

WORLD ENDURANCE RECORD FOR RADIO-CONTROLLED AEROMODELS

A few seconds before 5 PM on September 21, 1981, a radio-controlled aeromodel called *New Faithful* was launched from a pasture near Brookeville, Md., and was kept airborne through dusk, night, dawn, morning, and until the engine was shut down at 1 PM on September 22 (Fig. 1). The regulations set up by the *Fédération Aéronautique Internationale* (FAI) were met, and the elapsed time of 20 hours 51 seconds was recognized as a world record for endurance. The preceding record, 16 hours 43 minutes, had been established a few weeks earlier by a team of aeromodelers headed by Dr. Plenny Bates of Cedar Rapids, Iowa.

For this hobby venture to establish a new world endurance record, the goal was "fly a long time," the approach was "keep it simple," and the schedule was "whenever ready." Some of the aeromodeling techniques and equipment employed may be of practical interest to those responsible for developing long-duration drones and remotely piloted vehicles (RPV's) for communication relays, decoys, surveillance, electronic countermeasures, and other uses. The idea that model airplane technology might be used to reduce the cost of operational military systems was very popular in the early 1970's, but mixed reviews of its merits have cropped up because some of the goals and expectations went out of bounds. Aeromodeling skills, materials, equipment, and test methods have nevertheless contributed to mini-RPV programs at APL (Fig. 2).¹⁻³ The reliability of these machines and the successful attainment of project goals have been gratifying. A number of other organizations have used aeromodeling with fine results in their R&D programs.

When *New Faithful* was exposed for its first test hop at the local club field, we heard: "Did you really build it that way or was it bent in a crash?" "It's an airborne anteater!" Although this droop-snooted, boxy model was baptized with many such derisive comments, some of the joshers eventually acknowledged its functional beauty. It is a descendant of *Old Faithful*, which set a world endurance record with a flight of 8 hours 52 minutes in 1964.⁴ Moreover, during the 1960's, similar droop-snooted, boxy machines set records for altitude (26,910 feet), closed-course distance (184 miles), cross-country goal distance (189 miles), and endurance (11½ hours).

If boxes don't try to move too fast, Mother Nature puts beautiful and useful curves in the invisible air flowing around them. Inside the boxes, wires, springs, fuel tubes, lacing cords, and shock-mounted

paraphernalia were spread from end to end. In operation, 25 explosions per second shook this machine as if it were being hit with a tympanist's mallet at *mezzo forte*. Cranks turned, valves slid, bearings twirled, gears whined, and springs pulled while push-rods and rocker arms beat a tickety-tack rhythm against the drone of vibrating drum-tight skins. The cacophony was compounded by a whooshing propeller and a piccolo-like whistle of air rushing into a tiny carburetor. Trillions of electrons were pushed by an alternator through a maze of chips, chokes, connector plugs, and a rainbow-colored harness of wires to move motors, gears, and linkages. Incandescent lights glowed on each wing tip where atmospheric ions were also being interrogated to provide reports on the bank angle. All this happened, not in the comfortable womb of a laboratory, but out in Nature's soggy, foggy, bumpy atmosphere. It was a very gratifying experience to coax this machine through more than 2 million thumps without a missed beat.

FEATURES OF *NEW FAITHFUL*

The crate-like appearance of *New Faithful* is a consequence of one FAI rule⁵ that limits all but scale models to a gross takeoff weight of 5 kilograms (11.02 pounds). Aerobatic and racing models seldom approach this limit, but for duration models this restriction means that the only way to increase fuel capacity is to decrease structural weight. Engine displacement is limited to 10 cubic centimeters (0.61 cubic inch), and the lifting surface area (wing and tail) is restricted to 1.5 square meters (16.15 square feet), but neither of these rules influenced this design. The wing was sized to fit inside a Toyota hatchback, and, although the largest permissible engine was installed, it normally loafed along at 20% of full power. A model having this size and configuration could probably climb out at a gross weight of 11 + kilograms (25 pounds); if it were loaded to this maximum with fuel, it would have the potential for a flight of 200 hours duration or 6400 kilometers (4000 miles) range. The FAI's technical rules are sensible. They promote safety, provide a common basis for worldwide comparison, and generate some tough challenges. The rule that permits only one pilot to handle the radio controls, however, would have to be repealed if endurance records much beyond the present one are to be made possible.

Development of the airplane was a matter of putting some old principles together in a functional way. Reliability was obtained by fixing or changing items

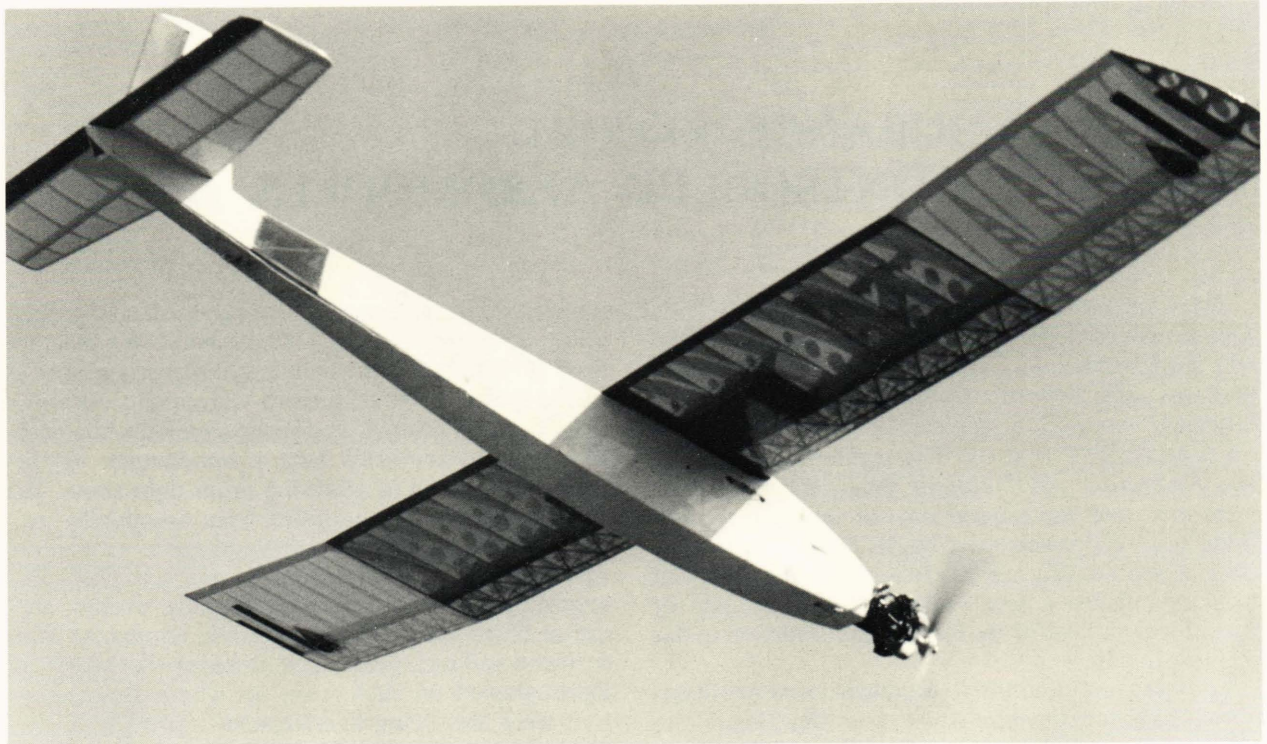


Figure 1 — Structural photo of airborne airplane (top), and crew at record attempt (bottom).

that failed during many hours of testing. The approach to solving problems was always to seek a simpler principle rather than to add complicated parts.

The key functional components are shown in Fig. 3. The engine is a modified OSFS60, where OS identifies the Japanese firm that manufactures the basic engine, FS means four-stroke, and the 60 indicates a 0.60 cubic inch displacement. Fuel is fed to the carburetor from a tank in the wing. Fuel flow rate and

pressure are steadied by an interdicting float chamber. Gravity is more dependable than pumps. Herein lies the reason for the "droop snoot."

A modified bicycle alternator is connected to an engine power takeoff through a 2:1 step-up gear train. Electric power from the alternator is rectified to DC, filtered, choked (RF), and delivered aft under the stabilizer where the radio-control receiver, servos, and a set of small (100 milliampere-hour) nickel-

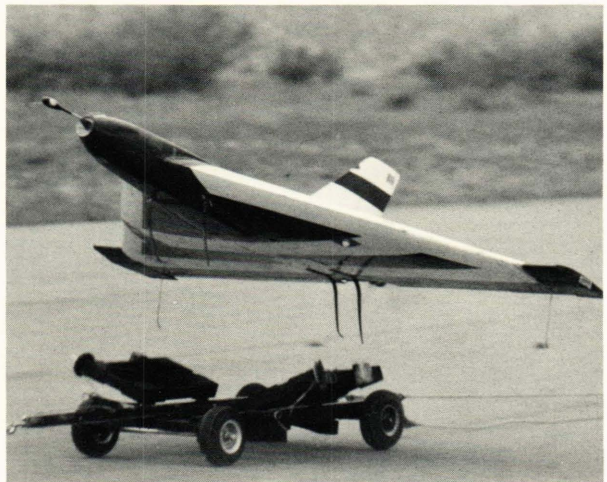
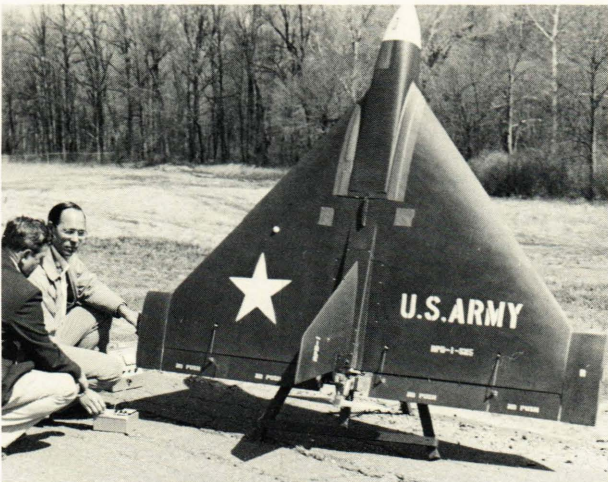
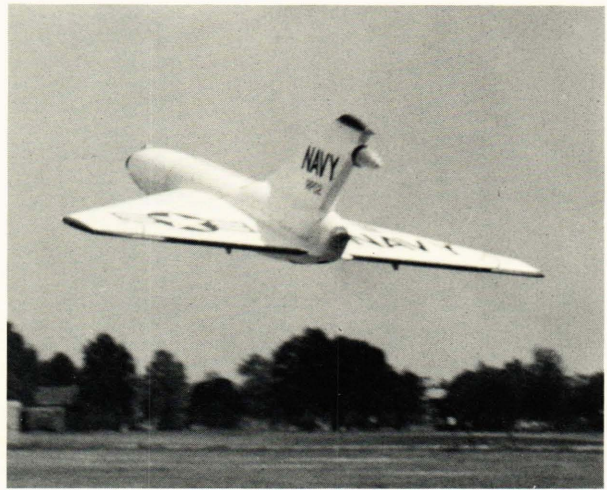
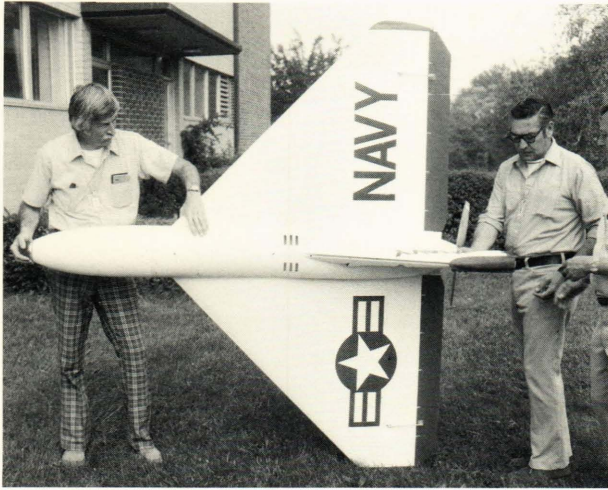
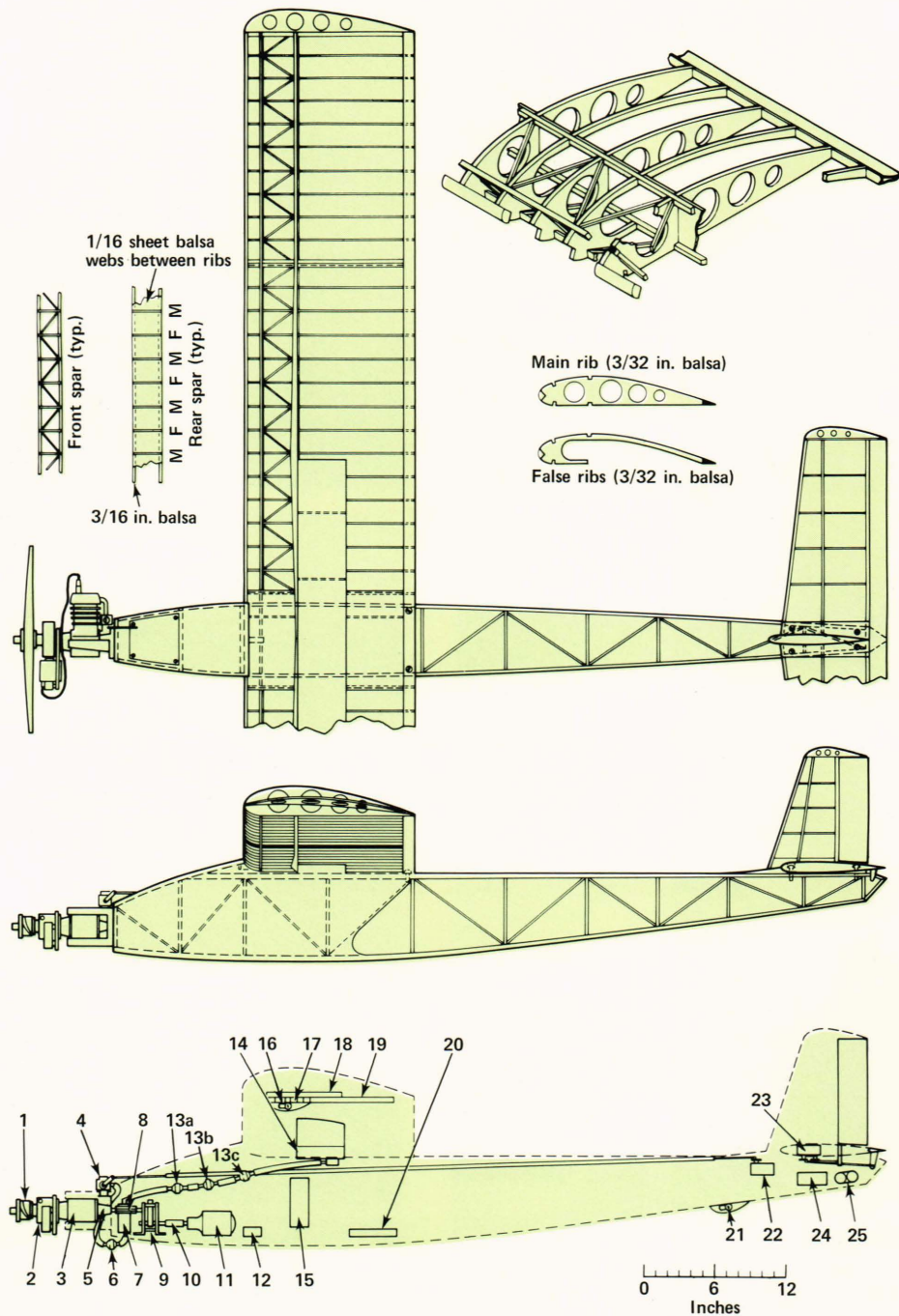


Figure 2 — RPD-1 and RPD-2 drones and the maneuverable atmospheric probe (MAP) vehicle designed and fabricated at APL.

cadmium batteries are located. The batteries provide electric power for a safe landing in case of engine failure. The alternator powers the control equipment and the three tiny lights needed on the wing tips and tail for night flying. Also on the wing tips are Static-master 2μ 500 ionization units used in an electrostatic autopilot that senses the vector of the electric field

that exists in the atmosphere and thereby provides automatic leveling of the wings.^{1,3,6,7} A small telemetry transmitter is situated at a station forward of the electrostatic stabilizer. Not shown is another vital unit, a small ground-based control transmitter that is normally portable but for this flight was tied to an automobile battery.



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|----------------------------------------------------------------------|--------------------------------------------------------|
| 1 Propellor, 16 inches diameter, 10 inches pitch | 14 Fuel tank with sump, also main center spar |
| 2 Magneto and flywheel | 15 Telemetry transmitter |
| 3 OSFS60 engine, modified | 16 Incandescent bulb, 60 mA @ 5 V in red or green lens |
| 4 OS10 carburetor, modified | 17 Staticmaster 2 μ 500 ionizer |
| 5 Cam housing and rear power take-off | 18 Grounded guard strip (copper tape) |
| 6 Filter made from chemist's filter paper | 19 Auxiliary ion collector (copper tape) |
| 7 Float chamber | 20 Electrostatic "autopilot" |
| 8 Flexible coupling (rubber auto fuel hose) | 21 Same as 16, white lens |
| 9 Two-to-one step-up gear train | 22 Throttle servo |
| 10 Flexible coupling (Tygon tubing) | 23 Elevator and rudder servos |
| 11 Bicycle alternator, rewound with no. 20 wire | 24 Kraft KP7F receiver |
| 12 Rectifier, filter | 25 Battery pack (100 mA-h) |
| 13 Filters: (a) 100 mesh metal; (b) 200 mesh nylon; (c) filter paper | |

Figure 3 — Structural drawing of *New Faithful*.

THE AIRFRAME

Balsa bridge-truss structures are efficient, easy to fabricate, and low in cost. Streamlining the boxes would add more weight than it is worth in this category of competition. Most of the airframe is made of "contest-grade" balsa, which has a density of 4 pounds per cubic foot and tensile and compressive strengths near 800 pounds per square inch. The main wing spar and fuselage longerons are made of a denser grade of balsa having a strength of 2000 pounds per square inch. The covering material is a Mylar-type film (called Monocote by the manufacturer, Top Flite Models) coated with a pigmented heat-sensitive adhesive so that it can be attached to the airframe with a clothes iron or other hot device. Wrinkles are easily removed by heat-shrinking with a blast from a hair dryer. The material weighs about 0.2 ounce per square foot, is fast and easy to use, and produces a smooth, colorful, and fuel-proof finish.

There is a bridge-truss spar in the wing. The front member protrudes in a way that promotes early onset of turbulence in the boundary layer. Usually, airplane designers try to keep boundary layers laminar over the first half of the wing chord, but with slow-flying models it is easy to induce the laminar boundary layer to persist too far, and then the flow can separate easily from the rear portion of the airfoil. If separation occurs — and it probably will if bumpy air is encountered — the result can be a drag force considerably larger than that associated with a tripped turbulent boundary layer, which tends to stay attached. *Caveat emptor!* If a super-low-speed conceptual design is being sold on the basis of wind tunnel or analytical predictions, divide the predicted endurance by two or build a cheap radio-controlled simulation for verification before deciding to spend a lot of money on construction.

The fuel tank, which does double duty as the center wing spar, is an assembly of 1/16-inch-thick sheets of contest-grade balsa, coated internally with polyester resin and covered externally with a single layer of fiberglass (3/4 ounce per square yard) impregnated with the same resin. Most polyester and epoxy resins are impervious to gasoline (the fuel, discussed later), but failures can result from additions of nitromethane, amyl nitrate, and other ingredients that modelers like to use to smooth out combustion in their small engines. To avoid building a wing spar that might dissolve during flight, many samples of balsa were coated with a variety of resins and placed in baby food jars containing candidate fuels. The array of samples was stored for months in a backyard greenhouse. This exposure to thermal cycling and solvents was a brutal test. Some combinations that looked satisfactory during the winter turned into messes by July. A polyester finishing resin distributed by Sig Manufacturing Co. was eventually chosen.

ENGINE MODIFICATIONS

The engine, as received, was designed to use glow-plug ignition, whereby a hot filament incites a diesel-

like compression ignition process. Glow-plug ignition is widely used in model engines because of its simplicity, light weight, and freedom from radio-frequency interference (RFI). Unfortunately, it does not work well with gasoline-based fuels. Most model fuels are methanol-based, with specific fuel consumption rates about three times those for gasoline. It is possible to increase the efficiency of these engines by increasing the compression ratio, but this causes very severe mechanical problems. Furthermore, fuel-air mixtures become extremely critical and sensitive to temperature and humidity changes. I toyed enough with such ideas to reach the conclusion that spark ignition, even with its heavy coils and RFI problems, was bound to be a better method. So, a magneto coil and flywheel from a grass trimmer engine (Lawn Boy, part #06823-07, -08) were mounted on the front housing, as shown in Fig. 4. The flywheel was originally round, but it was cut to a dumbbell shape to reduce weight. A word of warning to modelers is in order. Don't try this dodge on an engine that turns up to the usual 9000 rpm. The dumbbell will fly apart. Taking fatigue into account, I would not trust this device above 5000 rpm.

The coil shown in Fig. 4 is called a solid-state magneto, in which the spark discharge is triggered by the same magnetic flux that energizes the coil. The inner secrets of this device seem to be proprietary, but two important observations can be made without knowing exactly how it works: (a) there are no points to wear out, and (b) it generates a milder form of radio-frequency noise than do either point systems or capacitance discharge systems. The RF noise can be effectively suppressed by putting a 10,000 ohm resistor in series with the plug and by putting a shield over the high-tension lead. For the maneuverable atmospheric probe (MAP) vehicle developed at APL, we used these coils to make a twin magneto for the 10 HP Herbrandson DYAD 160 engine shown in Fig. 5. Capacitance-discharge ignition systems are usually used on mini-RPV engines of this type. They work but are



Figure 4 — Modified OSFS60 engine.

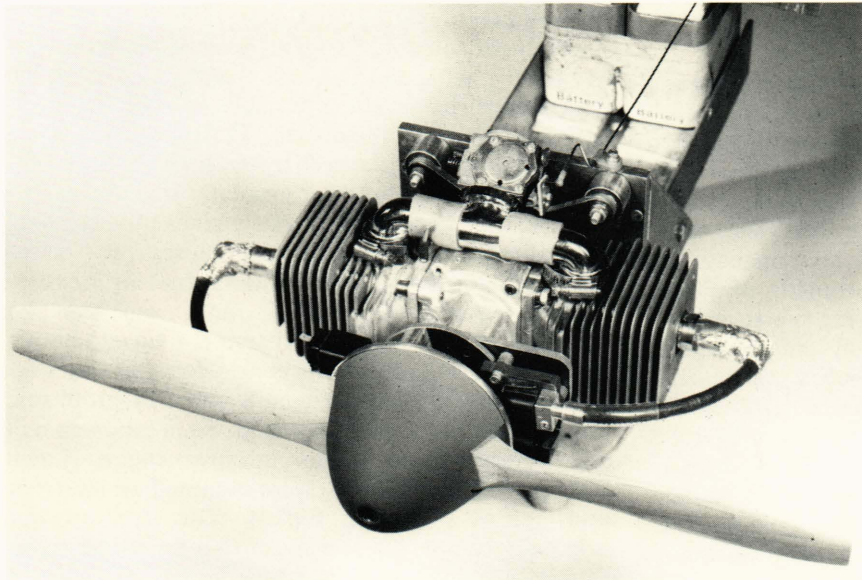


Figure 5 — MAP DYAD 160 engine.

more complex and tend to create ancillary problems. The chain goes like this: First, a heavily taxed alternator has to provide extra power. Next, a rectifier and voltage regulation system must be over designed to withstand a pulsating load, or else other parts of the RPV system will malfunction. Several efficiency losses occur in these processes, the product of which is a spark that is friskier with RFI, so heavier shielding is needed, and this bulkiness encroaches on space for other components. The MAP vehicle has been operated in some grueling environments in muggy Maryland as well as in the dusty, hot deserts of the southwest. Its engine always comes to life when the propeller is spun and has never stopped in flight. Some of the flight conditions included low idle at 13,000 feet altitude.³

Until about 1979, all engines being mass produced for hobby use were of the two-stroke type and, until this flight in 1981, all world records in all power categories had been established with such engines. Although I had experimented earlier with homemade, four-stroke engines, which inherently have better fuel efficiency, perfecting an engine for duration takes lots of spare parts so no serious effort was made to use such a design until the OSFS60 appeared. For a first of its kind on the market, it is remarkably well built. I have run one more than 400 hours, and bearings, piston fit, and compression are practically as good as new. Some problems, however, showed up in the valve, rocker-arm, and cam system, partly because very little lubricant was being used in an effort to attain high fuel efficiency. Valve clearances had to be reset every 3 hours, and after 24 hours the push rods were too short to permit further adjustment. This problem was partially fixed by weakening the valve springs and replacing the push rods with pieces of Allen hex-wrench material (5/64 inch across the flats). The tips of these push rods and also the tips of the cam follower pins were hardened by heating them

with a microtorch to about 1600°F (near an orange glow) and quenching in water. No annealing or tempering was done after the quench.

Next, the valve-drive cam started to wear. This problem was mitigated by adding oil to the fuel and drilling a small breather hole in the crankcase aft of the cam. Oil was thereby blown through the cam housing. Now the valve system was good for 50 hours between adjustments, but carbon buildup on the valves and spark plug choked the engine to a stop about 10 hours after each valve overhaul job. Here we reached into an old bag of tricks for polyisobutylene, a chemical used in the manufacture of synthetic rubber. This viscous liquid does a pretty good job of lubricating metals, and instead of producing carbon particles, it cracks mostly into combustible hydrocarbon molecules when heated. Presto! Very little carbon is formed, and fuel efficiency is increased, using 93% premium-grade, unleaded gasoline and 7% polyisobutylene.

The most tedious work dealt with the carburetor. A radio-controlled fuel needle valve could have been installed but would have defied the simplicity rule. Instead, a built-in means of keeping the fuel-air ratio constant throughout the power range was sought. A rotating-barrel type carburetor from a tiny 1.5 cubic centimeter (OS10) two-cycle engine was adapted to the inlet manifold. A mercury manometer was attached to monitor inlet-manifold pressure, and fuel was fed to the engine via a float chamber from a 50 cubic centimeter graduated burette. The needle valve was first adjusted for lean, but smooth, running at full throttle, which was usually around 4500 rpm. From periodic readings of the pressure and the fuel level in the burette, a number proportional to the fuel-air ratio was calculated. Additional sets of data were recorded for lower throttle settings. The fuel-air ratio never stayed constant with a stock carburetor. Usually, the mixture became very rich at low power.

A shaped notch in the carburetor barrel was needed. The notch shape was found by grinding a little, testing the fuel-air ratio, grinding a little more, testing again, etc. I got it right on the third carburetor on the fifth weekend.

CONTROLS

In the fuselage, the radio equipment was placed far aft to reduce the chances that ignition noise would cause jitter and excessive current drain by the servos. As it turned out, this precaution was not really necessary because very effective shielding was eventually installed. The nickel-cadmium batteries, a special Hi-Rate type obtained from ACE Radio Control Corp., can withstand severe overcharging so there was no need for a voltage regulator. The telemetering unit sensed the current flowing into or out of the batteries, and a monotonous musical note from the receiver gave pleasant assurance that all was well on board. Servo motions could be detected as a superimposed buzz, and, since the charging current changed with engine rpm, the pitch of the tone indicated engine speed. Interference or glitching due to weak signals could also be detected by the presence of a scratchy noise, but this ominous sound wasn't heard during the record flight.

The polyhedral angle of the wing minimizes spiral instability of the basic model, but fuel shifting from one side of the wing to the other during uncoordinated turns generates quite a load of rudder work for the pilot. So the electrostatic stabilizer (Fig. 6) was used for automatic wing leveling. For this flight, the aluminum box was removed, and the total weight of the system was reduced to 1¾ ounces, equal to more than 1 hour's worth of fuel — a good trade. Devices of this type can also be used to stabilize pitch attitude,^{1,3,6,7} but the feature was omitted in this instance. Instead, a long tail moment and large stabilizer were used. This simple expedient provided a substantial margin of inherent pitch stability and precluded potential troubles related to servo wear and extra current drain in an active pitch-stabilization loop.

SHAKE, SHAKE, SHAKE

Eventually, a continuous, "hands-off" run of 50 hours was made. For this run, the engine was

mounted on the aircraft, which was, in turn, suspended on elastic lines to allow the entire flight-ready assembly to vibrate as if airborne (Fig. 7). One often hears the builder of a new airplane exclaim, "It flew right off the drawing board." That effusion signifies bad practice. At APL, our rule for a mini-RPV is "shake it at least 15 minutes per pound," the rationale being that the weight is usually a measure of the amount of failure-prone equipment on board.

PRACTICE, PRACTICE, PRACTICE

For trials to work the "air bugs" out of the system, all of the components were installed in a model made from relics left over from 1960's record attempts. In flights during dusk and dawn periods, the airplane cannot be seen very well, but neither is it dark enough to see the small red, green, and white navigation lights. The electrostatic stabilizer was found to be a big help during these periods, as well as during the night when visual determination of the attitude of the airplane was based solely on the orientation of the three tiny incandescent bulbs. At the planned flight altitude of about 1500 feet above the ground (or 2000 feet above sea level), the array was closely spaced, the color contrast was not strongly discernible, and staring at these star-like wanderers amongst Orion and other rocks of the heavens had a hypnotic effect that mesmerized even the most keyed-up senses. My limit was 3 or 4 hours. But an FAI rule states that no assistant pilots are allowed to use the control transmitter. The electrostatic stabilizer served very effectively toward overcoming this roadblock. Instead of having to pay attention and compensate for spiral instability, I was able to close my eyes, relax on a chaise longue, and momentarily pulse the control stick hard over in response to verbal commands from observers who could do the staring in relays.

The pretested equipment was transferred into a new airframe for a July 4 baptismal flight. By mid-August, the assembly had been tortured 75 hours on the ground and 25 hours in the air, and confidence in the machine was very high. The remaining task of flying 20 or so hours for official witnesses would call for some truly dedicated people. "Exciting boredom" is what someone called it during previous record flights. Care was taken to pick helpers and to

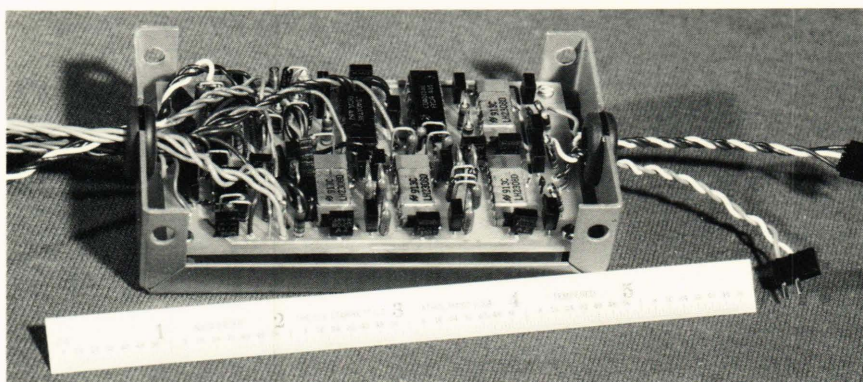


Figure 6 — Electrostatic autopilot.

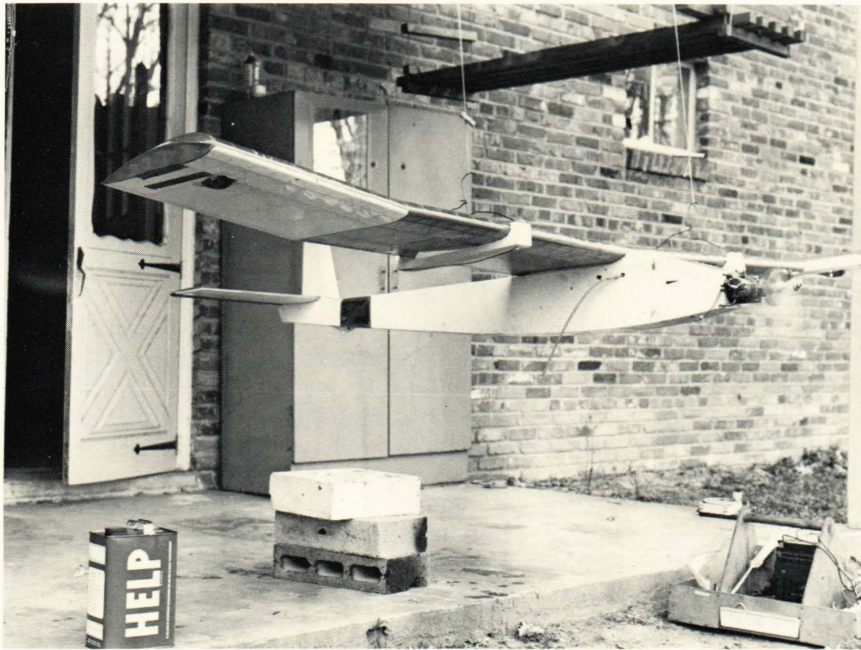


Figure 7 — Vibration torture rig.

ask for officials whose qualities included patience, stamina, and a sense of humor.

Weather loomed as the last barrier. The model is strong enough to withstand fairly severe turbulence, but to avoid unpredictable thunderstorms and keep the pilot's work to an acceptable level it seemed wise to wait for the calm that is a characteristic of equinoctial highs (convectively stable masses of hot air) that frequently stagnate in our area during the last half of September. Synoptic information from many sources was watched for the signs that usually precede the favorable conditions. September 12 and 13 were great, but the crew and officials were off in Virginia running a scale competition. A series of rapidly moving cold fronts followed. On September 20, the crew gathered under drizzling clouds and went through a test run of official weighing, launching, and timing procedures. The next afternoon, an occluded front stretched west-east from Kansas City to Philadelphia, with rain 100 miles north of our field. We decided to see how far we could get even though there was a 15 mile per hour wind from the southeast and an overcast of cumulostratus clouds, and these conditions usually presage bad flying weather.

THE RECORD FLIGHT

The launch went off as planned at 5 PM. By 7:30 PM it was dead calm on the ground, but there was obviously a flow at 1500 feet, for the model sat nearly stationary, its airspeed matching the wind, which must have been nearly 20 miles per hour from the southeast. By 8:30 PM, the observer method was working well in a clear, star-laden sky. Two artificial satellites were seen about this time. The boredom was relieved by philosophical discussions inspired by these sightings. By midnight, the observers were so practiced at giving yaw and pitch trim commands

that they were competing to see who could hold this new constellation stationary for the longest period. There were long times when it could be mistaken for a star. I slipped into drowsiness and missed a few commands. To stir my attention, George Pickrell jumped up onto a box and bellowed, "Holy cats! There are three guys coming over the hill on camels!" There's nothing like a healthy guffaw to keep a party alive.

About 2 AM, a heavy ground fog formed. It stayed through the rest of the night but never grew thicker than about 75 feet. Sideways, visibility was only 50 feet, and there would have been no way to accomplish a safe landing if the engine had failed. Vertically, the navigation lights and stars could be seen through a cone-shaped hole. By 5 AM, the wind aloft had shifted to the west — the front was moving away. The visibility cone, however, had diminished to about a 20° included angle; ground equipment, crew, and blankets were soaked with dew; and tension was building because we had never flown through a very foggy dawn. But with six pairs of eyes and two pairs of field glasses, we made it. By 9 AM, thermal convection and winds (about 10 miles per hour at ground level) were causing the model to bounce more, so the nighttime observer procedure had to be abandoned. By 10:30 AM, husky bumps were causing excessive currents in the electrostatic stabilizer system, so we had to shut that aid down as well. At 1 PM, we were 3½ hours past the prior record. Inasmuch as a broken wire or servo failure could result in a landing more than 500 meters from launch, an event that would scrub any record claim, the engine was shut down. A gust blew the airplane toward my wife's shiny new Honda during final approach. In the interest of continued harmony, there was no choice except to pull up, over her car. The model was ignominiously impaled on a corner pole of

the cook tent, 10 meters from the launch point. We were home, nonetheless, with a valid claim to the record.

INFERRED RESULTS AND THEIR IMPLICATIONS

The gross takeoff weight of this model was 4.98 kilograms (10.96 pounds). Of this, 1.73 kilograms (61 ounces) was fuel. When the model landed, 0.89 kilogram of fuel was still in the tank. Thus, this model has a theoretical capability for a flight in excess of 40 hours. The fuel consumption rate of 42 grams per hour (1.5 ounces per hour) is impressively low, but there is no miraculous engine efficiency involved in this performance. As evidence, consider the following points. The model was flown at about 25 miles per hour through most of the flight. It probably has a lift-to-drag ratio of about 10 at that speed. Assuming a propeller efficiency of about 0.75, the specific fuel consumption is found to be about 1.03 pounds per horsepower-hour. This rate is a third to a half that of comparable two-cycle engines, but it is still nearly twice that of some larger, four-cycle engines used on manned aircraft. Further improvements in the engine are, therefore, theoretically possible, but they would not be easily achieved in this small size.

The model's "gas mileage" figure is 1500 miles per gallon, and its estimated "FAI legal" range (without wind) is nearly 1000 miles. The engine's fuel specific impulse is an astounding 39,000 seconds (pounds force-seconds per pound mass of fuel). Full-scale aircraft engines seldom exceed 5000 seconds at their higher flight speeds. This impulse-speed relationship is an important factor that could lead to great endurance for slow-flying drones or aircraft; consequently, efforts to exploit this advantage would be fruitful. But a word of advice is in order: atmospheric turbulence can sharply reduce duration of flight. On very calm nights, this fully loaded model climbs to and cruises at a ceiling of about 2000 feet above sea level with the engine at minimum throttle, 2900 rpm. On days with thermal turbulence and breezes, an average engine speed of about 3700 rpm (requiring twice the power) is needed to keep the same weight airborne, i.e., to regain altitude that is lost during unintentional maneuvers caused by convective turbulence. The extra power required is not believed to be significantly related to laminar-flow separation effects discussed in connection with the caveat delivered earlier. Hence, in some cases, the factor "two" may not be a large enough "optimism" divisor.

One can speculate that 200-hour endurance might be obtained by an all-out "legal FAI," 5-kilogram aeromodel if human factors and weather were not limiting. Such a model would be designed for utmost structural efficiency and would make use of carbon fibers, Kevlar, titanium, cobalt-samarium magnets, lithium batteries, solar cells, and tough microfilm coverings. It might employ a tandem wing of maximum allowable area and a lightweight, electrostatic

pitch stabilizer to allow equal loading of both surfaces. It would fly still more slowly, with consequent greater specific impulse. Its range capability would be more than sufficient for a west-to-east transatlantic flight (with some very difficult logistics problems). I would rather try something easier like launching at Moab, Utah, at the upper end of the Grand Canyon. The terrain avoidance features of the electrostatic stabilizer would make the machine fly down the valley.³ We could hop a jet to Hoover Dam and sit in a bar telling flying stories while waiting for the machine to arrive a day later.

Besides providing useful knowledge about how to achieve good engine performance and aerodynamic efficiency at low flight speeds, this venture showed again that simple, lightweight, low-cost electrostatic stabilizers can be useful. They have not been used very much except in APL programs. Some forms of adverse weather can cause malfunctions. Furthermore, inadequate understanding of the underlying electrostatic principles has caused confusion in some quarters about their capabilities. Improved characterization of the physical processes involved in both these problem areas would help establish sound engineering procedures for designing functional installations. It is hoped that this article will stimulate technical interest and that some of the factors that influence the performance of electrostatic stabilizers will be exposed to rational investigation in the near future.

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