

The “*Kolben Sondierung 1*”
AEROSPACE 204H / 404H
DESIGN REPORT

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1.0 Introduction

Throughout the existence of the Aerospace 204/404H class, building a one-person sailplane has always been the major focus. Over time, the difficulties and frequent setbacks along the way were found numerous and overwhelming by all the students and instructors. For example, members of the class put countless hours into the Falcon fuselage only to just recently fit the halves together properly. Likewise, the wings of the Falcon have demanded major repairs over the years.

This accumulation of obstacles has proven to be the precursor of a new goal in the class. This goal is to design a sailplane that can be built with ease, while avoiding many of the impending complications occurring over the course of the plane's fabrication. With an easy effective design as a goal, such a sailplane was designed. The innovative ideas along with the theory of aerodynamics, structures, and stability learned throughout the semester will be presented in this report introducing the "Kolben Sondierung 1" (KS-1).

2.0 Design Goals

The design goals are based on ease of building, but safety, time restraints, and space limitations cannot be overlooked. The goals are specified along with *JAR-22* requirements* and other basic considerations that need to be discussed in the design process.

2.1 Easy Build

The main project specification, demanded that manufacturing was to be completed in two academic years or less.

2.2 Space Limitation

Since the downsizing of the lab, space is now a constraint. For instance, a wing span of greater than 19 m (approx.) would not fit in the lab.

2.3 Use of Available Materials

Due to monetary concerns, components should be incorporated in a manner that the total price does not exceed the budget.

2.4 Launching Ability

Two methods of launching were considered, winch launch and car tow.

2.5 Velocity Constraints

Given $V_{\min} \approx 20\text{-}25$ knots, $V_{\max} \approx 60$ knots, and calculated $V_{s_{\min}} \approx 42.2$ ft/s.

2.6 Modular Design

Vehicle design and fabrication will occur in sub groups. All components will be integrated at final assembly. Such separation of the labor involved has proven necessary in order to satisfy the time constraint.

* These requirements and considerations were found in Fred Thomas's "Fundamentals of Sailplane Design" on page 61 and page 73, respectively.

2.7 Carry a Pilot

Naturally, the sailplane will undertake in manned flight. Further, the vehicle must carry a pilot the size of an average male.

2.8 Structural Design

The sailplane must follow JAR-22 guidelines in order to insure structural integrity.

3.0 General JAR-22 Requirements

3.1 Flight

take off and landing, stability and control, performance, and cruise.

3.2 Structure

Wings, empennage, control surfaces, dive brakes, landing gear, fuselage, tail boom, and cockpit.

3.3 Design

Safety factors, gust loads, maneuvering loads, flight loads, ground loads, and material properties.

3.4 Equipment

Installations of flight instrumentation: push-pull rods, pull-pull cables, ailerons, flap-brake system.

3.5 Limitations and Information

Airspeed limitations, weights and balances, markings and placards, flight and maintenance manuals

4.0 Basic Considerations

The following issues were addressed during the design process:

4.1 Structural Weight

Airfoil thickness, wingspan, aspect ratio, materials used.

4.2 Stiffness

wing must be rigid enough to prevent excessive elastic deformations and flutter, but also flexible enough to prevent gust failures.

4.3 Manufacturing Costs

budget constraints, easy to maintain and/or repair.

4.4 Cockpit Layout and Visibility

glider performance, largely depends on the pilot; this included making the cockpit as comfortable as possible so that the pilot can fly at his/her optimal level at all times.

4.5 Flying Qualities

handling qualities are more important than aerodynamic performance for the scope of this project.

4.6 Ground Handling

assembly and disassembly must be relatively easy and not exhausting. The possibility of landing out in a field was considered.

5.0 Design Specifications

5.1 Fuselage

For the fuselage skin, the necessary considerations were pilot entry and seating, streamlined shape, and crashworthiness. Using fiberglass and epoxy the nose and cockpit area will be constructed from the Griffin molds. Two foreword and three aft bulkheads will add structure as well as connecting points.

5.1.1 Attachment

A simple pin will join the wing and fuselage. The joint will connect two bulkheads with a long pin, which will act as a hinge for the wings to connect. The fuselage–tailboom junction will be accomplished by running the tailboom through holes in two rear bulkheads, which will then be epoxied on with a few layers of glass. The bulkheads will be united by a central steel frame consisting of hollow tubes welded together. The frame will also act as a mounting interface for the strut.

The main attachments for the aircraft occur in the mounting cage, located between the fore and aft bulkheads in the fuselage. The main wing pins to the fuselage and to the struts for ease of transportation and to reduce the bending moment at the root rib. The tailboom is epoxied into the mid and aft bulkheads to react all torsion and bending associated with empennage loading. A Dacron shroud smooths the contour of the fuselage between the aft bulkhead and the tailboom.

Figure 5.1.1a shows the mounting cage from the underside, with a view of the strut and tailboom assembly (note that the wings are shortened for clarity).

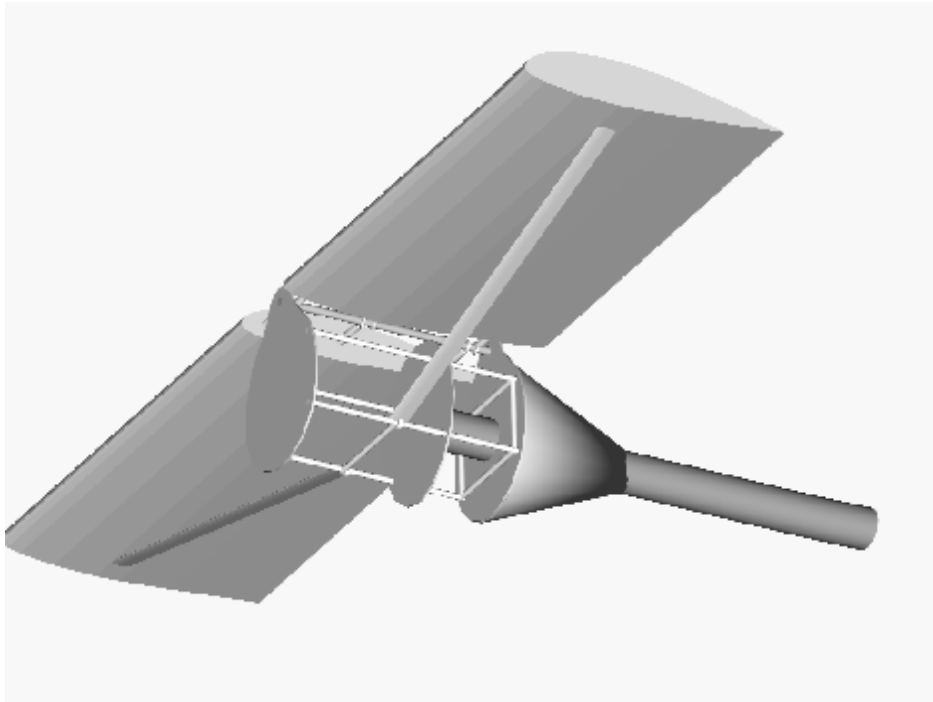


Fig. 5.1.1a

Figure 5.1.1b shows a close-up of the wing-fuselage pin joint. The hinge-pin is a steel tube that can be bolted to the bulkheads during pre-flight assembly. Aluminum connectors attach to the hinge-pin from three locations on each wing. The connector tubes pass through both the root rib and a second hard-point rib.

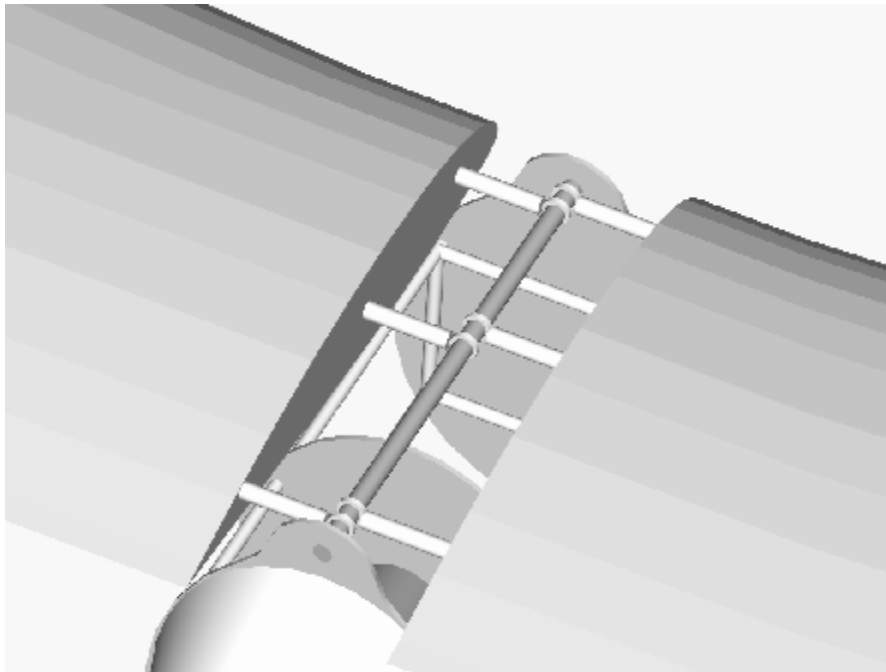


Fig. 5.1.1b

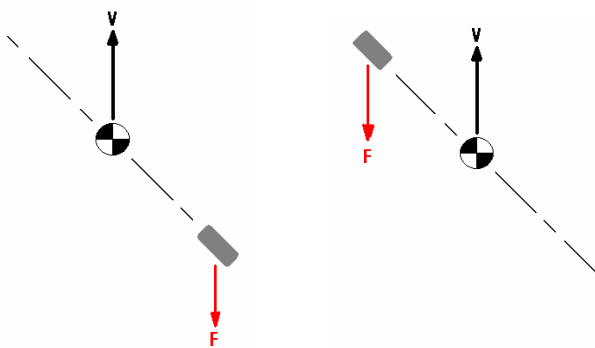
5.1.2 Crashworthiness

The crashworthiness was based on the calculations done for the Griffin and Falcon. Simple cockpit rails, secured on the outer edge of the bulkheads, will help absorb energy upon impact and cause the fuselage to buckle out away from the pilot. For vertical impact, a layer of high-energy absorbent foam will be inserted between the fuselage skin and the seatpan; the foam along with the landing skid will act to absorb a portion of the impact force.

5.2 Landing Gear

5.2.1 Configuration

The first major consideration was to select a nose-wheel or tail-wheel configuration. In a tail-wheel configuration, the main wheel is placed ahead of the CG so that the aircraft will also rest on its tail wheel. Likewise, for a nose-wheel configuration, the main wheel is behind the CG to allow the aircraft to rest on its nose wheel. When a sailplane touches down on its main wheel, that wheel begins to generate a friction force. If the sailplane does not touch down straight, the friction force of the wheel will not be in line with the CG. Hence, a moment will be generated. The diagram below illustrates these effects. The dashed line represents the longitudinal axis. The gray rectangles represent the main wheel and have their friction forces displayed.



Nose-Wheel

Tail-Wheel

The moment generated in the nose-wheel configuration will try to straighten the sailplane and align the longitudinal axis with the direction of motion. The moment generated in the tail-wheel configuration will worsen the situation.

Because of this restoring nature associated with the nose-wheel, its configuration was selected for the design. It has offered easier handling and tracking, which will improve safety in the hands of less experienced pilots.

5.2.2 Skid

Next, the nose-wheel and nose-skid were compared. A nose skid will provide ample friction to eliminate the need for a brake system. Other advantages of the skid were found in safety. A nose skid will provide additional strength to the bottom of the fuselage, which will help protect the pilot during an accident. A skid will also help prevent the fuselage from being punctured by tree branches, fence posts, etc., should such dangerous circumstances arise.

The skid can be constructed from a hard wood such as oak. Rubber should be used to absorb the inevitable shocks. A steel wear plate can be used at the point of contact with the ground to prolong the life of the skid. The assembly should be attached to the fuselage with bolts so that it can be removed for replacement or maintenance.



5.2.3 Suspension

The fabrication of a typical suspension system would be tedious and violate the easy-to-build guidelines. The most practical solution is to use a large tire at low pressure. With this properly sized tire, the air inside the tire will sufficiently dampen rough landings. Since there are no equations for tire sizing, the tire sizes of similar aircrafts were examined.

The Schweizer 1-36, a fairly light and slow sailplane, vaguely resembles this newly introduced design of the KS-1. It features a generous main wheel of 13" diameter and 5" width. By comparison, this wheel size should be sufficient for the design of the KS-1.

5.2.4 Tail-Wheel

The weight of the sailplane will rest on the main wheel and nose skid with pilot aboard. However, it is anticipated that the glider will rest on the main wheel and tail when empty. For ground handling, a small tail wheel is needed.

5.3 Wing

The wing is a simply tapered SM-701 planform with the following:

$$b = 50$$

$$c_{\text{root}} = 4 \text{ ft}$$

$$c_{\text{tip}} = 2 \text{ ft}$$

$$\lambda = 0.5$$

$$AR = 17.4$$

The wing will consist of a D-tube made up of fiberglass–foam sandwich. The shear web and ribs will also consist of fiberglass sandwich panel material, whereas the spar caps will consist entirely of unidirectional E-glass. Aft of the D-tube the wing will have Dacron fabric covering. The sandwich panels of the ribs will be cut out in two sections with CNC tools. To assemble the wing, the fore sections of the ribs are aligned in a rig. Four-ounce pre-cured fiberglass is epoxied onto the leading edge. Foam core is epoxied onto the fiberglass base, and the outer layer of fiberglass is applied. The spar is epoxied into place to finish the D-tube.

The mid-section ribs are aligned against the D-tube in a jig, and are epoxied into place. Fiberglass fillets are applied in the corners between the ribs and the D-tube spar. Mounts are created for the ailerons by truncating the trailing edges of the affected ribs and epoxying on sandwich panel hard points. A wood trailing edge is epoxied onto the end of the full-length ribs, and gussets are applied to increase durability. Finally the wing aft of the spar is covered with Dacron. Figure 5.3a shows an exploded cross-section of the wing.

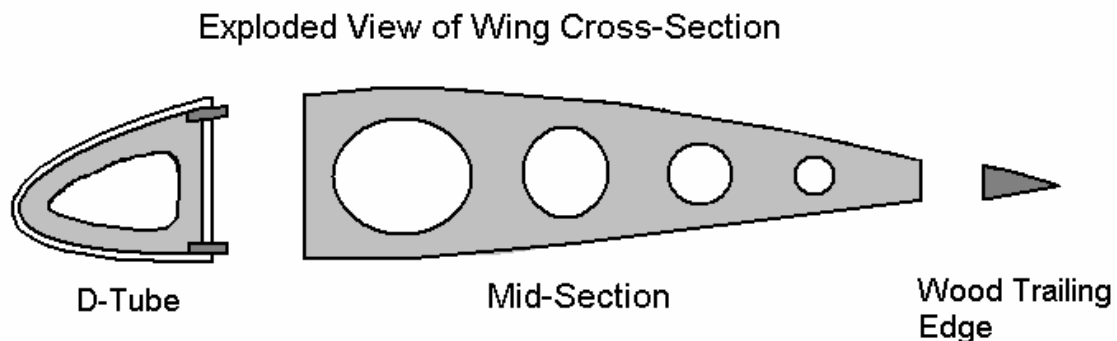


Fig. 5.3a

5.4 Tailboom

The tailboom will be a prefabricated carbon tube with an outer diameter of 6 inches and an approximate inner diameter of 5.5 inches. This tube can be purchased from a supplier for a reasonable price, thus greatly reducing the production time of the sailplane.

5.5 Empennage Sizing and Design

Through an iterative process, the sizing of the tailboom and horizontal and vertical tails were found.

5.5.1 Horizontal Tail

For the horizontal tail, $0.35 < V_H/V_W < 0.55$ is assumed. V_w was determined to be 2419 ft². Values for the tail moment arm were assumed and then the area was calculated using the horizontal tail volume equation. The chords and span can be determined from the area using an assumed aspect ratio. Several of these initial values were tabulated until an acceptable geometry was found. The final results are listed below.

$$\begin{aligned} \text{AR} &= 5.5 \\ S &= 14.75 \text{ ft}^2 \\ b &= 9 \text{ ft} \\ c &= 1.64 \text{ (mean geometric chord)} \\ \lambda &= 0.7 \\ l_H &= 17 \text{ ft (tail moment arm)} \end{aligned}$$

The tail moment arm is roughly the tailboom height.

5.5.2 Vertical Tail

The vertical tail size was found by assuming a vertical stabilizer volume comparable to that of similarly configured sailplane designs. An area can then be determined through the vertical stabilizer volume equation. With an assumed aspect ratio, the chords and span can be determined.

$$\begin{aligned} \text{AR} &= 1.5 \\ S &= 10.165 \text{ ft}^2 \\ b &= 3.90 \text{ ft} \\ c &= 2.60 \text{ (mean geometric chord)} \\ \lambda &= 0.7 \\ l_v &= 17 \text{ ft (tail moment arm)} \end{aligned}$$

5.5.3 Attachment

The simplicity of design has been taken into account in the design of the vertical and horizontal tail. The flat plate construction for both the vertical and horizontal tail was selected to simplify and shorten construction time. Two pins along the tailboom and fiberglass applied from the side of the surface to the tailboom will attach the vertical tail. The rudder is constructed of the same flat plate design. The horizontal tail is constructed to be removable for ease of transportation. Further, an aluminum tube is set through the tailboom. The horizontal tail will then be placed over the exposed aluminum tube and pinned with vertically oriented pins.

5.6 Cockpit Ergonomics

5.6.1 Instrumentation

The instrumentation for this aircraft will consist of a compass, an airspeed indicator, a variometer, a yaw string, and an altimeter. These instruments are the minimum requirements the FDR has solicited for experimental aircraft. In addition, all other accessories have been removed from the cockpit design in order to fulfill the project's main objective, which is to reduce costs and labor as much as possible.

The instrument panel will consist of a detachable aluminum plate with the altimeter, airspeed indicator and variometer in the middle of the panel and the compass on top of the dashboard. Furthermore, the yaw string will be taped to the sailplane's canopy. The altimeter will measure the aircraft's altitude, and the variometer will be used for soaring. In addition, the airspeed indicator will display the sailplane's speed, which will not exceed 60MPH, and the yaw string will be used for coordination.

| Instrument | Size | Range | Style | Part-No | Price | Store |
|--------------------|-----------------------|--------------|---------------|---------------------------|--------------|---|
| Airspeed Indicator | 3-1/8 in | 0-75 MPH | Pitot | 10-02945 | \$223.00 | http://www.aircraftspruce.com |
| Color Marking kit | ----- | ----- | ----- | ----- | \$4.95 | http://www.wingsandwheel.com |
| Altimeter | 3 pointer in Hg scale | 20,000 ft | ----- | ----- | \$345.00 | http://www.wingsandwheel.com |
| Compass | ----- | ----- | Airpath model | C2300 Panel mount compass | \$99.00 | http://www.wingsandwheel.com |
| Variometer | ----- | ----- | ----- | ----- | \$350.00 | http://www.wingsandwheel.com |

Fig.5.6.1A: Instrument description. It should be noted that for safety concerns the airspeed indicator has a range of 10-20% higher than the never exceed speed. Furthermore, a mechanical variometer will be used to avoid installing an electrical system.

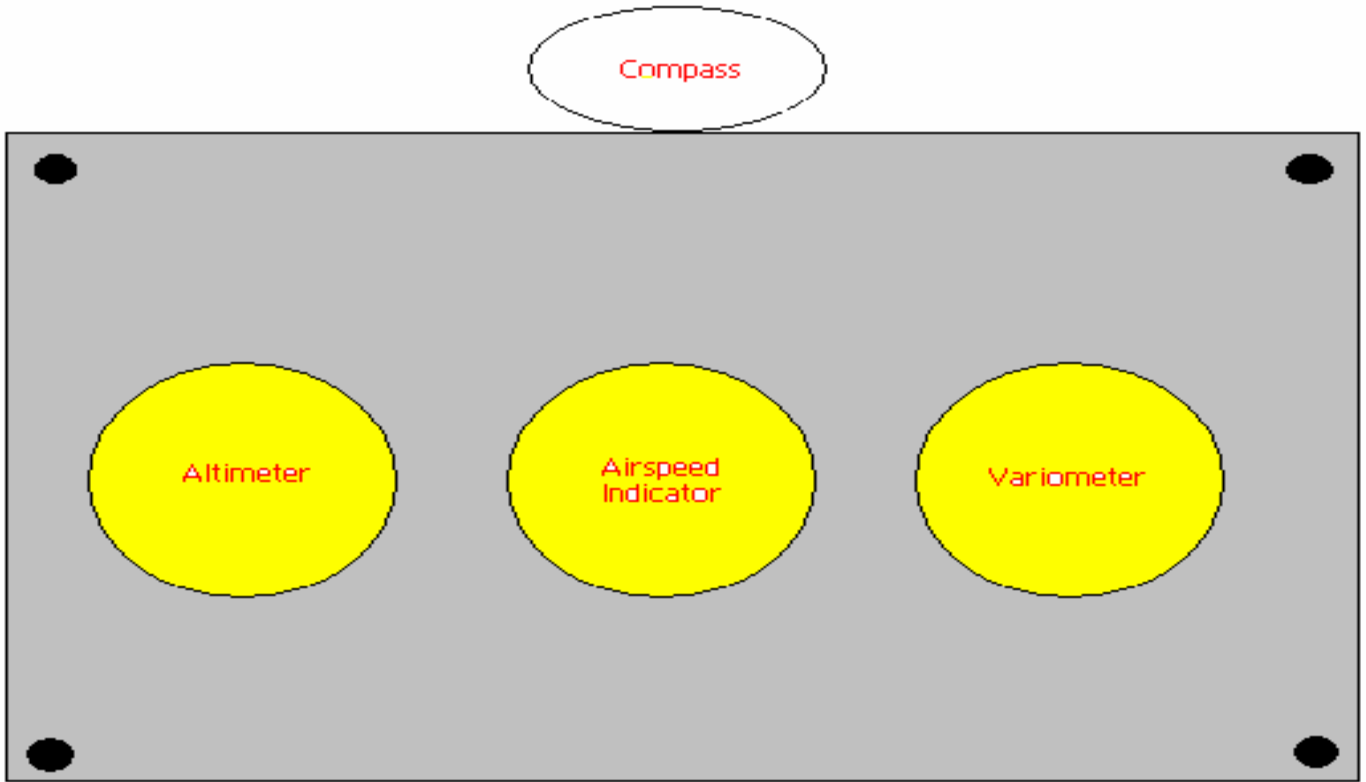


Fig.5.6.1B Instrument Orientation



Fig.5.6.1C: The color marking kit will be used to satisfy the FDR regulations for airspeed indicator by highlighting the different tolerable ranges in airspeed for the aircraft.

5.7 Control Mechanisms

The pilot seat will be upright, fixed, and nonadjustable since different sized seat cushions will be used to compensate for the pilot's size and shape. Temper foam will also be used on the seat to cushion for crash safety. Furthermore, the controls for the cockpit will be kept conventional since it will be easier to install them than an adjustable seat mechanism. The controls will consist of the following:

- Adjustable rubber pedals (will buy)
- Center stick (aluminum)
- Spoiler handle on left
- Release knob at base of panel (yellow or red)
- Hinge canopy on right side

5.7.1 Ailerons

The ailerons will be controlled with a pull-pull system running from the yoke to the wing trailing edge. A bell crank will translate the pull-pull input to a push-pull rod connected to the aileron.

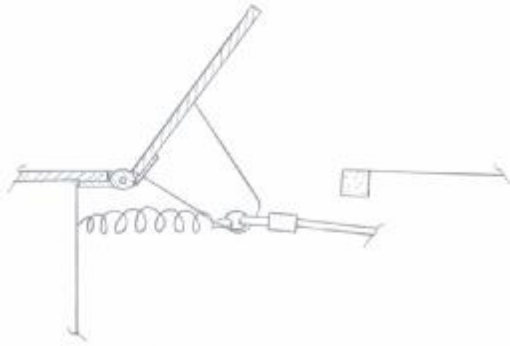
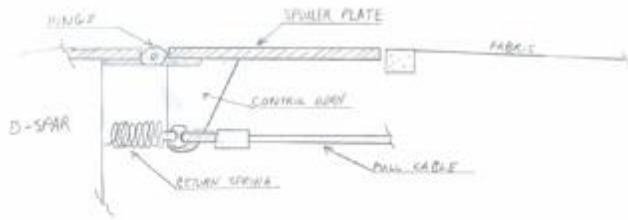
5.7.2 Elevator and Rudder

Controls for the elevator and rudder will be pull-pull cables connected to the yoke and rudder cables respectively.

5.7.3 Spoilers

The spoiler blades will be flat pieces of aluminum. Since our airfoil is fairly insensitive, it should be acceptable that the spoilers don't follow the airfoil contour. They will sit in a fiberglass spoiler pan such that they are flush with the upper wing surface. The spoiler pan will keep debris out of the wings as well as provide sealing to minimize interference drag. Spoiler plates will be hinged to the trailing edge of the D-tube with piano hinge.

Spoilers will be held in their closed position by springs. They will be deployed by a cable which pulls on a control horn. Cables were selected instead of pushrods because they are lighter, cheaper, and easier to route. The cables will disconnect at the wing root to allow for removal of the wings.



6.0 Stability and Control

The stability of a glider is dependent upon the location of its center of gravity and neutral point. In order to be stable, the center of gravity must lie in front of the neutral point. A range of acceptable CG locations was found. In order to do this, the neutral point location must be known. This was calculated using the neutral point equation located on page 479 of Aerodynamics, Aeronautics, and Flight Mechanics. This point was determined to lie 1.97 ft aft of the leading edge at the root. The CG typically lies between 5-10% of the mean aerodynamic chord in front of the neutral point. This yields a CG range of 1.74 ft to 1.85 ft behind the leading edge.

7.0 Drag Build-Up

A spreadsheet format was used to help outline an approximation for the total drag. The sailplane was broken into four main parts: fuselage, wing, horizontal tail, and vertical tail. The drag was calculated individually and then combined to approximate the total drag.

7.1 Parameters

There are several parameters used throughout the drag build-up. Their values are listed as follows:

- Weight = 460 lbs
- Sea-level conditions are assumed:

$$\text{Density } (\rho) = 0.002377 \text{ slugs/ft}^3$$

$$\text{Kinematic Viscosity } (\nu) = 0.000157 \text{ ft}^2/\text{s}$$

7.2 Wing

An approximation for our span-wise efficiency factor was used to help compile further data: $e = 0.94$ (linear tapered wing planform). Also, the SM701 airfoil data was used in calculations.

7.2.1 Calculations

In starting, two columns were created for velocity in knots and feet per second; the data began at 25 knots and ended at 60 knots. Next a C_L was calculated for each velocity:

$$C_L = \frac{2W}{\rho V^2 S}$$

Then the induced drag coefficient was found using:

$$C_{Di} = \frac{C_L^2}{\pi e AR}$$

Where the aspect ratio and is defined as:

$$AR = \frac{b^2}{S}$$

Then the Reynold's Number was calculated at each velocity:

$$Re\# = \frac{Vc}{\nu}$$

Next, the C_D for each velocity was found from the C_L vs. C_D graph of the SM701. The calculated C_L was used to locate the corresponding C_D on the graph.

The drag of the wing was found by totaling the drag at each velocity; which is found using:

$$D = 0.5\rho V^2 S(C_{Di} + C_D)$$

7.3 Horizontal Tail

The drag for the horizontal tail is calculated similarly to that of the wing. Though for the horizontal tail C_L is assumed to be a constant 0.15 for all velocities. This is due to the airfoil characteristics. Because C_{Di} varies only with C_L , C_{Di} is also constant for the horizontal tail. Though the C_D changes since Reynolds's Numbers will vary for different velocities.

7.4 Vertical Tail

Again, the drag is calculated similarly to that of the wing. But, C_L is assumed to be zero because the vertical tail is not a lift-contributing factor on the glider. Thus C_{Di} will also be zero. The profile drag is the only contributing drag component for the vertical tail.

7.5 Fuselage

This portion of the drag build-up is by a far the most complicated method. Because of the fuselage's geometry, it must be broken up into sections to adequately approximate its total drag.

For simplicity, transition from laminar to turbulent flow was assumed at the canopy; approximately 2 ft from the nose of the glider.

To begin, the glider was broken into 1 ft sections. At each point the circumference was determined for use in later calculations.

| x (ft) | h (ft) | X (ft) | h (ft) | x (ft) | h (ft) | x (ft) | h (ft) | x (ft) | h (ft) |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 0 | 0 | 6 | 11.7 | 12 | 8.42 | 18 | 3.67 | 24 | 3.67 |
| 1 | 3 | 7 | 11.9 | 13 | 6.49 | 19 | 3.67 | 25 | 3.67 |
| 2 | 4.17 | 8 | 11.7 | 14 | 4.42 | 20 | 3.67 | 26 | 3.67 |
| 3 | 8.81 | 9 | 11.6 | 15 | 3.67 | 21 | 3.67 | 27 | 3.67 |
| 4 | 10.1 | 10 | 11.2 | 16 | 3.67 | 22 | 3.67 | 28 | 3.67 |
| 5 | 11.1 | 11 | 10.5 | 17 | 3.67 | 23 | 3.67 | | |

At each length and velocity, Reynold's Numbers were calculated for each velocity. These velocities were also used to calculate skin friction, C_f , and drag was calculated using C_f for C_D . For laminar flow skin friction is found using:

$$C_f = \frac{0.664}{(Re)^{1/2}}$$

and for turbulent flow:

$$C_f = \frac{0.0576}{(Re)^{0.2}}$$

Drag is then found using:

$$D = 0.5C_f \rho U^2 S$$

for both laminar and turbulent flow. The drag for each velocity is then summed up for both the laminar and turbulent flow cases to achieve the total drag for the fuselage. (It may be useful to note that these are Blasius Solutions – flat plate solutions; flat plates were used for the empennage and fuselage.)

7.6 Total Drag

The drag was calculated for each of the above four sections individually and then combined for a total drag. To compensate for inference drag the total drag is multiplied by 10% and added to itself to generate a new total drag:

$$NewD_{total} = (D_{total})10\% + D_{total}$$

Trim drag has been neglected in these calculations due to its effects not being large enough to be worth consideration under the given flying conditions.

7.7 L/D

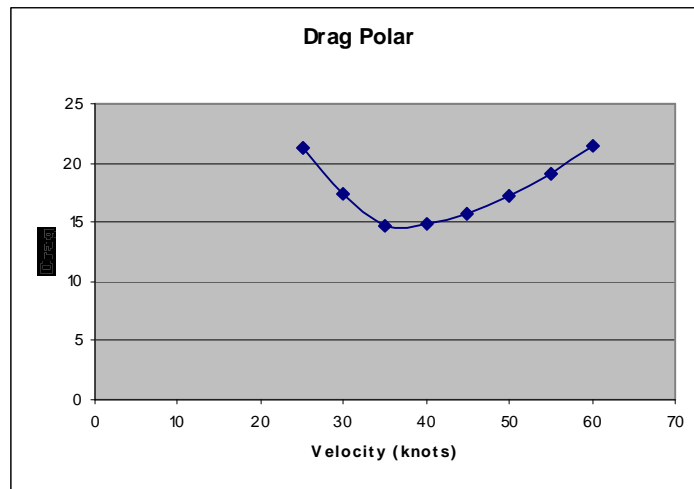
The lift to drag ratio for each velocity can be calculated for the total drag. Notably, the assumption that $L = W$ must be made to do so (weight does not vary).

$$\frac{L}{D} = \frac{W}{D_{\text{total}}}$$

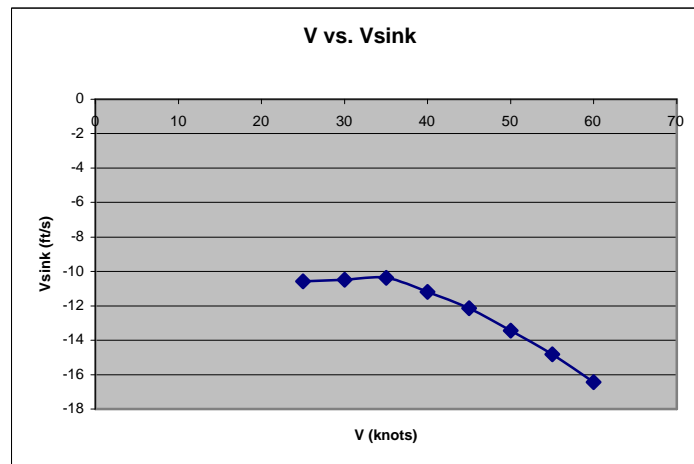
7.8 Drag vs. Velocity

The drag polar, drag plotted vs. velocity, shows the quadratic relationship between lift and drag (as can be seen from the graph).

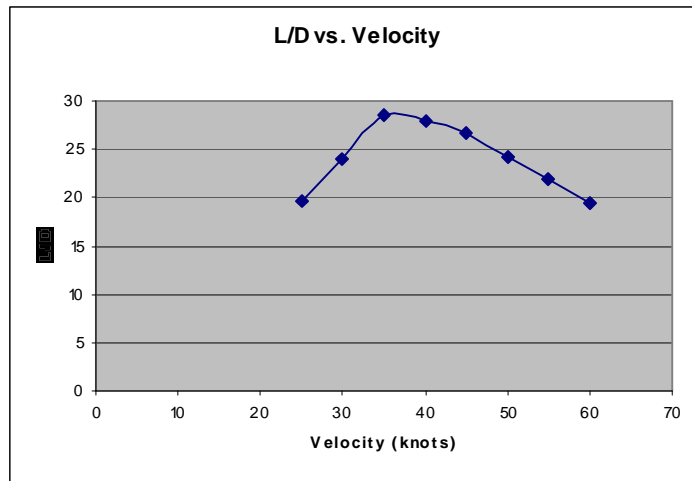
$V_{\text{min}} \sim 42.2 \text{ ft/s}$



7.9 Velocity vs. Vsink



7.10 L/D vs. Velocity



8.0 Loads

8.1 V-n Diagram

The load diagrams were calculated using standard JAR-22 procedures. The following values were assumed in order to calculate critical points on the diagram:

$$C_{d\min} = .03$$

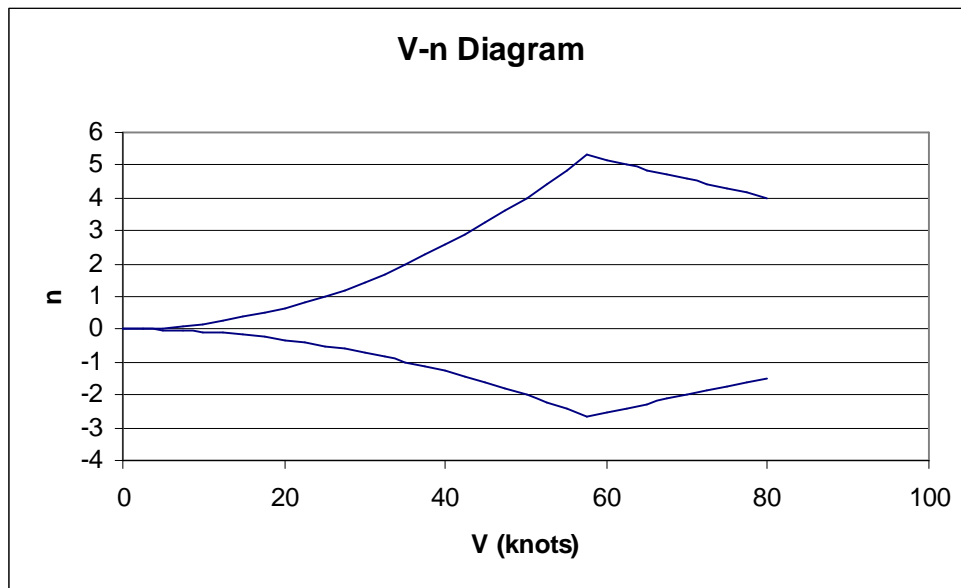
$$V_{s1} = 25 \text{ kts (Stall speed)}$$

These yield the following values:

$$V_A \approx 58 \text{ kts (Design maneuvering speed)}$$

$$V_D \approx 80 \text{ kts (Design maximum speed)}$$

8.1.1 Maneuvering



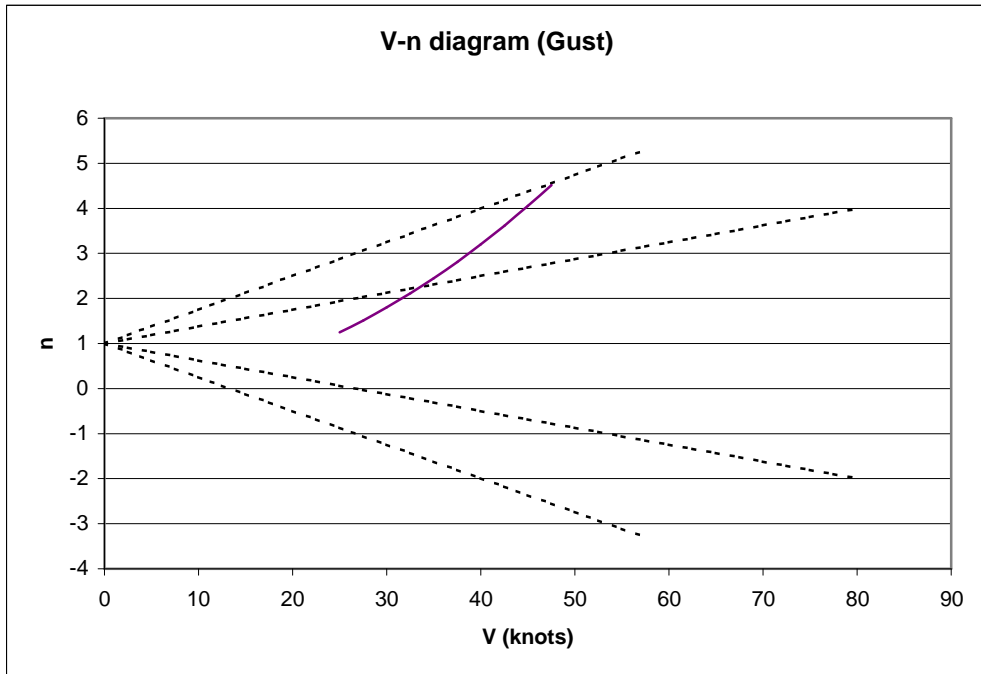
8.1.2 Gust

For the gust load case, the load curve is found by plotting the equation in part (a) of JAR 22.341 using gust cases of ± 7.5 m/s and ± 15 m/s. The following values were used to solve the equation:

$$\rho = 1.190 \text{ kg/m}^3 \quad (\text{density at 1000ft})$$

$a = 5.6$ (slope of wing lift curve)
 $k = .432$ (gust alleviation factor)
 $\mu = 5.12$ (non-dimensional sailplane mass ratio)

This can be plotted along with a do not exceed loading from the JAR-22 to find the gust envelope.



8.2 Flight Forces

8.2.1 Spanwise Lift

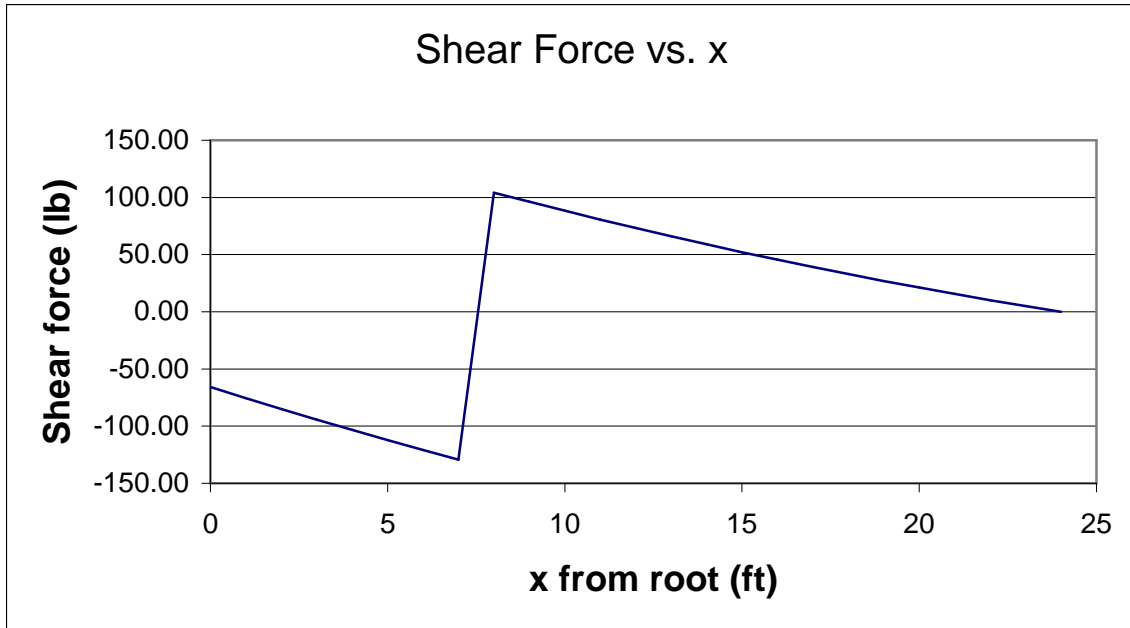
The lift distribution was approximated as proportional to the chord such that the total lift was equal to the weight.

8.2.2 Spanwise Drag

The drag distribution was approximated as proportional to the chord such that the total lift was equal to the weight.

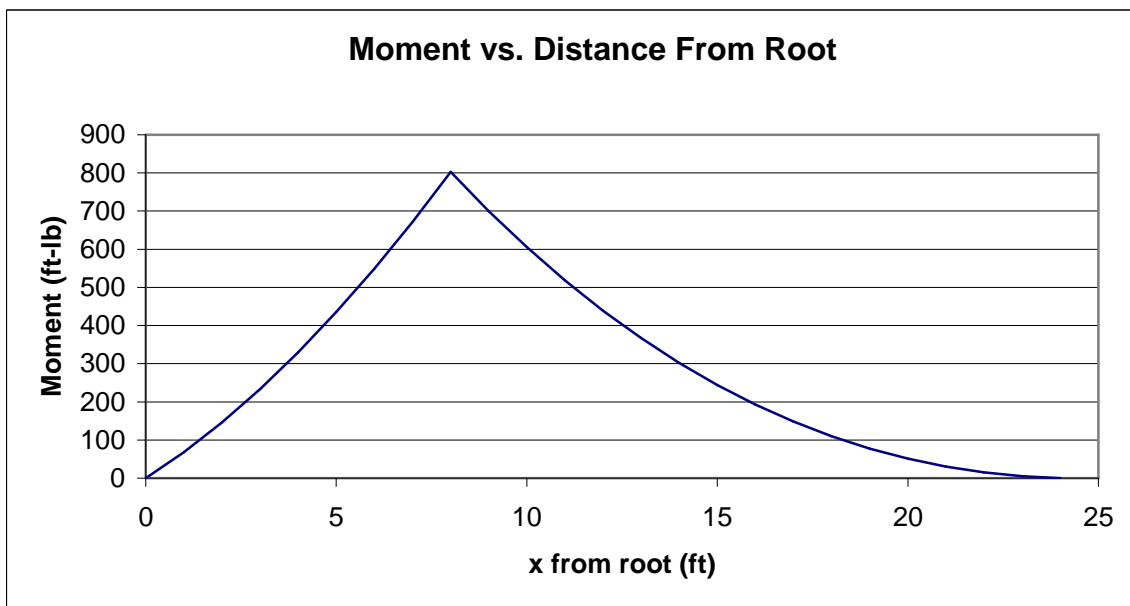
8.2.3 Spanwise Shear

The strut takes most of the shear force due to lift, which can be seen in the shear graph.



8.2.3 Spanwise Moment

The maximum moment occurs at the strut, and causes the moment at the root rib to go to zero.



9.0 Weight Estimate

The following weights were found by comparing similar components on existing aircraft:

| | |
|-----------------------|---------------|
| Fuselage | 80lb |
| Vertical Tail | 10 lb |
| Horizontal Tail | 13 lb |
| Wing..... | 180 lb |
| Max Pilot Weight..... | 177 lb |
| Total..... | 460 lb |

10.0 Cost Estimate

The following prices for each component were found using internet search and

| | |
|-----------------------|---------------|
| Instrumentation | \$1500 |
| Covering..... | \$1500 |
| Hardware..... | \$650 |
| Composites..... | \$2000 |
| Tailboom | \$750 |
| Misc..... | \$2000 |
| Total | \$8400 |

12.0 Conclusion

Through innovative design and supporting calculations, the KS-1 has proven to be an easy-build sailplane whose fabrication is well within the reach of the AERSP 204H/404H students. The clever utilization of prefabricated parts in conjunction with a relatively simple, modular design has established a sailplane design that, in the least, has paved the way to a breath of knowledge. Further, the KS-1 may change the entire effectiveness of the sailplane class. In the future, the class will have found that a sailplane can be built within a reasonable time as opposed to wasting countless hours in a fabrication standstill. Consequently, with the breakthrough design of the KS-1, the sailplane class can take new shape and soar to new heights.