FLEXIBLE WINGS FOR TRANSPORTATION

Francis M. Rogallo, Delwin R. Croom,
and William C. Sleeman, Jr.

NASA Langley Research Center
Hampton, Virginia

Presented at the International Congress of Transportation Conferences

Washington, D.C.
May 31-June 2, 1972

720579

Flexible Wings for Transportation

Francis M. Rogallo, Delwin R. Croom, and William C. Sleeman, Jr.
Langley Research Center, NASA

THE ORIGINATORS of the flexible-wing concepts in the late 1940s created a completely flexible lifting surface with a parachute-like tension structure in which the wing surface shape is maintained by the balance of forces between the airload on the surfaces and the tension in the suspension lines, and flexible wings that could have several types of localized stiffening (1, 2).* The early experimental work was conducted largely by flying the wings as kites.

There are many potential uses for flexible wings in astronautics, some of which were discussed in a talk to the American Astronautical Society in 1963 (3), but the present paper will be limited to their use for transportation of passengers and cargo from point to point on earth and to emergency use of flexible wings in connection with more conventional aircraft. It will cover the following subjects: gliding and soaring, towing, powered flight, air-dropped wings, rocket-launched wings, and emergency wings.

All of these subjects are covered in part by the technical papers listed in the Appendix, and these references will not be individually cited in the paper. Some additional sources, mostly from recent periodicals, will be given as references for those who may wish to search the literature.

From a study of the six composite figures presented, it will be obvious that most of the vehicles shown could have been used to illustrate more than one mode of launch or flight. For example, vehicles being developed for rocket launch were usually tested by air drop and/or released after aerial tow.

*Numbers in parentheses designate References at end of paper.

DISCUSSION

GLIDING AND SOARING - One of the earliest anticipated uses for flexible wings was gliding from hills or mountains to lower elevations (1). B. H. Palmer and others made flexible wings and began gliding down the California hills about 10 years ago, and this application has recently achieved prominence although it is as yet only in the realm of sport (4-9). D. Kilbourne (9) demonstrates one of these hang gliders in Fig. 1. Ridge-soaring flights of over an hour duration have already been achieved with relatively crude flexible-wing hang gliders. It is anticipated that in the near future flexible-wing gliders will be developed that will be almost as easy to carry and store as a pair of snow skiis and will enable the pilot to move with great freedom about mountain areas by intelligent use of slopes and the wind, even as the soaring birds have been doing through the ages. Such wings would not require a snow cover, and they could fly over surface obstacles. A small monthly publication called "Low and Slow," published by Faust (9), is largely devoted to this kind of flying.

TOWING - Flexible-wing tow gliders for sport purposes (Fig. 2) were developed about 10 years ago by T. H. Purcell, Jr. (10). Concurrently, NASA built and flew the Paresev test vehicle, and the U.S. Army and Ryan Aircraft Co. developed and flight-tested a variety of towed gliders for aerial delivery of cargo and equipment (Fig. 2). Some of the unmanned gliders were sufficiently stable in tow to require no control inputs from the beginning of the takeoff run until the end of the landing run at the destination. It was also demonstrated that they could be released at altitude and radio-controlled to a chosen landing point. Several different Army ground vehicles,

ABSTRACT

Flexible wings for transportation involves the use of flexible fabric-like lifting surfaces that can be folded or packaged before and after use. This paper is limited to uses of flexible wings for transportation of passengers and cargo from point to point on earth and to emergency use of flexible wings in connection with more conventional aircraft. It covers the following subjects: gliding and soaring, towing, powered flight, air-dropped wings, rocket-launched wings, and emergency wings.

including a jeep, were converted to towed gliders by attachment of simple flexible wings, as was a sled loaded with cargo. Another demonstration of towing capability was made by NASA and North American during development of the Gemini paraglider. Other examples of the potential usefulness of this aerial tow capability in transportation are gliders in which the cargo may be any fluid enclosed in rolling tanks, or it may be any structure too large to be transported on the ground because of surface obstacles.

The advantages of towing in transportation on the ground and on the water are well established. The same advantages of surface towing are present in aerial towing, the most obvious one being that a larger or a heavier load may be towed than can be carried in the towing vehicle. In the air, moreover, the

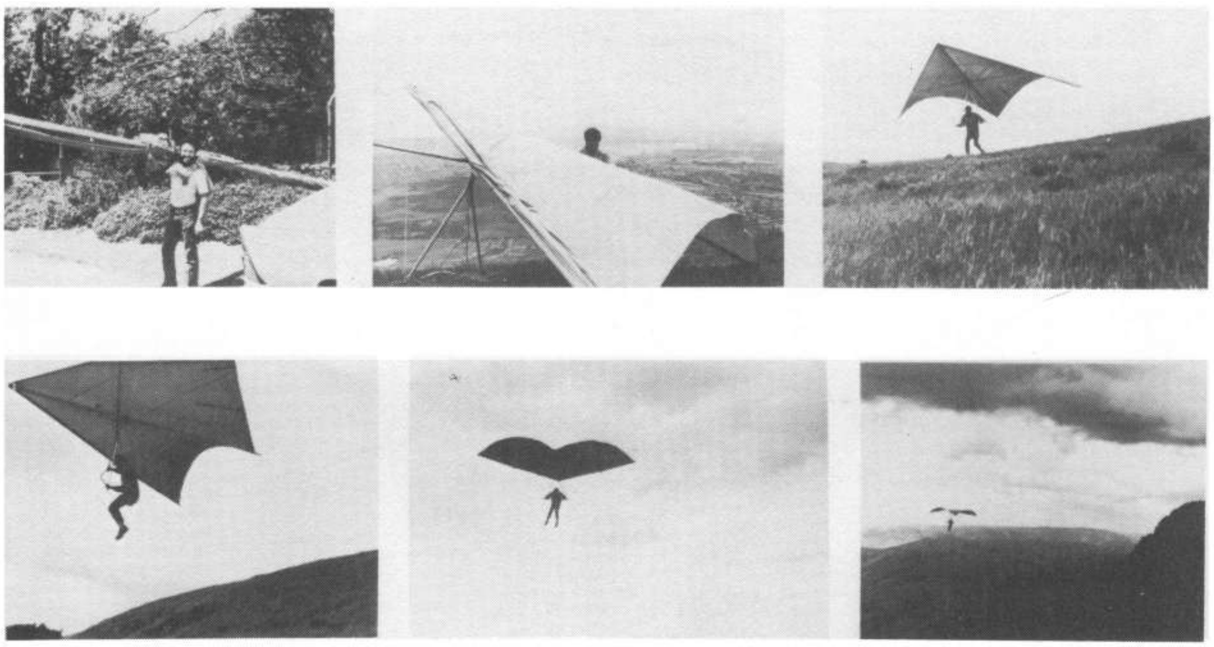

Fig. 1 - Flexible-wing hang glider used for gliding and soaring (courtesy of Low & Slow)

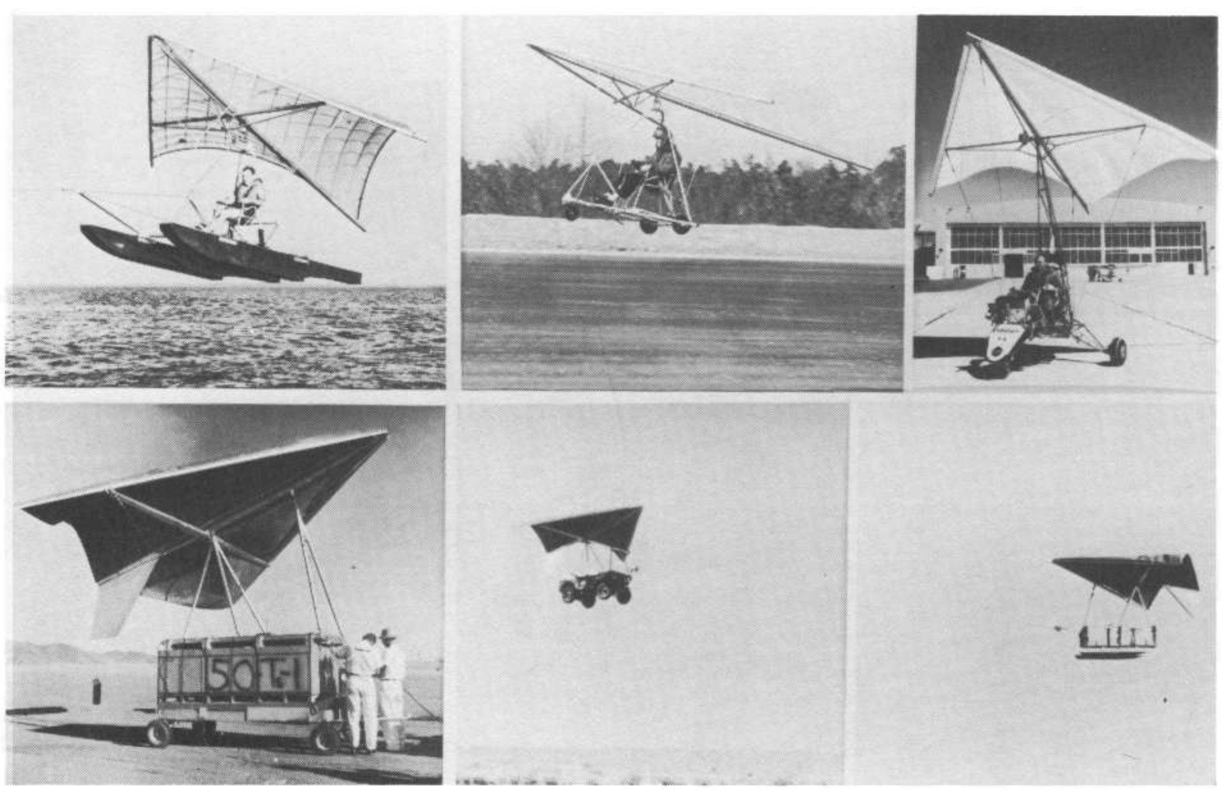

Fig. 2 - Flexible-wing tow gliders

weight is not limited by the capacity of roads and bridges, and the size is not limited by clearance through tunnels, bridges, overpasses, and the many other surface restrictions.

POWERED FLIGHT - It is a logical step from the simple hang gliders previously described to a powered, minimum airplane with folding flexible wings. At least one experimenter has made this step. Palmer, after building and flying many foot-launched flexible-wing gliders, designed, built, and flew two powered aircraft that might be described as minimum airplanes. (See Fig. 3.) Both had a seat mounted below a flexible wing and above a tricycle gear. One had two 7 hp engines; the other had one 15 hp engine mounted behind the seat and driving pusher propellers. These aircraft, with empty weights of about 150 lb each, took off and flew—one of them to over 800 ft altitude—with Palmer at the controls.

The Ryan Flex-Wing and Fleep aircraft, built for the U.S. Army (Fig. 3), were flying flat-bed trucks that functioned surprisingly well, considering the very early state of flexible-wing technology at the time they were designed. Much higher performance is now possible and, of course, much larger vehicles could be built.

T. H. Purcell, Jr., whose small "Flightsail" glider (Fig. 2) shared with the Ryan Flex-Wing airplane the honor of being among the first man-carrying flexible wings, has continued his flexible-wing research and development for more than 10 years. He has designed a flying boat equipped with a flexible wing that can be folded to the side of the hull by the turn of a crank from inside the cockpit to allow convenient storage, transport, maneuvering on the water through narrow passages and into boat slips, and safe anchorage or beaching without fear of being capsized by sudden squalls. Some of his work is described in Ref. 11; he is continuing with this work and hopes soon to fly the completed flexible-wing powered flying boat.

The automobile is the most popular form of transportation in this country. Many people believe that eventually someone will develop a flying automobile that will also find widespread use. That man could be M. P. Taylor, who has been working on the problem for many years and has developed an attractive little sports car that also flies. (See Refs 12 and 13.) In its present form, however, it has rigid wings and tails that constitute a rather large trailer behind the car for ground transport. A possible solution to this problem was suggested in the last paragraph of an early flexible-wing story (1) as follows:

> "But the most intriguing possibility is the use of this non-rigid wing as the lifting component of a combination auto-airplane. When the airplane alighted, the wing would simply be folded up, chucked into the baggage compartment and forgotten. The auto would then drive away unencumbered."

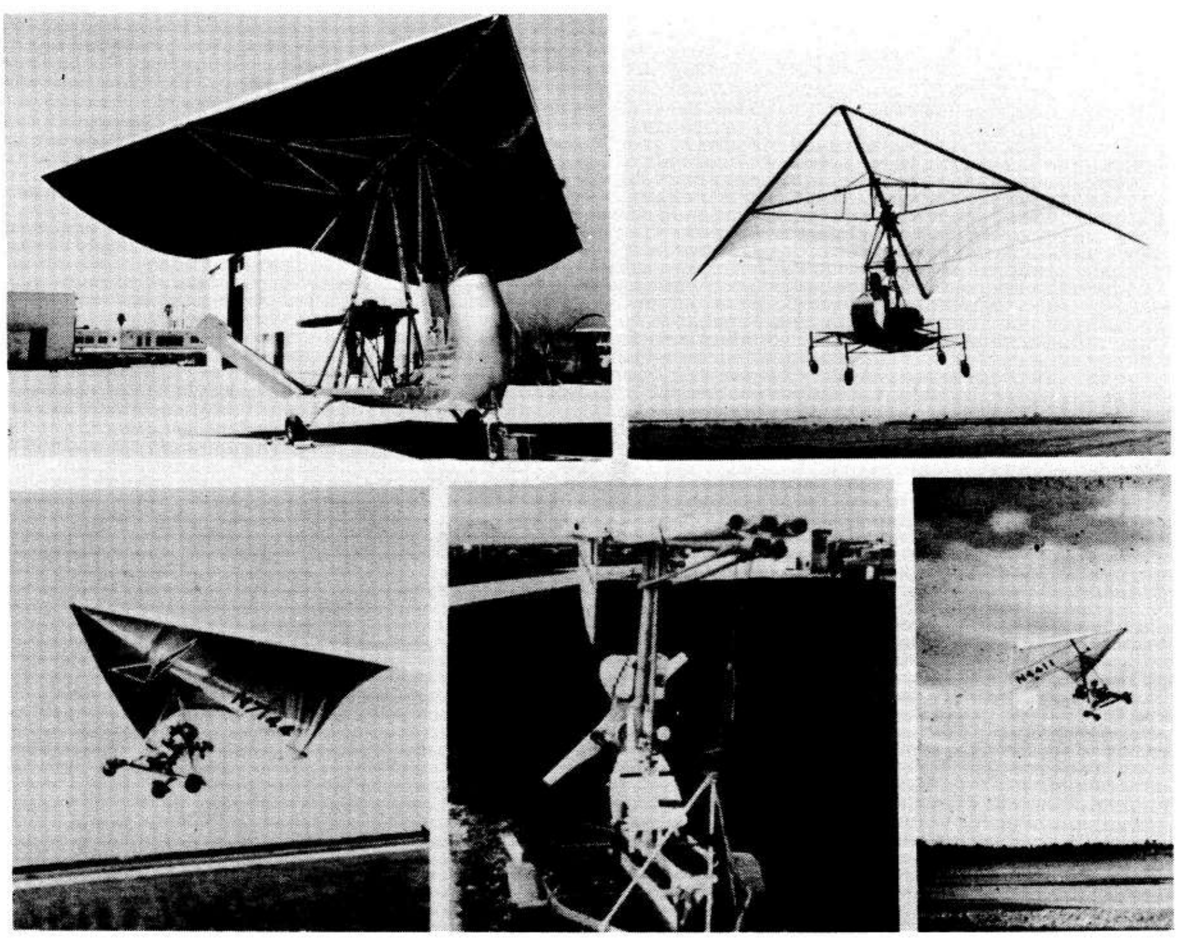

Fig. 3 - Flexible-wing powered vehicles

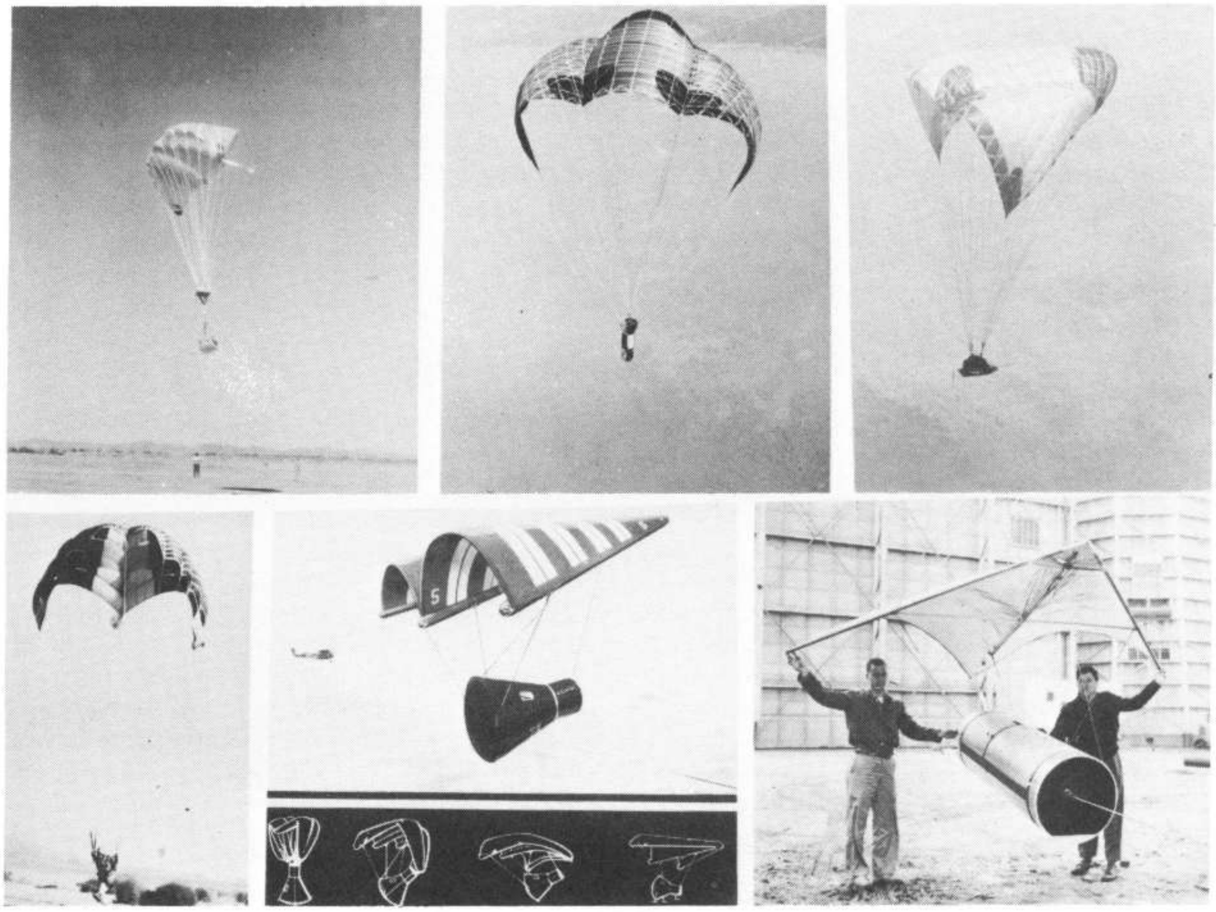

Fig. 4 - Flexible-wing air-dropped vehicles

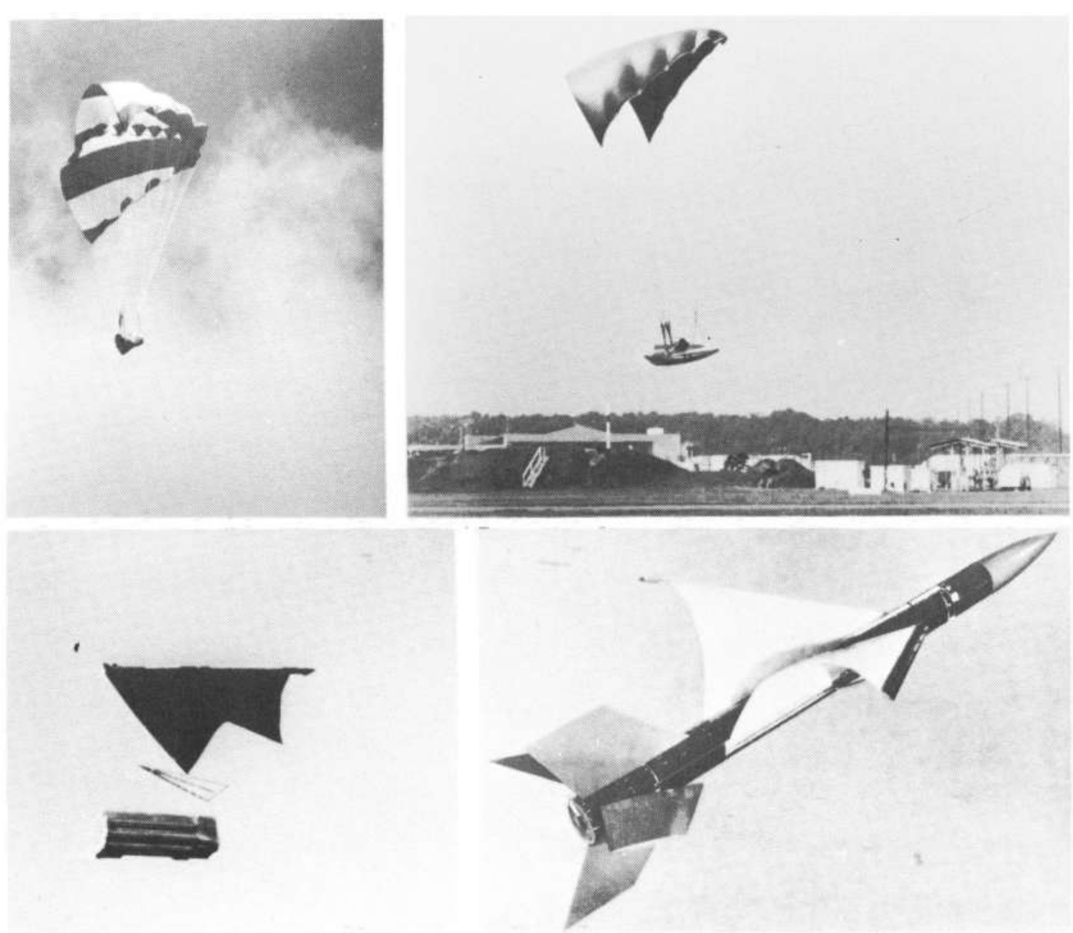

Fig. 5 - Models of flexible-wing rocket-launched vehicles

When that story was written in 1949 (over a year before its publication), the authors visualized the use of all-flexible wings for flying automobiles. Probably a higher performance flexible wing with rigid booms will be better for this purpose.

The senior author of this paper designed and built a propeller-driven automobile that was licensed in California about 40 years ago, and it was operated there for several years without any mishaps. Adding a flexible wing to an air-drive automobile may be a practical means of attaining a flying automobile. Eventually, some backyard inventor may develop a practical solution, but it could be done much sooner if sponsored seriously by the government or some segment of the transportation industry.

AERIAL DROPPING - People and cargo can be transported in conventional aircraft to the vicinity of a chosen destination, air dropped by deployable flexible wings, and guided to the desired landing point. Such a method will provide rapid air transportation to inaccessible areas that do not permit aircraft landings or where landings might be undesirable. If a radio beacon is placed at the desired landing point, air-dropped delivery by flexible wing can be accomplished even in zero visibility. Such capabilities are a welcome addition to the transportation spectrum. Examples of air-drop systems using all-flexible wings are shown in Fig. 4—an individual, a cargo package, and the largest system tested so far, a 4000 ft^2 wing that has carried 6000 lb.

Also shown in Fig. 4 is an example of an inflated-tube flexible wing that was successfully deployed and flown after air drop—the Gemini paraglider. Inflated-tube designs offer somewhat higher performance than the all-flexible wings. Even greater performance may be achieved with deployable metal frame gliders, some of which have also been successfully tested tested, as, for example, the recoverable booster model in Fig. 4.

ROCKET LAUNCHED - A rocket-launched suborbital transport system for long-range, high-speed transportation might be practical if all components could be recovered for reuse. Models of boosters, capsules, and lifting-body reentry vehicles (Fig. 5) have been successfully controlled and landed by means of flexible wings. In these tests, the loads were suspended below the wings on flexible lines. The Dornier Corp. of Germany developed a sounding rocket with attached flexible wings that were folded snugly at the side of the rocket during launch. In descent, the wings were unfolded to permit a controlled glide to a chosen landing site (see Fig. 5). In a sub-

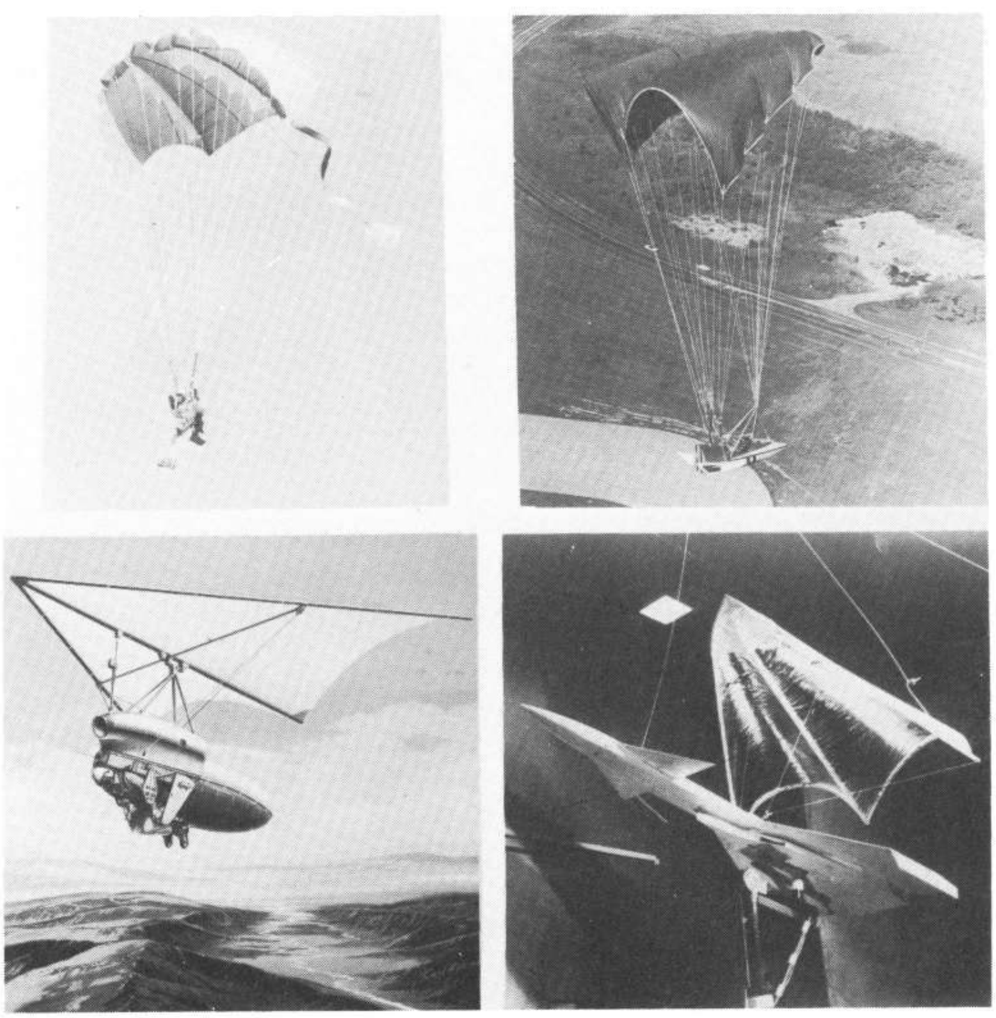

Fig. 6 - Flexible wings for emergency use

orbital transport system, the flexible wings could be erected in space for a relatively slow descent into the atmosphere, or the wings could be deployed in the atmosphere after a faster reentry, as envisioned for the lifting body of Fig. 5. Rocket-launched suborbital transports offer a means of transporting people and cargo great distances on earth at speeds greater than the SST and without sonic booms over inhabited areas. For the kind of transports envisioned, flexible wings might well be a more practical solution than rigid wings. A serious study of this application should be initiated now.

EMERGENCY WINGS - Flexible wings can provide a means of getting safely to the ground from conventional aircraft in an emergency. As a personnel parachute substitute (Fig. 6), a flexible wing would provide a controllable gliding capability, allowing the pilot a wide choice of landing points. Also, a wing could provide the same vertical rate of descent as a parachute of 10 times as much area, or a much lower rate of descent with the same area as the parachute.

An ejection seat is being developed that will enable a pilot to fly away by means of a flexible wing and jet engine attached to the seat (Fig. 6).

These techniques could be applied to a multipassenger compartment roughly similar to the lifting body, or to a complete aircraft (Fig. 6), enabling a relatively slow, safe landing at a chosen point within the glide range, or at a greater distance if some thrust were available, as in the fly-away ejection seat previously mentioned. For emergency wings, as for many of the gliding wings previously discussed, it would be possible to effect an aerial hookup and tow to a chosen destination. It has been demonstrated that in-flight retrieval of flexible wings can be relatively simple.

CONCLUDING REMARKS

Until now, flexible wings have been used in only a few of the many possible applications discussed in this paper. It is our hope that this paper may arouse serious effort to initiate research and development that could result in other applications that would come into general use. Flexible wings have been investigated primarily by NASA and the U.S. Army, but this work was stopped by lack of funds resulting from the national effort to cool the economy. Flexible-wing technology is now in search of a serious sponsor, and one or more should come forth to ensure that this technology will go forward and provide the many benefits of which it is capable. Also, it may be time for a little heating up of national and world economy which is in danger of becoming supercooled.

REFERENCES

1. Francis M. Rogallo, "First Flexible Kite." Ford Times, Vol. 43, No. 3 (March 1951), pp. 25-29.
2. G. S. Rogallo and F. M. Rogallo, "Flexible Kite." U.S. Patent No. 2,546,078, March 20, 1951.
3. Francis M. Rogallo, "Parawings for Astronautics." Space Rendezvous, Rescue and Recovery. Advances in the Astronautical Sciences, Vol. 16, Pt. II (1963), pp. 3-11.
4. B. H. Carmichael, "Some Primitive Flying Experiences." Sport Aviation, Vol. 20, No. 8 (August 1971), pp. 20-22.
5. Anita Verschoth, "He's at it Again, as High as a Kite." Sports Illustrated, Vol. 35, No. 16 (Oct. 18, 1971), pp. 60-62, 65.
6. Anon., "Did Someone Say Slow and Low?" Soaring, Vol. 35, No. 12 (December 1971), pp. 24-25.
7. Dennis Shattuck, "Fly Like the Wright Brothers for Under $25." Science and Mechanics, Vol. 42, No. 12 (December 1971), pp. 44-46, 96-97.
8. Russell Hawkes, "Happy Birthday, Otto Lilienthal!" National Geographic, Vol. 141, No. 2 (February 1972), pp. 286-292.
9. Low and Slow Magazine, Issues 1-12. Published by Joe Faust, Santa Monica, California.
10. Page Shamburger, "Fun and Frolic With a Purcell Flightsail." Air Progress Homebuilt Aircraft, Spring-Summer 1967, pp. 28-29, 88.
11. Thomas H. Purcell, Jr., "The Flightsail VII." Sports Aviation, Vol. 18, No. 5 (May 1969), pp. 42-47.
12. Bob Grant, "This Car Really Flies." Popular Mechanics, Vol. 136, No. 2 (August 1971), p. 87.
13. Frank A. Tinker, "I Flew It." Popular Mechanics, Vol. 136, No. 2 (August 1971), pp. 88-91, 176.

APPENDIX
A SELECTED BIBLIOGRAPHY OF PARAWING PUBLICATIONS

Recent requests for a bibliography of parawing publications have prompted a computer search of literature on flexible wings available from 1962 to the present. This literature search and a working list of references previously compiled have provided the information from which the present bibliography was selected. A comprehensive listing of references on flexible wings has not been attempted because it was believed that a more concise bibliography of basic research information would be more useful. Inasmuch as a large part of the present technology for parawings was developed by NASA or under its sponsorship, a complete listing of available NASA publications on parawings has been attempted. In like manner, a significant amount of work on applications of parawings and paragliders for military use has been conducted by the U.S. Army Transportation Research Command (TRECOM), Ft. Eustis, Va., and basic references reporting this work are included.

Many talks and papers on flexible wings have been sponsored by various technical societies. A few of these papers have been included in this bibliography; however, this type of reference has not been generally included because many of these papers were based on research that was later published in a more complete form in a formal report.

A definitive and complete bibliography can be assembled only when the technology has become static. In this respect, it is hoped that the present compilation represents a status report on information presently available and that it will prove useful to those interested in flexible-wing technology.

TERMINOLOGY

There has always appeared to be some confusion in regard to the terminology used at different times to identify various flexible-wing configurations. It may be helpful, therefore, to provide some definitions of terminology that have evolved over the past decade.

PARAGLIDER - The originators of the flexible-wing concept in the late 1940s created a completely flexible lifting surface with a parachute-like tension structure in which the wing surface shape is maintained by the balance of forces between the airload on the surfaces and the tension in the suspension lines, and flexible wings that could have several types of localized stiffening. The early experimental work was conducted largely by flying the wings as kites; consequently, the first flexible wings tested in NASA wind tunnel and flight investigations in the late 1950s were known as flexible kites.

Early applications under study by NASA for flexible kites, such as recovery of the Saturn booster and manned spacecraft, appeared to warrant a more suitable name for the recovery system. The term "paraglider" was used, therefore, to identify the gliding, deployable wing being investigated in studies of recovery of the Saturn booster and other space and aeronautics applications under way at about the same time. Inasmuch as the wing configurations being investigated in these studies had rigid-tube or inflated-tube leading edges and keel and a sweptback planform with a flexible fabric canopy, the term "paraglider" was generally accepted as descriptive of this type of wing.

PARAWING - Early potential applications for flexible wings involved their use as a gliding descent system for various space and aeronautical vehicles. Other applications that involved powered or towed vehicles, however, did not use gliding flight over the major portion of their operation, and the gliding connotation did not appear appropriate. It also appeared desirable to use a term that described the lifting surface without regard to the type of use for it, and the name "parawing" was derived to meet this need. The term "parawing" was originally intended to refer to a broad class of aeroflexible lifting surfaces, with both stiffened and unstiffened leading edges and keels. In general practice, however, the names "parawing and paraglider" came to be used interchangeably to describe wings with stiffening members, and the broad-class connotation of parawing was not widely recognized.

ALL-FLEXIBLE PARAWING - A new term was needed to differentiate between parawings that had rigid or inflated stiffening members and parawings that were completely flexible with no structural or stiffening members. The name "all-flexible parawing" was selected to denote a class of flexible wings that had a flexible fabric lifting surface, a pure tension structure, and for which the shape of the surface is determined by the balance of forces between the airloads on the canopy and the tension in the suspension lines, that is, the original concept in its purest form.

GLIDING PARACHUTE - The advantages of being able to steer or change heading on a personnel parachute have long been recognized, and techniques and modifications to standard personnel parachutes to provide steering capability have been explored for many years. In the 1950s and 1960s, parachutes were modified to provide some forward velocity by venting air from the rear portion of the canopy. Many of these gliding parachutes could be steered with relative ease and were capable of providing about half as much lift as drag. Later design refinements increased ratios of lift to drag to near 1.0 for gliding parachutes of roughly hemispherical shape. The term "gliding parachute" can be considered to identify a class of descent devices that produce lift in gliding flight that is equal to, or less than, the drag.

FLEXIBLE WINGS - The term "flexible wings" identifies a broad class of fabric or membrane lifting surfaces that provide more lift than drag in gliding or powered flight. Included in this definition are paragliders, parawings, and several other gliding, fabric wings of various planforms and shapes that have been developed since the introduction of the flexible-wing concept.

NASA TECHNICAL NOTES

1. Francis M. Rogallo, John G. Lowry, Delwin R. Croom, and Robert T. Taylor, "Preliminary Investigation of a Paraglider." NASA TN D-443, 1960.

2. Rodger L. Naeseth, "An Exploratory Study of a Parawing as a High-Lift Device for Aircraft." NASA TN D-629, 1960.

3. Donald E. Hewes, "Free-Flight Investigation of Radio-Controlled Models With Parawings." NASA TN D-927, 1961.

4. Edward C. Polhamus and Rodger L. Naeseth, "Experimental and Theoretical Studies of the Effects of Camber and Twist on the Aerodynamic Characteristics of Parawings Having Nominal Aspect Ratios of 3 and 6." NASA TN D-972, 1963.

5. Paul G. Fournier and B. Ann Bell, "Low Subsonic Pressure Distributions on Three Rigid Wings Simulating Paragliders With Varied Canopy Curvature and Leading-Edge Sweep." NASA TN D-983, 1961.

6. Robert T. Taylor, "Wind-Tunnel Investigation of Paraglider Models at Supersonic Speeds." NASA TN D-985, 1961.

7. Howard G. Hatch, Jr. and William A. McGowan, "An Analytical Investigation of the Loads, Temperatures, and Ranges Obtained During the Recovery of Rocket Boosters by Means of a Parawing." NASA TN D-1003, 1962.

8. Paul G. Fournier and B. Ann Bell, "Transonic Pressure Distributions on Three Rigid Wings Simulating Paragliders With Varied Canopy Curvature and Leading-Edge Sweep." NASA TN D-1009, 1962.

9. Jim A. Penland, "A Study of the Aerodynamic Characteristics of a Fixed Geometry Paraglider Configuration and Three Canopies With Simulated Variable Canopy Inflation at a Mach Number of 6.6." NASA TN D-1022, 1962.

10. Joseph L. Johnson, Jr., "Low-Speed Wind-Tunnel Investigation to Determine the Flight Characteristics of a Model of a Parawing Utility Vehicle." NASA TN D-1255, 1962.

11. Robert E. Shanks, "Experimental Investigation of the Dynamic Stability of a Towed Parawing Glider Model." NASA TN D-1614, 1963.

12. Paul G. Fournier, "Pressure Distributions on Three Rigid Wings Simulating Parawings With a Varied Canopy Curvature and Leading-Edge Sweep at Mach Numbers From 2.29 to 4.65." NASA TN D-1618, 1963.

13. Dewey E. Wornom and Robert T. Taylor, "Aerodynamic Characteristics of a Flexible-Canopy Paraglider Model at a Mach Number of 4.5 for Angles of Attack to 360° and Sideslip Angles From 0° to 90°." NASA TN D-1776, 1963.

14. Garrison P. Layton and Milton O. Thompson, "Preliminary Flight Evaluation of Two Unpowered Manned Paragliders." NASA TN D-1826, 1963.

15. Sanger M. Burk, Jr., "Free-Flight Investigation of the Deployment, Dynamic Stability, and Control Characteristics of a 1/12-Scale Dynamic Radio-Controlled Model of a Large Booster and Parawing." NASA TN D-1932, 1963.

16. William C. Sleeman, Jr., "Low-Speed Investigation of Cable Tension and Aerodynamic Characteristics of a Parawing and Spacecraft Combination." NASA TN D-1937, 1963.

17. Joseph L. Johnson, Jr. and James L. Hassell, Jr., "Full-Scale Wind-Tunnel Investigation of a Flexible-Wing Manned Test Vehicle." NASA TN D-1946, 1963.

18. Rodger L. Naeseth and Thomas G. Gainer, "Low-Speed Investigation of the Effects of Wing Sweep on the Aerodynamic Characteristics of Parawings Having Equal-Length Leading Edges and Keel." NASA TN D-1957, 1963.

19. Joseph L. Johnson, Jr., "Low-Subsonic Characteristics of a Model of a Supersonic-Airplane Configuration With a Parawing as a Landing Aid." NASA TN D-2031, 1963.

20. Charles E. Libbey, "Free-Flight Investigation of the Deployment of a Parawing Recovery Device for a Radio-Controlled 1/5-Scale Dynamic Model Spacecraft." NASA TN D-2044, 1963.

21. Charles E. Libbey and Joseph L. Johnson, Jr., "Stalling and Tumbling of a Radio-Controlled Parawing Airplane Model." NASA TN D-2291, 1964.

22. Robert E. Shanks, "Experimental Investigation of the Dynamic Stability of a Towed Parawing Glider Air Cargo Delivery System." NASA TN D-2292, 1964.

23. W. Pelham Phillips, "Low-Speed Longitudinal Aerodynamic Investigation of Parawings as Auxiliary Lifting Devices for a Supersonic Airplane Configuration." NASA TN D-2346, 1964.

24. Joseph L. Johnson, Jr., "Low-Speed Force and Flight Investigation of a Model of a Modified Parawing Utility Vehicle." NASA TN D-2492, 1965.

25. Delwin R. Croom, Rodger L. Naeseth, and William C. Sleeman, Jr., "Effects of Canopy Shape on Low-Speed Aerodynamic Characteristics of a 55° Swept Parawing With Large Diameter Leading Edges." NASA TN D-2551, 1964.

26. B. Gamse, K. W. Mort, and P. F. Yaggy, "Low-Speed Wind-Tunnel Tests of Large-Scale Inflatable Structure Paraglider." NASA TN D-2859, 1965.

27. Frank M. Bugg, "Effects of Aspect Ratio and Canopy Shape on Low-Speed Aerodynamic Characteristics of 50.0° Swept Parawings." NASA TN D-2922, 1965.

28. Joseph L. Johnson, Jr., "Low-Speed Force and Flight Investigation of Various Methods for Controlling Parawings." NASA TN D-2998, 1965.

29. Delwin R. Croom and Paul G. Fournier, "Low-Subsonic Wind-Tunnel and Free-Flight Drop-Test Investigation of a Paraglider Configuration Having Large Tapered Leading Edges and Keel." NASA TN D-3442, 1966.

30. Joseph R. Chambers and Peter C. Boisseau, "A Theoretical Analysis of the Dynamic Lateral Stability and Control of a Parawing Vehicle." NASA TN D-3461, 1966.

31. Frank M. Bugg, "Low-Speed Tests of 50°-Swept Parawings Applied to a 0.17-Scale Model of a Manned Flight Vehicle." NASA TN D-3493, 1966.

32. Charles C. Smith, Jr. and George M. Ware, "Wind-Tunnel Investigation of the Flight Characteristics of a Model of an Aspect-Ratio-6 Conical-Parawing Utility Vehicle." NASA TN D-3673, 1967.

33. Charles E. Libbey, George M. Ware, and Rodger L. Naeseth, "Wind-Tunnel Investigation of the Static Aerodynamic Characteristics of an 18-Foot (5.49-Meter) All-Flexible Parawing." NASA TN D-3856, 1967.

34. Rodger L. Naeseth and Paul G. Fournier, "Low-Speed Wind-Tunnel Investigation of Tension-Structure Parawings." NASA TN D-3940, 1967.

35. James A. Weiberg and Kenneth W. Mort, "Wind-Tunnel Tests of a Series of Parachutes Designed for Controllable Gliding Flight." NASA TN D-3960, 1967.

36. Frank M. Bugg and William C. Sleeman, Jr., "Low-Speed Tests of an All-Flexible Parawing for Landing a Lifting-Body Spacecraft." NASA TN D-4010, 1967.

37. Marvin P. Fink, "Full-Scale Investigation of the Aerodynamic Characteristics of a Model Employing a Sailwing Concept." NASA TN D-4062, 1967.

38. Sanger M. Burk, Jr. and George M. Ware, "Static Aerodynamic Characteristics of Three Ram-Air-Inflated Low-Aspect-Ratio Fabric Wings." NASA TN D-4182, 1967.

39. James H. Siviter, Jr., "Flight Investigation of Capacitance-Type Meteoroid Detector Using an Inflatable Paraglider." NASA TN D-4530, 1968.

40. Richard L. Barton, David L. Eichblatt, and Robert H. Moore, "Experimental Verification of Scale Factors for Parawing Opening Characteristics." NASA TN D-4665, 1968.

41. George M. Ware and Charles E. Libbey, "Wind-Tunnel Investigation of the Static Aerodynamic Characteristics of a Multilobe Gliding Parachute." NASA TN D-4672, 1968.

42. Alice T. Ferris and H. Neal Kelly, "Free-Flight and Wind-Tunnel Studies of Deployment of a Dynamically and Elastically Scaled Inflatable Parawing Model." NASA TN D-4724, 1968.

43. Thomas G. Gainer, "Investigation of Opening Characteristics of an All-Flexible Parawing." NASA TN D-5031, 1969.

44. G. Kimball Miller, Jr., Byron M. Jacquet, and Douglas B. Price, "Fixed-Base Visual Simulation of Pilot-Controlled Descents of an Advanced Apollo Spacecraft With an All-Flexible Parawing." NASA TN D-5049, 1969.

45. Robert H. Moore, David L. Eichblatt, and Theodore F. Hughes, "Experimental Scale Factors for Parawing Opening Characteristics With Dimensional Ratios From 1:1.3 to 1:3." NASA TN D-5071, 1969.

46. George M. Ware, "Wind-Tunnel Investigation of the Aerodynamic Characteristics of a Twin-Keel Parawing." NASA TN D-5199, 1969.

47. Michael D. Falarski and Kenneth W. Mort, "Wind-Tunnel Investigation of Several Large-Scale All-Flexible Parawings." NASA TN D-5708, 1970.

48. Harry L. Morgan, Jr., "Performance and Deployment Characteristics of a Twin-Keel Parawing With Various Amounts and Permeabilities of Porous Material in Outer Lobes." NASA TN D-5793, 1970.

49. Rodger L. Naeseth, "Model Wind-Tunnel and Flight Investigation of a Parawing-Lifting-Body Landing System." NASA TN D-5893, 1970.

50. Blair B. Gloss, "The Determination of the Shape and Inertial Properties of an All-Flexible Parawing." NASA TN D-5900, 1970.

51. Harry L. Morgan, Jr. and Charles F. Bradshaw, "Aerodynamic and Deployment Characteristics of Single-Keel Slotted Personnel Parawings." NASA TN D-5911, 1970.

52. Rodger L. Naeseth, "Low-Speed Wind-Tunnel Investigation of a Series of Twin-Keel All-Flexible Parawings." NASA TN D-5936, 1970.

53. G. Kimball Miller, Jr., "Fixed-Base Visual Simulation of Obstacle Avoidance During Terminal Descent of Advanced Apollo Spacecraft With an All-Flexible Parawing." NASA TN D-5940, 1970.

54. Paul G. Fournier, "Low-Speed Wind-Tunnel Investigation of All-Flexible Twin-Keel Tension Structure Parawings." NASA TN D-5965, 1970.

55. Paul G. Fournier and William C. Sleeman, Jr., "Wind-Tunnel Studies of Effects of Construction Methods, Design Details, and Canopy Slots on the Aerodynamic Characteristics of Small-Scale All-Flexible Parawings." NASA TN D-5974, 1970.

56. Harry L. Morgan, Jr. and Austin D. McHatton, "Aerodynamic and Deployment Characteristics of Multi-Stage Canopy and Suspension-Line Reefing Systems for a Twin-Keel All-Flexible Parawing." NASA TN D-6306, 1971.

NASA TECHNICAL MEMORANDUMS, X

1. Delwin R. Croom, "Deployment Loads Data From a Free-Flight Investigation of All-Flexible Parawings at Small Scale." NASA TM X-2307, 1971.

2. Delwin R. Croom, "Deployment Loads Data From a Free-Flight Investigation of 4,000-Square Foot Wing Area All-Flexible Parawings." NASA TM X-2326, 1971.

NASA CONTRACTOR REPORTS

1. M. R. Mendenhall, J. N. Nielsen, and S. B. Spangler, "Investigation of Methods for Predicting the Aerodynamic Characteristics of Two-Lobed Parawings," NASA CR-1166, 1968.

2. J. N. Nielsen, S. B. Spangler, S. S. Stahara, and A. L. Lee, "An Exploratory Aerodynamic and Structural Investigation of All-Flexible Parawings." NASA CR-1674, 1970.

3. Jerome H. Milgram, "Section Data for Thin, Highly Cambered Airfoils in Incompressible Flow." NASA CR-1767, 1971.

4. Paul M. Kenner, Frederic T. Churchill, and Ralph B. Holt, "Geometric Aerodynamic, and Kinematic Characteristics of Two Twin-Keel Parawings During Deployment." NASA CR-1788, 1971.

5. Eugene M. Linhart and W. Carey Buhler, "Wind-Tunnel and Free-Flight Investigation of All-Flexible Parawings at Small Scale." NASA CR-66879, 1969.

6. John H. Moeller, Eugene M. Linhart, Warren M. Gran, and Larry T. Parson, "Free-Flight Investigation of Large All-Flexible Parawings and Performance Comparison With Small Parawings." NASA CR-66918, 1970.

7. N. R. Christensen and R. R. Snodgrass, "Paraglider Landing System Test Program." NASA CR-92224, 1965.

U.S. ARMY TRANSPORTATION RESEARCH COMMAND, FT. EUSTIS, VA.

1. E. Rouzee Givens, "Flexible-Wing Cargo Gliders." Vol. 1-Final Program Summary Report, TCREC TR-62-3A, September 1962.
2. E. Rouzee Givens, "Flexible-Wing Cargo Gliders." Vol. II-Design Criteria and Aerodynamics. TCREC TR-62-3B, September 1962.
3. F. Landgraf, W. L. Everett, and J. H. Burich, "Flexible-Wing Manned Test Vehicle." TCREC TR 62-25, June 1962.
4. B. E. Kurz, "Flexible-Wing Individual Drop Glider." TRECOM TR-63-26, July 1963.
5. Ryan Aeronautical Co., "Flexible-Wing Precision Drop Glider." TRECOM TR-63-64, December 1963.
6. R. Gibson and B. E. Kurz, "Flexible-Wing Precision Drop Glider Operational Test and Evaluation Program." TRECOM TR-63-78, March 1964.
7. J. Everett Forehand, "The Precision Drop Glider (PDG)." TRECOM Res. Tech. Paper 64-21, April 1964.
8. H. Kredit, "XV-8A Flexible Wing Aerial Utility Vehicle." USATRECOM TR 64-55, February 1965.
9. F. Landgraf and P. F. Girard, "XV-8A Flexible Wing Aerial Utility Vehicle." USATRECOM TR-64-74, February 1965.
10. N. Sakamoto and G. Cota, "Flexible Wing Air Cargo Glider Delivery System." USATRECOM TR-65-11, May 1965. (Also available from DDC as AD-615908.)
11. G. Cota and N. Sakamoto, "Flexible-Wing Light Utility Glider." USAAVLABS TR-66-2, August 1966. (Also available from DDC as AD-640987.)
12. John W. Sobczak, "Investigation of Deployment and Landing Loads With a Limp Paraglider." USAAVLABS TR 66-82, September 1966. (Also available from DDC as AD-646578.)
13. Ryan Aeronautical Co.: "Flexible-Wing Towed Universal Glider." USAAVLABS TR-67-57, October 1967. (Also available from DDC as AD-666248.)
14. J. F. Irvine, "Inspections, Repairs, and Modifications, and Flight Test of the Flexible-Wing Manned Test Vehicle, XV-8A." USAAVLABS TR-68-30, 1968. (Also available from DDC as AD-680316.)
15. Robert G. Slayman, Herbert Q. Bair, and Thomas G. Rathburn, "500-Pound Controlled Airdrop Cargo System." USAAVLABS TR-70-31, September 1970.

U.S. NAVY-OFFICE OF NAVAL RESEARCH

1. F. K. Goodwin, A. R. Kriebel, and J. N. Nielsen, "Theoretical Aerodynamics of Flexible Wings at Low Speeds. Pt. I-One-Lobed Parawings." Vidya Rep. 84 (NONR-3728/00), 1963. (Also available from DDC as AD-422736.)
2. R. Barakat, F. K. Goodwin, J. N. Nielsen, and M. Rudin, "Theoretical Aerodynamics of Flexible Wings at Low Speeds. Pt. II-Two-Lobed Parawings." Vidya Rep. 133 (NONR-3728/00), 1964. (Also available from DDC as AD-601848.)
3. A. R. Kriebel and J. N. Nielsen, "Theoretical Aerodynamics of Flexible Wings at Low Speeds. Pt. III-Approximate Results for Wings of Large Aspect Ratio." Vidya Rep. 146 (NONR-3728/00), 1964. (Also available from DDC as AD-606059.)
4. J. A. Burnell and J. N. Nielsen, "Theoretical Aerodynamics of Flexible Wings at Low Speeds. Pt. IV-Experimental Program and Comparison With Theory." Vidya Rep. 172 (NONR-3728/00), 1965. (Also available from DDC as AD-617925.)
5. J. A. Burnell and J. N. Nielsen, "Theoretical Aerodynamics of Flexible Wings at Low Speeds. Pt. V-Engineering Method for Estimating Parawing Performance." Vidya Rep. 209 (NONR-3728/00), 1965. (Also available from DDC as AD-628579.)

TECHNICAL PRESENTATIONS

1. Francis M. Rogallo, "Paraglider Recovery Systems." Paper presented at IAS Meeting, Man's Progress in the Conquest of Space, St. Louis, Mo., Apr. 30-May 2, 1962.
2. Francis M. Rogallo, "Flexible-Wing Research and Development." Paper presented at Aero. Sys. Div. Proc. of Retardation and Recovery Symposium, Dayton, Ohio (Nov. 13-14, 1962), pp. 195-213.
3. Francis M. Rogallo, "Parawings for Astronautics." Paper presented at Specialists Meeting, Space Rendezvous, Rescue, and Recovery, Edwards AFB, Calif., Sept. 10-12, 1963. (Also available as NASA TM X-51047.)
4. Robert W. Fralich, "Stress and Shape Analysis of a Paraglider Wing." Paper presented at ASME Winter Annual Meeting, New York, N.Y., Nov. 29-Dec. 4, 1964. (Also available as NASA TM X-51958.)
5. Delwin R. Croom, Francis M. Rogallo, and William C. Sleeman, Jr., "Resume of Recent Parawing Research." Paper presented at Course on Aerodynamic Deceleration at the Univ. of Minnesota, July 8, 1965. (Also available as NASA TM X-56747.)
6. Francis M. Rogallo, "NASA Research on Flexible Wings." Paper presented at International Congress of Subsonic Aeronautics New York, N.Y., Apr. 3-6, 1967. (Also available as NASA TM X-59738.)
7. William C. Sleeman, Jr. and Thomas G. Gainer, "Status of Research on Parawing Lifting Decelerators." Jrl. Aircraft, Vol. 6 (1969), pp. 405-409. (Also available as AIAA Paper 69-10.)
8. M. R. Mendenhall, J. N. Nielsen, and S. B. Spangler, "A Review of Methods for Predicting the Aerodynamic Characteristics of Parawings." Jrl. Aircraft, Vol. 5 (1968), pp. 597-605. (Also available as AIAA Paper 68-10.)
9. J. Everett Forehand and Herbert Q. Bair, "Parawing Precision Aerial Delivery System." Jrl. Aircraft, Vol. 6, No. 5 (1968), pp. 463-469. (Also available as AIAA Paper 68-958.)
10. W. Pittelkow, "A Recoverable and Reusable Sounding Rocket." U.N. Paper 68-95445, U.N. Conference on Exploration and Peaceful Uses of Outer Space, Vienna, Austria, 1968.
11. Francis Rogallo, "Flexible Wings." Astronautics and Aeronautics, August 1968, pp. 50-54.
12. William C. Sleeman, Jr., "Glide Performance of Ad-

vanced Parawings." AIAA Paper 70-1186, Aero. Decel. Systems Conf., Dayton, Ohio, 1970.

13. E. M. Linhart and J. H. Moeller, "Parawing Technology for Spacecraft Land Landing–A Progress Report." AIAA Paper 70-1187, Aero. Decel. Systems Conf., Dayton, Ohio, 1970.

14. Charles F. Bradshaw, George L. C. Menard, John Sobczak, and Ralph J. Speelman, III: "Hi-Glide Personnel Canopies–Efforts Toward Identification of Requirements." AIAA Paper 70-1194, Aero. Decel. Systems Conf., Dayton, Ohio, 1970.

15. P. M. Kenner, "Structural Analysis of a Parawing During Deployment." AIAA Paper 70-1196, Aero. Decel. Systems Conf., Dayton, Ohio, 1970.

16. D. L. Clemmons, Jr., "Some Analysis of Parawing Canopy Behavior During Free-Flight Deployment." AIAA Paper 70-1189, Aero. Decel. Systems Conf., Dayton, Ohio, 1970.

17. R. L. Bass, III and J. J. Bertin, "Theoretical Investigation of the Lift and Drag Characteristics of Flexible Parawings at Subsonic Speeds." Jrl. Aircraft, Vol. 7 (1970), pp. 130-137.