DESIGN OF AN UNMANNED VEHICLE FOR LAUNCHING SAILPLANES

(FEASIBILITY STUDY)

By Sridhar V. Rao, Matthew Greenman, Christopher Tunney and Chad Lagace'

Presented at the XXIV OSTIV Congress, Omarama, New Zealand, 1995

Abstract

The advent of the GPS (Global Positioning System) has caused a revolution both in aviation and non-aviation navigation. A GPS bought for domestic use relays position with much better accuracy and is more reliable than a million dollar INS (Inertial Navigation System) or IRS (Inertial Reference System) used by airliners.

Few, though are aware that the GPS is causing a revolution in the guidance of vehicles as well. Remotely controlled vehicles such as target drones and missiles in the past used Inertial Guidance systems mounted on very expensive high speed gyroscopes. The advent of technology has made it far more cost effective to replace them with a Differential GPS mounted on Ring Laser gyroscopes using solid state circuits with no moving parts (Texas Instruments bought such equipment recently from vendors such as Honeywell). The cost of such gyroscopes is plummeting every day.

This improvement in technology inspired me to design the airplane which I present in this article. Its sole mission is to function as a launch vehicle for sailplanes. Piloting the airplane remotely by ground operators makes it extremely cost effective due to the considerable weight shaved off by the absence of a tow pilot as well as equipment required for the accommodation of occupants in the airplane.

Introduction

The design of a remotely piloted airplane used for launching sailplanes is presented. Its guidance and flight path is controlled remotely by operators on the ground throughout the launch operation.

Aero-towing with conventional aircraft such as the Bellanca Scout or the Piper Pawnee is extremely expensive. The tow plane must exercise full throttle during the launch. Owing to its much lower Lift to Drag ratio as well as performance when compared with that of a sailplane, reducing the weight of the tow vehicle is very critical to the cost of operations.

Thereby, the design of a remotely piloted vehicle for launching gliders is a very attractive consideration. Considerable weight is shaved off due to the absence of a tow pilot, equipment for the comfortable accommodation of occupants in the tow aircraft, large fuselage as well as instrumentation. After completing the Conceptual Design, even a very conservative performance estimate showed that the vehicle would have only 500 lb take-off gross weight, requires only a 120 hp engine, and even then provide climb rates of up to 600 fpm for very heavy sailplanes such as the ASH-25 or the Grob-103.

Mission Statement

A typical glider launch operation with this vehicle is almost identical to that executed using a currently available tow plane. The design mission for the RPV (Remotely Piloted Vehicle) can be summarized as follows:

1) Warm up and Take-off
2) Climb and Release
3) Loiter
4) Descent and Landing

Design And Initial Sizing

In our design, we shave off considerable weight from the craft by eliminating the cabin entirely. While the engine and its power are the same as the type seen in two-seat General Aviation aircraft (our calculation showed that 120 hp is ideal), there is no tow pilot or a conventional airframe. Instead, most of the weight is attributed to the engine, the landing gear, wing and control surfaces. Thereby, we have an airplane whose weight is significantly less than that of existing tow planes, and this would enable gliders to obtain very high rates of climb in addition to considerably reduced operating costs.

This airplane is mostly made up of a typical engine in the 120 hp category. The engine is covered with a conventional cowling and a standard fixed pitch propeller. Extending from the cowling is a main wing which can generate sufficient lift to support the craft at about 40 knots. This airplane also flies as fast as 60 knots. These speeds have been chosen because a wide range of sailplanes fly comfortably in this range. A boom extends from the back of the engine the other end of which is attached to a conventional tail surface. The airplane is radio controlled which implies that all controls are attached to the same type of servo-actuators typically found in target drones. To provide ground clearance for the propeller, a small, non-retractable tail dragger landing gear system is installed on the aircraft.

TOGW Estimation:

The decision was made early in the design process to incorporate metal, wood and other standard construction materials into the aircraft design. The availability and manufacturability of these materials will significantly lower the development and manufacturing costs of the aircraft. Composite construction was also considered, but it was determined that the associated high development manufacturing costs exceed the cost saving gained by the reduced empty weight of the aircraft.

Take Off Gross Weight was estimated based on the design mission statement. An aspect ratio of 7.8 and a L/D of 15 were chosen as design target parameters to estimate the Take Off Gross Weight. A payload of 100 lb (not including the glider) was chosen as an initial estimate of the weight of the fly-by-wire control system.

An initial Take Off Gross Weight estimate of 400 lb was calculated using the correlation for metal/wood constructed home built aircraft found in Table 3.1 of Raymer [Ref. 3]. This estimate was used to determine the initial wing loading and the power loading estimates. A revised Take Off Gross Weight estimate of 470 lb was then found using the correlation for metal/wood home built aircraft found in Table 6.2 of Raymer.

The above correlations were intended for home built passenger aircraft rather than unmanned utility aircraft. So, these correlations were compared to a component build up weight estimation. The component weight correlations for General Aviation aircraft found in Chap. 15 of Raymer gave an unrealistically high Take off Gross Weight estimation (over 1000 lb). From data on existing Remotely Piloted Vehicles (Ref. 8), it was concluded that the component weight correlations were not valid for smaller pilotless aircraft. A component weight build up using actual engine and other component data was used to estimate a Take Off Gross Weight of 500 lb. This estimate, confirmed by the initial and revised Raymer correlations, was used in sizing the aircraft.

Wing

The wing of the aircraft is designed to meet a low stall speed of 30 knots, and to maintain cruise speeds close to 60 knots. The design group determined that a very low wing loading is required to meet the stall criteria. Based on the wing loading calculations from Raymer (Ref. 3), a wing loading of 3.66 was chosen. A study relating wing loading to stall speed performance is made using contemporary small homebuilt aircraft. This correlation, included in Appendix F., is used to confirm the low wing loading requirement. In addition to meeting the stall speed requirement, the aircraft is designed to cruise at a maximum of 60 knots. This requirement enables the aircraft to tow a large variety of high and low performance sailplanes. Split flaps are used to attain the desired stall speed, while allowing a wing area small enough to reach the cruise speed requirement. A diagram of the wing is included in Appendix A.

A NACA 4412 airfoil section is used over the entire span of the wing. This airfoil section has a high design lift coefficient ($C_L = 0.4$), a relatively high maximum Lift Coefficient ($C_L = 1.51$) and stalls at a moderately high angle of attack ($a = 12$ degrees). These airfoil characteristics, when combined with a low wing loading, satisfy the 30 knot stall speed requirement. The airfoil characteristics are taken from Ref. 2, and are included in

Appendix B.

The wing has an aspect ratio of 7.8, typical of existing General Aviation aircraft. The wing incorporates neither Geometric nor Aerodynamic Twist; this design simplifies the manufacturing process and reduces the production time and cost. To approximate an elliptical lift distribution, the wing has a Taper Ratio of 0.5. The Wing Span is 29.7 feet, the Mean Aerodynamic Chord is 3.95 feet, and the wing reference area is 113.1 square feet. The wing is swept back 2 degrees to delay stall and increase the longitudinal stability of the aircraft. The wing has an incidence angle of zero degrees with the fuselage. The aircraft has a long wing configuration for aesthetic reasons.

Split flaps are installed on the inboard 50% span of the wing, and account for the trailing 20% of the wing chord. Split flaps have been chosen to reduce aircraft manufacturing and assembly costs. The flaps are deflected about a hinge from 0 degrees down to 60 degrees. With the split flaps fully deflected, the airfoil maximum lift coefficient increases by 27.8%. Ailerons are installed on the outboard section of the wing, from 55-99% span, and occupy the trailing 25% of the chord. The wing tips are also swept up to increase the stability of the aircraft. Also to increase stability, the wing has a dihedral angle of 2 degrees.

Tee Tail

A Tee Tail is used on the aircraft to increase the aerodynamic efficiency, and to reduce the overall tail size. In addition, the Tee Tail is also easier to manufacture and adds style to the overall design (Ref. 3, page 69). The Tee Tail aids yaw and pitch control of the aircraft. The tail has been sized using the tail volume method described in Raymer (Ref. 3). A c_{vt} of 0.04 taken from Table 6.4 in Raymer is used to calculate an estimated vertical tail area of 12.5 square feet. A c_{bt} of 0.5 taken from Table 6.4 in Raymer is used to calculate an estimated horizontal tail area of 20.79 square feet. When a constant tail chord of 3.0 feet is used, a horizontal tail span of 6.93 feet is achieved. All tail surfaces use a NACA 0012 airfoil. The aspect ratio of the vertical tail is 0.51 and has a length of 3.0 feet. Rudders occupy 20% of the trailing edge chord along 10% to 90% of the vertical tail. Elevators occupy the last 20% of the vertical trailing edge chord along 10% to 90% of the horizontal tail.

Landing Gear

Due to the simplicity of the airplane's design, the landing gear is a very simple tail dragger configuration. The main wheel booms are made from composites (fiberglass) and are aligned outwards to provide a spring effect on hard landings. This is a very simple alternative to incorporating shock absorbers. In addition, the wing attachments for the booms are 20 inches from the airplane's longitudinal centerline. This provides for sufficient stability on the ground even against a propeller generating a high torque at full throttle. Raymer's correlation in Table 11.1 indicates a main wheel landing gear diameter of 10.4 inches. The width is about 4.0 inches. The correlation in Chapter 12 of Raymer indicates that the weight of the main wheels is about 27.2 lb each. As for the tail wheel, the indicated diameter is 2.6 inches and the thickness is 1.0 inches. The weight of the tail wheel was calculated to be 4.5 lb. In the air, the main wheels are aligned outward at 30 degrees with respect to the vertical. On hard landings, the alignment reaches a maximum of 45 degrees. The booms are 51 inches in length (this length is provided to give the propeller a minimum of 1.2 feet of clearance from the ground on hard landings).

Engine Sizing and Configuration

For the sizing of the engine, we used Table 5.3 of Raymer and checked this against the values used by conventional tow planes. Appendix D shows the calculations and assumptions used for determining the horsepower requirements for our tow plane. The required power was found by adding together the power needed for a powered sailplane and a composite homebuilt aircraft. The composite homebuilt correlation was used to model our tow plane as we feel that this most closely approximates our design. Since our tow aircraft will be more aerodynamic than a standard aircraft owing to no cockpit area, the required power for our tow plane would be lower. Thus, we believe our calculations to be conservative. Using the above method, we determined that 120 hp would be needed for our tow aircraft. The Cessna 152 uses a 108 hp engine and has a Take Off Gross Weight of 1100 lb (Jane 1985-86). Our tow vehicle has a higher output engine and a lower T.O.G.W.; thus, we believe the engine to be properly sized for the towing of any size sailplane.

For the physical characteristics of our aircraft, we relied on a correlation using existing engines. This correlation is shown in Appendix E and relates currently available engine parameters against the maximum power available for Take off. All data obtained for the correlation was for in Jane's *All World Aircraft* 1992-1993. Only non-turbocharged piston engines were analyzed due to cost concerns and because our aircraft's design mission does not require high altitude flight. Turbo-prop engines were immediately ruled out due to their higher cost when compared to piston engines.

Additional requirements for our engine include a higher output alternator. This is required to provide the additional power needed for the control servos. An electric starter is also to be included. The aircraft has the potential to be started using an auxiliary power system on the ground but we felt that for safety reasons an integrated electric starter would be better. Besides the standard accessories, the engine must also have an electronic control system to monitor all the engine functions. This is needed to ensure proper operating conditions at all times, for example, when the sailplane releases, the engine management computer must be able to reduce the throttle accordingly in order to prevent red-lining the engine.

Shown below is a summary of the engine specifications:

Horsepower	120
Engine Configuration	4 Cylinder Normally Aspirated Piston Engine
Engine Control System	Electronically Controlled monitoring all engine functions (including fuel mixture & engine RPM)
Weight	220 lb
Height	23 in
Width	32 in
Length	30 in

Data obtained from Engine Correlation is shown in Appendix E. The engine cowling will be slightly larger due to mounting and cooling requirements.

Propeller

The propeller chosen for our aircraft is a 2 blade fixed pitch design. The two bladed design was chosen to reduce the weight when compared to a three blade design. The fixed blade will be optimized for the climb configuration. Using a propeller sizing correlation found in Raymer (Ref. 3, page 221), we found the propeller diameter required to be 6' 1" (the propeller calculations are shown in Appendix D). The 6' 1" diameter propeller correlated well with the data for a Cessna 152 which had a 5' 9" propeller for a 108 hp engine. Since we are using a standard front engine configuration with a fixed landing gear, there should be no problems in ensuring proper ground clearance. Currently, we are using a ground clearance of 1.2 ft which should allow for landing on rough or grassy fields. The blade tip speed of the propeller was also analyzed to ensure that the tips do not enter the transonic range; there were no problems found during our analysis. The assumed propulsive efficiency is 90% for the climb condition for which it is optimized.

The table below summarizes the propeller specifications.

Propeller Type	Fixed Pitch (Optimized for Climb)
Number of Blades	2
Diameter	72.8 in (6' 1")
Efficiency During Climb	90%
Ground Clearance	14 in

Fuel System

The fuel system for the aircraft will be stored in two discrete tanks located within the wings of the aircraft. The fuel tanks will be connected through a common connection thereby eliminating the need for switching between tanks. In addition, the connection between each tank will have a one way valve attached to ensure that the fuel from one tank does not inadvertently flow into the other tank during a turning maneuver. The tanks for each wing will be capable of holding approximately 2.5 gallons of fuel each with an assumed usable fuel capacity of 4 gallons total.

The tanks were placed inside the wings rather than within the fuselage due to concerns about possible leakage effects on the electronic controls which would have been located next to the tank if it were placed within the fuselage. The placement of the fuel within the wing also helps with the weight and balance of the aircraft.

Guidance and Control

The RPV flight pattern is defined by preprogrammed waypoints (approximately 10 minutes apart) stored in an onboard computer. At any time during the flight, the air vehicle operator can change the waypoints, or command the RPV to go into a loiter mode. The RPV receives data transmission bursts at periodic intervals while in the line of sight of the operator. Since the aircraft is designed to take off and land at the same airport, this control scheme is very practical. In the event that the data link transmission is interrupted, the RPV continues its flight according to the last set of instructions. An automatic engine shutoff, fuel dump and parachute deployment system are incorporated into the aircraft design in the event that the RPV control becomes unrecoverable.

The flight control subsystem includes a flight control electronics package, an attitude reference assembly, air data transducer, four servo-actuators, a power supply, and a near infra-red source landing aid. The electronics package provides computation capability for navigation, guidance and control of the RPV. The attitude reference assembly is made up of a Differential GPS, a three-axis assembly of Ring Laser Gyroscopes with no moving parts, and a small computer to provide coordinate transformation calculations. Air transducers provide barometric altitude and airspeed information to the electronics package, where it is combined with outputs from the attitude reference assembly to provide signals to the servo-actuators controlling the ailerons, elevators, rudder and throttle. An airborne data terminal receives command signals and returns status information to the remote ground station. The control system is powered by a DC engine driven alternator, and contains a reserve battery in case of an engine failure.

Stability

Stability can be easily attained for this craft by observing three (3) steps in its design: 1) Center of Gravity of the tow vehicle is moved significantly ahead of the aerodynamic center so that the tail surface generates fairly strong downward lift, 2) the wing tips of the main wings are curved up to provide good longitudinal stability and 3) a very large vertical tail is used to prevent the aircraft from developing Dutch Rolls. Several observations have been made for the design and construction of model airplanes, target drones and other radio controlled vehicles during this study. We discovered that providing stability to this tow plane is very easy. Even though it has an extremely large propeller for its size and is considerably overpowered, we concluded that this factor does not hinder its ability to fly or tow.

Safety Considerations

Three types of emergencies are involved in a towing operation: l) a rope break on tow, 2) the towing craft goes out of control and is unrecoverable, and 3) and engine failure on tow.

A rope break below 200 feet altitude above the ground is the most dangerous situation. When this happens, the glider pilot must not make a 180 degree turn to head back but find an alternate spot to land out. To alert the operator to a rope break, a force transducer installed in the tail hook of the RPV sets off an alarm on the ground while simultaneously triggering a loiter mode in the RPV.

If the RPV goes out of control and is deemed unrecoverable, an automatic engine shutoff switch is activated, and a parachute is deployed. The RPV descends for a touchdown with minimal damage to its components. In an engine failure, the aircraft operator must immediately deploy the parachute. Engine failures are easily anticipated and the glider pilot must be ready to release immediately in such an event and avoid the tow plane.

Performance Estimates

Preliminary performance estimates were calculated for the remotely piloted vehicle, using correlations found in Chapters 5 and 17 of Raymer. These estimates are only initial estimates and are subject to change in future revisions. A summary of performance estimates is contained below:

Cruise Speed Range	40 - 60 knots
Cruise Speed at 4000 ft w/min Power	54 knots
Take-off Distance for Rough Field	600 ft
Landing Distance for Rough Field	650 ft
Rate of Climb	550 ft/min

Regulations And Marketability

This important factor would present widely varying types and magnitudes of hurdles in different parts of the world as countries differ sharply in their policy of Air Space Management. For example, in the United States, the FAA requires RPV's to be operated only in extremely sparsely populated areas with very little Air Traffic. Such operations may be performed only at the Government's approval. The vehicle must have either a parachute of a self detonating device to avoid damage to property when the radio control malfunctions or gets out of range. The authors have not studied regulations regarding other countries; we are only aware that European countries and sparsely populated countries such as Australia are more liberal.

In addition, certification for the RPV for commercial operations would prove to be very costly. We are also concerned about overcoming a psychological factor which involves glider pilots being first hesitant to be towed by an unmanned aircraft.

In spite of the above mentioned hurdles, we are confident about this vehicle's success in the future. Certification may be eventually acquired by first operating this vehicle in countries which have very liberal Flight Regulations and Policies. The RPV may then be certified in countries which are more strict after its initial success is proven.

Conclusions And Recommendations:

Using our innovations, we have produced the design of an extremely lightweight Remotely Piloted Vehicle that would allow gliders to attain very high rates of climb in addition to very low operating costs. These costs would stem from the fuel for launching the gliders as well as the frequency of engine overhaul between the launches.

Even though a market is right now difficult for the reasons mentioned above, we believe that persistence at pursuing the usage of this aircraft will pay off and benefit operators around the world considerably in the long run.

References

1) Taylor, J.W.R.; *Jane's All World's Aircraft* 1992-1993; Jane's Publishing Company Limited, London; 1987.

2) Abbott and Von Doenhoff, *Theory of Wing Sections*, Dover, New York, NY 1959

3) Raymer, *Aircraft Design: A Conceptual Approach*, AIAA, Washington, D.C., 1989

4) Thurston, D.; Water Wings; *Sport Aviation Magazine*; Experimental Aircraft Aviation, Oshkosh, MI; Jan 1969.