WOOD'S TECHNOLOGICAL COMING-OF-AGE

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By

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In the inevitable postwar struggle of raw materials for commodity markets, wood will meet intensified competition from metals, plastics, ceramics, glass, and other products. But wood, like competing materials, will be available in improved forms -- for the centuries of empiricism in the use of wood are drawing to a close and at last wood is technologically coming of age.

War has tremendously accelerated the process. Even now a number of new products of the forest are already serving the war effort, and the ironing out of technical shortcomings and production difficulties of other forest products is being so stimulated that developmental work ordinarily requiring years is being accomplished in months.

Some of the new wood derivatives and modified wood products are so altered as not to be recognized as wood; others look like wood but magnify wood's major virtues and add to its versatility. Notable among the improvements in properties is the reduction of swelling and shrinking characteristics of normal wood that have often limited its serviceability.

Some of the newer wood products already established in the service of war production and now past the period of development and trial, are in use in the construction field.

Moisture-resistant plywood is notable in this field. The development of ordinary plywood, a product that dates back hundreds of years, made wood available in large sheets having properties more nearly uniform in all directions than normal wood, but it was only when weather-resistant glues were developed that this material assumed major importance as a material for outdoor uses, especially for housing and for industrial and farm structures.

A considerable portion of the effort toward mass production of housing, conventional, prefabricated, and demountable, achieved significant headway only with the development of water-resistant phenolic-resin glues for structural plywood.

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One of the earliest successful efforts to design a practical factory-fabricated system of building units for house construction based on plywood took place at the Forest Products Laboratory of the Forest Service, U. S. Department of Agriculture. Using the monocoque or stressed-skin principle common in aircraft design, plywood-covered building units planned to a 4-foot modulus, complete with insulation, moisture barriers, wiring, etc. were designed, and several model houses were erected on the Forest Products Laboratory grounds at Madison, Wisconsin, and are still giving satisfactory service after 8 years of testing, observation, and occupancy.

The plywood covering of all the wall, floor, roof, window, and door units was glued, rather than nailed, to a light structural framework. One model house, when it was demolished to make way for another structure, showed ample resistance to wracking tests not likely to be encountered in anything short of a hurricane.

The stressed skin principle implies that, unlike conventional frame walls which consist of a heavy framework on which coverings are suspended as dead loads, the stressed skin panels divide the weight of the structure between the frame members and the glued-on plywood -- hence the light framework used and relatively thin exterior walls (3 inches) and the ease and speed with which the units can be erected.

The Forest Products Laboratory prefabrication system, with modifications suggested by the various fabricators' and erectors' experience, has been widely adopted and its influence is seen in the thousands of prefabricated plywood units that now shelter workers in war crowded communities.

Heavy timber construction has made two important advances in recent years -- modern connectors for improving timber joint strength and glued laminated arches -- both items coming into considerable use just in time to help build many war structures, from shipways to camp recreation centers.

The weakest links in any conventional timber construction obviously are the joints, where loads are passed from one wooden member to another. Because of the relatively small cross sections of the steel bolts used, these transmitted loads are applied as shearing forces on areas of an inch (or less) of wood. Modern connectors are iron, steel, or even wooden, rings, plates, or dowels inserted between timbers and surrounding the bolts to bring greater areas of wood into bearing and consequently to greatly increase the over-all strength of an entire timber structure.

To illustrate the effect of the metal connectors, wood radio towers formerly were limited to a height of about 100 feet because of the limitations of joint strength. Such towers, connector jointed, can now be erected to a height of 300 to 400 feet.

The use of connectors has been estimated to have saved 400,000 tons of steel in 1942, beside assuring joints 4 to 5 times as strong as anything possible with bolts alone. In many wood shipways, factories, warehouses, railroad bridges, and similar structures connector-built joints are the literal sinews of war.

Other limitations of wood in the structural field have been surmounted by the engineering of large glued wood arches. Wood structural members are no longer limited by the practical size limits of timber coming from the mills, nor limited in shape by the fact that tree boles bear little resemblance to trusses or arches.

The use of glued arches in this country received real impetus when the Forest Products Laboratory undertook basic investigations and tests and published data that made it possible for American construction men to design wood arches on sound engineering principles. Arches in use today vary from flat ellipsoid types with a clear span of over 150 feet to small gothic type arches that have been used to build small churches having surprising architectural appeal, resulting from using the arches as a conspicuous feature of the interior.

Laminated arches are fabricated to order at the factory, shaped to the function which they are to perform, with thick sections where stresses are concentrated; curved and tapered to follow side wall and roof slopes and to conform to the varying concentrations of load. Glued arches are classified as slow burning and require no special sheathing to guard against sudden failure in case of fire.

Hundreds of tons of steel have been saved during the period of preparation for war and since Pearl Harbor by the employment of glued laminated wood arches in factories, hangars, drill halls, and similar structures. Seagoing counterparts of the glued wood arch are the glued laminated ship keels and frames now going in hundreds of small naval craft to take the place of hewn timbers of large cross section.

The demand for moisture resistant plywood construction for both airplanes and naval craft has led to new refinements in the fabrication of plywood that will inevitably be of permanent service in consumer goods. Perhaps the most striking development in this field has to do with the molding of weatherproof resin-bonded plywood to the curved shapes associated with marine architecture and the requirements of aerodynamics.

Where ordinary die molding will not suffice to produce parts having pronounced curvature or curvature in two planes, fluid pressure molding or so-called bag molding is resorted to. In this procedure strips of thin plywood coated with glue are laid up on the contours of convex or concave molds, and held in intimate contact with the mold by inflating or deflating a pressure bag or blanket against them until the glue has been set by heat supplied to the mold or bag.

The principle can be illustrated by laying strips of paper over the contours of a tea cup, covering the whole with a rubber toy balloon and exhausting the air until atmospheric pressure molds the rubber and strips to the contours of the cup; or by lining the inside of the cup (a concave mold) with the paper strips and inflating the toy balloon inside the cup.

Half fuselages, complete with bonded structural members, have been produced by bag molding, as have also small boat hulls, and many small aircraft units such as nose and tail cones, and air ducts and scoops. Complete planes made up of molded units have been built and successfully flown.

The most recent group of new wood products includes "impreg," "compreg," "hydroxylin," "papreg," and "uralloy" and commercial products similar to these Laboratory creations. These materials, illustrating the scientific approach to modification of wood properties, show the most striking improvement over the usual properties of wood. This can be credited to the fact that all owe their origin to chemical or physical modification of the basic cellulose-lignin units of minute wood structure. All of these products base their invention on the knowledge that lignin, the cementing substance which surrounds and binds the cellulose fibers, can be plasticized by chemical treatment and made to flow, and on the fact that the physical behavior of wood can be made more stable by bonding added chemical groups to the cellulose of the fiber wall and the interfiber lignin. The result of proper application of these facts is to fortify wood against its primary shortcomings, pronounced moisture fluctuations and resulting swelling and shrinking, susceptibility to fungus organisms, and to fire, and in some instances deficiency in strength properties.

Impreg is resin-treated laminated wood with a high degree of moisture resistance (hence low swelling and shrinking) and improved resistance to decay, fire, and to surface checking and weathering. In the manufacture of this product sheets of veneer are impregnated with a water solution of resin-forming chemicals, then dried and cured to cause the resin to polymerize or set within the wood. The treated veneers are laid up and hot-press bonded with resin glues to form a superior plywood. Success of the resin-impregnation treatment is dependent on selection of a resin and impregnation method that brings about not only introduction of resin to the hollow interior or lumen of the fiber but also a chemical bonding of the resins to the cellulose fiber wall itself. Thus the fiber is altered chemically and is no longer free to exercise fully its affinity for water and to swell as moisture is absorbed and shrink when moisture is given up.

Impreg resembles natural wood unless dyes are added to the impregnating resins. When light-fast dyes are found for impreg it will be possible to produce this durable material in colors completely permeating at least the outer thickness of veneer, thus obviating the need of any other finish.

Compreg in the making receives the same initial treatment as impreg but the simple curing treatment of the resin-treated sheets is replaced by hot pressing at varying pressures, depending on the properties desired. As the resin has a plasticizing effect on the lignin, the resin-treated wood compresses much more readily than untreated wood at the same pressures so that under moderate pressure the stack of veneer is compressed to a third to a half of its original thickness -- thus acquiring added density. At the same time the resin diffused through the veneer sheets bonds them into a solid panel with considerably increased homogeneity. The resulting product has resistance to moisture, shrinking and swelling, fire, and decay equal to or better than impreg, but its density has been doubled and it has acquired a surface hardness of 60 to 90 as compared with that of plate glass at 100. The compreg takes a high gloss from the platens of the press, but the outstanding feature of the finish is that in effect it permeates the whole panel. Scratches on the surface can be removed by sanding and buffing without other treatment and cut surfaces can be brought to a high finish by similar treatment.

Compreg can be produced in thin sheets, amenable to molding techniques, or in thick blocks suitable for such purposes as the carving of propellers. As a matter of fact propellers of compreg are in production both by carving and by the molding from pretailored assemblies of resin-bonded and impregnated plies. Other aircraft parts, such as radio antennae masts, chart cases, and bucket seats, are in production.

The most immediate allure of compreg to the layman is its attractive appearance and its appeal to the sense of touch. It is hard, highly polished, heavy (specific gravity 1.0 to 1.3), and usually richer and darker in color than the wood from which it was laminated. Due to the concentrations of resin between plies, laminations running out on curved surfaces give an attractive synthetic "grain" independent of the actual grain of the wood. Shrinking and swelling of compreg are negligible, actual submersion tests of 50 days showing a swelling of only 3.6 percent. As compreg resists water, alcohol, and mild acids, and is not permanently spotted by these materials, its suitability for table and bar tops and similar uses is apparent.

It should perhaps be pointed out that compreg is a specialty product, not too costly for military aircraft, but not yet within the price range of common structural materials. On the other hand, especially if quantity production results in lowered costs, it seems reasonable to expect that compreg will come into its own in the postwar period for fine furniture items, architectural details, and similar uses where attractive appearance, high durability, strength and easy maintenance are essential.

Combinations in which high durability compreg faces are formed on cores of impreg or untreated wood in a single operation suggest one way in which both weight and cost can be reduced in sheet or molded materials having most of the advantages of full compreg.

Hydroxylin is wood's own entry in the field of low-cost general purpose plastics. Made in two forms -- molding powder and laminating sheets -- both from hardwood wastes, it is classed as a low-cost plastic and has certain desirable properties notably high acid resistance. Its future should be influenced by its performance in war material and by production experience gained by war contractors who will apparently be the first to use hydroxylin in quantity.

Made in only one color -- jet, glossy, black -- hydroxylin is in effect a lignin plastic with a cellulose filler. In making the molding powder, sawdust or wood chips -- mill run of either straight hardwoods or softwoods -- is hydrolyzed with a weak acid or aniline to convert part of the cellulose in the wood to sugars which are removed by washing. This operation increases the percentage of lignin in the resulting "mash", which is dried and milled to a fine powder and to which a small amount of any one of a number of plasticizing agents may be added to lower the flow point of the lignin. The cellulose remaining in the molding mixture acts as a filler -- just as wood flour does in many common phenolic molding materials -- to increase the strength. Water resistance of the mixture is dependent on the amount of lignin present. The cellulose derived sugars referred to as a byproduct of the hydrolysis process could be processed by fermentation to produce ethyl alcohol in operations large enough to guarantee continuous production.

Hydroxylin is relatively hard and strong, has high electrical resistance, and can be cut with machine tools like metal. It is relatively light in weight (specific gravity 1.40) and bonds well to metals such as brass, bronze, and aluminum. The hydrolyzed wood sheet can be laminated under heat and pressure to form, under double curvature if desired, a material that has promise for many uses.

Efforts of one war contractor to get into production with a hydroxylin battery box for military airplanes appear to be nearing success. In this case the wood-derived material will replace hard rubber -- now out of the picture because of war scarcity -- with a significant saving in weight because of the greater strength per unit weight of the hydroxylin.

One of the most recently developed products of wood conversion to receive attention is papreg -- a high-tensile-strength plastic-like paper laminate which is being tested for the production of stressed parts in aircraft as a substitute for light metals. Resin-impregnated paper laminates are by no means new, but papreg is unique in that among such laminates its strength properties are such as to merit serious attention -- notably on the part of aircraft designers for objects taking considerable stress. The significant technical development of papreg is being carried out by the Forest Products Laboratory with a view to its potentialities as a substitute for aluminum in military aircraft, hence detailed information on its production and on its properties remain in the class of classified restricted information, available only to manufacturers and processors authorized by Government war agencies to receive such information to aid the national war effort.

The following quotation from an official release sums up the information that is available to the public:

"An improved paper-base plastic equaling aluminum in tensile strength on a weight basis has been developed and is being produced experimentally in the form of aircraft parts, including wing ribs, wing tip skins, and control surfaces.

"Experimental data thus far obtained in laboratory tests indicate that the product has twice as great tensile strength as any paper laminated plastic hitherto produced; that it can be molded to desired shapes at temperatures and pressures and on equipment now used for making plywood; that it is resistant to moisture and remains extremely stable at both high and low temperatures, and that it is more resistant to scratching and denting than aluminum. The plastic has a smooth surface, eliminating the necessity for special finishes and coatings.

"Tests also indicate that it does not splinter, tear, nor flower out when pierced by bullets.

"The properties of papreg, which can be varied to meet special needs, also give promise for use in water craft ranging from small boats to cargo vessels, and in the hulls of flying boats."

Papreg is another product of high durability, strength, and stability that has obvious possibilities for consumer goods, particularly since it might be given a variety of decorative treatments. At present, however, little thought has been given to consumer uses; its future in this field will be determined by economic competition of the raw materials after the war.

Uralloy -- urea-plasticized wood -- has not reached a stage of refinement as advanced as the other products described, but it is capable of modification in ways that should make it practical for many postwar uses. Essentially the process of making uralloy consists in soaking green wood in a solution of urea, drying it and heating it to about the boiling point of water and shaping it or bending it at this temperature.

This type of processing results in a product which is thermoplastic -- capable of being returned to its original shape on reheating -- but a thermosetting product can be made by adding a resin-forming chemical to the urea solution and altering the subsequent treatment. The thermosetting type of uralloy retains its shape on reheating and has moisture resistance that is lacking in the thermoplastic form. Control of the thermosetting process can also be used to resinify the wood and produce simple hardening.

Initial experiments on uralloy were made with oak, which appears to be especially suited to the treatment. Other woods, however, have been made into various forms of uralloy with success.

In addition to the new products that have been mentioned there is an indication that it will be possible to make additional forms of moisture-stabilized wood without resort to full resin impregnation.

It is also obvious that there are manifold possibilities of combining impreg, compreg, papreg, plywood, and untreated wood. Intriguing also is the prospect of surfacing light woods or other light filler substances with durable face plies to produce a variety of so-called "sandwich" materials.

The success obtained with plywood-faced balsa in constructing the doughty British Mosquito bomber of daylight bombing fame will no doubt be the forerunner of a considerable line of "sandwich" combinations that will find their way into peacetime commodities.

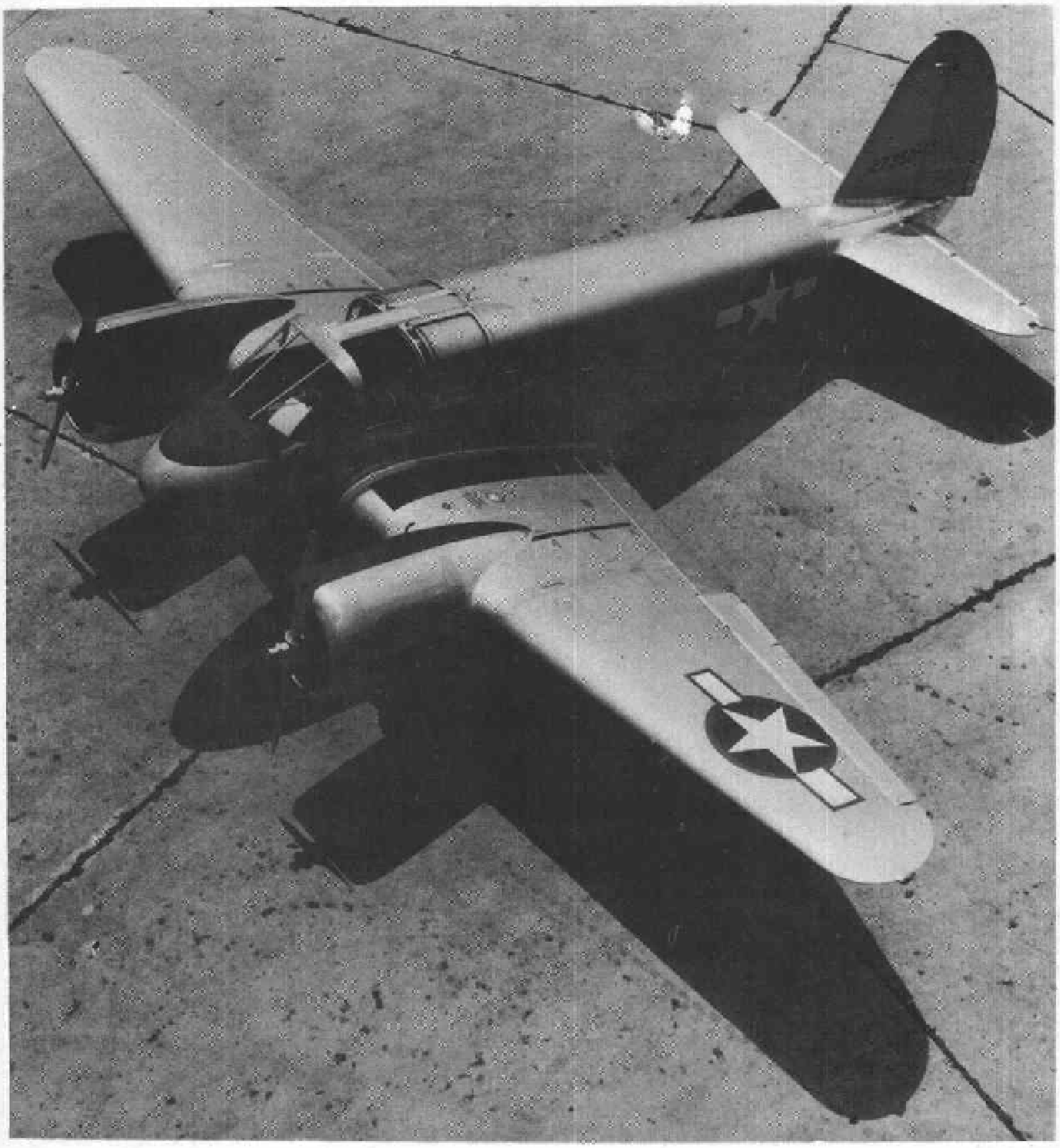
Some new wood derivatives and new wood processing methods, not immediately applicable to war needs, lie dormant in chemists' notebooks. An example is the hydrogenation method for processing lignin, the binding constituent of wood that until recent years has been a good deal of a chemical mystery. By subjecting aqueous solutions of lignin from waste pulping liquor or other sources to hydrogen under pressure, a variety of alcohols, oils, and an alkali-soluble resin have been recovered. The alcohols include methyl alcohol (wood alcohol or methanol) and propyl alcohol, and previously unknown products of the hydrogenation include a hard, glossy, amber-colored resin that may prove useful for plastics and lacquers, and several derivatives of propyl cyclohexane, some of which are thick viscous oils and others thin and toxic in nature. The apparent utility of these products has not been subjected to practical tests.

When the whole wood complex is subjected to hydrogenation, the lignin fraction is resolved into the components just described and the cellulose may be recovered in the form of a bleachable pulp of normal fiber length.

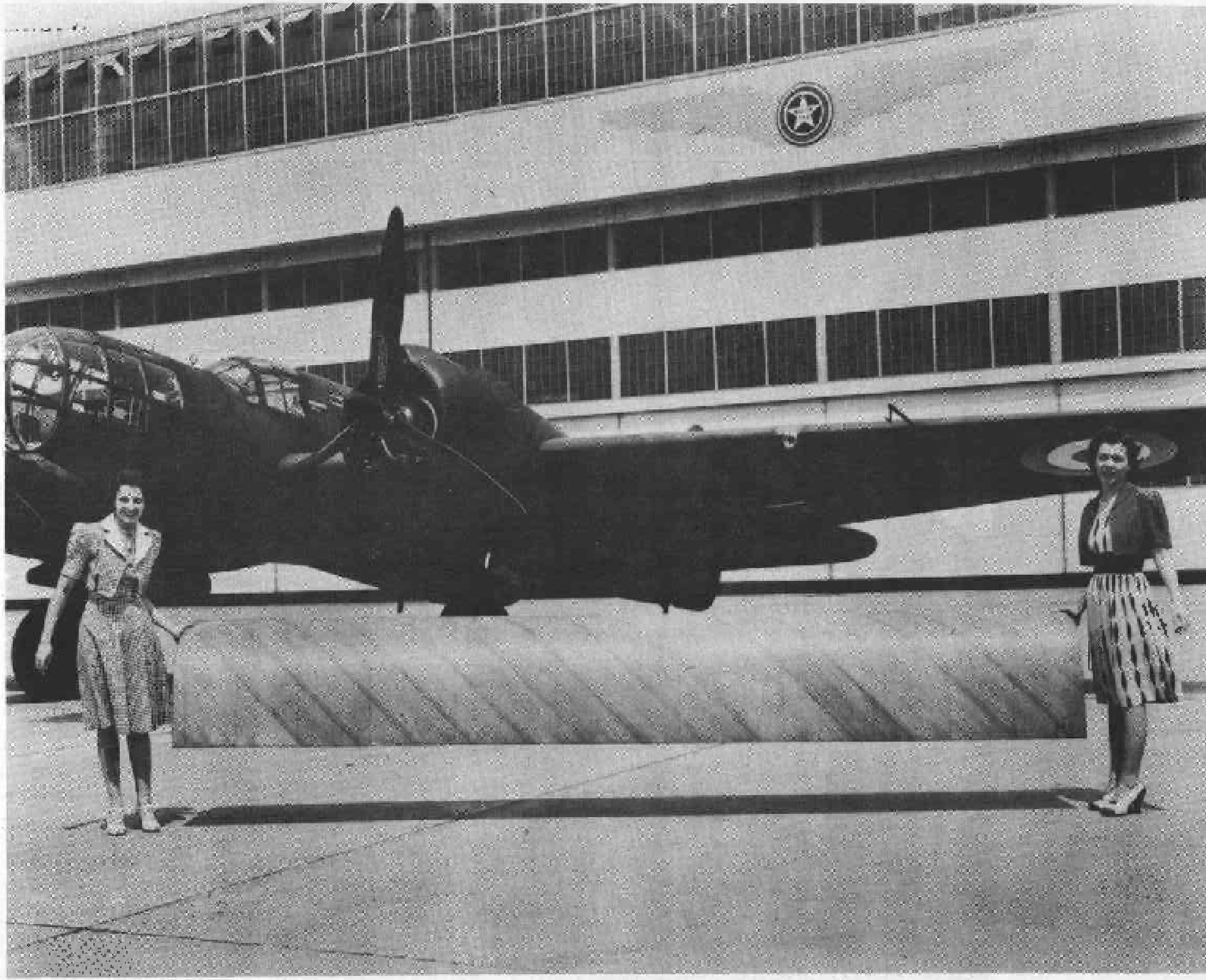
Certain products and uses of wood which return to public attention again and again with the impact of novelty are not emphasized here because they are not new. There is at least a quarter of a century of know-how and experience behind such developments as silk-like (rayon) and wool-like textile fibers from wood, automotive fuel from wood or charcoal, ethyl ("grain") alcohol, and edible sugars from wood. Rayon, of course, has been manufactured largely from wood in this and other countries for years to the extent of several hundred million pounds per year. The other forest products mentioned have been and now are in use in parts of the world where economic conditions permit.

Encouraging thing about most of the new wood products mentioned is the progress that has been made in overcoming inherent characteristics of raw wood that have limited the scope of competition with other materials. Furthermore, the prospect for continued improvement of the products and the refinement of others, already under development under the mantle of military security is most encouraging.

There is sound scientific basis for optimism regarding the future of wood. Research at the Forest Products Laboratory and in colleges and industrial laboratories over the last third of a century has filled in long-sought details on the fundamental chemical and physical structure of wood, especially for the lignin component, and has provided the approach to new conversion processes and better control of established processes. The most promising products of wood now finding their way into important military uses and shortly to serve civilian needs had their beginnings in fundamental research, not in the uncertain resources of unguided imagination or cut-and-try empiricism. The properties of wood can now be controlled and balanced one against the other with certainty and precision.



Maximum substitution of wood and plywood for metal has been effected in building this Beechcraft trainer and thousands of similar training planes now in use by the AAF.



Modern resin-bonded weather-resistant molded plywood was used in this 14-foot, 41-pound bomb-bay door for a Martin bomber. Supported at either end the door is strong enough to support the weight of nine people without serious deflection.

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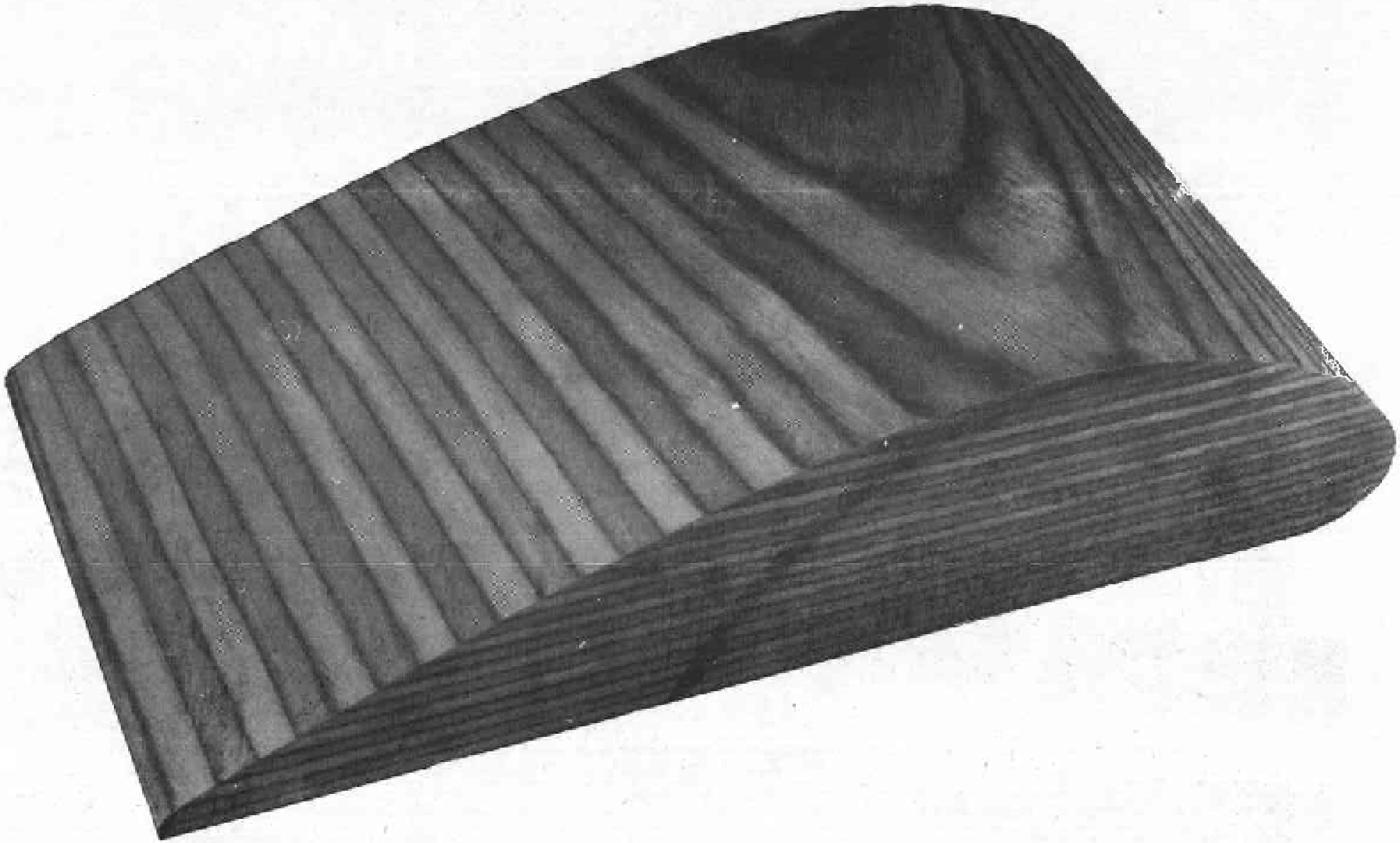

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Section through a compreg propeller.

Hydroxylin molding powder, experimental mold, and test moldings of an ash tray.

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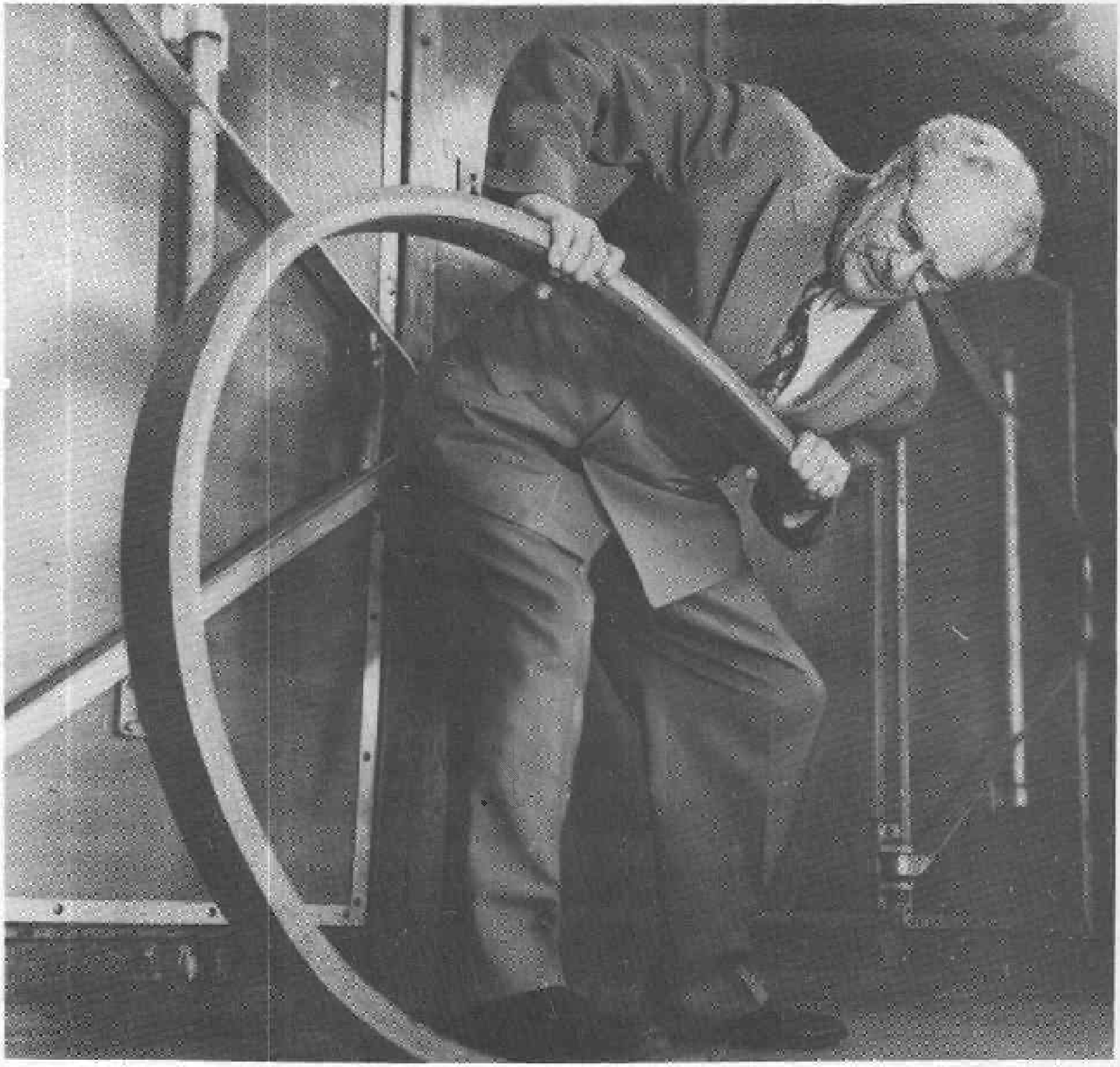

Illustrating the flexibility of a 2 by 4 of uralloy.