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Project Sunrise

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-- NOTES --

PROJECT SUNRISE

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Abstract

At 10:00 a.m. on the morning of November 4, 1974, a large lightly built aircraft rose silently from the California desert, it was powered entirely by the solar cells in its wings. The new Age of solar powered flight had arrived.

Sunrise, the world's first solar powered aircraft was conceived, designed, built and flown by Astro Flight, Inc., pioneers in the field of electric powered aircraft.

Sunrise was designed to use solar power to lift itself to a sufficient altitude during daylight hours to enable it to glide all night and still find itself above the clouds at dawn. In this manner, unencumbered by the limitation of fossil fuels, Sunrise has unlimited range and endurance.

This paper describes the air vehicle, structure power plant, and propulsion subsystems, and gives calculated and measured performance.

Sunrise is a Concept

The concept of Sunrise, a solar powered vehicle of extended range and altitude was a natural extension of the pioneering work done by Astro Flight in the field of electric powered fixed wing aircraft. The use of solar power although heavy in terms of watts per pound and expensive in terms of watts per dollar has one singular feature, the energy source is inexhaustible. Since the solar flux at sea level is sometimes obscured by clouds, the solar powered vehicle will seek the clear regions of the upper atmosphere where it can bask in the unattenuated sun, free from high winds and atmospheric turbulence. During the night-time hours, the Sunrise will glide hundreds of miles toward its destination at speeds much higher than prevailing winds and then beginning its climb back to loiter altitude with the first rays of sunlight. This behavior is somewhat modified in polar climates where the flight path is at constant but somewhat lower altitude on a circling orbit running from the midnight sun. Since polar flights are limited to summer months, both north and south poles can be circled to provide low altitude polar orbits on a year around basis. The vertical diurnal flight profile for a vehicle with the same power and weight as 7404-02 but with the array smooth to 8 mills is shown. Also shown is the polar orbit altitude for the same vehicle. Yet, the behavior and attributes of Sunrise are quite different from other present day air vehicles. It may prove quite useful in many ways yet undreamed of.

The Flight Demonstration Program

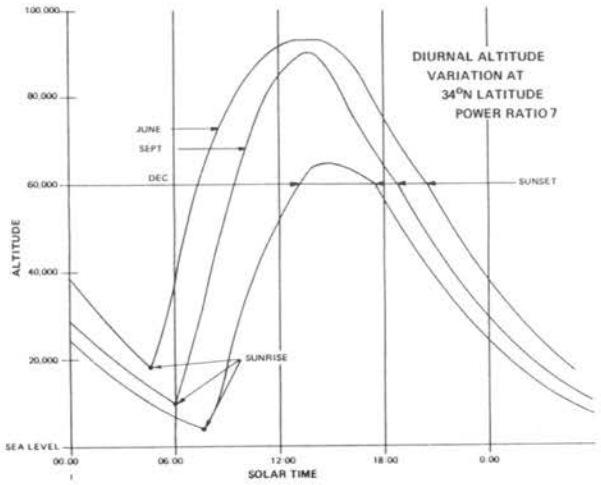
In lieu of building a 100 feet span prototype vehicle to carry the tactical 50 pound payload invisioned by the customer, and in lieu of doing yet another paper study, contractual discussions which began in 1971 were finally concluded in 1974 in which Astro Flight would build and fly a one third size scale model of the tactical bird to demonstrate the feasibility of the Astro Flight concept. The ARPA contract was received in April 1974 and first flights of Sunrise took place on September 17, 1974. Scores of flights were made during the fall and winter months of 1974 and spring months of 1975. For various technical reasons the round solar cells used on vehicle #1 proved undesirable and a second vehicle was contracted for on June 10, 1975 and built that summer. It made its maiden flight on September 12, 1975.

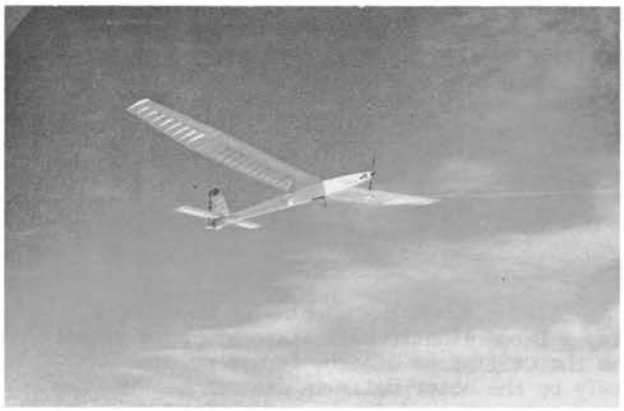
The objectives of the flight demonstration program was to verify the feasibility of the specific performance promised in the original Astro Flight proposals. These specific objectives were satisfied during this flight demonstration program.

1. The ability to build a complete airframe weighing less than two ounces per square foot of wing area.
2. The ability to assemble large solar arrays having a specific power density of 100 watts per pound.
3. The ability to convert electrical power to thrust horse power at a weight of less than three pounds per horsepower.
4. The ability to achieve sink rates during glide of one foot per second.
5. The ability to climb to high altitudes on solar power.

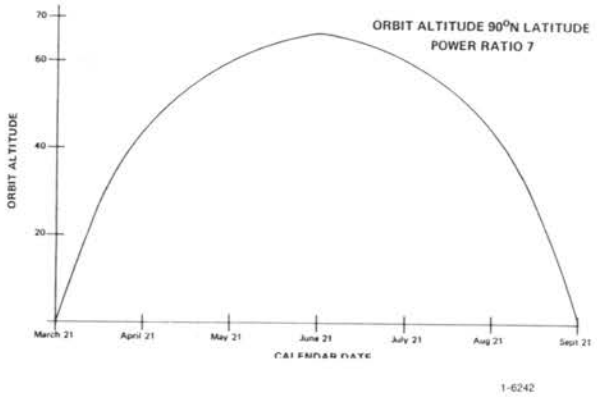
The Sunrise Air Vehicle

Astro Flight models 7404-1 and 7407-2, solar powered remotely piloted vehicles are shown on the opposite page. The vehicles weighed 22.5 pounds gross weight and were powered by a single .6 hp permanent magnet motor with a speed reducer and a wooden fixed pitch propeller. The power for the electric motor was generated by a bank of four solar arrays affixed to the upper wing surface and capable of generating 570 watts of electrical power (air mass zero normal solar incedence). The vehicles were positively stable on all axis and flew hands off for extended periods. Model 7404 was controlled by rudder and elevator during takeoff and landing and navigated by rudder command when out of sight. Sun sensing was used for heading reference and this proved itself when during flight test the vehicle was lost to ground tracking stations for an extended period of time, yet the operator was able to navigate the vehicle back into the vicinity of the takeoff location and ground tracking was reestablished.





LAUNCH OF 7404-02 AT NELLIS AFB
RANGE 63, SEPTEMBER 1975

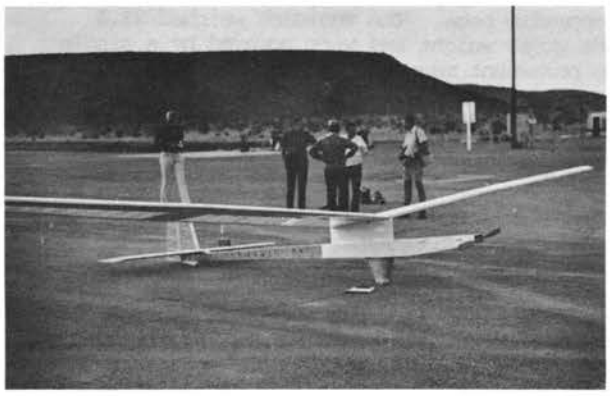


The Aerodynamic Configuration

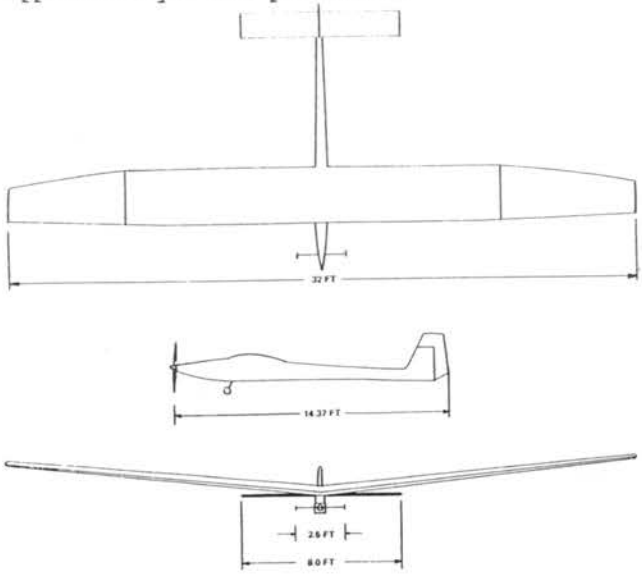
The aerodynamic configuration is shown in 3 views. It is a high wing monoplane propelled by a .6 hp motor driving a 30" fixed pitch propellor. No ailerons are provided, rather the design utilizes a 6 degree dihedral coupled to a balanced rudder. Pitch control is effected by a rather small elevator attached to a normal stab. The single wheel undercarriage with tail skid and outrigger wires proved adequate in every landing. Takeoff was assisted by utilizing the stored energy in a stretched 50 meter length of bungee cord attached with a drop away hook attached to the landing gear bulkhead.

The air vehicle has a stall speed of 14 feet per second and a cruise speed of 20 to 30 feet per second at sea level. The climb rate is rather modest compared to other fixed wing aircraft and varies from 100 to 400 feet per minute depending on altitude and sun angle. At operational altitude the speed is considerably higher and approaches 100 feet per second.

The power off sink rate is considerably lower than any known high performance sailplane and is approximately 1 foot per second.



7404-01 AT CAMP IRWIN, BICYCLE LAKE
CALIFORNIA, OCTOBER 1974

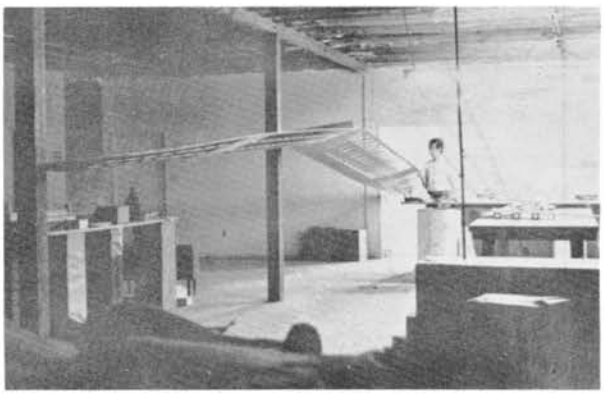


GENERAL ARRANGEMENT - 3 VIEW

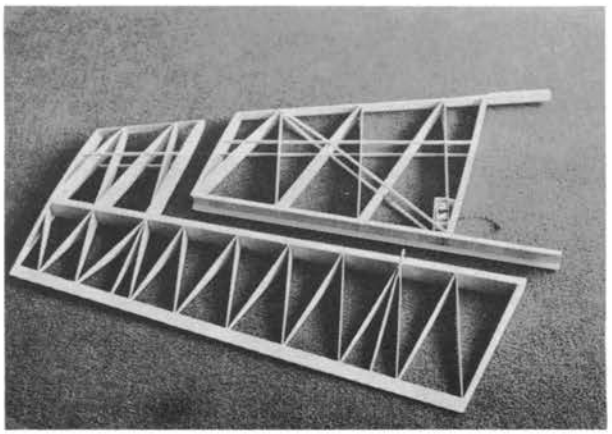
Air Frame

The air vehicle Astro Flight Model 7404 is a high wing monoplane propelled by a single tractor propellor. The configuration is orthodox and the areas and moments resemble a powered sailplane. Construction of the wing utilizes a box spar with spruce caps and balsa webs, to take bending loads and a balsa sheeted D tube leading edge to withstand torsion and fore-aft loads. The outer wing panels are removable by and are secured with a single ¼ inch steel bolt at the main spar. The fuselage utilizes a Warren truss made of douglas fir and ash blocks to take single point loads such as landing gear, wing, and tail attachment points. The entire frame work is covered with mylar sheet attached with industrial adhesive and shrunk in place by the application of heat.

The wing span is 32 feet, length 14.37 feet, height 3 feet, wing area is 90 square feet, and gross weight 22.8 lbs. The structure accounts for slightly more than half of the gross weight of the vehicle. Propulsion is provided by a .6 horsepower electric motor driving a 30 inch fixed pitch wooden propellor through a six to one reduction drive. When full loaded the wing loading is four ounces per square foot, which translates into a stall speed of 13.3 feet at sea level and a cruise speed of 81 feet per sec at 60,000 feet altitude. This extremely light surfact loading makes ground operation difficult in even light winds. The vehicles have flown in 25 mph winds which are almost twice stall speed and landed in these winds. This is analagous to landing a J-3 cub in 75 mph winds. Scores of flights were made in these hazardous conditions.



WING READY FOR STATIC TESTS



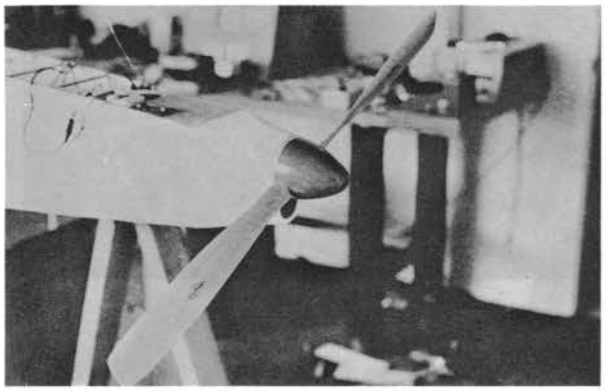
VERTICAL STAB ASSEMBLY
STRUCTURAL WEIGHT FOUR OUNCES

WEIGHT STATEMENT
ASTRO FLIGHT MODEL 7404-02

AIRFRAME		
Wing	3496 gr	
Vertical stab	213 gm	
Horizontal stab	408 gm	
Fuselage	834 gm	
Airframe subtotal		4951 gm
PROPULSION		954 gm
POWER		2523 gm
COMMAND AND CONTROL		
Command receiver	200 gm	
Servo actuators (5)	270 gm	
Sensors	176 gm	
Encoder	149 gm	
Telemetry transmitter	83 gm	
Lithium battery for c&c	494 gm	
Command and control subtotal		1372 gm
BEACON (X-BAND)		586 gm
AIR VEHICLE GROSS WEIGHT		10,386 gm

The Solar Power Subsystem

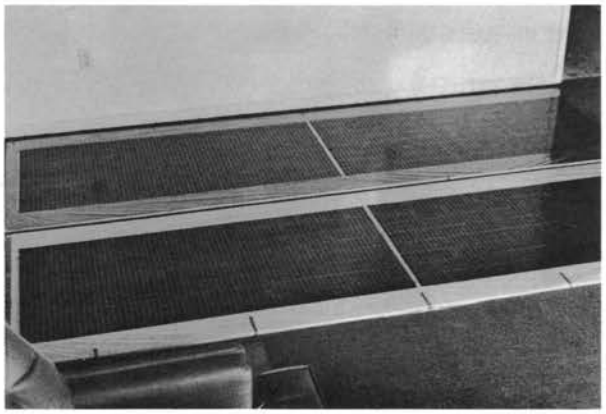
The solar power subsystem for Astro Flight Model 7404-02 consisted of four arrays of 1120 2 x 4 cm solar cells wired in series parallel to provide 37 volts at 3.8 amperes each. These arrays were attached to a one half mil mylar substrate which was in turn attached to the wing structure with industrial adhesive. The circuit was arranged to provide to the motor terminals either 15 amps at 37 volts or 7.5 amps at 74 volts. In actual tests the panel delivered slightly more power and provided a maxium of 580 watts. It weighed 5.5 lbs with all wiring and cabling and connectors. The bare cells weighed 4.5 lbs. The array worked well, its specific weight was 105 watts per pound as compared with the design goal of 100 watts per pound.



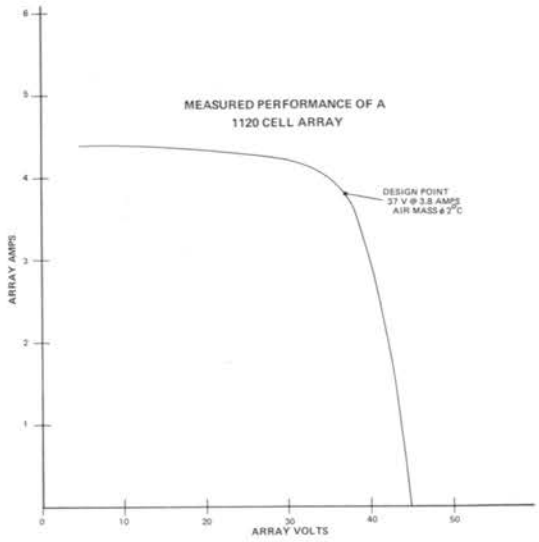
POWER SUBSYSTEM UNDERGOING LAB TESTS

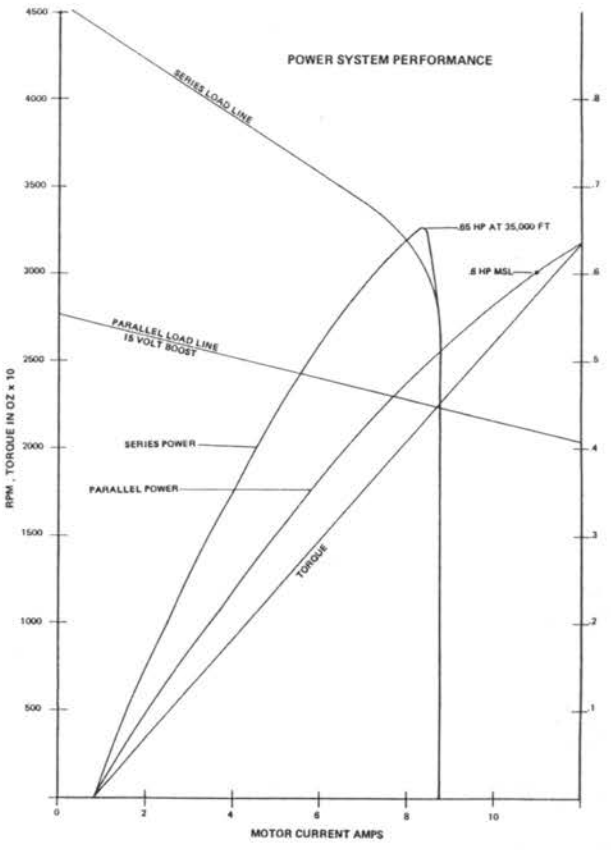
The Propulsion Subsystem

The propulsion subsystem consists of a high efficiency ball bearing permanent magnet DC motor driving a timing belt speed reducer coupled to a 30 inch diameter 16 inch pitch wooden propellor. The motor features a rare earth magnet and weighs 18 ounces yet produces more than .6 horsepower. The complete propulsion system weighs only 2.1 lbs. giving a specific weight of 3.5 pounds per horsepower.



SOLAR PANELS





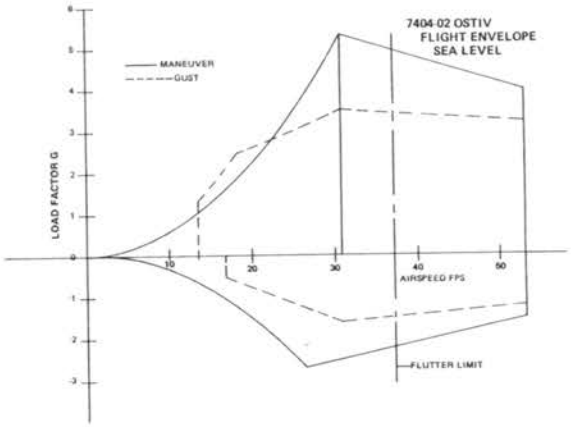
The Flight Envelope

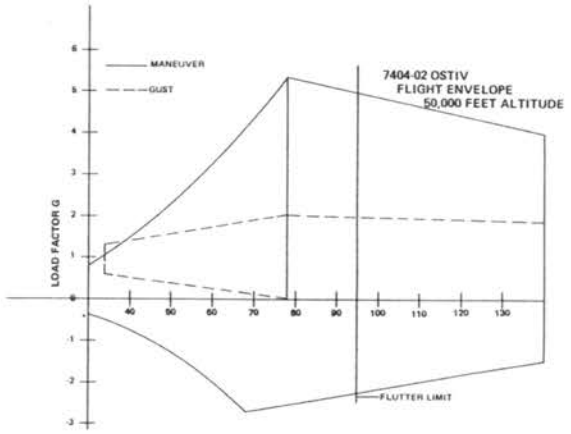
The basic flight envelope for Astro Flight Model 7404 was determined using the OSTIV method as described in the document OSTIV Airworthiness Requirements for Sailplanes, September 1971. The results of these calculations are shown in the facing page. The requirements for sea level operation and operation at 50,000 feet altitude were calculated. Since wing torsional stiffness resulted in a flutter speed limit of less than V_d this speed is shown on the diagrams.

Summary

The Sunrise Program under sponsorship of ARPA and the Air Force Systems Command demonstrated the feasibility of solar powered flight. Ways of harnassing the unique behavior and attributes of these solar powered vehicles is now being explored.

I believe that the first solar powered flight of November 4 may prove to be as historic an event in the history of aviation as the first flight at Kitty Hawk.





-- NOTES --