opened up again and continued to glide. Another struck the net at the far end of the building, turned around and glided back toward us. I have rolled them up and thrown them into the air; they unroll, open up and glide down.

Control is relatively simple - differential operation of the wing lines for lateral control and of the fore-and-aft lines for longitudinal control as can be demonstrated with these models. If I shorten the line to the right tip, the glider will turn to the right. If I shorten the rear line relative to the front lines, the glider will trim at a higher angle of attack. That is the way we did it in our glide tests.

As to performance we have as yet no quantitative data, but feel that a useable maximum lift coefficient of about 1.0 and an L/D of over six are attainable with flexible gliders of essentially this design. We estimated an L/D of four in some of the glides at the spin-tunnel building where no particular effort was made to adjust and trim the model to determine the best L/D. You will notice, for example, that the bridle lines, about 50-pound test braided nylon are way over strength and over size and probably contribute considerable unnecessary drag. Also, other shapes, perhaps of higher aspect ratio, may have better performance.

Essentially this design could be scaled up to carry people or useful loads. Such a glider could be towed into the air by an automobile, boat, airplane, or powered winch, or it could be launched from a tower or any high point of ground, or it could be dropped from an aircraft. One might even be able to soar with such a device. Propulsion could be provided by propellers, jets, or flapping wings. The device might be used as the lifting component of a flying automobile, or as an auxiliary wing for an airplane. The possibilities of its use both in war and in peace are numerous.

Fuselage-Loaded Flexible Aircraft

A flexible-winged aircraft, either powered or unpowered could be built with the useful load carried in a fuselage and the wing tip reactions taken by external braces, either wires or struts, as shown in this sketch. If wires are used, it might be desirable to incorporate a light structure to support the wings when not in flight, if they are too limber to support their own weight. The arrangement shown here is not very clean aerodynamically, but would be light, cheap, and rugged, and the wings could be rolled up for storage. It is thought to be suitable for low-powered airplanes or small low-speed gliders. Wing plan form and tail arrangements to give good performance, stability, and control, and suitable propulsion means, when necessary, are subjects for further investigation, but from our work with kites we feel that there are many flyable configurations. We have flown almost every conceivable shape of flexible kite.

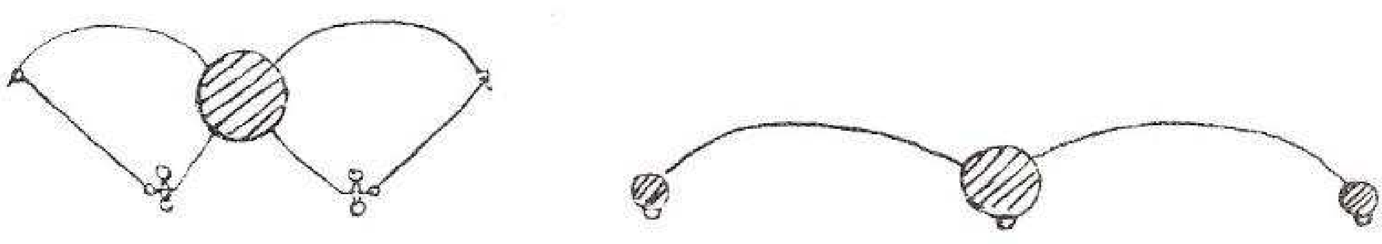
Fuselage- and Tip-Loaded Flexible Aircraft

Very clean flexible aircraft can be designed if loading is allowable at the wing tips as well as at the fuselage, as indicated by the accompanying sketch. The landing gear is buried in the fuselage and tip pods. Wing plan form and tail arrangements and means of propulsion are purposely not shown because many arrangements are possible and should be the subject of extensive investigation.

Aircraft of the type envisioned would not only be very efficient at subsonic speeds but should be even better at supersonic speeds relative to conventional aircraft because negligible wing thickness could be used, thereby eliminating the wing wave drag and interference drag that result from wing thickness. It is also to be expected that lift characteristics may be improved by use of very thin wings.

Concluding Remarks

To summarize, the invention of non-rigid lifting surfaces has been accomplished, kites have been developed that are far superior to previous designs, one promising glider configuration has been developed and tested in model form, and several interesting configurations of gliders and airplanes have been suggested, all utilizing aeroflexible lifting surfaces. The discussion has purposely omitted mention of non-aircraft applications such as for propulsion of boats, ice sleds, or wheeled vehicles; and hydrodynamic applications where it is often desirable to generate a force at right angles to the relative stream velocity, either up, down, or sideways. I mention these other areas of application in closing only to further illustrate the possible broad applications of the principles discussed.



Fuselage loading only

Fuselage and tip loading

Cross-sections of aeroflexible aircraft