Static Test of an Ultralight Airplane

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This paper describes the work necessary to perform the static test of an ultralight airplane. A steel reaction gantry, loading whiffletrees, hydraulic actuation system, and instrumentation systems were designed. Load and stress analyses were performed on the airplane and on the newly designed gantry and whiffletrees. Load cell calibration and pressure indicator calibration procedures are described. A description of the strain and deflection measurement system is included. The engine, propeller, fuel, and pilot were removed and replaced with masses to fulfill center-of-gravity requirements prior to testing. Data obtained to date are compared to the analytical predictions.

Nomenclature

C_L	= wing lift coefficient
d	= displacement, mm
F_{cu}	= ultimate compression stress, ksi
h	= altitude, ft
M_x	= wing bending moment, N·m
n	= limit load factor
R_N	= nose wheel reaction, lb
R_L	= left main wheel reaction, lb
R_R	= right main wheel reaction, lb
S	= wing area, ft^2
V	= airplane speed, ft/s
W_0	= empty weight, lb
W_{BF}	= basic flight design weight, lb

Introduction

AS the service life of the fleet of ultralight vehicles increases, the number of fatal accidents is expected to increase as well. Several cases have been documented by the National Transportation Safety Board[1] in which the integrity of the structure was questioned. When similarities between cases occur, it is logical to formulate a plan to investigate the basic behavior of a typical vehicle.

The opportunity to formulate a plan presented itself in early 1985. Research on the aerodynamics and flight characteristics of an Airmass Sunburst "C" was drawing to a close and a master's thesis by Blacklock[2] was published. Consequently, a full-scale ultralight airplane was available for further research. A proposal was written and presented to the NASA Langley Research Center. The primary goal of this proposal was to perform a structural test to destruction of an ultralight airplane.

The structural floor and the ultralight airplane specimen are shown in Fig. 1. To perform a static test, a steel gantry and its sway bracing was designed.[3] Similarly, the upper and lower whiffletrees were designed and integrated with the loading device. Finally, the strain and deflection systems were designed. This paper describes the details of the work accomplished.

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Analysis

Design Criteria

In the early days, an airplane had to be able to carry the limit load without permanent deformation and the ultimate load for 3 s passing the static test sequence was a time of joy and celebration for the structures engineers. Nowadays, aircraft are governed by much more rigorous specifications. The static strength requirement has been retained, but is now only one element of a much larger array of specifications under a comprehensive umbrella known as the structural integrity program. Among the factors included are: corrosion, durability, damage tolerance, and flutter. Aircraft that are to be certified prior to use must meet or exceed specifications. These requirements are specified in either Federal Aviation Regulations or Military Specifications and the "meet or exceed" phrase is satisfied by analysis or by test or both.

A set of design guidelines for an utralight has been published by the Powered Ultralight Manufacturers Association (PUMA).[4] However, there are no specifications governing the structural integrity of an ultralight airplane. For this analysis, the ultralight was treated as though it were a normal category general aviation airplane governed by FAR-23. All related Mil-Specs and Mil-Standards were invoked as well.

It should be noted that student interest in this research project was very high. One student elected to write a report on a structural integrity program for ultralights,[5] probably the only one of its kind in existence.

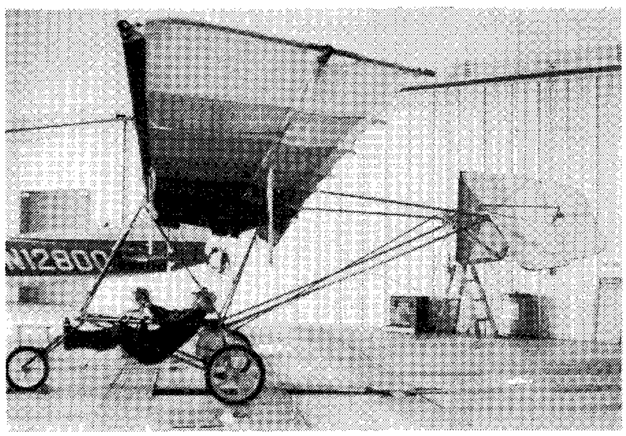

Fig. 1 Sunburst "C" ultralight.

Table 1 Lift distribution

Speed (maneuvering)	69 ft/s
Altitude h	1000 ft
Weight W_{BF}	468 lb
C_L (max)	1.48
S	150.9 ft^2
n (limit)	3.8

Table 2 Weight breakdown of test aircraft, lb

Structure	
Tube WG-1	5.31
Wing skins	16.25
Landing gear	
Wheel-nose	3.12
Main wheels and tires	10.90
Rear axle	7.01
Seat	8.71
Powerplant	
Engine and propeller	78.38
Muffler	5.70
Propeller shaft	8.88
Misc., each < 3 lb	Remainder
W_0 Weight empty	277.48
Fuel	15.52
Pilot ("Bellerophon")	175.00
W_{BF} Basic flight weight	468.00

Lift Distribution

Ordinarily, a structural test engineer begins with air load distributions as "known" values. Both spanwise and chordwise pressure distributions must be given beforehand to allow determination of "patch" loads. For this ultralight, six spanwise and two chordwise stations were selected to simulate the subsonic pressure distribution. In reality, the airfoil behavior is unknown, since it is only sail cloth stretched over the front and rear spar tubes. During a maximum positive load factor condition, the airfoil is taut and has a particular set of ordinates. During any other flight condition, including inverted flight, the ordinates are variable.

Since an air load distribution was not available, one was calculated using a quasivortex lattice method. This work was done by a student who favored this method and the analysis was performed with ease.[6,7] With this knowledge, patch loads could be determined. Those data were incorporated in the upper whiffletree design. The design maneuvering speed at a limit load factor of 3.8 was 69.0 ft/s. (See Table 1.) The spanwise lift distribution is shown in Fig. 2. The spanwise drag distribution was assumed to be negligible.

Dead Weights

The weight breakdown for our test condition is given in Table 2. The engine, propeller, shaft, and mounts were removed and replaced with a mass whose magitude and center of mass were correctly located. The lower whiffletree mass was included to correct the 1g dead weight loads. Fuel was replaced with water of the correct weight.

Our ultralight pilot, named Bellerophon, was constructed of army coveralls, worn-out army boots, a cap, and a mask (Halloween) for cosmetic purposes. The cap was adorned with a NASA logo. Bellerophon's center of gravity was built up with concrete cylinders at the buttock and thigh locations. The remainder was constituted from plastic bags and Kaw River sand. Weighing and loading him into the aircraft required the assistance of four strong students.

Overall airplane weight and center-of-gravity location was checked and rechecked by actual weighings with three balance scales under the wheels. Results of the weighings were: $R_N = 11.49$ lb, $R_L = 127.0$ lb, $R_R = 133.2$ lb, for a total of 271.69 lb. (See Fig. 3.)

Point Load Calculations

With many scientific developments, the creators of the breakthrough cannot foresee the eventual applications of their work. Likewise, Joseph Fourier could not have known that his work with sines and cosines would be used to calculate air load pressures on an ultralight airplane nor could Fred Whipple have known that his method would be used to approximate that air load.

The upper whiffletrees are simple three-point beam pairs made from ordinary 2×4 and 2×6 pieces of lumber. There are five "tiers" of trees. The first is the highest and the fifth the lowest. The trees are connected with heavy-duty turnbuckles. Tier 1 is connected to the steel gantry with a single steel strap. Tier 5 is just below the wing and is in direct contact with the tubular spars. Plywood bearing plates are used to spread the load along the spars. Tiers 1–3 are the spanwise trees, while tiers 4 and 5 assure the chordwise center-of-pressure location. With no load in the actuator, the ultralight is suspended above the hangar floor in straight and level flight.

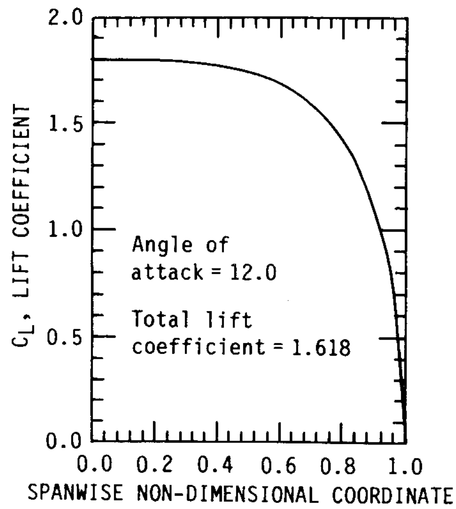

Fig. 2 Wing spanwise lift coefficient.

The upper whiffletree arrangement for the left-hand wing is shown in Fig. 4.

The lower whiffletree is a loading mechanism as well. A pair of steel straps connect at the engine mount holes and the U-straps bear directly on the fuselage cage tubes. These whiffletrees are commercial grade steel and are designated tiers 6 and 7. Tier 6 is adjacent to the fuselage and tier 7 (the lowest) connects to the 10,000 lb hydraulic actuator. A load cell is in series with the actuator. These linkages are bolted directly to a floor fitting where they are reacted. The floor fitting, called the "alligator," was specially designed for that purpose. It is located directly below the air load center-of-pressure vector P, shown in the lower whiffletree sketches (Figs. 5 and 6). All of the lower whiffletree members are made from standard AISC steel sections: rectangular tubing, tees, and flat straps.

Internal Loads Analysis

A stress analysis of the wing structure was performed using the air loads discussed above. Availability of the Polo finite-element method and its ease of use were the reasons for its selection.[8] Results are given in DeAlmeida's report.[6] The flying wire loads at the design limit load factor of $n = 3.8$ are:

Forward inboard 44 lb
Aft inboard 65 lb

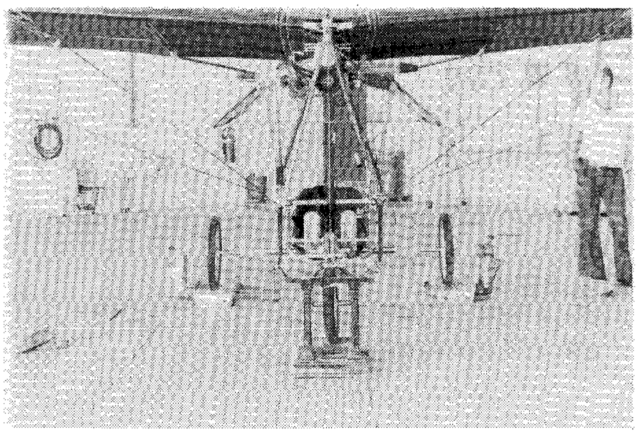

Fig. 3 Weight and center of gravity.

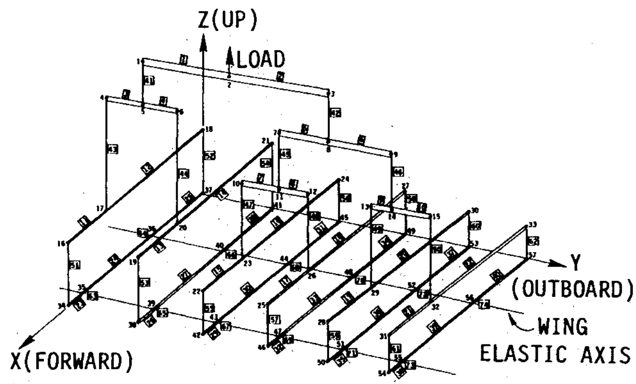

Fig. 4 Upper whiffletree.

Forward outboard 222 lb
Aft outboard 145 lb

Wing bending moments M_x and spar displacements d are shown in Figs. 7 and 8.

Systems Design

For this study, the test rig was divided into four independent systems. The design and assembly of each system is described below.

Hydraulic System

A 3000 psi hydraulic system was designed to apply the load. An Allis-Chalmers 10,000 lb, 8 in. stroke actuator and a Prince hand pump were purchased from a surplus machinery supplier. A pressure gage and short hydraulic lines were obtained from the same supplier. A schematic of the hydraulic system is shown in Fig. 9.

The Boeing Company supplied the hydraulic lines, a four-port Barksdale valve, and several hydraulic fittings. The 2 gal reservoir and hydraulic oil were purchased locally. These parts were assembled and the lines purged of air by two students. The system was tested during the two-by-four destruction test described below.

Load Cell System

A 5000 lb Baldwin-Lima-Hamilton load cell has been in the Aero Department for a number of years. A pair of load cell "eyes" had to be purchased to match the special internal threads. The eyes have 1 in. diameter self-aligning bearings. A pair of links connect to a smaller eye at each end. The smaller

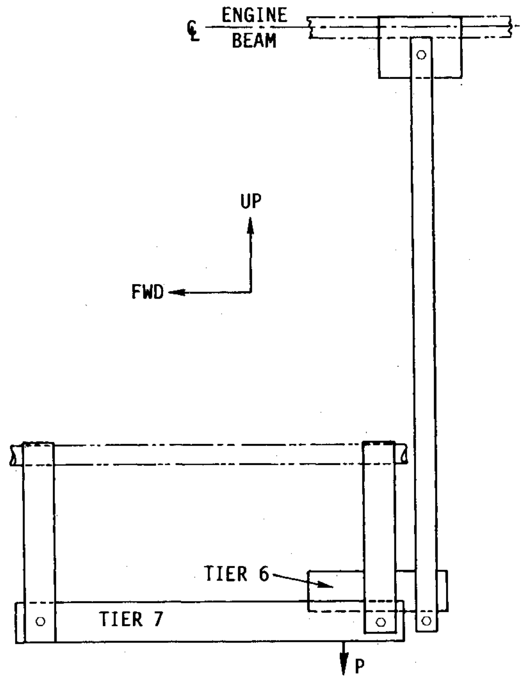

Fig. 5 Lower whiffletree, left side view.

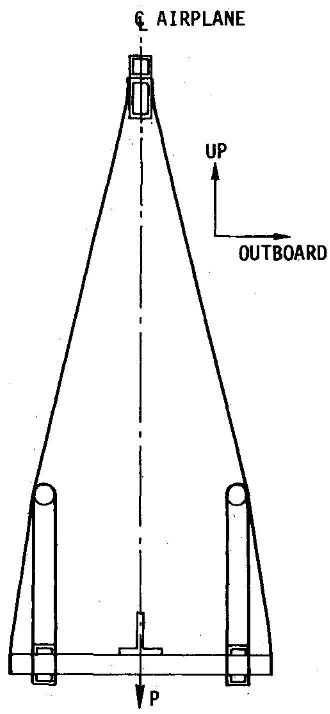

Fig. 6 Lower whiffletree, rear view.

eye shaft could then be gripped in test machine jaws. Excellent linearity was achieved. A calibration constant was determined to be 82 lb per unit readout.[9]

Deflection Measurement System

Large deflections were measured with a sliding scale system. In hazardous situations, a telescope or transit was used. This was the case when cable failures were imminent. When deflections were small (less than 1 in.), a dial indicator was used. Tip deflections of 3.70 in. limit were expected. The sliding scale concept was proved during the wood bending destruction test, which was recorded on video tape.

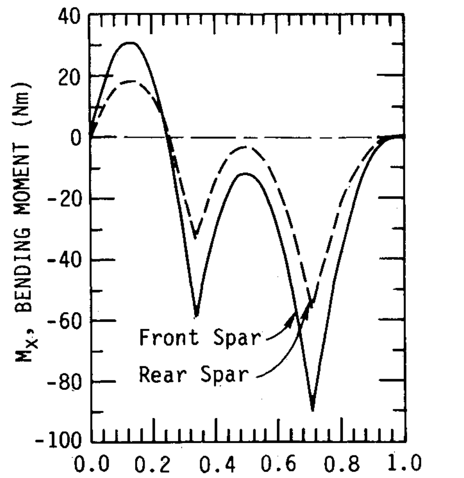

Fig. 7 Wing limit bending moments.

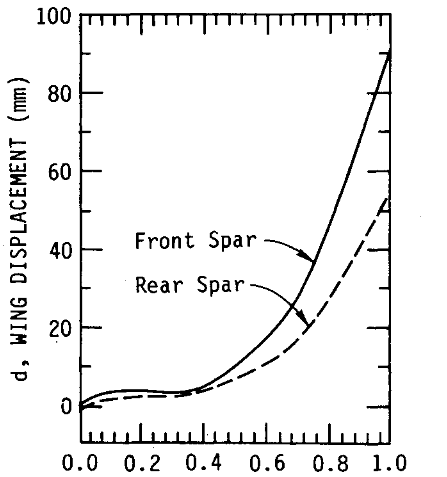

Fig. 8 Wing limit deflections.

Strain Measurements System

All strain gages were single-element foil gages from Micro Measurements. A 10 channel switch and balance unit and a strain readout unit were available from previous research. The strain gage terminal board was borrowed from the Aerospace Medical Research Laboratory. The resulting strain measurement system design was proved during the tube tension component tests described below. Data were taken with a Vishay-Ellis switch and balance unit and strain indicator.

Component Tests

Tube Compression

Compression tests of the 6061-T6 tubes were run to verify the heat treat level. The ultimate stress in compression was: F_{CU} (measured) = 47.8 ksi and F_{CU} (MIL-HDBK-5A) = 42.0 ksi.

Wood Bending

Wood bending tests were performed on a pair of medium-grade "S-P-F" lumber. The test simulated an upper whiffletree and was performed to spot check the modulus of rupture of "spruce-pine-fir," another unknown. Both the stress magnitude and the failure mode were missed. The modulus of rupture in bending, not to be confused with the civil engineering design value, was estimated to be 9600 psi. The wood beam ensemble failed in horizontal shear and "prying" near the point of maximum moment. The magnitude was 85% of the predicted ultimate load. For this test, the load-deflection curve was linear up to 50% of the failure load.

Cable Tension

Cable testing was very interesting and informative. Four assemblies of ⅛ in. diameter, 7×19 aircraft cables were designed to represent the "flying wires" on the ultralight. They were fitted with thimbles, grommets, tangs, and Nico-press clamps. Failure load for the cable is estimated to be 1740 lb. None of the cables carried more than 975 lb. All "failed" by the cable sliding out of the Nico-press fitting. Cable testing is incomplete at this time. All cables will be fitted with double clamps and retested in an attempt to rupture the cable strands. Special safety precautions have been taken to keep humans out of a 100 in. cable whipping lethal radius drawn with each cable end as an arc center.

Recommendations

1) Unscathed portions of the ultralight, such as the wing tip, can be sawn off and used in future wind-tunnel work. The two-dimensional lift and drag coefficients should be obtained from minimum to maximum C_L.

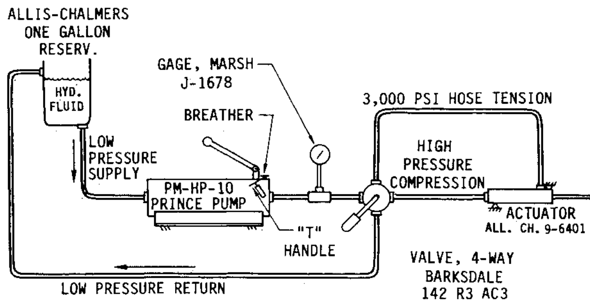

Fig. 9 Hydraulic system.

2) Almost nothing is known about the behavior of an ultralight structure under repeated loads. A durability and damage tolerance research program is highly recommended.

Acknowledgments

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[10](All) Engineering Drawings, University of Kansas, Lawrence, (125 drawings total).