OLD FAITHFUL

World Endurance Record Radioplane

M. L. Hill

The radio - controlled airplane model, *Old Faithful*, was described by a writer in the popular press as being as ungainly as a pelican flying inverted with a beak full of fish! He went on to say that in spite of this, it was attractive because it was functional.

Indeed, when contrasted to the highly streamlined and elegantly painted models that are commonplace in radioplane aerobatic competitions these days, *Old Faithful* is rather unsightly. But its unaesthetic lines fit its purpose, which was to beat the world endurance record of 6 hr, 13 min., held by Mr. A. Malikov of Kiev, Russia. This was accomplished on Sept. 18, 1964, with a flight of 8 hr, 52 min., 25 sec.

This flight has since been officially homologated by the Fédèration Aéronautique Internationale (FAI), a venerable organization, quartered in Paris, that has cognizance over all forms of international aviation and space competition. Requests for such homologation are made by the U.S. Academy of Model Aeronautics, a nonprofit organization having about 20,000 members in the United States. The Academy is affiliated with the National Aeronautics Association, which has responsibility for monitoring and promoting U.S. participation in international competition in the categories of full-scale aircraft, rocketry, parachuting, soaring, model aircraft, and several others.

It is of interest to note that due partly to a special push made by the NAA since about 1960, the U.S. now holds 289 full-scale aircraft records and Russia, the chief competitor, holds 122. The Academy of Model Aeronautics is now launched on a program to correct the international record distribution in their own area, which is now 14 for Russia and 7 for the U.S., out of 32. At least part of the reason for this uneven distribution is that aeromodeling is included more formally as a part of the technical training of young engineers in Russia. As a result, there are a number of professional modelers who teach or work in their government institutes, and these people are urged to do their

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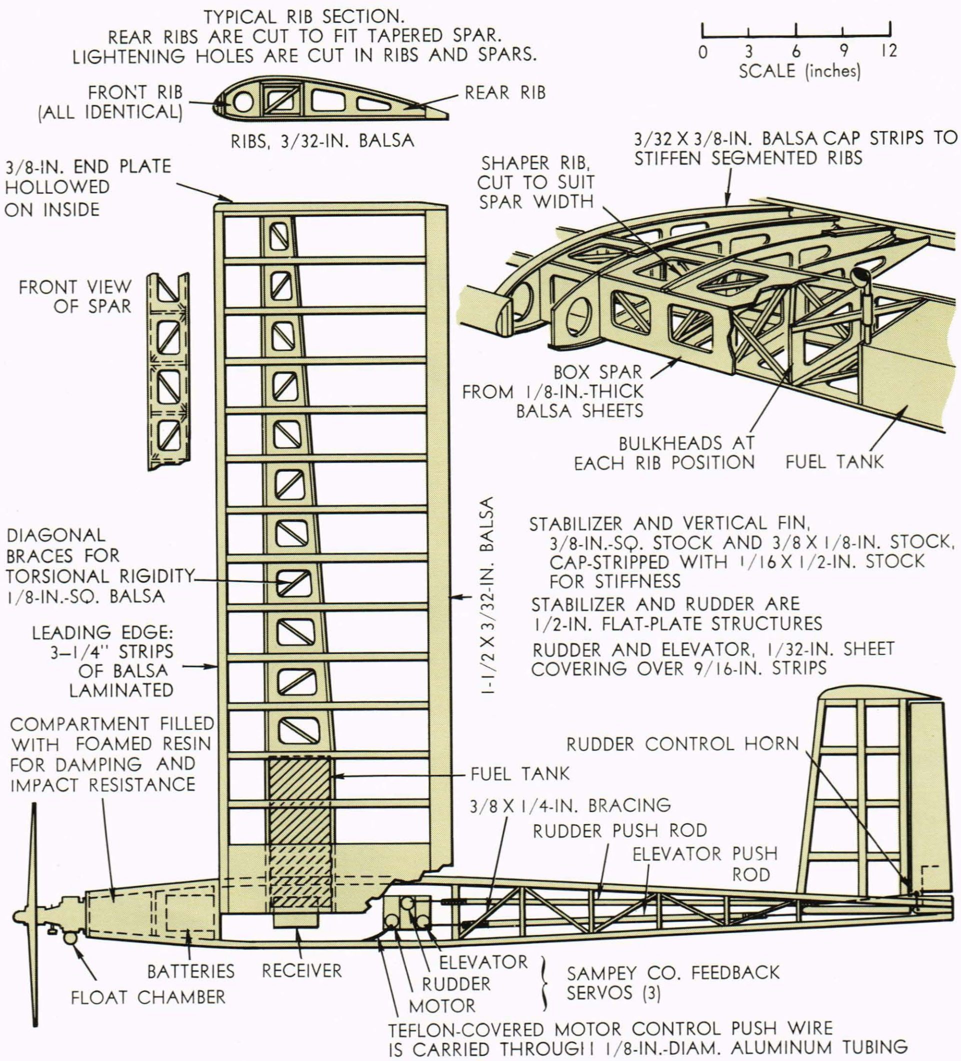
Shortly before going to press the editors were advised that Mr. Hill has recently flown a radio-controlled model similar to *Old Faithful* a total distance of 174 miles on a closed course. This new world record exceeds by nearly 40 miles the former record held by a Russian.



Top view of *Old Faithful*, emphasizing the strong, lightweight inner structure.

best to keep competition records in their country. It is gratifying to note, on the other hand, that the hobby approach and the competitive system of industry in the U.S. have led to radio control and model equipment that is superior to that available anywhere in the world. This situation has been clearly demonstrated in the three world championship aerobatic competitions that have been held to date, from which the U.S. teams have brought home the championship each time. The lag in world records exists mostly because there was little active interest or effort in this country until about 1962.

Old Faithful is a direct descendant of *Skyrocket*, a model used by the author to establish the current world altitude record of 13,328 ft in July 1963.[1] In fact, the stimulation for the endurance attempt came from some flights of *Skyrocket* with a 2-lb camera on board. The photographs were interesting, and with but a little more effort it might have made a usable reconnaissance drone. But the more impressive observation was the ease with which that large model could lift the extra weight. Subsequent tests showed it had no difficulty lifting a 5-lb payload and that basically it was capable of establishing a duration record. This observation started a development program that provided a little over a year of fascinating hobby activity.

The ungainly appearance of *Old Faithful* was dictated by requirements quite different from aerobatic models which fly at speeds up to 100 mph and are capable of every aerobatic maneuver in the full-scale handbooks plus a few that would never be tried by even the most daring pilot. The FAI rules limit gross takeoff weight of models to 5kg (11.023 lb), and this restriction automatically imposes minimum structural weight as one of the prime requisites for a successful model. *Old Faithful* could probably lift off 20 lb gross weight and fly for perhaps 24 hr

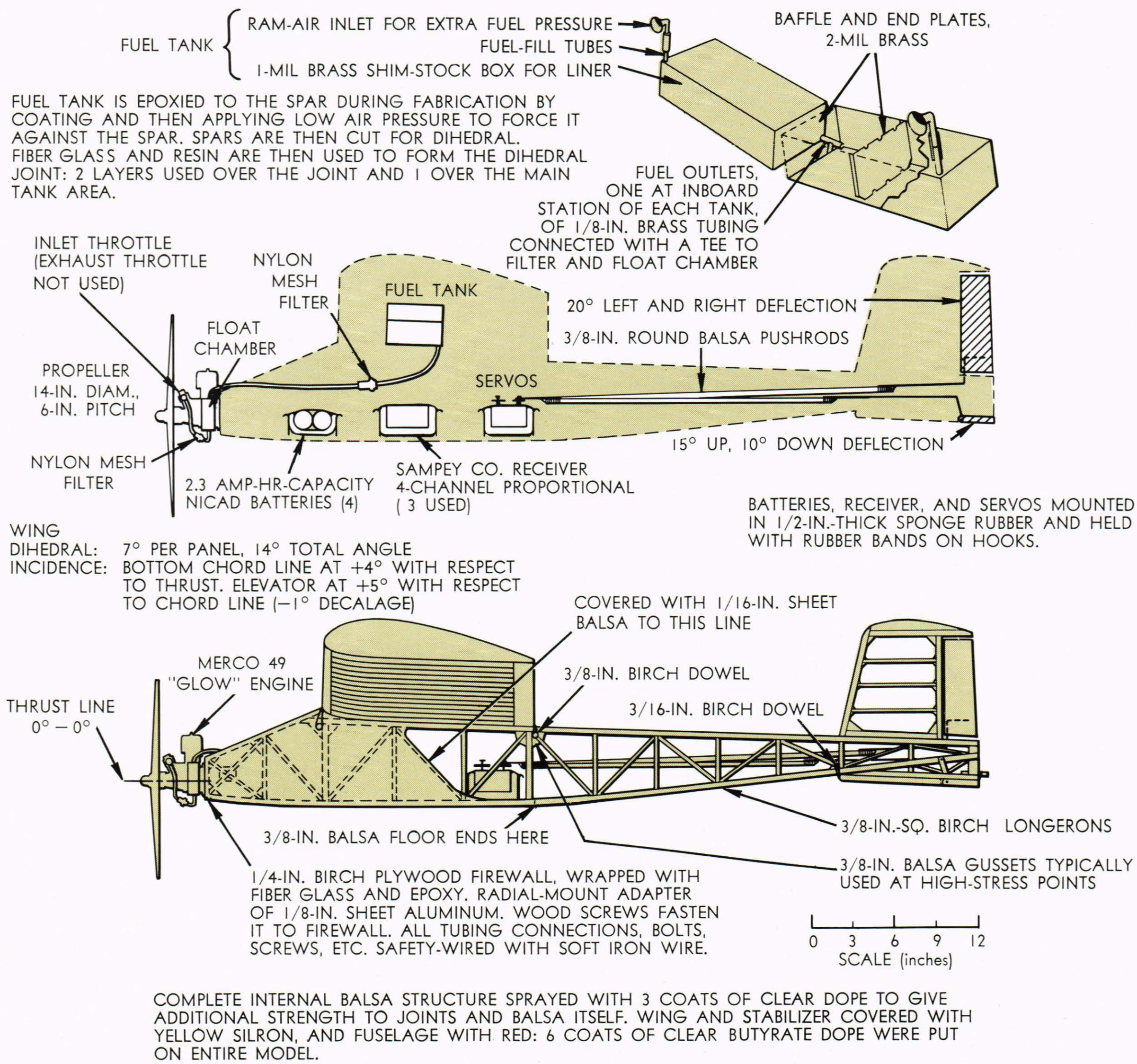
[1] M. L. Hill, "Skyrocket, World Record Altitude Model," *Science and Mechanics,* **35**, Mar. 1965, 89–97.

were it not for this restriction.

Under existing rules, however, the only way of increasing fuel capacity to beat the world endurance record was to minimize structural weight. The simple box-like structure using balsa-wood "bridge truss" construction was a natural consequence, for the high strength-to-weight ratio of balsa wood cannot easily be surpassed, particularly if full advantage is taken of its directional or grain properties. Most of the airframe was built with what has become known as "contest" balsa, a light-weight grade that weighs about 4-5 lb/ft^3 and is used primarily for 2-ft-wing-span, indoor, free-flight models that weigh less than 0.1 oz and which have been flown for over 45 min. using a rubber motor weighing 0.05 oz.[2] The tensile strength of this lightweight balsa is typically about 800 psi; harder grades used for aerobatic models range upward to 4000 psi.

Examination of the accompanying drawings of *Old Faithful* reveals that a number of specialized materials were used in addition to the balsa. Fiber glass-resin combinations are familiar materials to the average modeler and were used for high-tensile-strength requirements. Also, foamed resins were placed for strengthening areas exposed to buckling stresses. The covering on this model was a lightweight cloth of silk and rayon made especially for model use. Total weight of the covering and clear butyrate paint was slightly under 6 oz. Nylon and brass were used for all components of the fuel system because most of the acrylic plastics, epoxy, or polystyrene resins are deteriorated slowly by the ingredients used in the fuel. I did not know of this fact, and learned it the hard way. Early in the project an

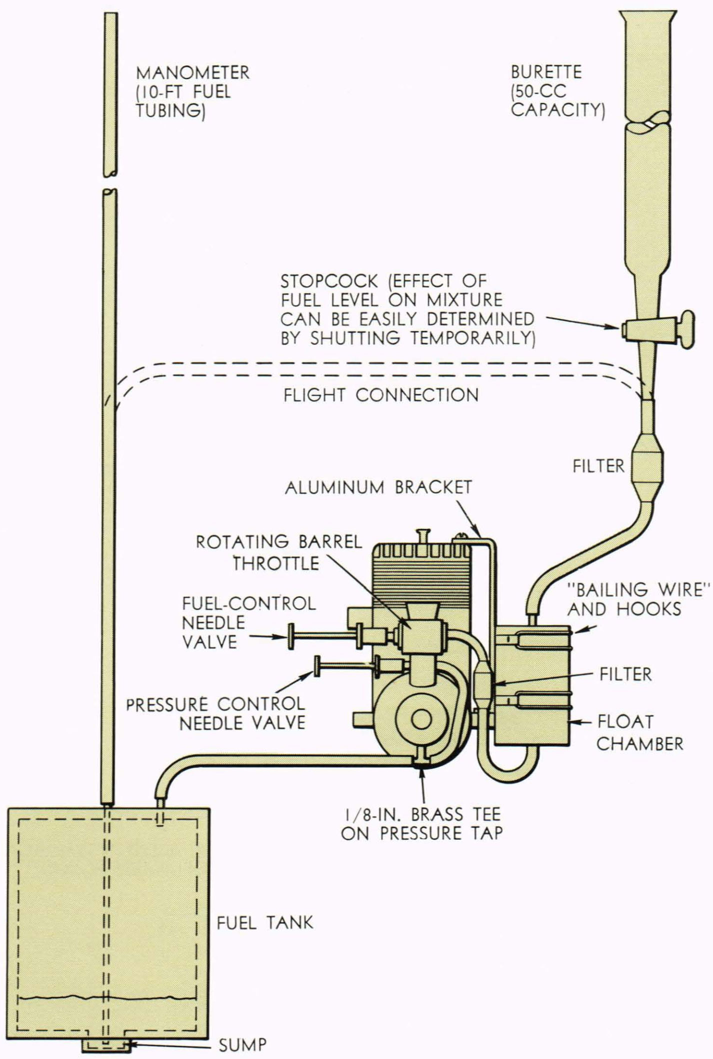
[2] M. Hacklinger, "Theoretical and Experimental Investigation of Indoor Flying Models," *J. Roy. Aeron. Soc.*, **68**, Nov. 1964, 728–734.



Side elevation of *Old Faithful*, showing the location of operating components and a detail of the fuel tanks.

epoxy-fiber glass tank was used, with gasoline fuel. Subsequent use of small additions of methanol and nitromethane resulted in softening of the epoxy and eventual rupture of the tank while airborne. The tank on this model was carried inside the fuselage and was pressurized to about 3 psi. The crew on the ground was not aware that a shower of fuel was spreading from stem to stern inside the fuselage, inundating the receiver, servos, and batteries. Needless to say, this early attempt ended in a crash! To add indignity to the crash, the site of impact was 30 ft up in a thorn tree surrounded by a briar patch! (One's equipment must be salvaged, even at the expense of one's dignity!) The fuel tanks in *Old Faithful* were contained in the wing, partly to avoid repeating this discouraging incident and also to economize on weight. By using the box spar in a dual role as external support for the tanks, it was possible to use very thin brass sheet for liners. The total weight of the tanks was slightly under 3 oz, a respectably low weight for carrying about 4.5 lb of fuel.

The radio equipment used was a commercially available unit that we modified to obtain low current drain from the nickel-cadmium batteries used for servo and receiver power. This transmitter-receiver unit has four independent channels of proportional control and provides for trim of all controls in addition to the joy stick used for normal flight control. Only three channels were used, one each for rudder, elevator, and engine control. Ailerons were not necessary since the yaw-dihedral combination provided built-in roll and bank stability.



Fuel system diagram, including the system used for measurement of fuel consumption rates.

The fourth channel of the radio could have been used for regulating fuel-air mixture, but as a result of the development of a suitable fuel this was not needed in the record flight. This fuel contributed greatly to the final success for it is very difficult to analyze and correct the lean or rich symptoms of such engines when they are airborne. At least a few serious endurance efforts by other modelers have failed because of pilot error in adjusting fuel mixture.

The total on-board weight of the control equipment was 26 oz, which included the 14-oz battery that had sufficient capacity for 40 hr of flight. The large battery did not result from optimism about the duration of the flight but rather from a decision to play very safe on this critical component. The final weight of the model, less fuel, was 6.5 lb. This left 4.5 lb for fuel, and it was known before takeoff that this should yield a flight of 9 hr $\pm$ 10% depending on the accuracy with which the fuel mixture was adjusted. Great care was necessary in setting the needle valve used for mixture control since we had to anticipate the effects of humidity and temperature that would occur later in the day.

By far the most interesting facet of this project was the development of a fuel and fuel system to sustain a long flight. The droopy nose of the model, plus the assembled paraphernalia on the engine, is probably the most unaesthetic feature of the model in the eyes of those accustomed to seeing shapely spinners and cowlings. The final fuel system used gravity feed from tanks in the wings, and was far simpler and more reliable than the pressurized fuselage tanks of the previous model. The large droop was necessary to obtain gravity feed even with the model trimmed for high angle-of-attack to support the fuel load early in the flight.

The heart of the fuel system was a float chamber (see photograph) developed specifically for this project. Diaphragm pressure regulators have been used by most previous record

"Glow plug" used in the endurance flight. (All photos are by Fremont Davis.)

holders because float chambers have problems associated with wear of the valve and frothing of the fuel due to vibration. By using a proportionating slide valve and by sizing the float chamber properly, both of these problems were overcome. Two nylon mesh filters were used, one upstream of the float chamber and the other upstream of the needle valve. Compared to diaphragm-regulated systems, the final fuel system was far more tolerant of fine dirt and dust that somehow found its way into the fuel in spite of the double filtering that was always part of mixing the fuel.

The fuel development was a fascinating game of blending uneconomical ingredients known to perform well in "glow-plug" engines, with gasoline which has exceptional economy but which normally will not burn in this type of model engine. The magnitude of this problem becomes obvious if one realizes that a typical aerobatic model uses standard fuel at a rate of about 1 oz/min. By carefully throttling power, the 4.5-lb payload of the model would have provided a highly unimpressive flight of a little over 2 hr on such fuel.

The first step in development of the fuel was to devise a method for rapid measurement of fuel consumption rates. With the system we developed (see illustration) it was possible to map completely the performance of a fuel during a test period of about 30 min. Readings of the burette level at a fixed rpm over a period of 3-4 min. provided data that were reproducible to within $\pm 2\%$. Many combinations of gasoline, alcohol, propylene oxide, nitromethane, and ethyl ether were tried. The alcohol was effective in diminishing pre-ignition, detonation, and overheating at high speed and also in spreading the range of tolerable equivalence ratios. The remainder of the ingredients were effective mostly in providing reliable ignition in low speed and in improving the tolerance to ambient temperature and humidity changes. Always the effort was to include as much gasoline as possible since this has a heat of combustion of about 20,000 Btu/lb compared to around 14,000 for the others.

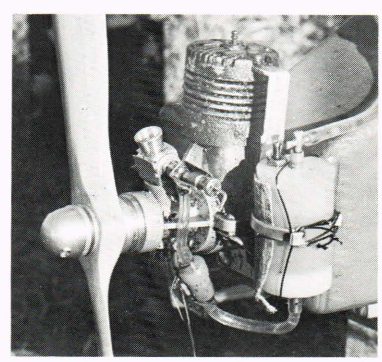
The glow-plug engine, which is now almost universally employed in models, operates on a semi-diesel principle. The glow-plug itself consists of a small coil, usually nichrome or platinum, that can be electrically heated for starting. Once started, the coil retains some heat during the exhaust and compression cycle and is sufficiently hot to ignite the gas mixture at the top of compression. A delicate balance of compression ratio and fuel characteristics is needed to prevent pre-ignition which causes divergent overheating and stalling of the engine. Alcohol is widely tolerant in these respects and is therefore commonly used.

The fuel used for the record flight consisted of a mixture of 10% castor oil, 20% alcohol and 70% lead-free (white) gasoline to which a 2% addition of nitromethane was made. The alcohol, in addition to minimizing pre-ignition, also allowed the use of castor oil which is immiscible in gasoline but which has been found superior to hydrocarbon oils for this work. The nitromethane addition was found to be the most effective agent for obtaining reliable ignition at low speed. About the same effect could be obtained with about 10% of ether or propylene oxide, but these quantities reduced fuel economy significantly.

One of the best of many "secrets" of this project (all of which, incidentally, are being published[3] to encourage broader competition) was the development of a special "glow-plug" that was very effective in smoothing out the combustion of gasoline mixtures. This consisted of several small coils of 0.02 in. diameter platinum wire that were spot welded to the base of the glow-plug so that they protruded into the combustion chamber. By experimenting with several diameters of wire and numbers of turns in the coils, a combination was found that altered the heat transfer characteristics of a commercial plug so as to provide a cooler surface of substantially larger area on which catalytic ignition occurred.

The life of the plug was improved remarkably by the modification. A number of modelers in all parts of the world have expressed surprise at the use of a glow-plug engine, for they typically have had failures of plugs after several hours of operation. The single plug developed here was used all spring and summer, and accumulated over a hundred hours of run time.

A re-examination of this catalytic ignition principle for special applications in modern automobile or aircraft engines could have important results. It is not inconceivable that it could lead to a more optimistic conclusion than was reached back in the early 1900's when red-hot iron rods were used as ignition sites in engines that actually started on some rare occasions. One advantage of this ignition system is the freedom from RF noise generated by the usual high-voltage spark systems. This is a valuable advantage in radio-control model work, for while the super-regenerative receiver used in my



This view of the engine that won the world endurance record shows the float chamber in position at the lower end of the gravity-feed fuel line.

[3] M. L. Hill, "Old Faithful, World Endurance Model," *Model Airplane News*, **61**, July 1965, 21–27.

model is not seriously affected by spark ignition, models with superheterodyne receivers would doubtless fly rather erratically if at all.

The flight of Sept. 18 was uneventful and rather dull compared with the intrigue of developing the model. *Old Faithful* was launched at 7:56 AM and landed at 4:48 PM. This is almost a complete description. The weather was dead calm, with a high overcast that prevented thermal turbulence. Weather maps had been a subject of careful study for several weeks, and the calm was obtained by scheduling the flight to coincide with the arrival of a high pressure area as it moved from Arkansas to Maryland. The silkiness of the air made it possible to trim the model at all fuel loads to fly at constant altitude with essentially "hands off" the control stick. There was little to do except hope that the engine would run through the "problem time," the high-ambient-temperature period from noon to about three o'clock. As one of the crew put it after about three hours of peering at the bright sky, "This is the most exciting boredom I've ever seen." At 2:15 PM, when the Russian record was surpassed, the model was cruising comfortably at about 4000 ft altitude. A little over 2.5 hr later, the engine stopped and the model touched down about 120 ft from the launch site, or well within the 1640 ft required by FAI. The fuel tanks were bone dry. Several of the rubberbands used to hold the wing onto the fuselage had been cut by a jag of fiber glass on the trailing edge of the wing. But luck was with the crew that day for the remaining rubber bands had done the job!

From subsequent measurements of the lift-to-drag ratio of the model, it has been possible to determine that a "fuel specific impulse" of about 6000 sec was obtained during this flight. This is probably a record in some unofficial model category, and it gives full-scale engines a run for the money since the recorded figures for this performance criterion of all types of aircraft and missile engines are typically below 5000 sec.[4] The big challenge in full-scale propulsion has always been to obtain large fuel specific impulse, which is more and more difficult to achieve as flight speed is increased. Probably what the present figure represents is that it is the only time anyone has bothered to measure the quantity while flying at a snail's pace of about 25 mph. Still another record that might be claimed is that the model traveled 350 ground miles per gallon of gas. This, of course, doesn't beat a soaring glider that has been flown six hundred and forty-seven miles non-stop on zero gallons of gas, but it does leave those efficient compact cars in the dust.

[4] W. H. Avery, "Twenty-Five Years of Ram-jet Development," *Jet Propulsion*, **25**, Nov. 1955. 604–614.

The straight-line distance that could be covered with the present model is about 225 miles without the assistance of tail wind, which is allowed. This is well over the straight-line record of 155 miles also held by Mr. Malikov of Russia. Plans are underway to use *Old Faithful* for this purpose during the coming summer. Its cruising speed is about 45 mph at full throttle, and this conveniently matches a safe cruising speed of an automobile on a curved super highway.

Several obvious improvements can be made to extend the endurance record to over twice what it now is. These include using a model with higher lift-to-drag ratio, which is easily possible, and the development of an ignition system and fuel that can be throttled to lower speed than was possible in this flight. A number of U.S. modelers are now working on aircraft with these features. Meanwhile, word has been received that the Russian modelers are preparing for a 24-hr flight. This is considered to be evidence that modelers the world over are optimists when things are on the drawing board. (Before the first flight tests of *Old Faithful*, a flight of 15 hr looked easy.) Whatever the outcome of the Russian effort, some of the American models under construction will be adequate to meet the challenge.

The value in a project such as this, and the reasons for undertaking it, are perhaps not obvious to the non-hobbyist. It is not like mountains, which some say must be climbed because they're there. Some of the developments of this project have commercial value in a hobby industry that is now quite large and still growing in this country. These could be exploited at a profit. But the more significant profit, to my thinking, is the value of the disciplines and principles that are learned. Many of these are applicable and useful in similar but more complex problems encountered in professional work. Failures can and did result, in this effort, from the smallest overlooked detail or invalid rationalization, and there was a genuine satisfaction in reasoning through a problem in its entirety and having correctly analyzed all of the critical points. The complexity of most modern professional projects, of course, requires specialization and assignment of such critical areas to various individuals. The simplified picture painted by a project such as this clearly emphasizes that in more complex efforts it is essential for the individuals involved not only to devise solutions to problems, but also to evaluate critically and report their shortcomings and advantages to those who have the responsibility of commitment. This discipline is not always of attractive flavor, but many serious modelers apply it to themselves so habitually that it becomes an inherent and sometimes useful part of all their thinking.

A number of my colleagues at APL provided knowledge which was of valuable assistance to this project. In particular, Dr. W. H. Avery, Dr. W. Berl, Dr. F. Billig, Dr. G. L. Dugger, Mr. W. B. Shippen and Dr. R. E. Walker contributed to understanding the problems of fuel blending and economy. Dr. F. Falk gave advice on catalytic ignition that was of help in developing the successful glow plug ignition system. Mr. R. H. Cramer, Mr. J. H. Walker and Mr. J. Hardgrave gave useful advice on optimization of the aerodynamic configuration and flight program, and Mr. J. M. Akridge solved several critical mechanical problems. Dr. W. A. Good and Mr. R. L. Hooper provided many suggestions and criticisms dealing with the construction and control of the model and also assisted in the flight tests and final flight. Many of these contributions were made amid the din of the lively conversation that is typical of the APL cafeteria, and the contributors were perhaps not always aware of the end use. I am pleased to have this opportunity to recognize and thank them for their help.