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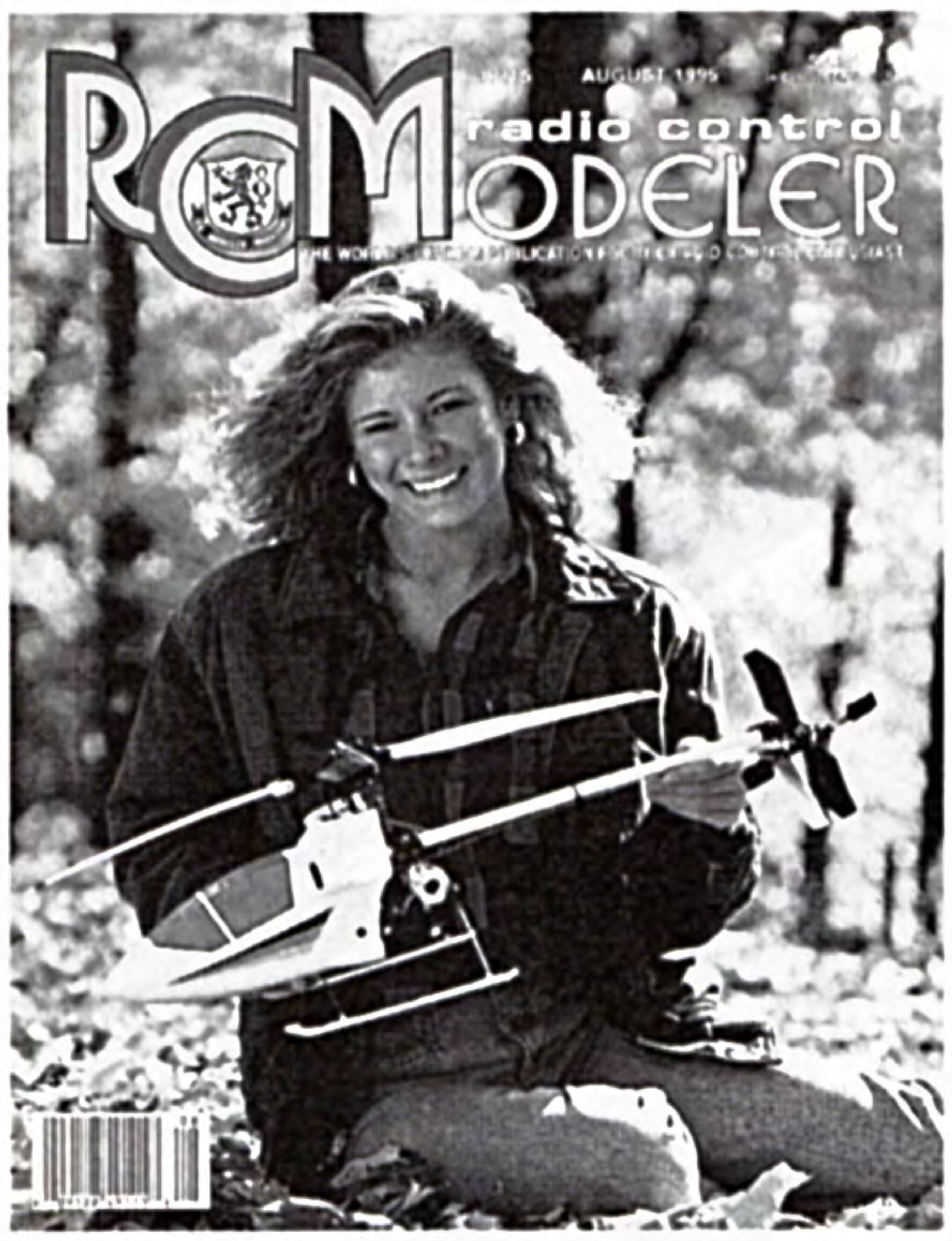
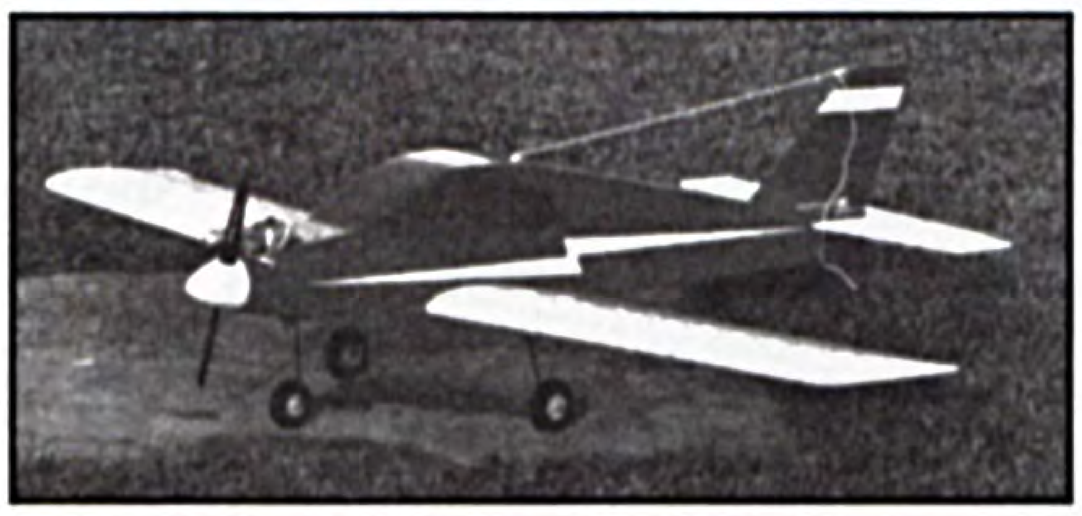


This Month's Cover — features Kystie Leigh Phillips of Rising Sun, Indiana, holding a Lite Machines' LMH-100 helicopter. Kystie is a sophomore at Purdue University. Photo by Dave Arlton of West Lafayette, Indiana, on Ektar 25 with Cokin A.198 filter. See article on LMH-100 helicopter beginning on page 162.

FEATURES

CONSTRUCTION



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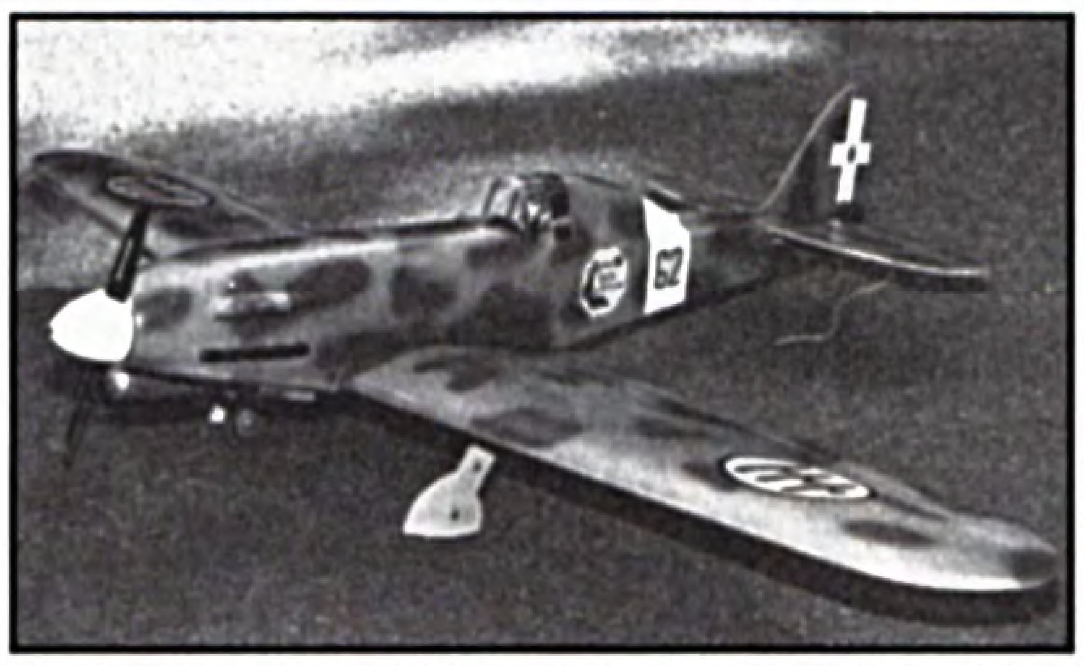
REVIEWS



DEPARTMENTS

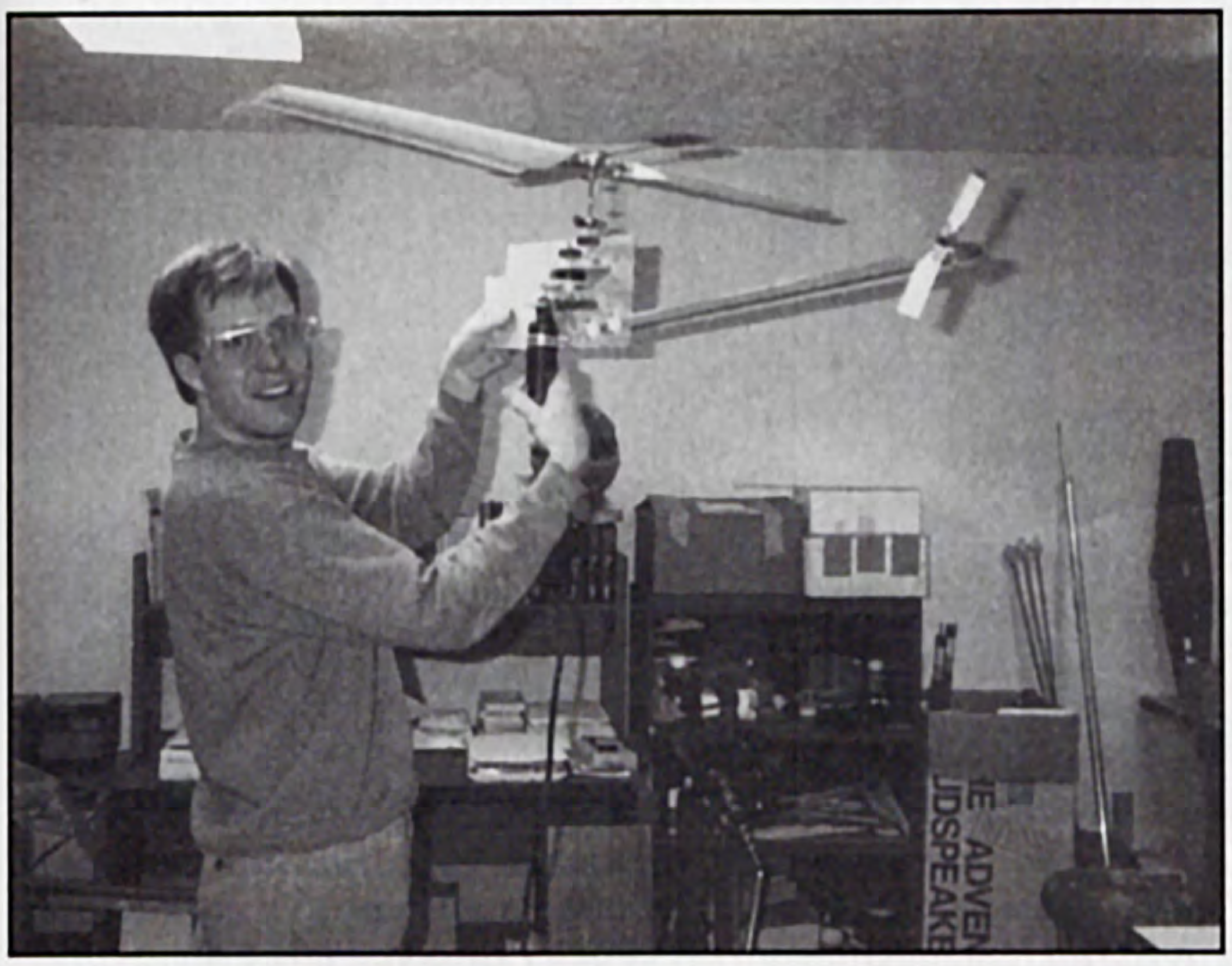
THE LITTLE CHOPPER THAT COULD

By Paul Arlton

A Brief History of the LMH-100 and Lite Machines Corporation

Slowly Paul pushed the throttle forward and the crackle of the engine intensified. The cloud of castor oil vapor floating around the fuselage danced and then darted away as the rotors accelerated. It lifted off the ground, and I could tell it was stable. I marveled as it hovered five feet off the grass. In order to sit still in the air, every force must be in perfect equilibrium. The main rotor must precisely counter the force of gravity and the side thrust of the tail rotor. The tail rotor must exactly cancel the torque of the main rotor. And to think that the power plant relies on a single piston .4 inches in diameter cycling at close to 300 times per second. It works. Amazing.

That was October 7, 1989. After many years of continuous development, Prototype II, a precursor to today's LMH-100 helicopter, finally left the ground. In case you're not familiar with the LMH-100, it is the first mass-produced 1/2A-class (.049 powered) helicopter in the world, and it flies on roughly the power consumed by a 75 watt light bulb. In comparison, .30 to .60 size model helicopters use ten to twenty times more power. The LMH-100 helicopter has features not found on other helicopters: semi-flexible main rotors that



Left: The "rotary glider" concept consisted of large slow moving blades running at 600 to 800 rpm. This apparatus powered by a Dremel motor tool (and held by yours truly) allowed tests to be performed indoors under controlled conditions. Note the two-stage gear reduction to the main rotor, and the torsion spring at the front of the tail tube driving the tail rotor. Right: This test stand (attached with rubber bands to a box weighted with pennies) was powered by an R/C car motor and flight box battery (in background). The fan caused the rotors to blow back, simulating windy conditions. We frequently used a hand-held strobe light to freeze motion when studying rapidly rotating mechanisms.

can fold up to reduce damage in crashes, a special Subrotor stabilizing rotor that minimizes the reversed airflow commonly found near the rotor hub, and a lightweight mechanical Arlton Gyro stabilizer that replaces the electronic gyro and extra capacity receiver batteries.

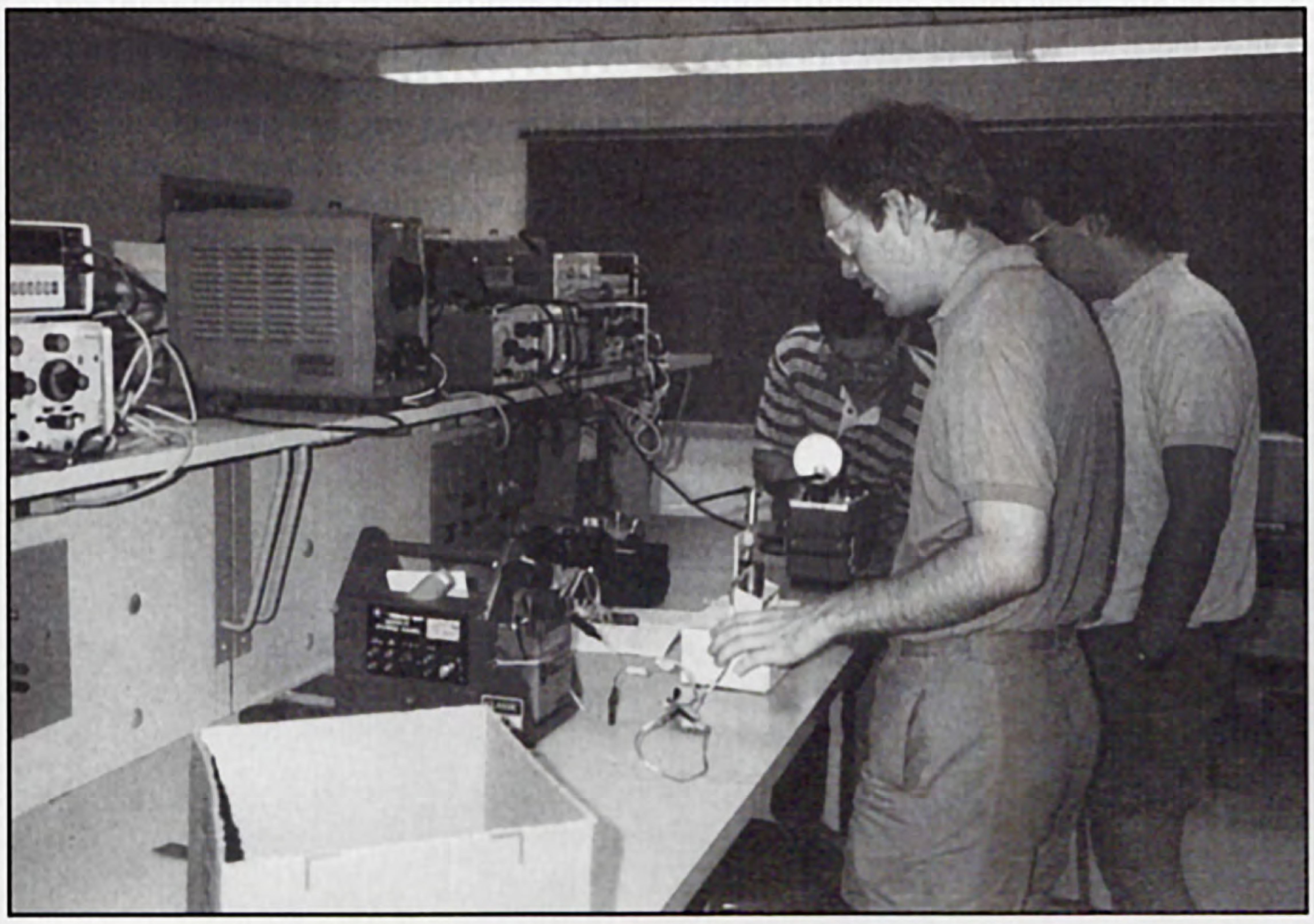
The LMH-100 evolved from a simple idea, and is the culmination of innumerable incremental advances in small-scale aerodynamics, material science, and manufacturing technology. But to the people involved in its development, the LMH-100 is more than a model helicopter, it's a learning experience. It's an excuse to learn about and apply new design and building technologies on a small scale that might otherwise involve many separate companies. The LMH-100 is a reflection of the people involved in its development (Dave Arlton, Paul Arlton, and Paul Klusman) who all contributed to the design, and who learned something in the process. What follows is a brief account of how the LMH-100 and Lite Machines Corporation came to be.

I am Paul Arlton. I like small, simple, cheap things. My favorite R/C airplane is a 2-channel Cox 049 powered F4F Hellcat I built from scratch in a weekend from Styrofoam and EconoCote for about $10.00. My brother, Dave, likes big, expensive, mind-numbingly complicated things. He is infatuated with his Schluter Champion helicopter and computer radio which together cost about $1600.00. I get hives flying something that expensive.

As a Christmas present in 1981, Dave received one of the first IBM personal computers. It cost about $4000.00 (I suggested a $350.00 Atari, but he wouldn't go for it). Having nothing better to do (than engineering homework) we developed an interactive graphic software simulation (a video game) in the early 1980's named GATO, that sold enough copies so that we did not have to find real jobs after college. We spent the next several years on our own, developing software and learning about computers. Although, we did not know it at the time, everything we eventually would do with the LMH-100 would hinge on our knowledge of computers.

One humid summer day in Indiana in 1988, Paul Klusman, an accomplished R/C helicopter pilot and friend of ours, brought over a free-flight rubber band powered helicopter he had designed. As I watched it fly, I thought it must be possible to build a small, simple R/C helicopter powered by a Cox 049, just for fun.

I knew from my college days in aero-



Left: The pennies in the box under the test stand rattled loudly at certain rotor speeds. Strobe tests in an electronics laboratory at Purdue University revealed that the soft basswood blades fluttered at high speed causing excessive vibration and drag. Right: Small amounts of aluminum melt easily with a propane torch. At 1300°F, molten aluminum will pour and splash as easily as water, so we were very careful and always wore appropriate safety gear.

Left: This sophisticated experimental casting/sintering apparatus for making gear molds involved a propane torch, brownie pan lined with kitty litter, and tank of compressed nitrogen on our back patio. We always perform delicate experiments such as this outdoors at night under the most adverse weather conditions. Right: This Cox 049 powered test mechanism preceded Prototype I. The main rotor and tail rotor are fully functional and ready to be mounted to an airframe with radio.

space engineering that slow speed and large span is an effective combination for airplanes (R/C gliders can carry a lot of weight with an .049) so I decided to try a "rotary glider" concept. I found low-speed airfoil data in the NASA Star documents at the Engineering Library at Purdue University, and built a rotor to test. In my spare time, over the course of several months, I made various slow-speed rotors from Styrofoam and balsa wood, and spun them with a hand drill. They moved volumes of air, but I had no idea how much lift they produced or the power they consumed, so I made a simple test apparatus from a sheet of plywood. As I developed various assemblies (like the clutch and tail rotor gearbox), I bolted them to the test stand to measure their performance.

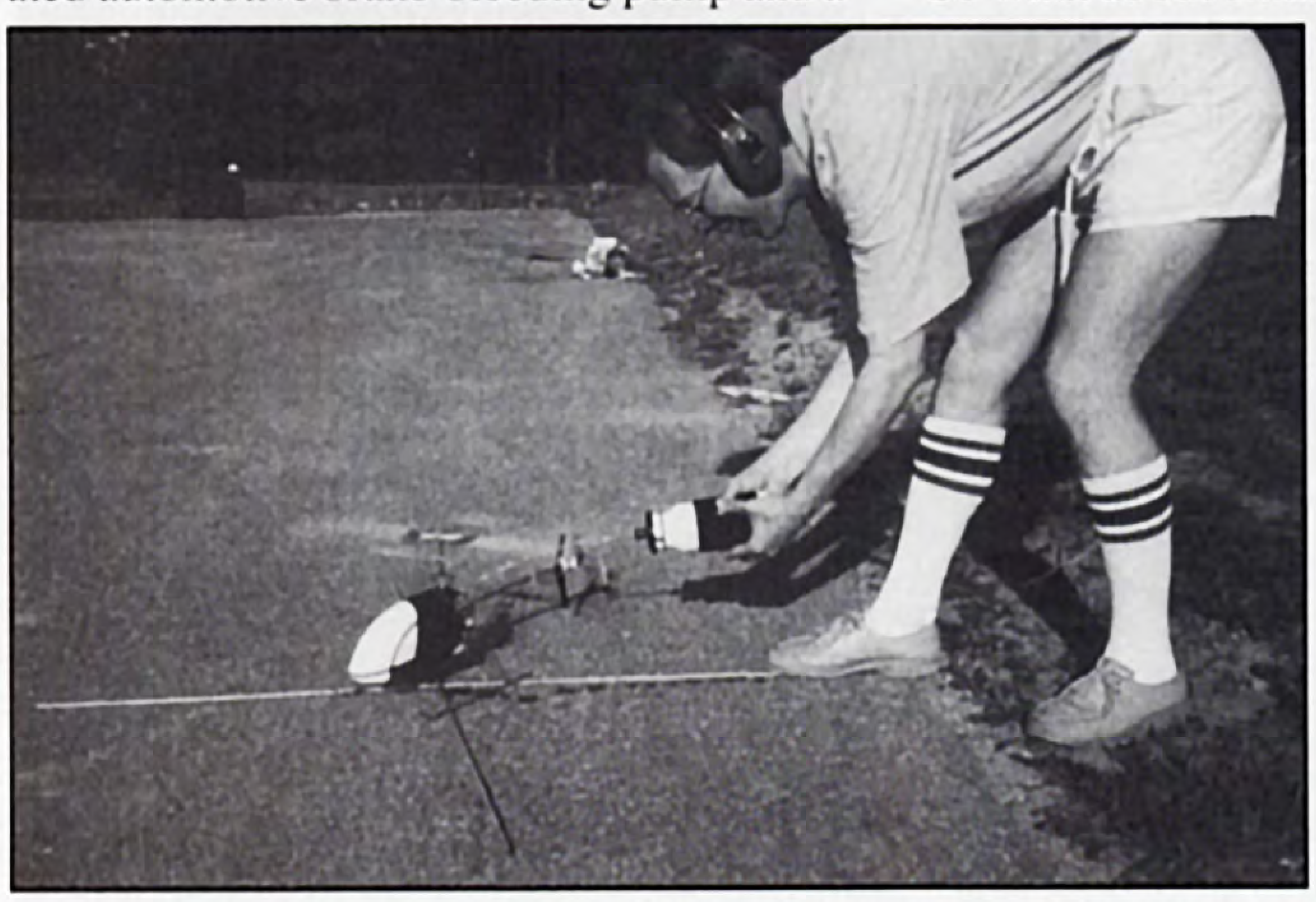
At this point, our most sophisticated prototyping tool was a hand-held Dremel motor tool. Since I had no good way of making complicated plastic parts, I usually built them of wood (birch sticks or plywood) and duplicated them using silicone rubber molds. With a mold I could make several identical parts to test. For a prototype gear box for instance, I would mix laminating epoxy and 20% to 30% of 1/8" milled glass fibers (by weight) in a Dixie cup, de-air the mixture in a vacuum chamber (a hand operated automotive brake-bleeding pump and a jelly jar), and pour the slurry into a silicone mold. When hard, the resulting material was mechanically similar to injection molded acrylic plastic. In a similar way, I cast gears from two-part polyurethane (94 Durometer hardness) purchased at our local industrial supply shop. Polyurethane is extremely abrasion resistant, and can simulate parts made from injection molded nylon.

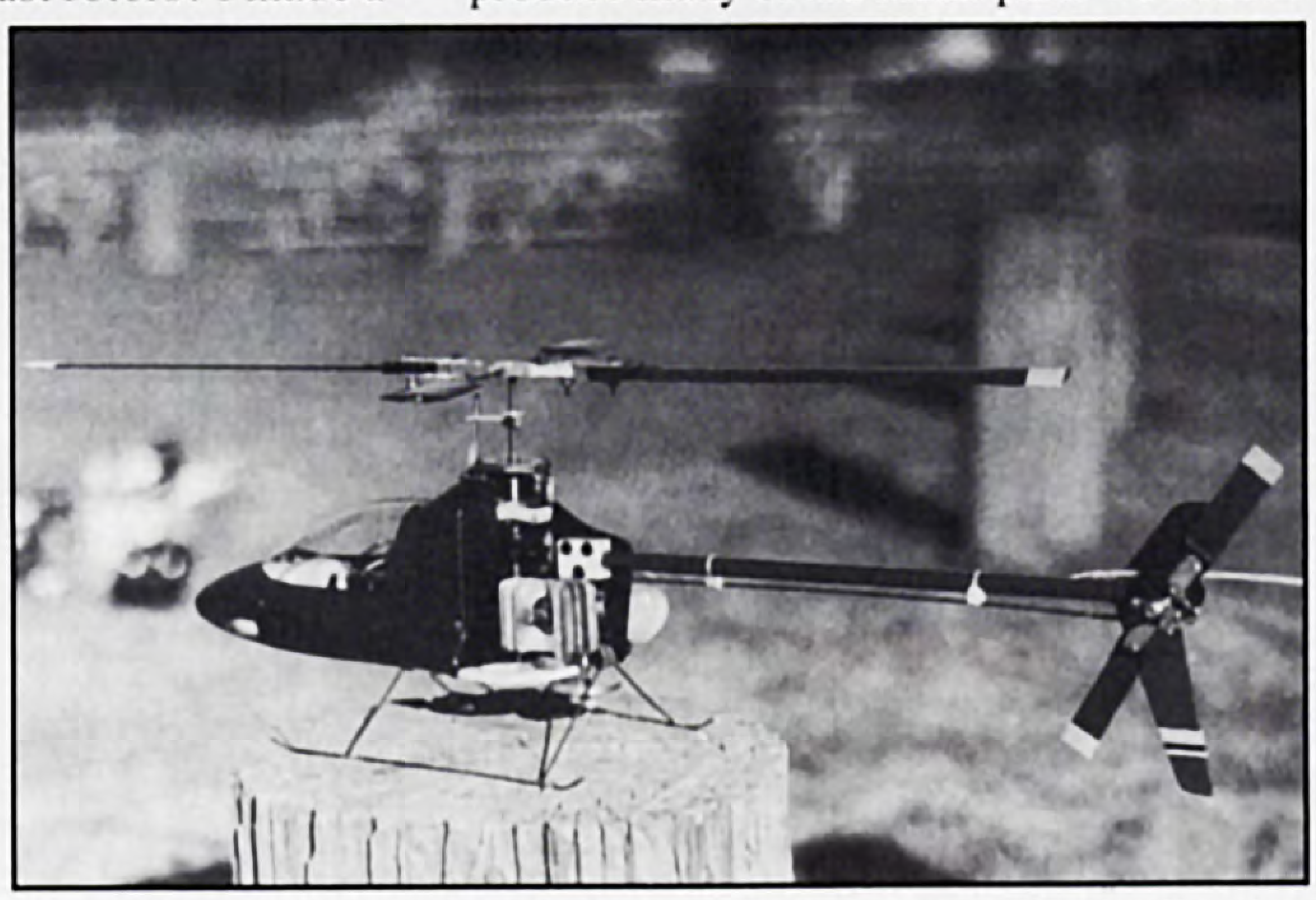
As I continued to develop parts, I found that I needed more sophisticated tools. We took the plunge and bought an air-conditioner vacuum pump (about $300.00) and a small Unimat hobby lathe and mill. We thought long and hard about the price of the lathe ($1100.00 fully tooled), but it was well worth it. Without that lathe we could never have made parts to the precision we needed; and even with good tools, my success rate in building prototype parts was about 25%. I usually made parts three or four times (punctuated with much stomping and swearing) before I got them right.

After many months of testing, it became clear that big, slow rotors could lift only about as much as the test apparatus weighed. There was no extra lift available for radio equipment. This situation prompted a reevaluation of the concept. Big, slow rotors produce a lot of lift, but they are also heavy. So what about small, fast rotors? I made a simple gear reduction mechanism for our Dremel (which, coincidentally, puts out about as much power as a Cox 049), and bolted on a 16" propeller purchased from our local hobby shop. It produced about half the lift generated by the large rotors, but weighed about five times less.

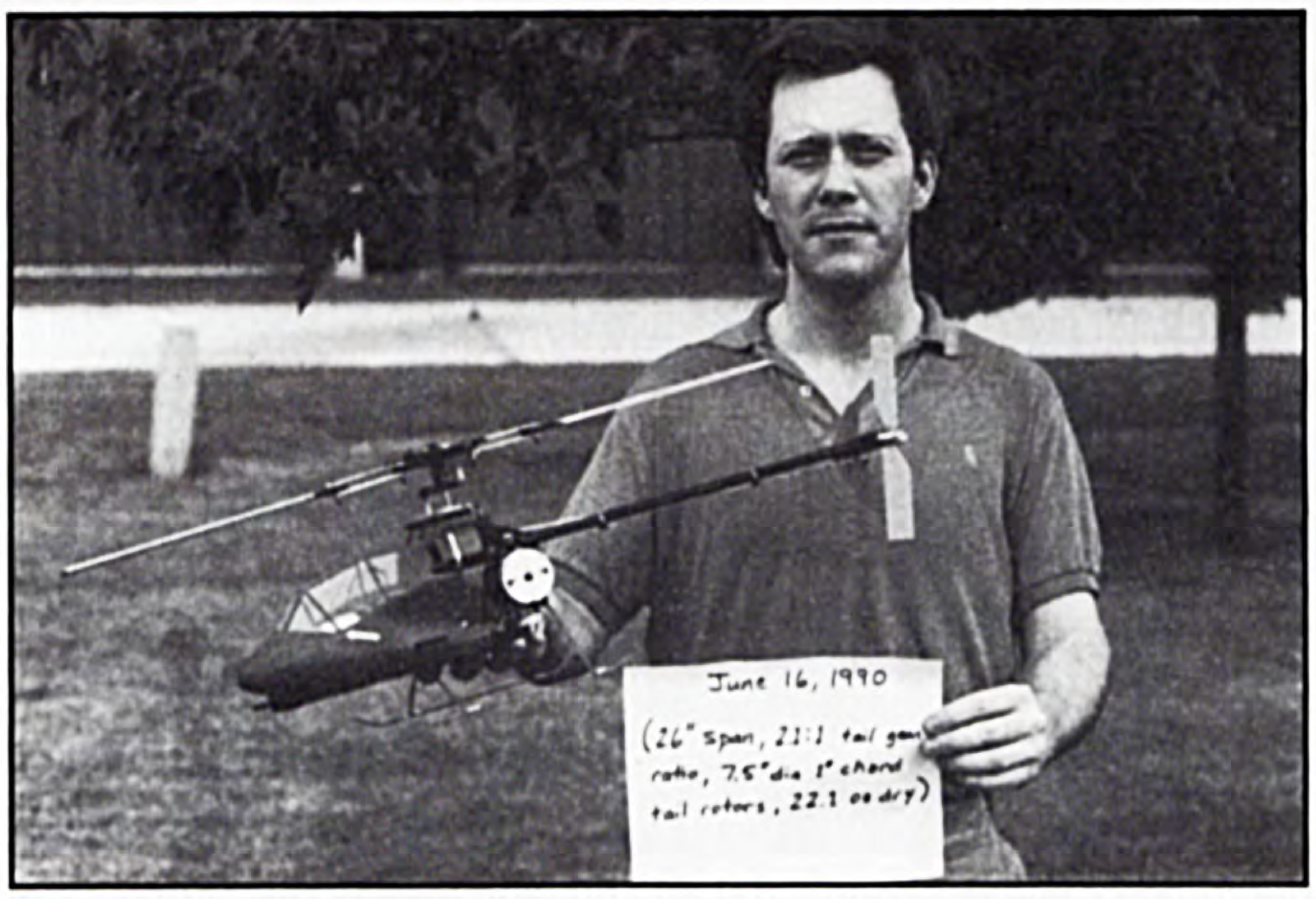
Armed with a new concept and the new lathe, I built Prototype I in 1989. It was a true R/C helicopter in every respect except one: it wouldn't fly. At 2300 rpm, the 18" main rotor blades sounded like turbines, but produced just enough lift to hop about an inch off the ground. It was puzzling that Prototype I could hop into the air, but would not stay there. We discovered that the engine heat sink we built was adequate only at low throttle settings. At high speeds, it quickly saturated with heat and the engine would start to seize. We were able to alleviate this problem temporarily by dousing the heat sink with water. As the engine cooled it produced noticeably more power, and the helicopter would hop. We tested Prototype I for many months with many different rotor heads and rotor blades. Although it never left the ground for an extended time, it validated the basic mechanism, and identified several weaknesses (such as the heat sink).

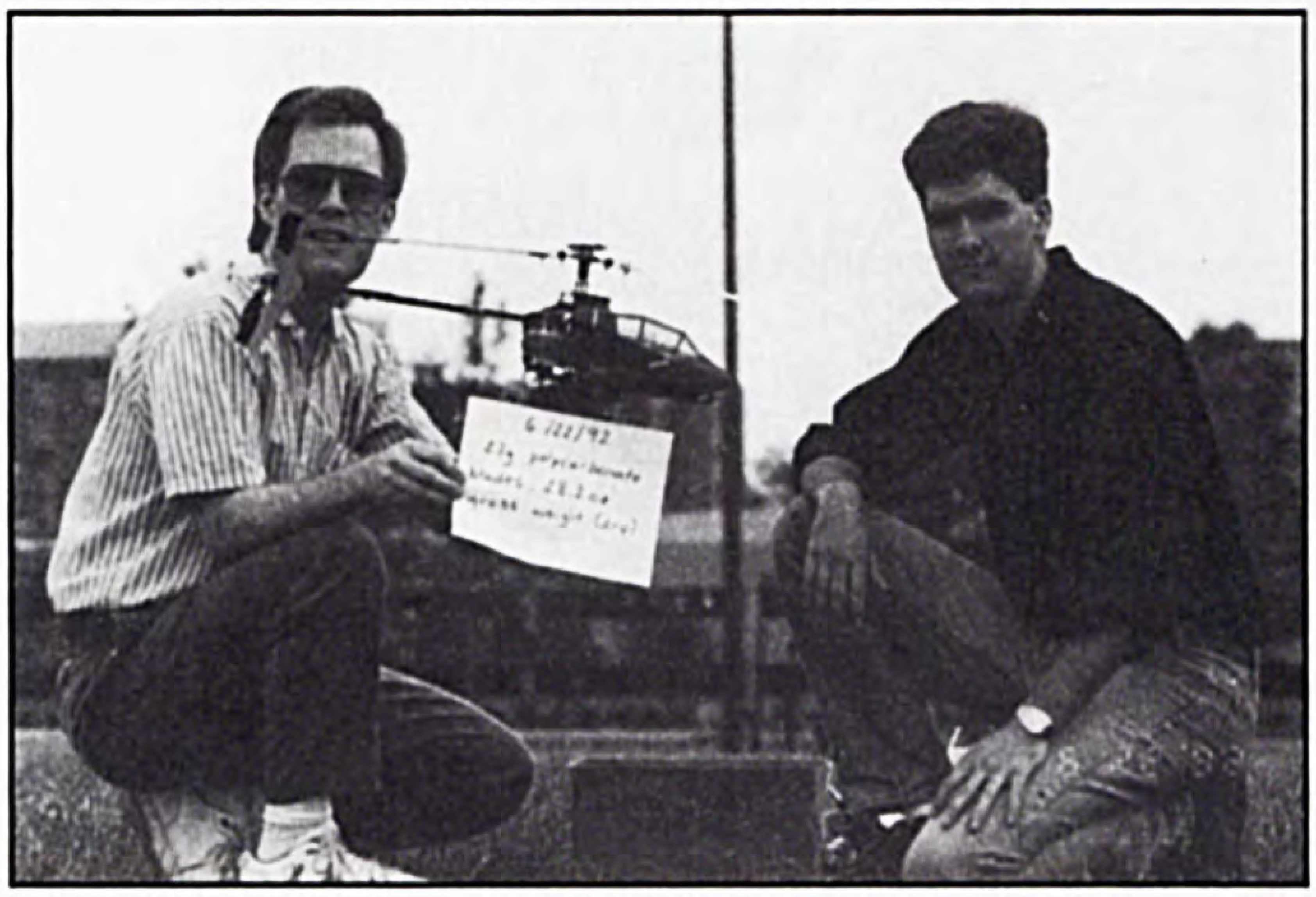
Even with our new lathe we could not produce many of the metal parts we needed





Left: Dave skillfully adjusts the temperature of an overheated Prototype I at our secret test flying site (a parking lot in the Purdue Research Park). Right: Prototype II had an ineffective sheet metal heat sink on the engine and no clutch. The receiver antenna wire hung out the back of a nylon tube running along the tail boom. After shortening the antenna several inches with the tail rotor, we decided to install a whip antenna on Prototype III.





Left: This early Prototype III has a Hiller-style rotor head, round sheet metal heat sink fins (forced between the engine cooling fins for better heat conduction), but still no clutch. We discovered that full-size Army helicopters employ olive-drab color schemes for a reason, and it is not to be seen more easily. Subsequent models used desert camouflage for increased visibility against trees. Right: This Prototype III features a centrifugal clutch, Bell-style rotor head and early tail rotor gyro stabilizer. Photo taken at Purdue intramural field, with test pilot Paul Klusman on right.

(such as the engine heat sink), so I visited the Engineering Library at Purdue and read about metal casting techniques. The results of our first attempts to cast molten aluminum into plaster molds were awful. Since *there was nothing to force the metal into the* details of the mold, the parts were only partially formed, and therefore, unusable.

I learned the detail of vacuum investment casting at the Purdue foundry where students cast jewelry. In this method, a plaster-like material called "investment" is poured over a part made of wax. Once the investment (plaster stuff) has hardened, the wax is burned out in an oven at 1250°F leaving behind a perfect mold of the part. Molten metal is then poured into the mold. When the metal has cooled, the investment is broken away and the part removed. The most interesting property of investment is that it is highly porous. When pouring the metal, a vacuum is applied to the mold that literally sucks the metal into all of the fine details.

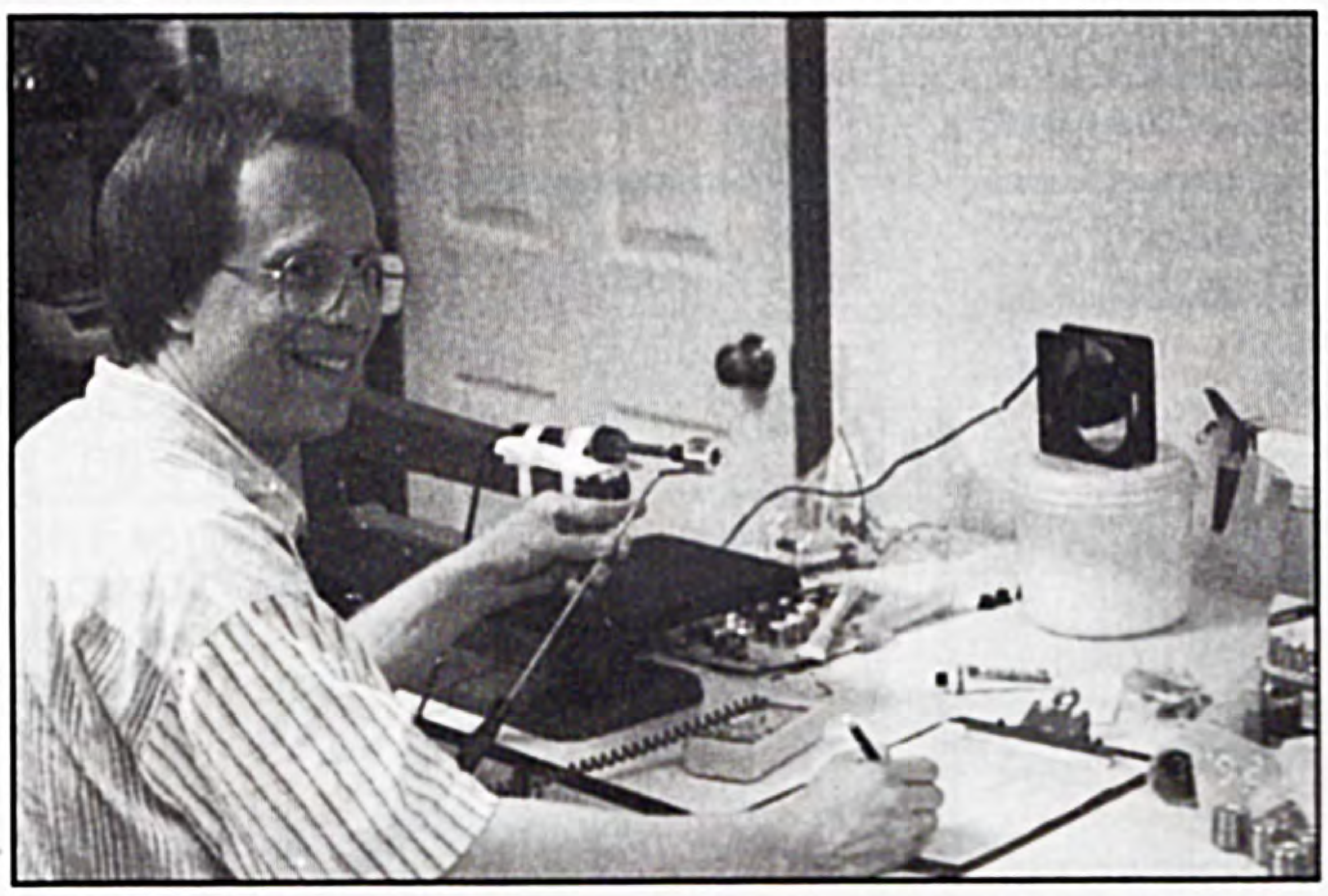
I had to purchase a small burn-out oven (about $400.00) for this process, but I already had the vacuum pump, and most casting supplies are readily available from jewelry mail-order outlets. I made the wax patterns (for parts like the heat sink and bevel gears) in silicone molds. We melted aluminum (for casting) with a propane torch in a stainless steel measuring cup. As a general rule, we cast only at night and in the most miserable weather conditions (usually freezing, drizzle, or tornado).

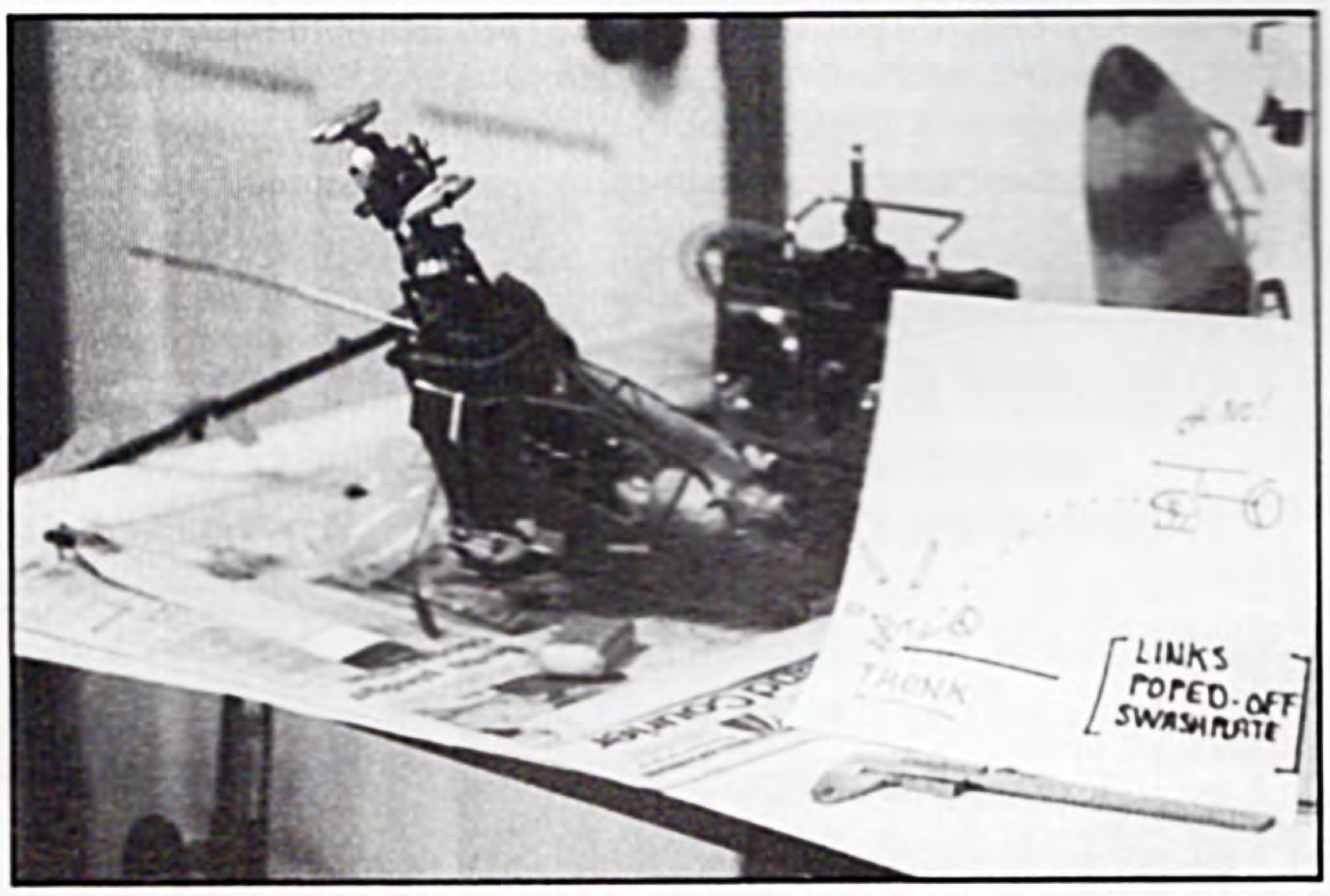
With our new prototyping capabilities we could produce almost any part we needed, but it was not feasible to refine the Prototype I design further because it was a collection of parts assembled without a plan. To develop weight and balance estimates for Prototype II, I carefully drew all radio, engine, and mechanical components on a computerized paint program (we didn't have a computer-aided-design or "CAD" system at the time). Prototype II was clearly an improvement over Prototype I, and could lift itself into the air. As soon as it left the ground, however, it was highly unstable and almost uncontrollable.

We eventually learned through testing and library research that stability in hover is governed by many variables including rotor speed, blade weight, blade balance, blade damping, flybar paddle weight, flybar paddle balance, and the ratio of pilot control input and flybar stabilizing input to the rotor blades. All of these variables must be adjusted correctly for a stable hover. We also found that rotors generally cannot be scaled up or down. The combination of rotor variables, and the aerodynamics of the rotor blades that work at one size, will not necessarily work well at any other.

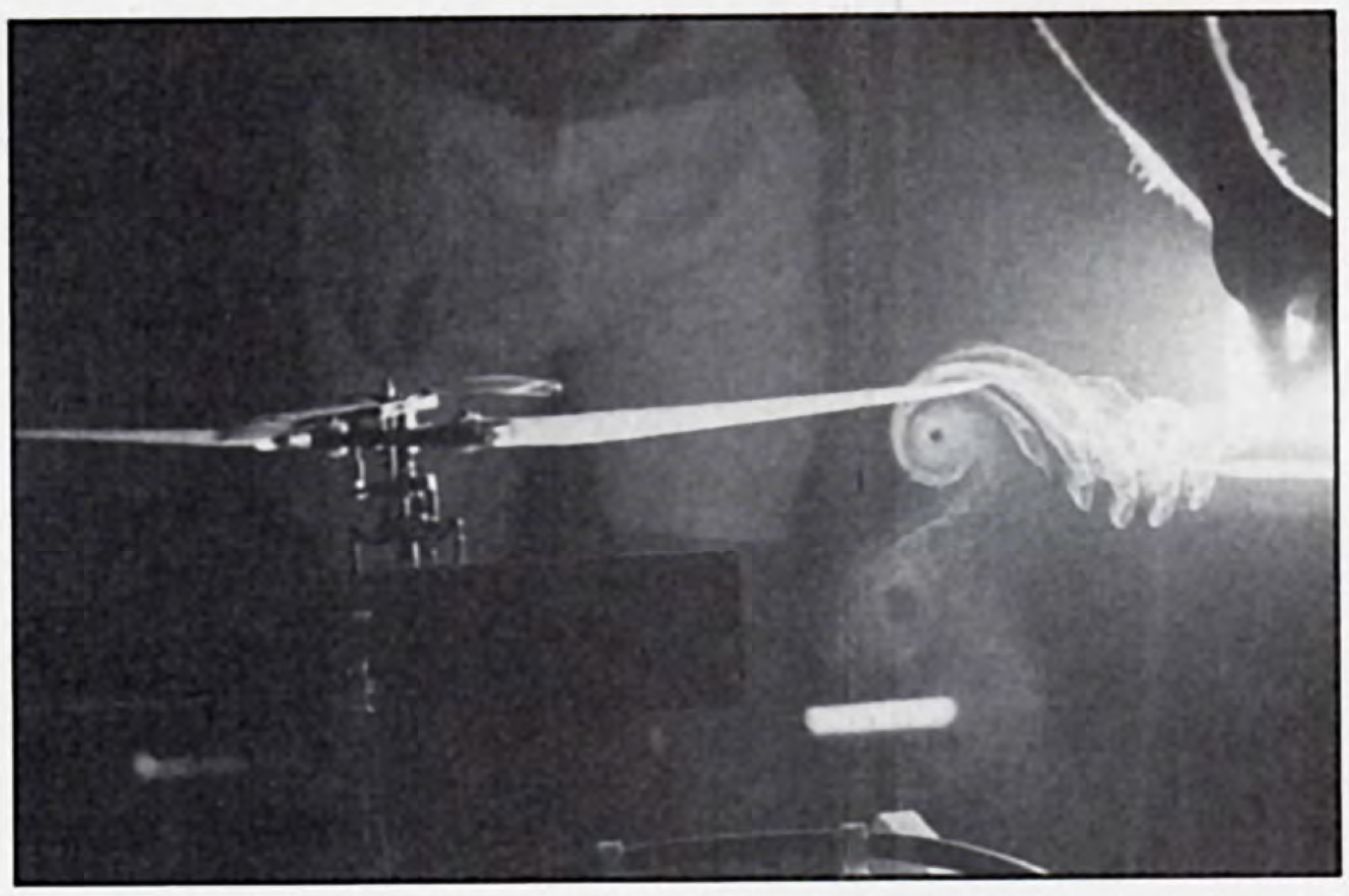
In 1990, we redesigned *every component* of Prototype II on a CAD system to an accuracy of .0001", and built a total of three Prototype III's (two to fly and one to show). We also devised the Arlton Gyro to keep the tail of the helicopter from swinging excessively. The Arlton Gyro operates like the electronic gyro needed for most R/C helicopters, except that it is amplified mechanically rather than electronically. This one mechanism above all others makes the LMH-100 practical. Besides being expensive, a typical electronic gyro weighs several ounces and operates from heavy batteries. This added weight can substantially impair the performance of such a small helicopter.

Over the following two years, we experimented with many different rotor head types: flybarless, Bell, Hiller, Bell/Hiller, Lockheed, indirect control, two bladed, four bladed, rigid, teeter, and dual damped-flapping. Most rotor heads were either unstable, uncontrollable, or both. Without careful blade design, flybarless rotors have a tendency to leap up into the air and immediately roll over. Bell heads (having no flybar





Left: Dave records temperature data with a thermocouple probe on a newly machined heat sink (expertly mounted on a soldering iron taped to a scroll saw). Airflow from the small fan (at right) simulates flow around engine in flight. Right: This crash would have been bad in a full-size helicopter -- attorneys, lawsuits, the works. As it was, we replaced the canopy and tail tube, fixed the cracks in the crutch, and were back out flying (with a different rotor head of course).



Left: Dave is developing a program for our CNC lathe at the lab. This machine cost more than $100,000.00, and makes heat sinks and other small metal and plastic parts. Right: During an experiment at the Purdue Aerospace Sciences Laboratory, Dave is holding a stick dipped in titanium tetrachloride near the test stand in order to visualize the vortex generated at the tip of the rotor blade. Titanium tetrachloride is a liquid that breaks down into titanium oxide (fine white powder) and hydrochloric acid when exposed to air. Within a few hours of this experiment, all of the exposed steel on the test stand was coated with rust caused by the airborne hydrochloric acid.

paddles) don't always turn when commanded. Lockheed heads (spring actuated controls) are controllable, but the control and stability functions are out-of-phase with each other. Hiller systems (flybar with paddles) and Bell/Hiller systems (direct blade control mixed with flybar and paddles) proved to offer the best mix of stability and control.

Luckily, Paul Klusman, our primary test pilot, could react quickly enough to the flight characteristics of the various rotor heads, that we never completely demolished any of the prototypes. The control links on one unusual hydraulically actuated system, however, had a nasty tendency to pop off in tight turns. I remember mentioning to Paul as the model passed by during one evening flight, that the swashplate linkages controlling the main rotor appeared to have fallen off. He concurred. Paul's subsequent landing led me to formulate the following aero-mechanical theorem of physics: **the energy of a landing aircraft is directly proportional to the number of times each piece bounces**. In this case, three bounces meant that landing energies were high.

Throughout 1990, with the machine's performance constantly improving, we searched for a company to produce our helicopter. Since Dave and I are fundamentally computer people, not manufacturing people, we felt best suited for designing, not manufacturing. Our idea was to design parts on our computers, and transmit the design data

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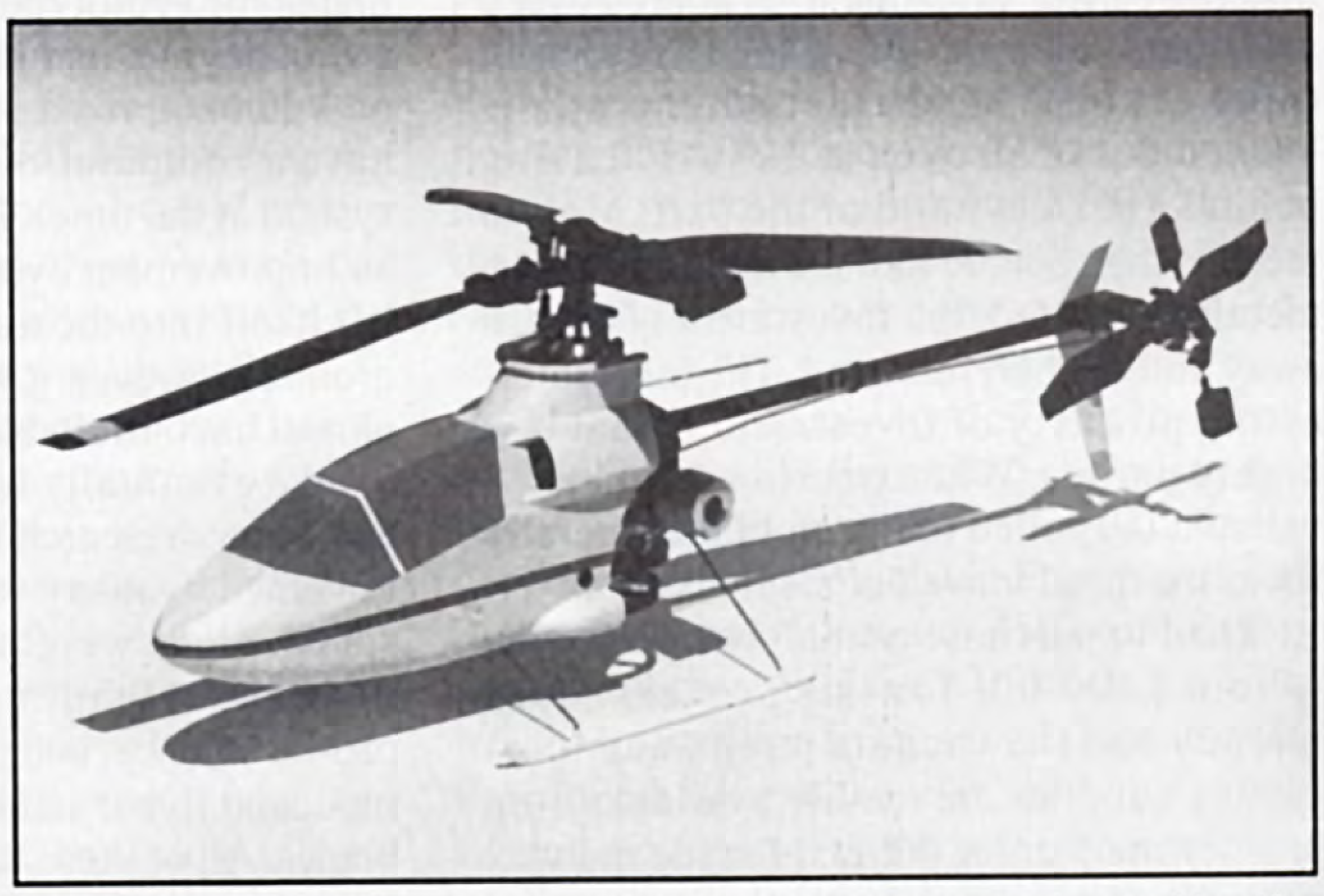
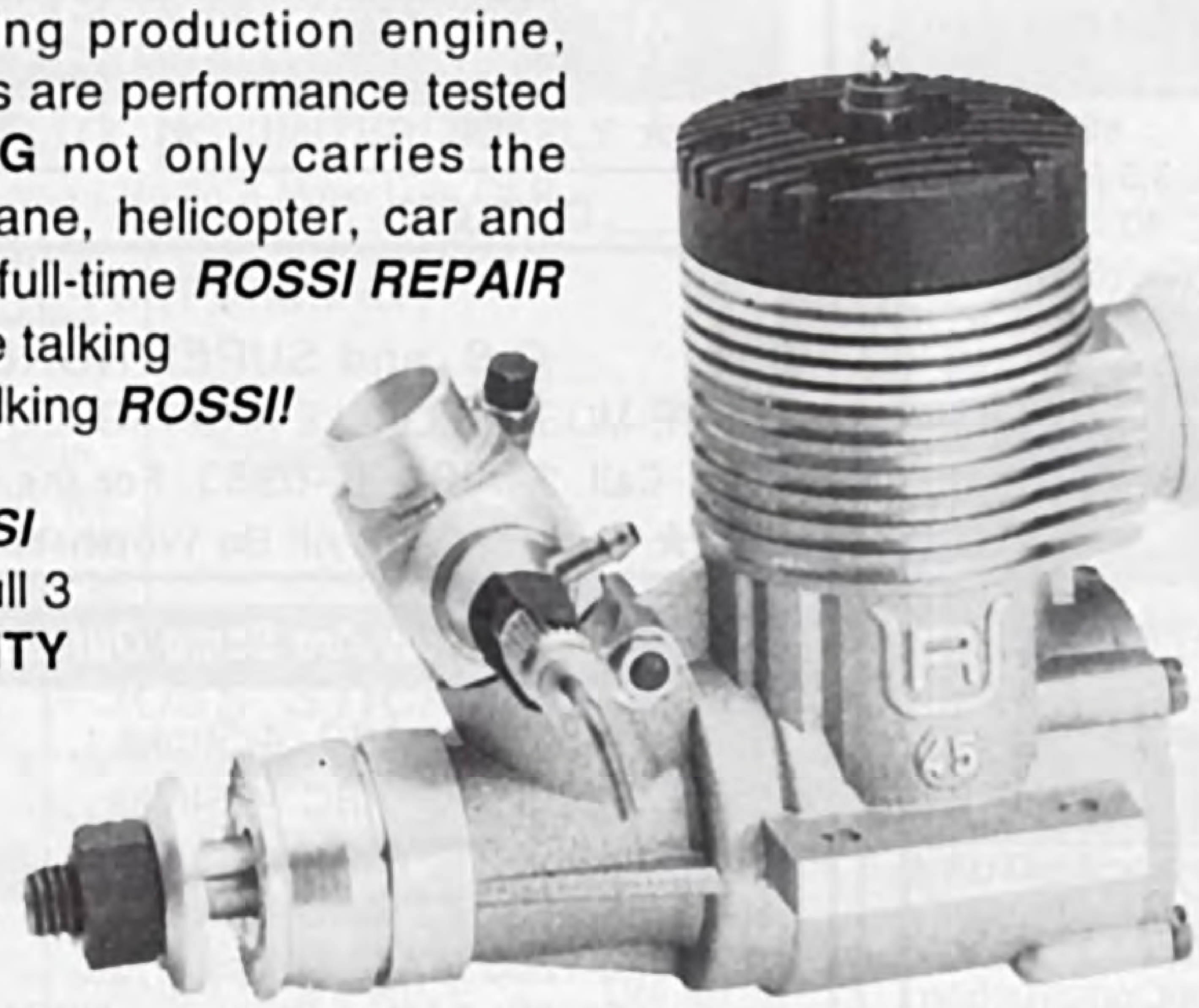


Left: Dave, Paul K., and mom assemble packaging, and pack LMH-100 kits at the lab prior to shipment. Mom is motivated by the thought that if we are not successful, Dave and I will be moving back home. Right: This is the first preproduction LMH-100 helicopter (assembled from preproduction parts) with Bell/Hiller style rotor head and Arlton Gyro stabilizer on the tail rotor. Roughly 20 copies of each part were produced for testing before production began. Notice the black rotor blades, white landing gear skids, and small stylistic crease in the canopy extending slightly forward from the lowest corner of the window.



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on diskette to a manufacturer who would then make injection molds and metal parts directly from the computer information. But we could not find a suitable company that used computers in this way.

Slowly the thought gelled that we could manufacture the helicopter ourselves (in hindsight, it was probably our brains gelling). So we designed the production process for each part in the helicopter, researched the necessary production equipment, developed a financial plan, and, with the great help of mom and dad, incorporated Lite Machines in 1991 at Flex Lab II in the Purdue Research Park. We located in the Research Park, in part, to make our facility accessible to Purdue students as a hands-on, real-world learning experience in manufacturing.

We started installing equipment at "the lab" immediately. It was a substantial psychological leap from our Unimat hobby lathe to our first CNC (computer numerically controlled) machine (a lathe costing more than $100,000 and weighing over 7000 lbs.). We also installed injection molding machinery and a CNC milling machine to make molds, and built a computer controlled machine to form fuel tanks. With the equipment in place, we set about building molds for the plastic parts and writing CNC programs for the metal parts. Since we had never done this before, we made it up as we went along, relying heavily on our programming experience with personal computers.

As time went by we encountered problems with the plastic part molds. The dimensions of the completed molds were not the same as the dimensions on our computer drawings. We eventually traced the problem to a mechanical defect in our new CNC milling machine which put it out of commission. This was a bad situation, but no situation is so bad that it can't get a little worse. The machine manufacturer sent us a partial solution to the mechanical defect, which allowed us to find more defects in the machine's computer hardware and software. And thus, it continued for over a year, each solution disclosing new problems. Without the mill, we couldn't make molds, and without molds we couldn't make choppers, so we had to take on outside work on our other equipment to make ends meet.

Eventually, we determined that the milling machine was better suited as a boat anchor, and purchased a new machine from a different manufacturer. At $50,000 this required a bit of soul searching and a substantial portion of mom's savings, but the new machine was worth every cent. In its first week of operation, we machined five injection molds. This compares to one bad mold produced by the first machine in the first year.

With the molds under control, we developed the construction manual and operator's guide for the LMH-100 (Lite Machines Helicopter-100), and ran the first batch of production parts. Dave machined the metal parts, Paul routed the wood parts, and I injection molded the plastic parts, so you know where to direct your ire if you're unhappy with a part in your LMH-100. Be forewarned though, Dave and Paul are very sensitive about the quality of their parts (don't worry about me, all of my parts are perfect). With the help of family and friends, we boxed up the first LMH-100 kits at the end of 1994, and started shipping in January of 1995. Now LMH-100 helicopters fly in countries all over the world.

The LMH-100 project taught us many things about our personal endurance, and our ability to overcome obstacles. On the one hand, we learned how much stress and uncertainty we can handle, since at times we were at our limits. On the other hand, we learned that with perseverance, and the support of family and friends, almost any problem can be solved or circumvented. We also discovered that obstacles can fuel the creative process. The .049 engine we selected created daunting design problems, but its small size forced us to design for efficiency. If more power were available, it is unlikely that the LMH-100 would have evolved as it did.

Regardless of our efforts, however, the

LMH-100 would have been impossible to develop without the proper tools and technologies, and our experience with the LMH-100 reinforces several general observations about tools we have made over the years. First, once you have tools (wrenches, vacuum pumps, computers, etc.), you will find uses for them that you could not have imagined. Second, it is often difficult to justify the purchase of an expensive tool for a single job. If you plan to do a job repeatedly, but consider buying a special tool only when you really need it, you may never get it. In this way, you may doom yourself forever to using tools ill suited to the task. You will also miss any opportunity to develop your ideas that you may have had, given the proper tools. Third, cheap tools are frequently not a bargain in the long run. When you consider the time and money you will expend trying to make up for the deficiencies of a cheap tool, you may decide that you can afford a better, more expensive version. Fourth, but not least important, computers are the most flexible general purpose tools ever devised. A thorough working knowledge of computers, computer programming, and software applications (such as spread sheets, word processors, and CAD/CAM systems) is one of the most valuable personal assets (besides money) you can have in engineering and business today.

As important as tools and technology are, they make a difference only if you have the knowledge and ability to properly employ them. A working knowledge of design and manufacturing technology takes time (years) to develop, and must be acquired in small steps, but it is soon forgotten without practical applications. Radio control modeling is a great way to learn about and experiment with technology, since most projects are small in size, short in duration, and require some basic engineering to get them working. Many hobby skills and technologies can be extended to larger projects outside the hobby. Now, maybe manufacturing a helicopter is not your idea of a good time, but who knows what you might discover if you try something new!