m
5

p. 8

DESIGN OF A REMOTELY PILOTED VEHICLE FOR A LOW REYNOLDS NUMBER STATION KEEPING MISSION

UNIVERSITY OF NOTRE DAME

N91-18166

Six teams of senior level Aerospace Engineering undergraduates were given a request for proposal, asking for a design concept for a remotely piloted vehicle (RPV). This RPV was to be designed to fly at a target Reynolds number of 1×10^5. The craft was to maximize loiter time and perform an indoor, closed-course flight. As part of the proposal, each team was required to construct a prototype and validate their design with a flight demonstration.

INTRODUCTION

There has been a growing interest in flight applications in the low Reynolds number range, specifically near 10^5. At these low Reynolds numbers, many different phenomena occur. One particular example is lift hysteresis. As an airfoil increases angle of attack in this flow regime, separation bubbles form that alter boundary layer development and influence both lift and drag performance. Through a small angle-of-attack range, these bubbles augment the overall lift of the airfoil. At higher angles of attack, the bubbles break down and may cause a sudden decrease in lift. If the angle of attack is then slowly decreased the bubble may reform and the increase in lift would again be present. There are also significant form-drag penalties associated with this Reynolds number regime.

Another problem faced in this particular application is that of weight constraints. Since the aircraft is flying a constrained, closed course and loiter time is to be maximized, optimally the cruise velocity should be kept to a minimum. This will keep the chord length, and hence the aircraft size, in a limited range. Therefore, for a given velocity range and limited planform size, there is a finite amount of lift that can generated by the craft. Therefore, to take off and maneuver, it is critical that the RPV is weight efficient. This requires selecting a proper propulsion system and aerodynamic configuration for this specialized mission.

There are several applications for which low Re RPVs may be used, both at high and low altitudes. At high altitudes they could be used for meteorological, communications, or reconnaissance purposes. At lower altitudes they could be used for surveillance, or in a rescue mission to locate survivors. Since this study involved nonconventional (nonairbreathing) propulsion systems, they could be used in any hostile propulsion systems, ranging from martian topography mapping to volcanic monitoring on Earth. Another use for these RPVs is in radiation-contaminated areas where human-operated craft would be unsafe.

REQUEST FOR PROPOSALS

The mission and semester project details were defined in the following request for proposals. This request placed some additional requirements and constraints on the basic mission specifications. The design teams were notified that certain aspects of the mission were open for modification, given sufficient justification for these changes.

FLIGHT AT VERY LOW REYNOLDS NUMBERS: A STATION KEEPING MISSION

Opportunity

Most conventional flight vehicles are designed to operate in a flight regime such that the Reynolds number based on mean wing chord is in excess of 10^6 and some currently operate approaching 10^8. Recently there has been interest expressed in vehicles that would operate at much lower Reynolds numbers, less than 10^5. Particular applications are low-speed flight at very high altitudes, low-altitude flight of very small aircraft, and flight in the atmospheres of other planets atmospheres such as Mars. There are many unique problems associated with low-speed flight that pose challenges to the aircraft designer and that must be addressed in order to understand how to exploit this low Reynolds number flight regime. Since many of the anticipated missions for this type of aircraft are unmanned, it is necessary to couple developments in unmanned aircraft development with our knowledge of low Reynolds number aerodynamics in order to develop an aircraft that can fly as slowly as possible at sea-level conditions. This study will help to better understand the problems associated with flight at these very low Reynolds numbers. Considering the potential applications, the aircraft must also be very robust in its control and be highly durable.

Objectives

1. Develop a proposal for an aircraft and associated flight control system that must be able to (a) Maintain level controlled flight and fly a closed-course at flight speeds corresponding to Reynolds numbers less than 2×10^5 and as close to 1×10^5 as possible. The greatest measure of merit is associated with achieving the lowest mean chord Reynolds number possible and maximizing the loiter time on a closed course. (b) Be maneuverable and controllable so that it can

fly a closed pattern and remain within a limited airspace. (c) Use a propulsion system that is nonairbreathing and does not emit any mass. (d) Be able to be remotely controlled by a pilot with minimal flying experience or an autonomous onboard control system. (e) Carry an instrument package payload that weighs 2.0 oz and is 2″ × 2″ × 2″ in size.

2. Take full advantage of the latest technologies associated with lightweight, low-cost radio-controlled aircraft and unconventional propulsion systems.
3. All possible considerations must be taken to avoid damage to surroundings or personal injury in case of system malfunction.
4. Develop a flying prototype for the system defined above. The prototype must be capable of demonstrating the flightworthiness of the basic vehicle and flight control system. The prototype will be required to fly a closed figure-eight course within a highly constrained envelope. A basic test program for the prototype must be developed and demonstrated with flight tests.
5. Evaluate the feasibility of the extension of the aircraft developed under this project to high-altitude station keeping application for atmospheric sampling.

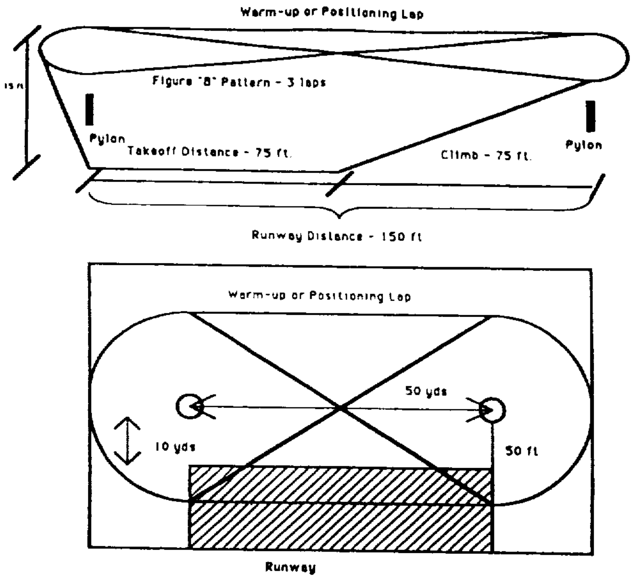

Fig. 1. Schematic of Closed Figure "8" Course

System Requirements and Constraints

The system design shall satisfy the following: (1) all basic operation will be line-of-sight with a fixed ground-based pilot, although automatic control or other systems can be considered; (2) the aircraft must be able to take off from the ground and land on the ground; (3) the aircraft must be able to maximize loiter time within a restricted altitude range on a figure-eight course with a spacing of 150 ft between the two pylons that define the course; and (4) the complete aircraft must be able to be disassembled for transportation and storage and fit within a storage container no larger than 2′ × 2′ × 4′.

In order to successfully satisfy the mission objectives, Design Requirements and Objectives (DR&O) were established by each design team. Principally, the constraints imposed by the confined flight course (see Fig. 1), by maximizing loiter time, and by the necessity for ease of installation and assembly had to be addressed and target parameters identified.

Evaluation of the mission requirements enabled each group to categorize the primary constraints. The ability to take off and land in a 150-ft strip, to establish effective stability and control for all flight speeds, and to execute low-speed turns while maintaining altitude were of extreme importance to satisfy the confined environment constraints. The ability to climb to cruising altitude in a reasonable time and to complete three figure eight patterns around two pylons were main considerations to satisfy the endurance requirements. Ease of installation of the instrument package and compactness for transportation were necessary to satisfy assembly constraints.

General guidelines allowed for minimum performance limits for the RPVs capabilities to be determined. The mission was to simulate low-speed flight at high altitudes, low-altitude flight of very small aircraft, or flight in another planet's atmosphere. In order to approximate these conditions, most groups chose a target Reynolds number of 10^5.

CONCEPT DESCRIPTIONS

The following summaries provide an overview of each of the six concepts. These summaries describe the final concept and address specific technical merits and limitations. Included are selected three-view representations of the aircraft. These summaries are meant to give a brief description of each design, and further technical detail on each proposal is available upon request.

The Drag-n-Fly

The Drag-n-Fly (see Fig. 2) is a remotely piloted, low Reynolds number vehicle. It was designed to maintain level controlled flight and fly a closed course at flight speeds corresponding to Reynolds number of 1×10^5. The success of the mission will be associated with achieving the lowest mean chord Reynolds number possible and maximizing loiter time on the course. The flight plan for the Drag-n-Fly calls for the vehicle to climb to a cruise altitude of 25 ft. Once achieved, the Drag-n-Fly will fly within a restricted altitude range on a figure eight course, complete three laps, and then a final oval to bring the RPV back around in preparation for landing.

The Drag-n-Fly is a high-wing, high-aspect ratio monoplane. The airfoil selected for the Drag-n-Fly was a Spica chosen for its high lift coefficient at low Reynolds number. The wing span is 8.5 ft with total surface area of 6 sq ft and aspect ratio of 12. There is no sweep or twist associated with the wing and the taper ratio is 1.0. The wing loading is approximately 7.1 oz/ft^2.

The propulsion system for the Drag-n-Fly consists of a 10″-diameter propeller mounted on the front of the vehicle. The 10-6 propeller is driven by the ASTRO 05 electric motor using eight 500 MAH nickel-cadmium batteries. This motor/battery combination was selected not only because it is capable of

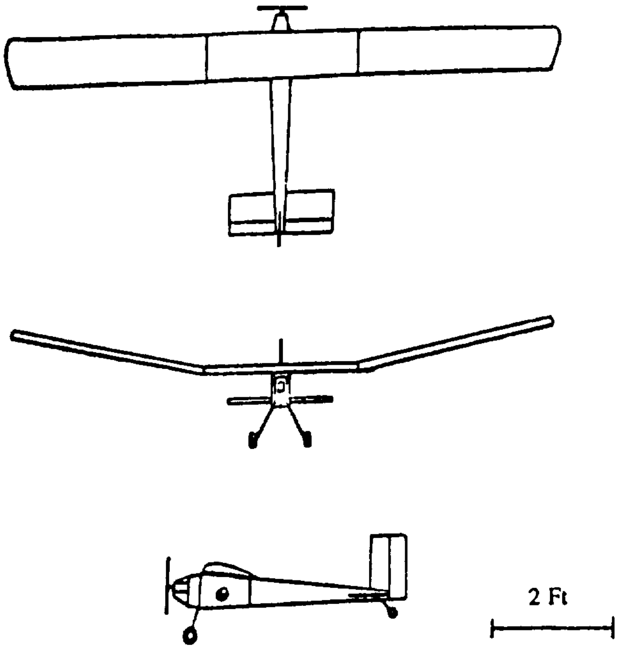

Fig. 2. Drag-n-Fly

providing the thrust needed to accomplish the mission, but also because of its light weight. An electronic speed control was also used to maintain altitude through the turns.

The primary fuselage structure was provided by four longerons running the length of the fuselage. The strongest part of the aircraft is the forward fuselage, since the motor and avionics are located in this region. This area will be reinforced by panels to increase the strength of the front fuselage. The spar/multirib wing design was selected for light weight and durability.

The vertical tail area is 0.5 sq ft and the horizontal tail area is 1.05 sq ft. Two movable control surfaces are used for maneuver control. A rudder will be implemented to control yaw and an elevator to control the pitch during the flight course, and both control surfaces will be actuated by mircoservos. Pitch-yaw coupling through wind dihedral is used.

The design for the Drag-n-Fly will meet the criteria for the present mission. Some areas of concern are accurate wing construction, control of the aircraft in flight (will the control surfaces deflect enough to maneuver the aircraft?), and very limited fabrication experience by the entire team.

The Stealth Biplane

The Stealth Biplane (see Fig. 3) was developed to serve as a remotely piloted vehicle designed to navigate a low-level figure-eight course at a target Reynolds number of 10^5. The basic biplane configuration was selected in order to increase the wing area while maintaining the required mean chord and still satisfying the "storage" requirements. This flight vehicle will combine the latest in lightweight radio-controlled hardware in conjunction with current low Reynolds number aerodynamic research to demonstrate feasible operation in a variety of applications. These potential low Reynolds number applications include high-altitude atmospheric sampling and search-and-rescue operations.

The completed prototype is designed to operate within a confined, closed course. Briefly, this course requires an unassisted ground takeoff followed by a climb to cruise altitude of 20 ft, in position to make the first left hand turn. Upon completion of the turn, a slight loss of altitude is predicted; however, during the straight cruise portion of the flight, this lost altitude can be regained. A similar right-hand turn and subsequent straight cruise completes one full lap around the course. Upon the completion of three full laps around the course, the Stealth Biplane will need to loiter back to the opposite end of the field for the landing run, where a full-stop ground landing will then be executed. This flight plan fulfills all imposed design requirements for normal operation.

Safe operation around such a course can be accomplished by an experienced ground-based pilot, but the pilot workload should be sufficiently light such that even an amateur can control the Stealth Biplane. In order to successfully rotate the Stealth Biplane and ascend to the mission altitude of 20 ft, a powerful propulsion system is required.

The electric motor that was selected to fulfill all the mission requirements was the Peck Silver Streak 035M electric motor, capable of producing a maximum static thrust of 11 N and a maximum power of 95 W. At this power setting, the engine operates at 13,000 rpm and uses an 8-in diameter, 4-in pitch propeller. This propulsion system derives its power from a power pack of 10 AA nickel-cadmium 1.2-V, 600-MAH rechargeable batteries. This entire powerplant will allow the aircraft to achieve its required cruising velocity of 28 ft/sec, with a maximum velocity of 40 ft/sec. This propulsion system was selected for its relatively low weight of only 10.6 oz,

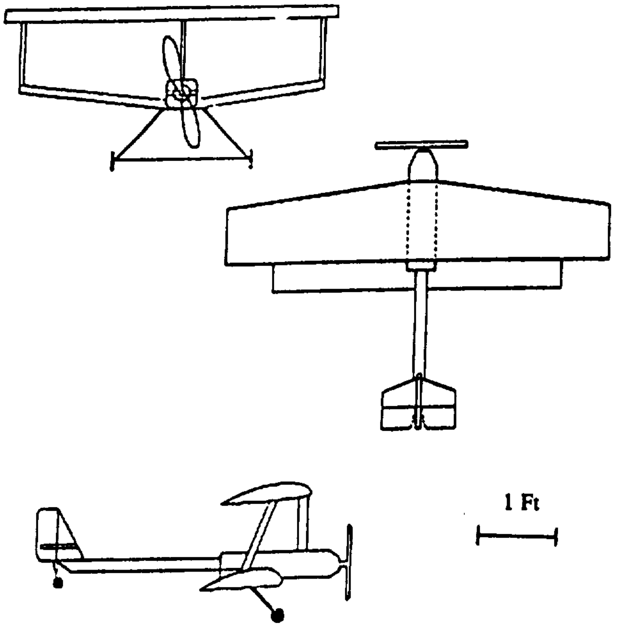

Fig. 3. Stealth Biplane

lowering the total aircraft weight significantly. The most important factor in selecting the aircraft propulsion system was obtaining the necessary power required for take off.

The Stealth Biplane will be receiving its lift from twin lifting surfaces in the form of a staggered biplane wing configuration. The top or main wing measures 4 ft in span, with a root chord length of 8 in, a taper ratio of 0.65, and a mean chord length of 6.6 in. The lower, staggered wing measures 3 ft in span, with the same root chord, taper ratio, and mean chord length as the top wing. The lower wing is staggered 3.2 in aft and 9 in below the leading edge of the main wing. Neither surface is swept; thus, the surface areas of the wings measure 2.2 ft^2 and 1.65 ft^2 for the top and bottom wings respectively. The airfoil selected for both surfaces is the Wortmann FX 63-137 airfoil. However, the lower wing has been augmented with a 5° droop of 13% of the chord at the leading edge, for an overall increase in L/D for that surface.

The construction of the Stealth Biplane requires a variety of fabrication techniques; the wing ribs, spars, and stringers will be fabricated from balsa, and the wing skin will be a mylar-based derivative. The fuselage is constructed from four balsa sheets in a boxlike configuration, with the propeller in the front of the aircraft and the components strategically placed to ensure static and dynamic stability of the Stealth Biplane. The empennage is a simple 1.5-in diameter cylinder that will connect the horizontal and vertical tails with the main fuselage. This length of the tail boom has been designed to provide optimum tail control while still minimizing the overall weight of the aircraft. The empennage (movable rudder and elevator) is constructed from simple flat plates of solid balsa, and the components are controlled by two microservos.

The Penguin

The Penguin is a low Reynolds number remotely piloted vehicle. It has been designed to fly three laps indoors around two pylons in a figure-eight course while maximizing loiter time. Although the Penguin's mission seemed quite simple at first, the challenges of such low Reynolds number flight are quite unique. In addition to the constraint of low Reynolds number flight, the aircraft had to be responsive in its control, highly durable, and very lightweight.

The Penguin's flight plan begins with takeoff on a runway of 150 ft. It will actually lift off in approximately 50 ft, and the remaining runway distance will be used to climb to the cruise altitude of 15 ft. The aircraft will then begin its three laps around the pylons. After completing the last lap, the Penguin will land and come to a stop in approximately 30 ft.

Aerodynamically, the Penguin is similar to standard taildragger sailplane designs. The 7-ft-span rectangular wing is mounted on the top of the fuselage and is canted at a 3° dihedral. It uses the Wortmann FX63-137 airfoil. The long fuselage is rectangular and is highly tapered aft of the wing. The empennage has standard horizontal and vertical tail surfaces.

Supporting the structure of the Penguin are two box beams for the fuselage and wing, and two simple beams in each of the horizontal and vertical tails. The box beam in the wing is located at the maximum thickness of the wing, while the simple beams in the empennage are located at the leading edge and the trailing edge (just prior to the control surfaces). The fuselage box beam runs the entire length of the aircraft. The forward section of the fuselage is much stronger than the aft since it supports the engine and the avionics as well as the load from the wings.

The Penguin is driven by an ASTRO 15 electric motor that provides more power than the RPV will need. The excess power may prove to be useful in a stall situation that may arise since the Penguin will cruise at a velocity close to the stall velocity ($V_{cruise} = 1.3\,V_{stall}$). A two-blade, 10-in-diameter propeller provides the thrust.

Since the RPV had to be highly maneuverable, it makes use of large rudder, aileron, and elevator surfaces. Its large horizontal and vertical tail surfaces are located far aft of the wing in order to provide static stability and are placed in the wash of the propeller for added effectiveness. The dihedral of the wing provides roll static stability.

Screem-J4D

The Screem-J4D (see Fig. 4) is a remotely piloted airplane with a high-aspect-ratio main wing and a conventional empennage giving it a "sailplane" appearance. It is designed to satisfy the required mission using a flight plan that calls for ascent to cruise altitude at 20 ft and then perform three figure-eight turns around pylons. Once completed, the pilot is to make use of any remaining power by loitering before landing the plane.

The propulsion system of the J4D consists of a propeller-electric motor combination with the engine mounted at the front of the fuselage. The 10-in diameter, 6-in pitch, two-bladed propeller is powered by an ASTRO 05 electric engine with 7 AA nickel-cadmium batteries. The system is capable of maximum power output of 50 W and has throttling capabilities. Of the available propellers, the 10-6 was best suited for the takeoff distance and maximum current draw constraints. The 05 engine was chosen for being most lightweight while still supplying adequate power.

In order to provide sufficient lift for low-speed flight, the J4D has an aspect ratio of 11.7 with an 8.2-in mean chord. The wing consists of a spar and rib construction with thin

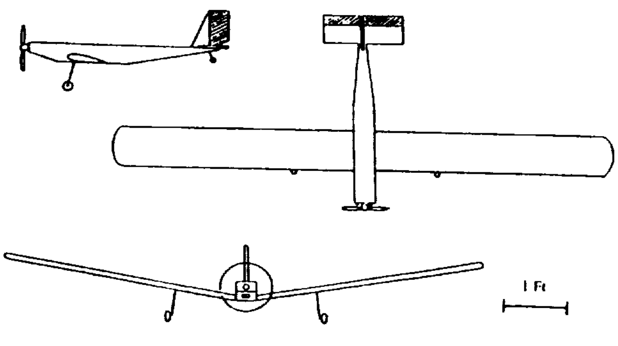

Fig. 4. SCREEM-J4D

plastic film skin. Its low mount and dihedral, in combination with the vertical tail, were designed to augment maneuverability. A major problem, however, is that due to the nature of a low-speed mission, there is little margin for error between the cruise and stall velocities. A square fuselage will contain the servos, engine, and payload, with adequate excess space so that the c.g. of the airplane is kept at about 33% of the chord.

A combination of directional and longitudinal control will enable the J4D to perform the figure-eight maneuvers. However, in order to avoid the construction and servo weight of ailerons, the rudder was designed to be over one-half the size of the vertical tail to insure that the proper roll control could be attained.

The Dawdler

The Dawdler (see Fig. 5) is a remotely piloted airplane designed to fly at low Reynolds numbers (10^5). The airplane will be flying a closed course in a controlled environment. The purpose of the design is to study the difficulties that arise in the design of a low Reynolds number aircraft. The Dawdler is a canard configured aircraft. It can also be considered a tandem wing configuration. The canard is designed to produce 30% of the total lift necessary to keep the aircraft in steady level flight. This configuration was chosen in order to attain an upward lifting force from the horizontal stabilizer.

The aircraft is designed to fly at 25 ft/sec, which requires a relatively small amount of power from the engine. However, a large amount of power is required for the aircraft to climb to the design altitude of 20 ft. Neglecting the takeoff performance of the aircraft, it was decided that the ASTRO 035 motor would supply enough power to keep the aircraft in steady level flight. One of the main reasons for picking the engine is its relatively light weight.

The takeoff will be accomplished via a remotely controlled, motorized cart assisted launch. The aircraft will be placed on top of a motorized cart that will accelerate the aircraft to a velocity of 45 ft/sec. At this speed, the aircraft will have enough kinetic energy to lift itself up to its cruise altitude. Once the aircraft reaches this velocity, the pilot can begin to raise the nose to lift it off the cart.

The Dawdler has a vertical tail mounted behind the wing for lateral stability and a rudder for yaw control. A 13° dihedral angle will be incorporated into the wings to assist roll control. Ailerons have been omitted from the design to reduce the number of servos and the associated structural complexity and weight. The canard will be fully movable for pitch control.

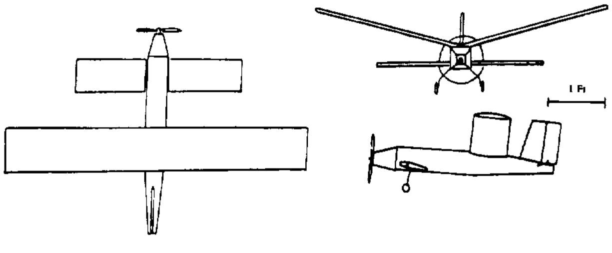

Fig. 5. Dawdler

FX/90

The FX/90 is a remotely piloted vehicle designed to satisfy the mission requirements and to investigate the unique problems involved in low Reynolds number flight. The aircraft will operate in a steady flight environment, free from significant atmospheric turbulence and weather effects. The aircraft will take off within 75 ft, and will climb to an altitude of 20 ft within an additional 90 ft of ground distance. The aircraft will then commence its flight plan, which consists of three figure-eight loops around two pylons spaced 150 ft apart. Upon completion of the three laps, the aircraft will travel around the flight envelope and return to the pit area for landing. It can do so under powered flight, or it can travel an additional 60 ft and then glide the remaining distance.

The F-90 has a 39-in fuselage constructed of balsa and plywood. The fuselage consists of two sections. The forward section is a 3.5 in × 3.5 in × 17 in rectangular structure in which the propulsion and flight control systems are located. The rear section is a 22-in boom with a truss structure and a square cross section that tapers to a point. The boom provides a moment arm for the tail surfaces. The length of 22 in is a compromise between the advantages of a longer moment arm and the disadvantages of the associated increase in weight. The truss construction was chosen for its high strength and torsional stiffness with minimal weight.

The landing gear for the aircraft is a detachable carriage on which the aircraft rests prior to takeoff. The aircraft accelerates for takeoff while on the carriage. At takeoff, the aircraft lifts off the carriage, and completes its flight plan without landing gear. Landing is accomplished by setting down on the smooth lower surface of the fuselage. The propulsion system uses a foldable propeller to prevent damage during landing.

The aerodynamic planform is a rectangular wing (no taper or sweep) with a chord of 9 in, a wingspan of 72 in, and is constructed entirely out of styrofoam. Styrofoam was chosen for its low weight and relative ease of construction. "Aircraft quality" styrofoam was chosen for its high strength and hardness and its smooth surface, which eliminates the need for a coating material. Special care must be taken when handling the wings, particularly the thin trailing edges.

The propulsion system consists of an ASTRO 05 engine and a 10-6 two-bladed propeller. The ASTRO 05 engine was chosen for its light weight and adequate available power. The 10-6 propeller was chosen for its efficiency in conjunction with the 05 engine and for its moderate diameter. The maximum velocity and rate of climb, as well as the maximum range and endurance, all exceed the design requirements due to an excess of available power and battery energy storage.

Control of the aircraft is accomplished through the use of two movable control surfaces: elevators for pitch control and a rudder for yaw control. In addition, a large dihedral angle was used to couple the yaw and roll axis. This allows for roll maneuvers to be accomplished through the use of the rudder, as well as providing adequate spiral stability. Ample rudder was provided in order to allow a high maneuverability, as required by the flight plan.

There are several areas of concern. At takeoff, the landing gear will detach while traveling at approximately 24 ft/sec, which is a safety concern. The aircraft flies at a high angle of attack, giving the aircraft a low tolerance to gusts, and is near stall during maneuvers. The impact of a landing without landing gear, as well as its effects on components of the aircraft, is relatively uncertain. Finally, the performance of the foldable propeller is not well documented, and its influence on the propeller performance was not evaluated.

System Technical Areas

The following brief sections address the problems in the five major technical areas: weights, structures, propulsion, aerodynamics, and stability/control. A final paragraph will then describe the concept prototypes and their flight demonstrations. Some of the basic parameters can be found in Table 1.

Weights

Each team was concerned about keeping the overall weight to a minimum. Table 1 also shows the overall aircraft weights. Each team used various means to cut weight. The FX/90 used detachable landing gear, while the Dawdler, which has no gear, was launched from a radio-controlled cart. Some teams chose smaller engines, while others built their fuselages with a lightweight truss design. The results were six strong aircraft with a maximum weight of 50.7 oz. Table 2 shows the weight fractions for each aircraft.

Structures

The structural problems consisted of constructing a lightweight aircraft that could withstand the loads required during flight, especially takeoff and turns, and the structures needed to be both lightweight and durable. Another problem consisted of providing adequate interior space to keep the center of gravity at the designed location. Material selection was a crucial part of the structural design, and Table 3 shows the materials used in each aircraft. Most of the truss configurations were modeled and examined using a finite element analysis program.

Propulsion

Perhaps one of the most challenging areas was propulsion. Each team needed an adequate propulsion system that would satisfy the nonairbreathing requirement. Electric, stored mechanical energy (rubber band) and stored compressed gas (CO_2) systems were considered. Only the electric systems appeared to provide the duration needed for this mission. Limited technical data were available on the lightweight, DC electric motors. Integration of the battery storage, electric motor performance and propeller selection proved to be critical in determining the success of the concepts. Takeoff power requirements far exceeded the low-speed steady-cruise requirements. Three groups decided on the ASTRO 05 engine, one chose the ASTRO 035, one the ASTRO 15, and one group used a Peck Silver Streak 035M. Some of the propulsion characteristics are found in Table 4.

Table 1. Basic Aircraft Parameters

Parameter	Drag-n-Fly	Stealth Biplane	Penguin	Screem-J4D	Dawdler	FX/90
V_{cruise} (ft/sec)	25.0	25.0	25.0	23.0	25.0	24.0
Endurance (min)	3.2	4.3	1.8	3.9	3.2	8.5
Weight (oz)	43.7	41.6	50.7	48.0	37.2	45.3
Area (ft^2)	6.0	2.2/1.65	4.67	5.46	3.25	4.38
Span (ft)	8.5	4.0/3.0	7.0	8.0	5.0	5.8
Length (in)	41.0	33.0	42.0	37.0	37.0	43.0
AR	12.0	7.3/5.5	10.5	11.7	7.7	7.8
Airfoil	SPICA	FX63-137	FX63-137	NACA 4415	Clark Y	FX63-137

Table 2. Structural Component Weight Percentages

Aircraft	Propulsion	Wing	Fuselage Empen.	Landing Gear	Avionics	Payload
Drag-n-Fly	30.7	19.2	19.2	8.1	18.3	4.5
Stealth Biplane	28.0	26.7	5.3	6.6	29.0	4.4
Penguin	34.1	16.8	21.9	8.0	15.2	4.0
Screem-J4D	33.7	28.5	20.2	5.0	8.6	4.0
Dawdler	29.5	21.4	21.2	7.7	15.2	5.0
FX/90	29.5	22.2	28.5	-	15.6	4.2

Aerodynamics

The primary purpose of the design project was to evaluate the influence that the very low Reynolds number flight regime would have on the aircraft design. Some of the problems in aerodynamics dealt with choosing an airfoil that would produce high lift coefficients without the risk of stall throughout the mission. Airfoil selection then involved investigating lift hysteresis, minimizing drag, and choosing the planform parameters. The airfoils that were selected ranged from the Wortmann FX63-137 (improved aerodynamics), to a traditional Clark-Y (ease of manufacturing). Profile drag prediction was complicated by the lack of data in this Reynolds number range particularly in the area of interference effects. Induced drag was minimized primarily by using the high-aspect-ratio wing planforms. In hindsight, the low Reynolds number aspect of the mission primarily influenced the selection of the mean chord since cruise speed requirements were dictated by initial minimum weight estimates and predicted available $C_{L\,max}$.

Stability and Control

Control concerns were primarily those of maintaining adequate static-pitch stability and the roll control necessary to perform the closed-course maneuvers. This was usually accomplished with two channels of control, elevator and rudder, in order to eliminate the weight and complexity of the additional control for ailerons. This was accomplished by using large dihedral and oversized rudders. This allowed the aircraft to turn by coupling the yaw and roll axes. The main concern in the area of stability involved static, longitudinal stability. Static margins were kept at 5-10%, and the center-of-gravity location was crucial to the success of each aircraft. Subsequent flight tests indicated that acceptable remote pilot control required even greater static margins.

Technology Demonstrators

Each design team constructed their prototypes during the last three weeks of the project. They were issued Futaba Attack 4 radio systems, as well as their respective engines. All construction took place in the Notre Dame Aerospace Design Lab, where simple construction equipment was provided for the students. At the end of the three weeks, a series of taxi tests was performed to test the systems and to check the aircraft for basic flightworthiness and controllability. All six aircraft experienced problems, especially in the areas of center-of-gravity placement, tuning of the control surfaces, landing gear stiffness and alignment, and propulsion system battery performance.

On 4 May, 1990, the flight demonstrations were held. Five of the six craft successfully performed at least a single complete figure eight. The sixth aircraft, the Stealth Biplane, was underpowered and could not takeoff unassisted. A hand launch was attempted that proved unsuccessful. Three of the aircraft, Drag-n-Fly, Screem-J4D, and the FX-90 exceeded the range requirements completing as many a 10 laps of the course. Most appeared to exceed their target cruise speeds but handled very well under the control of an experienced pilot. Considering the lack of experience of the builders and the time constraints placed on the teams, this flight demonstration was considered a great success, and showed the students the difference between a conceptual success and success in the real world.

Table 3. Structural Materials

Aircraft	Wing	Fuselage	Empennage
Drag-n-Fly	Spruce/Balsa	Spruce/Balsa Plywood	Spruce/Balsa
Stealth Biplane	Balsa	Balsa	Balsa
Penguin	Spruce/Balsa	Spruce/Balsa	Spruce/Balsa
Screem-J4D	Spruce/Balsa	Spruce/Balsa Plywood	Spruce/Balsa
Dawdler	Spruce/Balsa	Balsa	Balsa
FX/90	Styrofoam	Plywood/Balsa	Balsa

Table 4. Propulsion Systems

Aircraft	Motor Type	Prop	Batteries	Volts	System Weight (oz)	Weight Fraction (%)
Drag-n-Fly	Astro 05	10-6	8 × 500 mah AA NiCad	9.6	11.3	34.8
Stealth Biplane	Peck 035	8-4	10 × 600 mah AA NiCad	12.0	12.6	28.1
Penguin	Astro 15	10-4	13 × 270 mah AA NiCad	15.6	15.3	30.1
Screem-J4D	Astro 05	10-6	7 × 600 mah AA NiCad	8.4	16.2	33.7
Dawdler	Astro 05	9-6	5 × 500 mah	6.0	11.3	35.4
FX/90	Astro 05	10-6	7 × 500 mah AA NiCad	8.4	16.0	36.3

CONCLUSIONS

The purpose of this course is multifaceted. The students entered the course with the knowledge required to complete the mission. The learning process involved the ability to incorporate that information into a design. They were shown the design process from start (the request for proposals) to finish (the prototype). They were immersed into many real world problems faced by engineers. These included working in a team and integrating seven engineers' ideas and work into one design. They were given the opportunity to experience the construction process, and how one must "bridge the gap" between a concept on paper and a flightworthy aircraft.

The students' results, namely their proposals and prototypes, indicate that the goals were achieved. Although they may soon forget their aircraft's design, hopefully what they have learned will help them wherever their careers take them.

ACKNOWLEDGMENTS

This project was supported by NASA/USRA Advanced Aeronautics Design Program. Technical assistance and guidance was provided by the Boeing Company under the coordination of Mr. Cal Watson and Mr. Robert Wickemeyer. The course was presented by Dr. Stephen M. Batill, and graduate teaching assistants David M. Carey and Todd V. Graves. Sections of this report have been edited from the final proposals submitted by each design group. Finally, thanks must go to Mr. Joseph Mergen, Mr. Joel Preston, and Mr. Mike Swadener for their technical assistance and advice throughout the semester.