2 Glidersonde Design

2.1 *Mission*

Understanding the mission of the aircraft is important to determining the size and configuration of the vehicle. The mission is shown schematically in Figure 2-1.

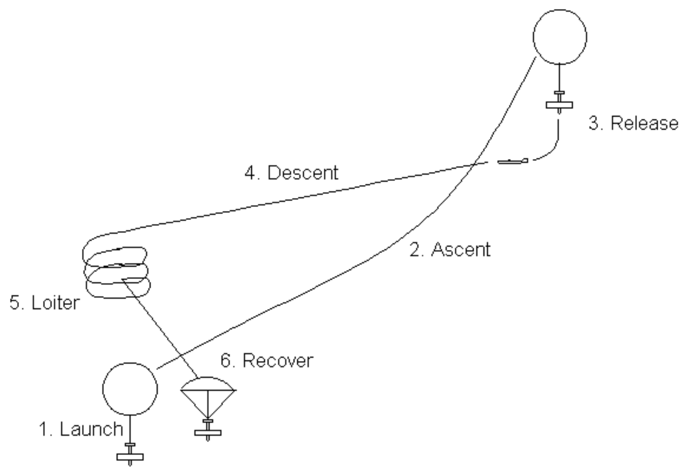

Figure 2-1 The Glidersonde Mission

The Glidersonde is carried aloft by a conventional gas-filled balloon measuring p-t-h and position data as it rises. At a preset altitude, the Glidersonde releases itself from the balloon. The aircraft naturally flies to a level attitude and the autonomous navigation system steers it to the home location. After reaching the home location, the glider circles while descending. At a preset altitude above ground, a parachute deploys and the glidersonde is recovered. The vehicle can then be refurbished and reused.

Data recovery can take one of two forms. The data can be stored internally in rewritable memory and downloaded after the vehicle is recovered or the data can be telemetered to a ground station as it is acquired. During the prototype stage, this second option was chosen to allow witnessing the position, speed, heading, and altitude of the glider during all phases of the flight.

2.2 *Aerodynamic Design Criteria*

In a Master's Thesis completed in 1998, Maselli proposed a simple model for designing the Glidersonde. His analysis was based on the assumption that the ascent time in the mission was equal to the descent time and using those assumptions and aircraft performance equations, he arrived at the conclusions that the vehicles true air speed must equal twice the average wind speed and that the lift to drag ratio (L/D) required is

$$\left(\frac{L}{D}\right)_{req} = \frac{2 \cdot V_{wind}}{V_{ascent}} \tag{2-1}$$

where V_{ascent} is the balloon ascent rate. Here we propose a less restrictive approach that will allow the choice of aircraft parameters to directly meet the design criterion that the glider be able to return home safely.

Assume the balloon ascends at a constant rate to a target height, H, in time T_1. The distance that the balloon moves downwind is then

$$X_{down} = \frac{V_{wind}}{V_{ascent}} \cdot H \tag{2-2}$$

Assume that the craft flies on a constant glide slope coming home and that it drops a total distance H, where

$$H = V_{yac} \cdot T_2 \tag{2-3}$$

where T_2 is the time to return and V_{yac} is the vertical speed of the glider. During this same time the craft moves a horizontal distance

$$X_{up} = \left(V_{xac} - V_{wind}\right) \cdot T_2 \tag{2-4}$$

where V_{xac} the horizontal speed of the glider. Since one can show that

$$\frac{L}{D} = \frac{V_{xac}}{V_{yact}} \tag{2-5}$$

Equation 2-4 can also be written as

$$X_{up} = \frac{L}{D} \cdot \left(1 - \frac{V_{wind}}{V_{xac}}\right) \cdot H \tag{2-6}$$

Neglecting, for the moment, the loss of altitude in recovery or turn-around, for the vehicle to return home safely

$$X_{up} \geq X_{down} \tag{2-7}$$

Substituting equations 2-2 and 2-6 into equation 2-7 yields the upper limit on the wind velocity of

$$V_{wind} \leq \frac{L/D}{\frac{1}{V_{ascent}} + \frac{L}{D} \cdot \frac{1}{V_{ac}}} \qquad (2\text{-}8)$$

in which the difference between the horizontal speed and the total speed of the glider has been ignored. Of course, the lift to drag ratio is a function of the speed of the aircraft as well as other design parameters. Thus to complete the analysis, this relationship must be established.

Following standard aircraft analysis[7, 8], the L/D ratio can be expressed in terms of the aircraft lift and drag coefficients as follows:

$$\frac{L}{D} = \frac{C_L}{C_D} = \frac{C_L}{C_{D0} + \frac{C_L^{\,2}}{\pi \cdot e \cdot AR}} \qquad (2\text{-}9)$$

where C_{D0} is the parasite drag coefficient***, e*** is the Oswald efficiency factor, and AR is the aspect ratio of the wing. For a rectangular planform, the aspect ratio of the wing is the span divided by the chord. The parasite drag coefficient, C_{D0}, represents the minimum drag and is affected by all components that are exposed to the airstream. An aerodynamically "clean" aircraft will have a small C_{D0} whereas a large C_{D0} is the result of a "dirty" or "draggy" design. The second term in the denominator of equation 2-9 is the induced drag and is caused by the inclination of the lift vector in the direction of the airstream.

The lift coefficient is related to the weight and speed of the aircraft by

$$W = \tfrac{1}{2} \rho S V_{ac}^{\,2} C_L \qquad (2\text{-}10)$$

where ρ is the air density, S is the wing area, and V_{ac} is the airspeed of the craft. By combining equations 2-8, 2-9, and 2-10, lift to drag ratio can be expressed in terms of the aircraft parameters and the speed

$$\frac{L}{D} = \frac{2 \cdot W / \left(\rho \cdot S \cdot V_{ac}^{\,2}\right)}{C_{D0} + \frac{\left(2 \cdot W / \left(\rho \cdot S \cdot V_{ac}^{\,2}\right)\right)^2}{\pi \cdot e \cdot AR}} \qquad (2\text{-}11)$$

Now choosing values for C_{D0}, W, ρ, S, AR, and e allows the computation of L/D as a function of V_{ac} using equation 2-11 and, using equation 2-8, a computation of the upper wind speed limit that this particular design can sustain and still return home safely.

An example plot of the upper limit of wind speed as a function of aircraft speed for the following parameters

C_{D0}	W	S	AR	e	V_{ascent}
0.025	7.0 lb	600 in^2	6	0.7	7 meter/sec

is shown in Figure 2-3.

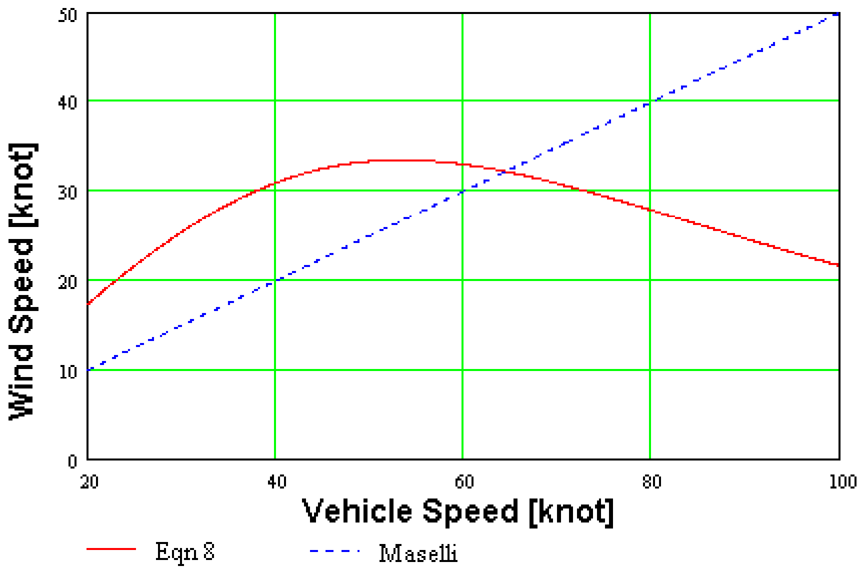

Figure 2-3 Max Wind Speed for Safe Return for a Glidersonde Vehicle

This particular vehicle, which is the prototype discussed in section 3 of this report, is not capable of returning to home if the average wind speed is above 32 knot. Although it could achieve speeds of up to 100 knot, the L/D ratio is too small at these speeds. The line identified as Maselli is based on the equal times for ascent and descent that was assumed in the earlier work. It is clearly conservative for the lower speeds but it is not obvious that, at the higher speeds the L/D required by equation 2-1 is not achievable.

Equation 2-8 also shows that the best flight speed for this particular design and ascent rate is about 55 knots. The ascent rate does affect both the max wind speed for safe return and the optimum speed of the vehicle. Reducing the ascent rate to 5 m/sec will reduce the max wind speed to 29 knots and the optimum vehicle speed to 49 knots.

Note that this analysis does not include the loss of altitude due to the vehicle dropping off the balloon and the loss caused by the glider turning around if it is moving down wind after separation. Consequently a safety factor should be included in using this approach to evaluate the max wind velocity a Glidersonde can endure and return home safely.

2.3 *Vehicle Design*

The object of the Glidersonde is to transport a conventional or custom instrument package aloft and return it to the launch point while allowing continuous measurement of meteorological data in the ascent and the descent phases of the mission. There are two options to consider in terms of recovering the vehicle for reuse. The first, pictured in Figure 2-1, is the use of a parachute which would be deployed at a fixed height above the ground level. The second option is to incorporate a conventional radio control system to allow a ground-based pilot to land the glider. As both of these options have merit in differing circumstances, both will be considered in this report.

The systems to be incorporated into the design include:

1. Instrumentation Package
2. Navigation system
3. Control actuators (servos)
4. Power supply
5. Recovery System
   a. Parachute
   b. RC Flight Control System
6. AirFrame

2.3.1 Instrumentation Package

The current effort is centered around an instrument package that measures 2.5 x 3.75 x 6 in and has an antenna that projects from one end a distance of 7.5 in and a sensor strip projecting from the side that measures 4.5 in from the case. A of the drawing is shown in figure 2-4.

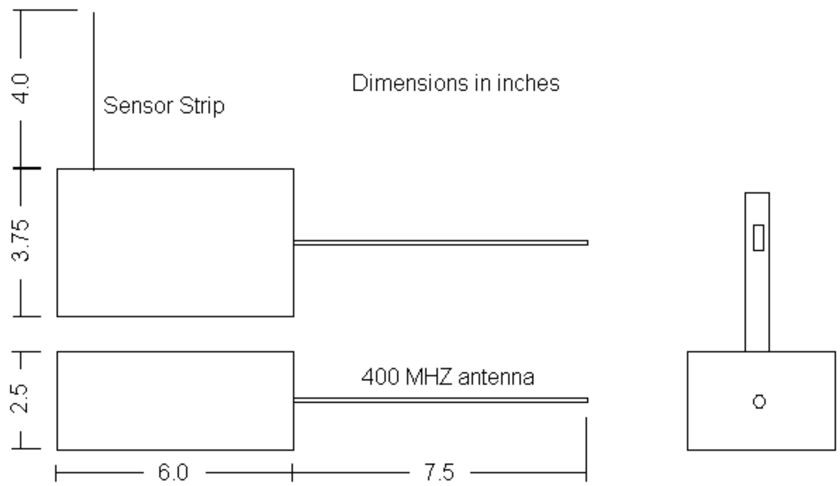

Figure 2-4 Meteorological Instrument Package

The bulk of this package is a closed-cell foam protective enclosure. The actual instrumentation is significantly smaller and is shown in Figure 2-5. The weight of the bare package is 50 gm.

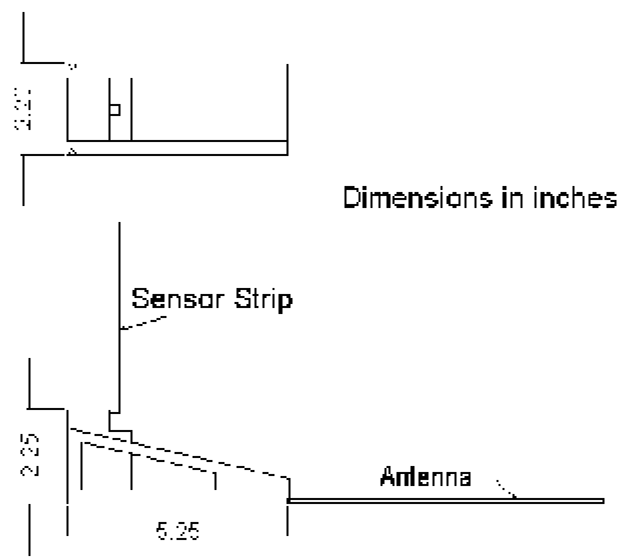

Figure 2-5 Instrumentation Package with Foam Enclosure Removed

There are three options for including an instrumentation package in the Glidersonde:

1. Include the full package as shown in Figure 2-4
2. Include the bare package as shown in Figure 2-5

3. Integrate the sensor into an alternate telemetry unit that is now being used to determine the position and altitude of the Glidersonde.

Option 1 has the disadvantage of increased size and weight although weight increase is not critical. However using the smaller sized package will allow much more flexibility in placement of the sonde without compromising the size of the vehicle.

Option 3 is actually the best choice from a design standpoint. The telemetry package is mandatory in order to be able to track the Glidersonde.

2.3.2 Navigation System

The navigation system consists of several components:

1) Navigation microprocessor
2) GPS antenna and receiver
3) Servos for actuating control functions
   a) Rudder
   b) Balloon Release
   c) Parachute or elevator
4) Batteries
5) Autopilot
6) Parachute or RC Receiver/switch

The navigation processor will be discussed in more detail in Section xx. For the moment, the size and weight are the only parameters that are of interest. The sizes and weights of the navigation system and other components are listed in Table xx.

Table 2-1 Size and Weight of Components

Item	Dimensions		Weight	
	in	[mm]	[oz]	[gm]
Computer	3.0 x 3.0 x 2.0	76 x 76 x 51	7.0	200
Computer Battery Pack	4.0 x 2.3 x 0.65	102 x 57 x 16	7.0	200
GPS	3.8 x 2.3 x 1.1	97 x 58 x 28	4.4	125
Autopilot	5.0 x 2.0 x 1.5	127 x 51 x 38	6.2	175
Servo (each)	2.3 x 1.8 x 0.75	57 x 44 x 19	1.6	45
RC receiver	2.0 x 1.3 x 0.75	51 x 32 x 20	1.6	45
RC Battery Pack	2.3 x 2.3 x 0.70	57 x 57 x 18	3.5	100
RC/Computer Switch	3.0 x 1.7 x 1.0	75 x 43 x 25	1.6	45
Parachute (folded)	7.0 x 4.0 x 3.5	178 x 101 x 101	8.6	245
Cables and switches			3.5	100
Telemetry System	4.5 x 2.0 x 1.5	114 x 51 x 38	4.4	125

The total weight of all of the components, including three servos, is 1400 gm or 3.1 lb.

2.3.3 Airframe

The analysis presented above indicates that, to achieve a penetration that would allow the Glidersonde to return safely in maximum average winds of 45 knots, the following aircraft parameters would suffice

$$W := 6\cdot\mathrm{lbf} \qquad C_{D0} := 0.011 \qquad e := 0.8 \qquad AR := 5 \qquad S := 300\cdot\mathrm{in}^2 \qquad V_{ascent} := 5\cdot\frac{\mathrm{m}}{\mathrm{sec}}$$

Larger wing areas and higher values of C_{D0} would yield smaller values of the maximum average wind speeds that the glider could handle. With this in mind, the configuration shown in Figure 2-6 should be capable of returning to home in average winds of 35 knots or less.

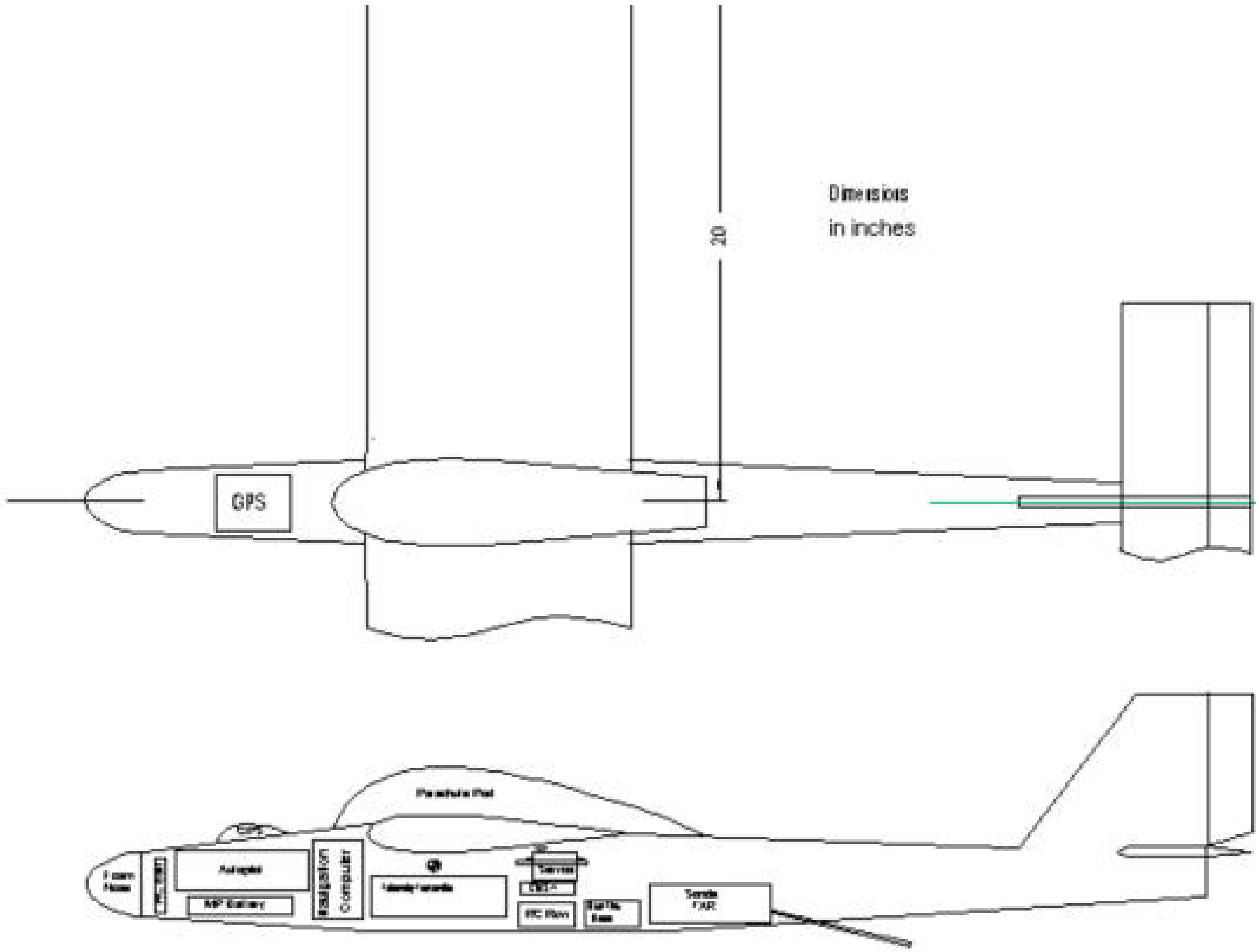

Figure 2-6 Glidersonde Airframe Configuration

The construction of the airframe shown in Figure 2-6 would follow common model airplane practice. The fuselage and fin is to be made of fiberglass cloth and epoxy resin layed in a female mold constructed from a male hardwood model of the exterior shape. The fuselage would be cast in two pieces, left side and right side, and joined after the two halves are removed from the molds. Formers and bulkheads will be installed in the fuselage at several positions (not shown in the drawing) to stiffen the structure and to prevent movement of the components in the airframe. The parachute pod is also a molded fiberglass/epoxy shell that will double as a drag chute when it is released.

The wing and horizontal stab will be constructed of a core of closed-cell light weight polystyrene foam covered with either a mylar covered thin foam board, thickness about 0.8 mm, or by vacuum bagging a light weight fibercloth/epoxy resin directly over the foam. The foam board has the advantage of ease and speed of construction and the fiberglass/epoxy has the superior strength and durability. The control surfaces will be mylar covered balsa wood or foam core with fiberglass/epoxy skins vacuum bagged as described for the wing.

The wing will be bolted to the fuselage so that it can be removed for access to the components and so that several wing of varying sizes can be used with one fuselage. The removable wing has several advantages. In addition to easy access to internal components, different wing sizes can be used for different missions. Also the wing will probably be the most easily damaged component, and the removable wing will allow replacement with less expense. The total weight of the airframe is estimated at 3 lb or 1360 gm.