N94- 25712

PROJECT ARES III

California State University, Northridge
Mechanical Engineering Deprtment
Northridge, California

Professors Dan Raymer, Phyllis Russell, and Tim Fox
Doug Meyers, Teaching Assistant

Steven Lovric, Robert Grabow, Manfred Epp, Warren Wynn Jr., Zoltan Mako, Gunther Linzner, Dante DeLeo, Chris Parker, Chris kelley, Leeor Gorstein, Yaron Shani, Enrique Chavez, and Yakem Habtemariam

Abstract

The mission of Project Ares is to design and fabricate an Earth prototype, autonomous flying rover capable of flying on the Martian surface. The project was awarded to California State University, Northridge (CSUN) in 1989 where an in-depth paper study was completed. The second year's group, Project Ares II, designed and fabricated a full-scale flight demonstration aircraft. Project Ares III, the third and final group, is responsible for propulsion system design and installation, controls and instrumentation, and high altitude testing.

The propulsion system consists of a motor and its power supply, geartrain, and propeller. The motor is a four-brush DC motor powered by a 50-V NiCd battery supply. A pulley and belt arrangement is used for the geartrain and includes light weight, low temperature materials. The propeller is constructed from composite materials which ensures high strength and light weight, and is specifically developed to provide thrust at extremely high altitudes.

The aircraft is controlled with a ground-based radio control system and an autopilot which will activate in the event that the control signal is lost. A transponder is used to maintain radar contact for ground tracking purposes. The aircraft possesses a small, onboard computer for collecting and storing flight data. To safeguard the possibility of computer failure, all flight data is transmitted to a ground station via a telemetry system.

An initial, unpowered, low-level test flight was completed in August of 1991. Testing of systems integration in the second low-level test flight resulted in loss of elevator control which caused considerable damage on landing. Complete failure analysis and repairs are scheduled for September of 1992.

Introduction

An ultra-high altitude, battery-powered, remote controlled aircraft has been developed to collect low Reynolds number performance data for the wing airfoil and propeller efficiency. The aircraft is designed to fly at an altitude of 104,000 feet and at a speed of Mach 0.2. The aircraft configuration is similar to that of a powered glider with a low power to weight ratio and an aspect ratio of 10. The aircraft has a wing span of 32 feet and a length of 20 feet while weighing only 62 pounds. It is constructed of carbon graphite, kevlar, mylar, styrofoam, and Nomex honeycomb.

The aircraft is controlled with a ground-based radio control system equipped with autopilot. The autopilot will engage if contact is lost between the ground station and the aircraft. If contact is not established after a predetermined time period, the self-destruct mechanism will engage, thus separating the wing from the fuselage. The aircraft is equipped with a transponder which assists in radar contact to assist the pilot in maneuvering.

Although originally designed to incorporate solar cells to power the motor, we were unable to obtain the cells that met our weight and power requirements due to their overwhelming cost. Nickel-cadmium (NiCd) batteries were selected to power the 1.4 horsepower DC motor. The motor is connected to an 11:1 gear reduction employing low weight, low temperature materials. The propeller is constructed from a composite of carbon and foam, and was specifically designed to provide thrust in a low Reynolds number environment.

The aircraft is equipped with a microprocessor possessing low power mode capability, analog to digital conversion, digital input/output, expandable data storage, and PC-compatible programming. The microprocessor is the heart of the data acquisition system which collects data such as motor rpm and power consumption, air temperature, propeller thrust, air speed, altitude, and the pressure distribution over the wing.

The testing will consist of a series of low-level test flights to test guidance and control and to calibrate data measurement equipment, as well as a high altitude test flight to measure low Reynolds number airfoil data and propeller performance. The aircraft is deployed to an altitude of 110,000 feet via a weather balloon with the nose positioned downward and then released. After a gradual pullout, the aircraft will then proceed to collect low Reynolds number data for the duration of the level flight.

Background

CSUN'S Mechanical Engineering department has a unique design program for the senior level student. The course is designed to imitate a "real world" engineering atmosphere. The students form an organization which is administered by several levels of student management. Faculty advisors are available for technical and administrative support. The program enables the student to experience the design process and actually build hardware. Many student projects have been used in nationwide competitions.

NASA/USRA funded CSUN'S Mechanical Engineering Department through the Advanced Design Program for a 3-year aircraft design project. The objective of the project was to design and build a prototype Mars aircraft to investigate Martian lower atmosphere and geological features as a prelude to a manned mission to Mars.

Last year's design team designed and fabricated such an aircraft and successfully completed an unpowered, tow-assisted test flight in August of 1991. This year's team is responsible for the design and installation of the propulsion system and controls and instrumentation. The low-level systems integration test flight of May 1992 ended when elevator control was lost due to engine interference with the control signal. The aircraft was heavily damaged on landing. This is an initial estimation of the failure, and more failure analysis is scheduled for the near future. Aircraft repair is also scheduled for the immediate future.

Vehicle Group

The Vehicle Group for Project Ares II has a different task than the traditional design and production of an aircraft. Project Ares III has inherited the aircraft the Project Ares II produced. As such, the Vehicle Group for Project Ares III was concerned mainly with preparing the airplane for flight. The majority of effort was directed toward repairing the fuselage, wing and tail. Other important tasks of the Vehicle Group were maintaining the weight and balance of the aircraft for stability, ensuring fail-safe considerations in the event of loss of radio contact, and coordinating with Propulsion and Controls & Instrumentation Groups for the installation of their various subsystems.

Although generalized discussions of the construction of the aircraft will be made, the reader should be familiar with the final report of Project Ares II. No attempt is made here to cover in detail the design considerations that went into fabrication of the aircraft. However, important aspects of the aircraft design will be reiterated whenever necessary, such as in discussion of stability and control.

Repairs-General

The aircraft has sustained some damage during the test flight that Project Ares II performed, as well as ground handling by both Ares II and Ares III teams. Additionally, installation of sensor packages in the wing and tail required stripping the mylar covering off the aircraft and recovering it.

Fuselage Repairs

In the case of the fuselage, the largest consideration was that the two halves were joined properly. There were four general types of repairs made on the fuselage: re-gluing the two halves together; patching areas where the halves did not meet; repairing areas where there was a length mismatch between the halves; and repairing one area of the tail that was cracked. Additionally, the paint and excess glue were removed from the fuselage in an effort to reduce weight.

Wing Repairs

The two innermost ribs, adjacent to the fuselage, were broken on the wing during assembly of the airplane. Replacement ribs have been fabricated and epoxied to the wing. These ribs have been laminated to the outside of the existing ribs to provide clearance between the wing and the fuselage. There were also some ribs that had fractured where lightning holes had been made. Graphite/Nomex sandwich doubles were epoxied to the broken areas. Additionally, the wing mylar was removed and re-applied in certain areas. This was necessary due to rips in the mylar and some areas that the Controls & Instrumentation Group needed to access to install various sensors inside the wing. The last step was to re-tension the mylar from last year that had not been replaced.

Tail Repairs

The tail mylar was replaced, again due to tears and to provide access to the tail for sensor mounting. This required removal of the elevator and the rudder and re-hinging of the surfaces. The hinges were full-length, made with wide mylar tape.

Stability

The neutral point of the airplane was calculated using the airfoil and fuselage data provided by the Project Ares II. The neutral point was determined to be 80 inches from the back of the spinner. This placed the neutral point at approximately 50% of chord. For 15% static margin, the required center of gravity was at 74 inches from the back of the spinner. The center of gravity was found by:

$$(Xnp-Xcg)/C = \%stabiltiy$$

where Xnp and Xcg are the distances from the datum (the back of the spinner) to the neutral point and center of gravity, respectively, and C is the mean aerodynamic chord of the wing. Weighing of the aircraft was delayed until just prior to the test flight.

Safety Considerations

A self-destruct mechanism is required for termination of the flight in case control of the aircraft is lost. This is accomplished by separating the wing from the fuselage at the wing attach point. The wing is held in place by two plates epoxied on the wing box. These plates fit between two plates in the fuselage that are held secure by two pins. The plates on the wing were cut in half, and two tubes were epoxied and riveted on both halves of each plate. Smaller tubes were epoxied inside the tubes on the upper plates to maintain alignment of the wing, and the two halves are held together by a connecting rod. In the event of loss of uplink signal, a 15-minute countdown timer would be started. At the end of 15 minutes explosive line-cutters would be activated, severing the rods, and allowing the wing to separate from the fuselage.

Test Flight

After all systems were installed, the wing and fuselage/tail assembly were weighed. The wing weighed 20.5 pounds and the fuselage and tail assembly weighed 50 pounds. This includes the weight of the landing gear (approximately 12 pounds) that will not be used on the high altitude flight. Once the aircraft was weighed and assembled for the test flight, a fairing was made between the wing and fuselage to reduce the interference drag. Then the aircraft was balanced, and the center of gravity was found to be too far aft. The aircraft was ballasted with weights to reach the proper center of gravity location.

Propulsion

The propulsion system was developed with the goal of providing the required thrust for level flight during which the data collection would take place. The propulsion system was divided into four separate tasks: power source, motor, geartrain, and propeller.

The plane was originally designed to incorporate solar cells as its power source for the propulsion system for both the Earth prototype and the actual future Mars explorer. However, the solar arrays that met power and weight criteria for this aircraft far exceeded our budget. This introduced a new twist into the scope of the propulsion system: 100% battery powered flight. The two main criteria for battery selection were energy density, weight, discharge rate, and costs. The batteries selected were to provide power to sustain the aircraft in level flight for a duration of two minutes. The batteries considered were: carbon-zinc, zinc-mercury, lithium, alkaline, and nickel-cadium.

Our final selection was the NiCd batteries. Their weight is 1.7 oz per cell, which was heavier than some of the others considered, but they provided the maximum current discharge of 30 amps. This far exceeded any of its competitors. Forty-eight cells would be required for the motor selected by last year's group at a total weight of nearly 5 pounds.

The motor selected by last years group is a four-brush DC motor built by Astroflight Inc. Performance tests yielded an output torque of 0.6 ft-lbs at approximately 12,000 rpm. The motor required 50 volts and 30 amps which are provided by our battery selection. Motor selection was based on power available, weight and size of the unit, type of motor, and costs. An initial range for horsepower requirements was made based on historical data ranging from fractional to 10 hp motor and backed up by the initial estimates of power required.

The geartrain was necessary because it was determined that the propeller being designed would operate much more efficiently at a lower rpm than the motor provided. The design considerations for the geartrain were light weight, maximum efficiency, and reliability. The expected life cycle was to be under 200,000 revolutions. A prominent concern dealt with the effects of the low operating temperature of approximately -70° Fahrenheit. The materials selected were required to maintain their strength and possible ductility for the duration of the flight.

The transmission methods considered were toothed Delrin gears, a chain and sprocket system, and toothed belt and pulley arrangement. The toothed belt and pulley arrangement were chosen because the others were much more sensitive to misalignments, displayed a higher weight, and operated at a lower efficiency. To ensure that the belts would not fracture due to the low temperatures, low temperature rubber belts reinforced with Kevlar strands were purchased. These belts maintained their ductility and strength even at these low temperatures. Self-aligning "swivel" bearings were designed and fabricated to combat the potential problem of shaft misalignment. The shafts used were hollow, anodized, 2024 aluminum.

The propeller provided the greatest challenge for the propulsion group. The propeller would have to be light in weight, possess high strength, as well as provide thrust in a low Reynolds number environment. Blade element theory was used to obtain the following calculated values that would meet the thrust requirements:

Radius: 3.9 feet
average chord: 0.45 feet
rotation angle @ hub: 85 degrees
rotation angle @ tip: 28 degrees
aspect ratio: 9

Construction was begun with the fabrication of a single blade plug that was used to construct a mold from which the actual propeller could be formed using composite material and foam.

Avionics

The role of the Avionics group was to design, test, and fabricate the flight control system, data acquisition sensors, and data recording subsystems for the Ares III Project aircraft.

In the design of the Flight Control System, two modes of controlling the aircraft were chosen. One is manual control via a modified radio-control model aircraft hardware.

This system is a Futaba 1024 Pulse Code Modulator which allows control of both elevator and rudder deflection as well as motor control. The Futaba output signal is only 1 watt and 50 MHz and must be amplified to reach the aircraft at high altitudes. This is accomplished by a 10 gain RF amplifier which boosts the control signal to a maximum allowable by the FCC of 1 watt. The signal is then transmitted through a high gain, mufti-element, directional Yagi antenna to the aircraft. The control signal is received via a unidirectional trailing antenna and delivered to a receiver. The receiver directs control of the control surfaces' servos and motor. In the event that the control signal is lost, the second mode of control, the autopilot, would assume control. The autopilot, manufactured by BTA Systems Inc., would lock the control surfaces into a predetermined position causing the aircraft to slowly spiral to ground level. The autopilot will unlock control in the event that the control is regained. The aircraft will also carry a miniature radio transponder to aid in tracking with radar.

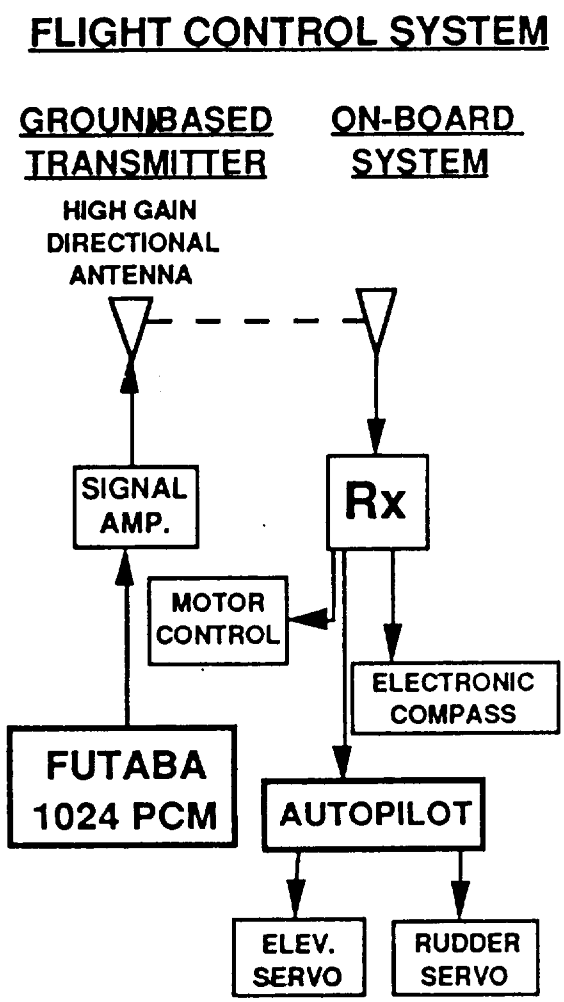

Fig. 1 Flight control system

The ultimate goal of our high altitude testing program will be to collect data to evaluate the performance of our design. This includes both vehicle flight performance as well as performance of various aircraft subsystems. For the evaluation of the vehicle flight characteristics, measurements of airspeed, altitude, inside air temperature, and outside air temperature will be taken. For the propulsion system, sensors will measure motor power, propeller thrust, and motor RPM. Additionally, differential pressure ports located in the wing will record pressure distribution along the chord-wise location on the wing. This data will be used to provide essential data to validate computational fluid dynamic modeling for low Reynolds number flights.

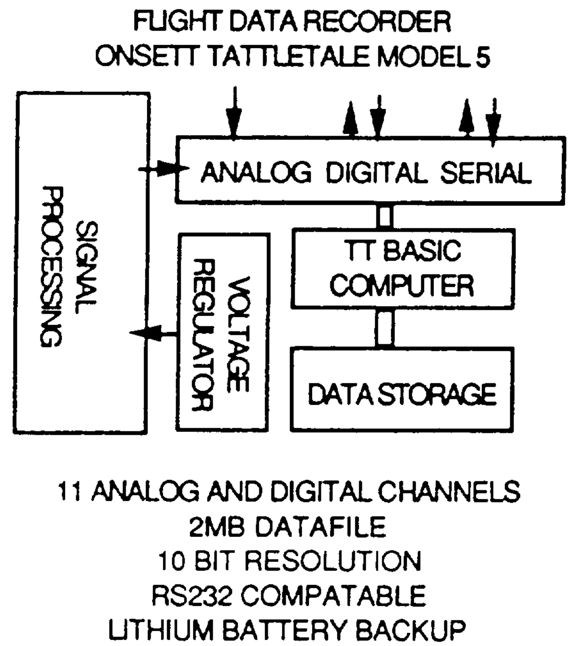

Fig. 2 Flight data recorder

This information will be stored for later retrieval by the Flight Data Recorder. The Flight Data Recorder (FDR), manufactured by Onset, Inc., uses the latest in large scale integration (LSI) and surface mount chip technology to pack essentially a complete microcomputer onto a board a few inches square. The FDR will also provide sensor signal conditioning and supply regulated reference voltages. Also, as a fail-safe in the event of flight failure, a telemetry or "downlink" was installed for data acquisition. The telemetry operation is essentially the same as the Flight Control system except that the signal is encoded in a serial format for eight analog and digital data channels. While providing a back-up system for data acquisition, the telemetry also is beneficial in that it allows for real-time data acquisition.

Because of the extreme temperatures encountered at flight altitude, the instrumentation package will be installed in an insulated, temperature-controlled avionics bay. The flight data recorder will be able to monitor and regulate the payload bay temperature with the aid of a small film resistance heater to a temperature above 0 degrees Celsius.

Power for the onboard avionics will be provided by NiCd batteries. A battery system consisting of 24 cells delivering 28 volts at 1200 mah will supply all avionics. The FDR will be independently powered with an additional battery backup in the event of main power loss. The complete controls and avionics package will have an installed weight of less than six pounds.

Test Flight

The Test Flight group dealt with two main areas of flight testing of the Ares aircraft: low level testing and high altitude test flights. Low level test flights have been carried out with the aircraft. The high altitude flight has been planned and found feasible, but due to complexity and cost, it has not been carried out.

Low Altitude Flight Testing

Low altitude flight testing has been carried out at El Mirage dry lake bed in California. The aircraft was towed by car to an altitude of several hundred feet. The cable was then released and the aircraft glided to a safe landing. Flight control was achieved with the use of the regular radio control Futaba unit. The pilot controlled the aircraft from a car while being driven behind and below the aircraft. Test flights were performed in the summer of 1991 and 1992. The 1991 summer flight was carried out with no avionics and proved the plane was stable and air worthy. The 1992 flight was carried out with full avionics to test system integration.

High Altitude Flight Testing

In order to test the Ares aircraft in a Martian-like environment, the aircraft would have needed to be towed to an altitude of 104,000 feet. At that altitude, the air density closely resembles the Martian atmosphere. The only safe way to deliver the aircraft to high altitude is via a helium balloon system. The plane would be hung from the balloon with a special release mechanism and launched nose down upon reaching altitude. After a short level test flight with full system information being recorded, the aircraft would glide to a landing site under control from the ground station. The pilot can glide the plane to the landing site with the aid of radar until eye contact is established.

The helium balloon system needed to deliver the aircraft to altitude was found to be very complex and costly. It was decided that the group would use the services of professionals since building and testing a balloon system of this type is a several year project in itself. Two organizations have been contacted, the National Scientific Balloon Facility in Palestine, Texas, and the Department of Atmospheric Science at the University of Wyoming. Both organizations have been involved in the project and, depending on the location and date of the flight, one would be chosen to perform the balloon ride to 110,000 feet and launch the aircraft.

Finding a test area for the high altitude test flight has also been a major task. After much discussion, the Federal Aviation Administration has refused to allow a flight in unrestricted, uninhabited airspace mainly due to the concern that the aircraft could wander into occupied airspace or crash in an inhabited area. Due to that restriction, the test flight has to be carried out within a restricted area big enough and high enough for the entire flight to be conducted inside the area. Several of these areas exist in the United States; most of them are controlled by various branches of the military. These areas were investigated, and it was determined that the cost of the radar facilities is substantial. Also, the safety review and damage assessment process required is complex and time consuming. At this time, negotiations are underway with Edwards Air Force Base in California and Hill Air Force Base in Utah to try to find ways to incorporate the cost of the test range services within the limited budget available to Project Ares III.

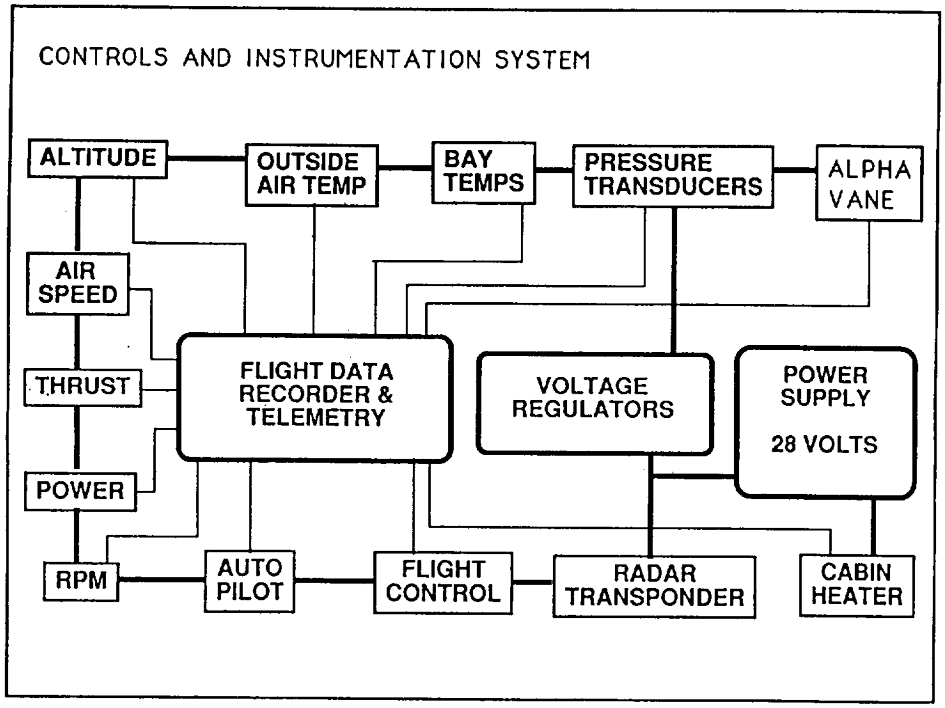

Fig. 3 Controls and instrumentation system

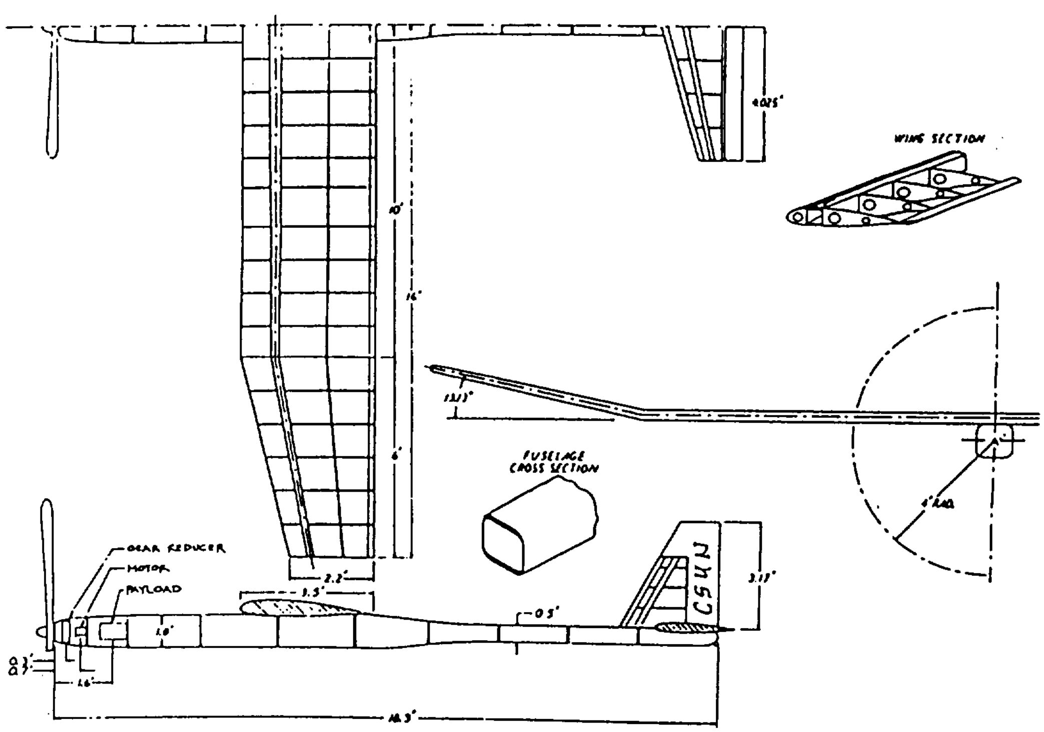

Fig. 4 Side view of Project Ares III