FOREST PRODUCTS LABORATORY

Supporting the Nation's Armed Forces with Valuable Wood Research for 90 Years

By Christopher D. Risbrudt, Robert J. Ross, Julie J. Blankenburg, and Charles A. Nelson

Editor's Note: As indicated in the text, this review article draws heavily on a doctoral thesis researched and written by Charles A. Nelson, who received his Ph.D. degree in history from the University of Wisconsin in 1964. The Forest Products Laboratory (FPL) issued a limited printing of the report, titled *History of the U.S. Forest Products Laboratory (1910-1963),* in 1971. Were it not for Dr. Nelson's thorough historical research, access to much of the record about the laboratory's forest products research in its first half-century would be difficult. The editor and other authors are grateful to Dr. Nelson and to the FPL staff in the early 1960s who assisted his research.

Preface

Founded in 1910 by the U.S. Forest Service to serve as a centralized, national wood research laboratory, the USDA Forest Products Laboratory (FPL) has a long history of providing technical services to other government agencies, including those within the Department of Defense (DoD). A recent search of FPL's library and correspondence files revealed that approximately 10,000 articles, reports, manuals, other technical publications, and communications have been generated and provided to the DoD since 1910. FPL has provided support on a broad array of technical questions—from designing lightweight packaging systems for transporting materiel to Europe and the South Pacific during World War II to assisting in the design and repair of motor mounts for minesweepers used in Desert Storm.

This article offers a brief review of some of the contributions FPL has made in support of the United States' military. Much of the material about FPL's efforts during World War I, World War II, and the Korean Conflict was taken—in many instances, quoted directly—from an excellent report on the history of FPL (1910-1963) prepared by Charles A. Nelson as a doctoral thesis in 1963 and later published by FPL (Nelson 1971). Technical reports found in FPL's library form the foundation for the remainder of the article.

World War I

The national defense activities of FPL during WWI can be grouped into four general research categories: aircraft, packaging, drying, and chemistry.

Top Left: During WWI, the Ordnance Dept. sent officers, enlisted men and civilians to FPL to learn fundamentals of boxing and crating construction for shipping materiel overseas. Top Right: This display shows key stages in the fabrication of a laminated wood propeller. Middle: AT FPL's propeller laboratory, effects of changes in humidity and temperature were carefully measured and recorded. Bottom Right: And during WWII, thousands of military and civilian logistics personnel learned to improve packaging and crating. Bottom Middle: An important benefit of packaging supplies in strong wood crates was the abililty to use sling loading, greatly speeding the transfer of needed supplies from landing craft to trucks. Bottom Left: Navy mine countermeasure vessels, or "minesweepers," rely on strong wood-to-steel connections to ensure their ability to withstand the sudden impacts of underwater explosions. Cover: Craftsmen in FPL's experimental propeller laboratory made laminated wood propellers that would undergo testing to quantify effects of humidity and temperature change.

Improving Aircraft Design and Materials

The first national defense investigation at FPL was initiated in April of 1917, when FPL was contracted to determine the effect kiln-drying, steaming, and bending have on the strength of Sitka spruce and other airplane woods. Based on previous work at FPL, methods and specifications for kiln-drying green spruce and other woods were developed for the War Department's Signal Corps. After providing original specifications, FPL conducted an extensive series of studies to determine the effect of kiln-drying. By the end of 1918, 100 kiln runs on 26 species of airplane woods had been completed. These runs provided the material for the approximately 100,000 specimens that were tested to determine strength properties.

FPL also was directly involved in the design and development of airplane parts such as wing beams, struts, elevator spars, wing ribs, and engine bulkheads. The goal was to maintain or increase strength while minimizing weight. In the spring of 1918, a severe shortage of wing-beam stock brought a request from the Signal Corps for an investigation of engineered built-up wing-beam designs. FPL test results indicated that two types, a three-piece I-beam and a box-section beam, were the most promising. The three-piece I-beam design was scheduled to go into production for use in the DeHaviland-4 (DH-4) airplane when the war ended. Further studies on the design of the DH-4 aircraft focused on the modification of wing ribs. FPL engineers speculated that DH-4 wing ribs could be lightened and strengthened by the increased use of plywood in construction. After a series of tests on several designs, FPL found one rib design that proved to be 30 percent lighter and more than twice as strong as the original design. This rib was about to be put into production at the time the armistice was signed.

Studies at FPL also led to improved strut design as researchers uncovered information relating to the exact strength requirements of struts, compared the suitability of different species, identified the defects in rejected struts, and determined to what extent existing methods of inspection needed revision. The most important information obtained revealed that the strictly visual system of inspection was unreliable. Accepted struts did not always prove strong enough under tests, and rejected struts often had adequate strength. FPL developed a nondestructive method of testing struts that was subsequently incorporated into specifications.

Plywood, recognized as a basic structural material for use in airplanes early in 1917, presented a host of difficult technical problems that drew the attention of FPL. The most pressing problem was that of obtaining sufficient quantities to meet the needs of expanding aircraft production. Airplanes used plywood in engine bulkheads, in the webs of wing ribs and beams, and in the fuselage. Late in 1917, when the U.S. Government decided to produce the DH-4 two–place observation plane in large numbers, an acute demand arose for waterproof plywood. The DH-4 planes, destined for France via ocean transport, would be subjected to varying weather and climatic conditions both enroute and in service at the front. The plywood used in these planes had to be resistant to moisture.

To increase commercial plywood, FPL researchers developed formulas for several improved glues made from both blood albumin and casein.

To increase commercial production of such plywood, FPL researchers developed formulas for several improved glues made from both blood albumin and casein. The formulas were supplied to manufacturers, and numerous companies became interested in manufacturing plywood. To further promote improved plywood, FPL scientists investigated commercial methods of glue and plywood manufacture in the field, suggesting improvements along the lines of mixing and applying, and at times analyzing all production factors at a particular plant to locate and solve some small, but important, trouble spots.

Allotments from the War Department enabled FPL to undertake another important aircraft research project: the equipping and operation of an experimental propeller plant. The central problem involved in propeller manufacture was to produce a propeller blade with sufficient stability to resist warp, twisting, and unbalancing of the blades with changes in humidity. Such defects had caused countless propeller failures. FPL established a special laboratory to investigate the problem. Begun in March 1918, the propeller research involved the manufacture, storage, and finishing of experimental propellers from seven species of wood under closely controlled conditions. Experimental propellers were produced at a rate of 10 a week, a schedule that called for work on a three-shifts per day basis.

More Efficient Packaging

FPL box and container research ranged from recommendations on the size and number of nails required for the most efficient box, to the complete redesign of boxes and containers. For example, a box designed to carry two Browning automatic rifles with equipment was redesigned to save both cargo space and material. A box originally designed to hold ten U.S. 1917 model rifles was redesigned at a savings of 33 percent in cargo space.

FPL also conducted special courses for military and civilian employees of various branches of the military. These courses involved intensive training in the construction and testing of packages and greatly improved inspection services. In all, 45 privates, 21 officers, and 23 civilians were trained under this program. One of the attendees, shortly after finishing the course, designed a cartridge case box that was accepted immediately as superior to former designs. The new design saved a reported $50,000 on the first contract and conserved shipping space valued at $100,000.

Kiln-Drying Research

Drying research at FPL during WWI was not limited to airplane woods. The problem of efficiently drying black walnut gunstock blanks arose in the months prior to April 1917. Allied forces had placed enormous orders for the British Enfield rifle in 1915-16. Consequently, the supply of air-dried black walnut was rapidly exhausted. First attempts by U.S. industry to kiln-dry black walnut blanks failed. At one facility, for example, 60,000 blanks were ruined. Faced with a lack of technical information on kiln-drying, the industry turned to FPL for assistance. Application of kiln-drying principles developed at FPL led to improved productivity.

When the United States entered WWI there arose an urgent demand for artillery wheels, escort wagons, and similar ordnance equipment, which required using oak. In May of 1917, the Bureau of Ordnance approached FPL for technical advice on how to kiln-dry oak. In response, scientists at FPL developed drying schedules that enabled manufacturers to dry 3-inch-thick oak material in 100 days. FPL researchers also developed new kiln designs; more than 240 kilns based on FPL- recommended designs were installed at 23 sites, including the Rock Island Arsenal in Illinois.

Chemistry Research

One study conducted at FPL during this time dealt with poisonous gas. In April 1917, FPL was asked to develop a highly absorbent charcoal that could be used in protective masks to absorb chlorine gas. FPL first examined commercial charcoals available at the time. None was found to be suitable. After FPL scientists discovered that beech charcoal satisfactorily absorbed chlorine, charcoal for gas masks was manufactured from beech until it was discovered that beech charcoal would not protect against the gases then being used by enemy forces. Coconut charcoal proved to be the best material for absorption of all poison gases. As coconut became scarce, FPL developed an acceptable alternative from hydrolyzed wood waste.

During the early part of the war, there was also a concern for an impending shortage of cotton linters for manufacturing nitrocellulose. In response, FPL developed several types of wood pulp suitable for nitration. These were nitrated at the Picatinny Arsenal in New Jersey and made into cannon powder. Other studies focused on the use of hemlock bark as a source of tannin, fiber-based shipping containers, and the development of waterproof shipping labels.

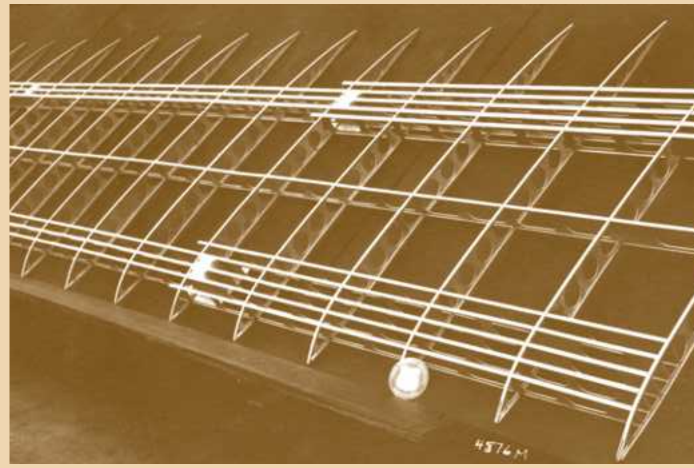
The need for alcohol was great and ways of supplying it important. FPL staff determined the yields of ethyl alcohol that could be obtained by dilute acid hydrolysis and fermentation from 24 species of wood and optimum cooking conditions for a single-cook process. This basic information led to the successful operation of two commercial plants during the war.

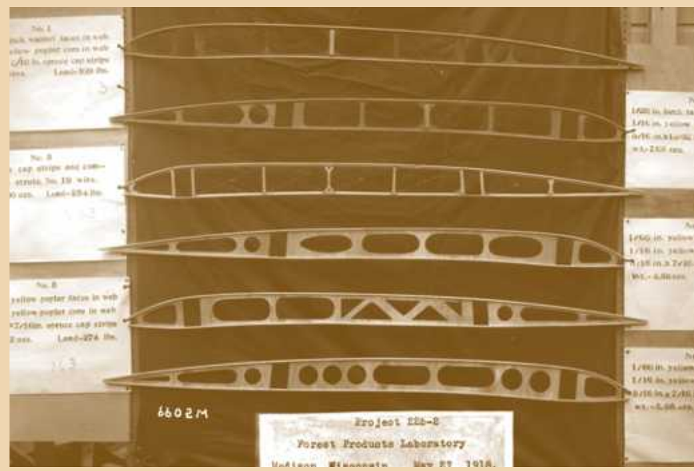
World War II

World War II created an insatiable demand for forest products in the form of lumber, plywood, paper, plastics, and other materials. Some 25,000 trainer aircraft and gliders were made of wood and plywood. Wood was used in great quantities to build fighting ships including minesweepers, submarine chasers, PT boats, and even battleships, not to mention the swarms of landing craft (Higgins boats) so important for amphibious invasions. Each minesweeper and submarine chaser contained enough timber to build ten average houses. The famous PT boat, with its spruce keels, mahogany planking, and plywood hulls, used 28,000 board feet of wood. The decking for the average battleship consumed 200,000 board feet of lumber, and the construction of a "Liberty" ship required nearly 700,000 board feet of lumber for shipway, staging, and scaffolding.

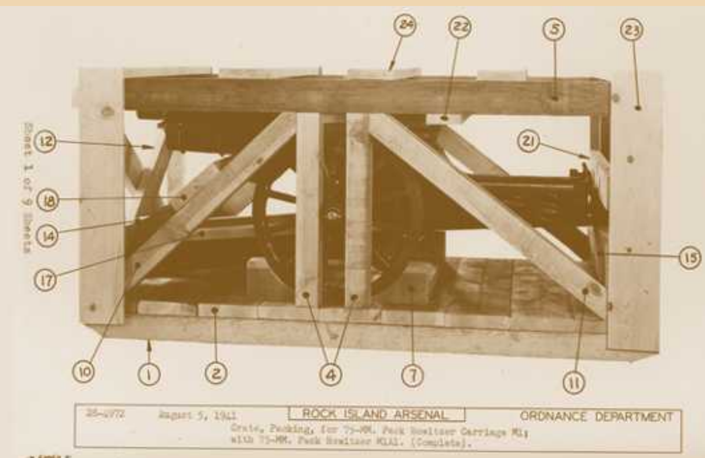
Three-hundred-thousand prefabricated housing units built largely of wood and plywood were needed to house the multitudes of war workers at production centers, while many thousands of other wood structures were erected at military encampments around the country and abroad. According to government data, it required 1,400 board feet of lumber to house each soldier, 300 feet to send them overseas, and 50 feet per month to keep them supplied. A military officer reported in 1944 that 61,547 tons of lumber were needed to land 100,000 soldiers on a typical Pacific island. Temporarily restoring the Italian port of Naples for use by the Allies required 50 million board feet of lumber.

Even more surprising was the tremendous quantity of lumber required for packaging the materials of war. For example, more than 700,000 different military items had to be shipped for the North African campaign—most of them packaged in boxes, crates, and paper cartons. Lumber requirements for boxing and crating increased steadily from 1942 to 1944, when nearly 17 billion board feet of lumber were consumed in domestic and military packaging.





TOP: By 1919, FPL researchers were demonstrating the strength of the internal web construction for an all-veneer wing. MIDDLE: The four lower wing ribs, designed using data provided by FPL, proved to have nearly twice the strength but only half the weight as the top two ribs, which were submitted by an airplane manufacturer. BOTTOM: Using a large rotating drum with built-in "hazards," FPL researchers tested the durability of wooden crates by subjecting the loaded crate to to sudden jolts and drops.



TOP: This FPL-designed crate holds two Browning automatic machine rifles and associated equipment that previously required two separate crates. MIDDLE: A packing crate for a 75mm howitzer carriage demonstrates the important role of wood in ensuring the safe transport of weapons to theaters of operations in WWII. BOTTOM: As the military increasingly relied on air transport to move materiel, reducing the weight of packing crates while maintaining their durability became of paramount importance.

The amount of lumber required to package certain military items is illustrative. For example, each 105-millimeter Howitzer took 711 board feet, each 40-millimeter Bofors antiaircraft gun required 1,040 board feet, while each bomber shipped overseas consumed 5,000 board feet of blocking and crating lumber.

In addition, the manufacture of cellulose compounds for explosives, plastics, and other products, and the spinning of great quantities of rayon for textiles used significant quantities of wood.

There was hardly a phase of the war economy to which wood did not contribute. Under Secretary of War Robert P. Patterson expressed the vital military role of wood when he declared in 1943 that “lumber comes close to the heart of the whole war problem. There are 1,200 different items of military and naval equipment that can use lumber [and] each day we find new and important ways to use wood in our weapons.”

Several wood-utilization projects of a national defense character had begun at FPL nearly two years before Pearl Harbor. Late in 1939 FPL initiated preliminary investigations relating to gas masks for the Chemical Warfare Service. About the same time the Rock Island Arsenal asked FPL to investigate the suitability of resin-treated wood for armor; the National Advisory Committee on Aeronautics wanted assistance on lumber specifications for spruce propellers; the Navy’s Bureau of Yards and Docks wanted lumber and plywood specifications for a naval airbase under development in Florida; and several commercial concerns sought technical advice in connection with emergency plywood orders for Great Britain and molded plywood parts for military aircraft.

At that time, FPL plans included the following proposed national defense activities: investigations to find substitutes for spruce in solid wood and plywood to meet the demands for training airplanes; studies of laminated gunstocks and the development of composite gunstocks; adhesive and plywood studies; the development of resin-impregnated wood for possible military uses; investigations of alpha-cellulose wood pulp as a possible substitute for pure cotton in the manufacture of explosives; charcoal for gas masks; fireproofing compounds; wood plastics from sawdust; kiln-drying investigations related to production of aircraft lumber and gunstocks; and the preparation of specifications for materials and processes.

In late 1941 the aircraft industry asked FPL to compile and disseminate the latest technical information on plywood and plywood structural systems, modern adhesives and gluing practices, finishes and finishing methods, laminated wood, and methods for testing aircraft woods. As a first step, FPL scientists prepared a series of reports on such subjects as testing for specific gravity, bonding practices, seasoning of aircraft woods, and the significance of wood defects on mechanical properties. Demand for these reports mounted swiftly as domestic industries converted to the manufacture of reconnaissance planes, trainers, and gliders—all of which were primarily of wood construction. These reports were sent to aircraft manufacturers, producers of aircraft lumber, plywood, and adhesives, and to a number of government agencies involved with mobilizing military production.

The reports, however, soon proved insufficient to fulfill the needs of engineers, inspectors, and other specialists concerned with wood aircraft production. A need existed for comprehensive publications covering the entire field of wood aircraft design and manufacture. Accordingly, on August 15, 1942, FPL issued two significant publications: *A Wood Aircraft Fabrication Manual* and the *ANC Handbook on the Design of Wood Aircraft Structures*.

A Wood Aircraft Fabrication Manual covered a broad range of technical subjects in wood technology: from materials production and shop techniques for the cutting and seasoning of aircraft wood and veneer to final finishing. It contained basic technical information for fabricators and inspectors on the handling of wood, plywood, adhesives, paints, and shop equipment used in actual production. The *ANC Handbook on the Design of Wood Aircraft Structures*, a revision of an earlier aeronautical board publication, consisted largely of structural analysis and design formulas and technical discussions related to the design of wood aircraft. Both publications incorporated the latest results of FPL research, supplemented with recent information obtained through visits to aircraft plants, adhesive manufacturers, and veneer and plywood producers.

The two publications received enthusiastic receptions by aircraft manufacturers and military authorities. G. A. Page, chief engineer of the Curtiss-Wright Division at St. Louis, Mo., wrote, "It [the *Design Handbook*] has expedited and facilitated our work in connection with the design of the C-76 airplane to a degree that is hard to estimate." The C-76, otherwise known as the Curtiss Caravan, was the first plane specifically designed to serve as a military cargo craft.

Even before publication of the two books, FPL scientists realized there were many problems related to aircraft design and fabrication for which data were incomplete, uncertain, or nonexistent. Solutions to such problems would only be found by continuing research. FPL conducted research to keep the manuals up-to-date, incorporating the results into revisions of both publications.

A few months later, FPL submitted a proposal to the Aeronautical Board calling for expanded aircraft research on developments already under way, including high-strength laminated paper plastics, hydrolyzed wood molding compounds, and the resin-impregnated composites. Army and Navy officials had expressed a great deal of interest in the possibilities of these materials for application in wood aircraft production, and the Aeronautical Board approved an FPL program known as the "Forest Products Laboratory General Research and Development Program."

One of the most promising FPL wartime developments in the general field of plastics was a paper-based laminated plastic known as "papreg." Among products made from papreg were gun turret parts for the B-24 Liberator bomber, gunner seats, gun shields, and aircraft ammunition boxes. "Compreg," a resin-treated compressed wood, was used in propellers, bearing plates, and fittings for aircraft as well as for aerial and radar antennae for high-speed aircraft.

World War II was also the transition period from wooden to aluminum aircraft, and again FPL played an important role. Aluminum can provide a lightweight aircraft, but the weak oxides that form on the aluminum surface prevent durable bonds. FPL scientists developed a surface-preparation process, termed "the FPL etch," that remains a standard method of preparing aluminum for bonding in the laboratory and is still used in some aircraft manufacturing.

ONE OF THE MOST PROMISING FPL WARTIME DEVELOPMENTS IN THE GENERAL FIELD OF PLASTICS WAS A PAPER-BASED LAMINATED PLASTIC KNOWN AS "PAPREG."

While FPL was contacting defense agencies for the expansion of aircraft research, another important aspect of FPL's wartime service had already begun to take shape. This was the packaging research program. FPL, with its experience working on packaging problems, had extensive technical data on container design. In September 1941, the Secretary of War, in a letter to the Secretary of Agriculture, requested that FPL "provide the [Army] Ordnance Division with the necessary technical information and advice regarding its packaging and container problems." That same month, FPL entered into a cooperative agreement with the Ordnance Dept. whereby Ordnance agreed to support an expanded packaging program and pledged additional funds to cover necessary expansion of staff.

The expanded packaging program became a special subdivision of Timber Mechanics called Materiel Containers. From October 1941 to September 1942 Materiel Containers performed three functions:

1. A staff of field consultants performed on-site service at arsenals, ordnance plants, and supply depots; all the consultants, drawn mainly from the ranks of industry, were experienced in packaging procedures.
2. A research staff at FPL handled special container design and development problems, prepared specifications and packaging manuals, and established performance standards.
3. A group of instructors provided training courses for officers, inspectors, and others on the basic techniques and fundamental principles of packaging.

Concurrent with the work on individual packaging instructions, FPL cooperated with the Ordnance Dept. and other agencies in preparing general publications on packaging. In all, nine manuals, 37 specifications, 1,500 packaging instructions, and numerous guides and directives were prepared. Among the most notable were: *U.S. Army Specification 100-14A, Army-Navy Specification for Packaging and Packing for Overseas Shipment; TM 38-305,*

During the first 15 months of packaging research at FPL, existing crating specifications were revised, saving the equivalent of one-half million tons of shipping capacity.

General Instructions for Corrosion Preventative Processing and Packaging; and *TM 9-2854, Instruction Guide, Ordnance Packaging and Shipping (Posts, Camps, and Stations)*.

Instructors for the ordnance packaging courses included staff from four universities. They gave four courses between April 13 and June 26, 1942, to a total of 61 ordnance inspectors and 37 FPL employees. Because of the great interest in the courses and the compelling need for expanded packaging research, the Ordnance Dept. significantly increased funding for fiscal year 1943. The funding enabled FPL to create a separate division to handle all the packaging courses as well as instruction on the subjects of aircraft wood inspection and fabrication for the Army and Navy. From April 1942, to the end of 1945, more than 16,000 military and civilian personal received training in 303 courses conducted at FPL or in the field. Of those trained, some 90 percent attended the 250 packaging courses, which ranged in length from a few days to two weeks. The 51 wood inspection and fabrication courses accomodated 1,345 personnel.

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In cooperation with the Navy, FPL conducted a comprehensive—and successful—program on laminating wood for ship timbers. This work grew out of a critical shortage of large, high-quality white oak and Douglas-fir timbers. By the end of the war, both straight and curved ship members were being laminated at several Navy yards as well as by private companies. One manufacturer, working with data provided by FPL, produced laminated skegs for the Higgins landing craft at a rate of 70 per day, producing 11,000 keels for landing craft and keels and stems for 100 PT boats in the space of two years.

Another interesting FPL project was a study on the performance of gasogens. Gasogens are devices attached to motor vehicles that convert wood and charcoal into a motor fuel. FPL undertook a limited study of gasogens in 1942. A U.S. Forest Service truck was equipped with a demonstration gasogen unit, and a series of road tests were conducted using a range of woods and charcoals.

Shortly after V-E Day, a Joint Intelligence Objectives Agency, consisting of representatives of the Department of Agriculture, Navy Department, War Production Board, and other agencies was created to collect information on scientific developments in Germany. The Forest Products Committee of this Agency selected technical personnel, mainly from FPL, to serve as representatives.

Korean Conflict

Much of the defense-funded research conducted during this time focused on the combining of materials—solid wood with metals, plastics, and paper—to form various sandwich composites. These composites were of interest because of their relatively low weight and high strength and stiffness. Military interest centered on the use of these lightweight materials for jet aircraft and rocket-propelled missiles. The Air Force and Navy Bureau of Aeronautics chose FPL to conduct this work because of the lab’s knowledge about adhesives, wood, paper and plywood. This specialized composites research involved the development of new adhesive systems capable of withstanding the extremes of high and low temperatures encountered in supersonic flight at high altitudes, techniques for bonding and fastening parts together, and engineering analysis and design criteria. FPL engineers developed design criteria for sandwich construction, providing data essential for the use of sandwich materials in aircraft, guided missiles, and in the building and transportation industries. This work was summarized in ANC-23 Bulletin, Part II, *Sandwich Construction for Aircraft*, published by the Air Force, Bureau of Aeronautics, and Civil Aeronautics Administration in 1955.

FPL staff also prepared, for the Army Corps of Engineers, the *Lumber and Allied Products Handbook* for Army, Air Force, and Navy officials engaged in procurement. The objective of this handbook was to instruct officials on how to requisition the proper sizes and quality of material needed for any given purpose.

1960 through Desert Storm

FPL continued its interest in packaging after the 1950s, resulting in several publications.

For the Air Force, FPL prepared Military Handbook 304, on Packaging Cushioning Design, which provided the means of applying sound engineering principles to problems of cushioning for a wide range of machinery, equipment, and instruments during transit. A cushion-selection indicator was also produced for the Air Force. Another important manual, the *Wood Crate Design Manual*, was produced by FPL staff.

Wood Enhancement Program

The Army's Picatinny Arsenal funded a two-phase program at FPL from 1988-89. The arsenal also provided funds to the U.S. Army Chemical Research and Engineering Center (CRDEC), Aberdeen Proving Grounds, Maryland, to assist FPL. The objective of the first phase of FPL's program was to develop a method for screening wood and wood-based products for resistance to chemical agents. Phase two's objective was aimed at evaluating various treatments and treatment methods for enhancing the performance of wood products used in pallets, consolidators, and skids. The screening protocol developed at FPL and approved by CRDEC in February 1989 used a simulant to identify materials that definitely would be unable to pass subsequent tests with chemical agents. It was, however, insensitive in identifying differences among treatments that subsequently were either marginally acceptable or unacceptable.

Several technologies were shown to improve the chemical resistance of wood or wood-based products. Fifty of the wood/treatment combinations examined passed the screening test at FPL and were submitted to CRDEC. At the completion of the program, one of these had passed the U.S. Army test with chemical agents. Ten additional materials were sufficiently close to passing that they were worthy of further consideration.

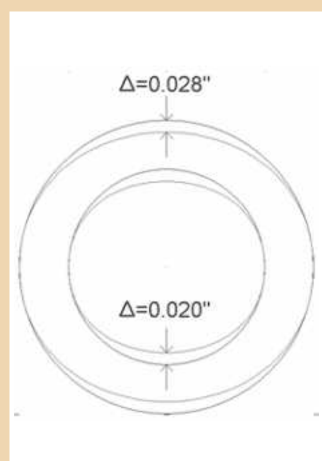
Mine Countermeasure Vessels

The U.S. Navy, Naval Sea Systems Command, Structural Integrity Sub Group and CASDE Corporation asked FPL for assistance in the design of bolted joints that connect steel saddles to white oak glued-laminated timbers that would be subjected to tension perpendicular-to-grain forces. These joints are representative of those used to connect equipment foundations (such as diesel engines) to hull frames in mine countermeasure vessels (minesweepers). FPL conducted a series of tests using two joint configurations: one configuration used five 1/2-inch diameter bolts and the other used five 1-inch diameter bolts. FPL found that the design was controlled by tension perpendicular to grain strength values.

As a follow-up, FPL was asked to develop options for field repair of this type of joint. Using the previously tested specimens, FPL engineers examined several repair techniques that could be installed under in-service conditions. The repair techniques examined included using large lag screws, epoxy adhesives, and plywood side plates. After repair, the specimens were again tested. Results of these tests revealed that all three repair methods performed well. The most promising repair consisted of using lag bolts in combination with the epoxy adhesive. Those repaired beams had strength values that exceeded original values.

Building Deconstruction

There exists in the United States a vast infrastructure of buildings and other structures that have been built wholly or partially from wood. Since 1900, more than 3,000,000,000,000 (3 trillion) board feet of sawn lumber have been produced, much of it still residing in the country's building infrastructure. As these structures age, lumber will become available for reuse through remodeling or dismantling. Currently, more than 50 percent of the nation's housing is 29 years or older, and an additional 30 percent is between 14 and 28 years old (more than 100,000,000 housing units exist in the United States, most of which are wood-framed). Nearly 15 percent of U.S. housing is at least 70 years old. In spite of the construction of more than 1 million new homes each year, it is estimated that by 2020, 70 percent of the housing stock will be 55 or older. This suggests that as the U.S. housing infrastructure continues to age, there will be a growing amount of lumber for reuse.



Nearly 90 years after the first research project on wood propellers, FPL investigated the effects of dry heat on wooden propellers for the Shadow® 200 unmanned aerial reconnaissance vehicle being used by U.S. forces in the Middle East. FPL combined time-tested manual examination with computer-aided analysis.
— Top photo courtesy of AAI Corporation

WORKING COOPERATIVELY WITH FPL, THE U.S. ARMY SUCCESSFULLY RECYCLED MORE THAN 4,700 CUBIC METERS OF LUMBER AND TIMBER

Maximizing the reuse of the recycled lumber resource has positive environmental impacts, among them:

— minimizing the amount of material destined toward landfills;

— minimizing further energy input because these materials can be used in their existing form; and

— conserving our natural resources and easing harvesting pressure on the existing forest resource.

In the past several years, FPL has partnered with the Department of Defense, in particular the U.S. Army's Twin Cities Army Ammunition Plant (TCAAP) in Minnesota, Fort Ord in California, and Fort Campbell in Kentucky, to develop deconstruction technologies for wood structures (Falk 2002). Working cooperatively with FPL, the U.S. Army successfully recycled more than 4,700 cubic meters (two million board feet) of lumber and timber from two large military industrial buildings at TCAAP. Additionally, FPL led an effort to develop cooperative research with the Fort Ord Reuse Authority and the West Coast Lumber Inspection Bureau to develop information on the grades of lumber reclaimed from deconstructed buildings.

Historic Preservation Practices

FPL has a long history of providing technical assistance to various segments of the Department of Defense on inspection and preservation of historic structures. Probably most notable have been FPL's continuing efforts to provide inspection and repair information for the USS Constitution, known as Old Ironsides. Launched in 1797, she is the oldest floating commissioned ship in the world and is still a part of the U.S. Navy. During its history, FPL has provided basic information on the wood used to construct the ship (live oak), advice on inspection methods, repair techniques and design information. More recently, FPL scientists studied methods to manufacture glued-laminated live oak timbers to serve as replacement timbers for deteriorated members in the ship.

Today, FPL researchers continue to address a variety of problems facing the U.S. military and its suppliers. In the summer of 2006, a phone call from a propeller manufacturer rekindled FPL's WWI-era research on wood propellers. The manufacturer, who supplied propellers for unmanned aerial vehicles, or drones, used for reconnaisance by the American military, wanted information about shrinkage or other effects of shipping the propellers, made in Florida, to hot and dry areas in the Middle East. In a few days, FPL researchers were able to determine the potential shrinkage and to suggest preventive measures.

Concluding Comments

This review supports a major conclusion—that the existence of a national laboratory with the technical skills, knowledge, and equipment necessary to solve the problems and meet the challenges of the United States military in critical times has saved the nation time, valuable resources, and, perhaps, lives. Had some of the major problems that were brought to FPL not been addressed effectively, much greater quantities of wood products would have been consumed by the military, with a concomitant drain on our forests. Further, military equipment would not have performed as well, resulting in greater losses.

Wood resources still play an important role in military operations, from pallets and other shipping materials, to buildings and transportation structures, to weapons components. Wood has been useful to mankind for thousands of years, in peacetime and war, and it appears this will remain true for decades to come. If our forests are managed wisely, and if we maintain and continue to build our intellectual capacity to meet the challenges of evolving human needs and changing wood characteristics, this amazing material that is wood will serve the nation well for years to come.

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Literature Cited

Falk, B. 2002. Wood-framed building deconstruction-a source of lumber for construction? Forest Prod. J. 52(3):8-15.

Nelson, C.A. 1971. History of the U.S. Forest Products Laboratory (1910-1963), U.S. Dept. of Agriculture. Forest Service. Forest Products Laboratory. Madison, WI. 177 pp.

Design of Wood Aircraft Structures, 2nd ed., 1951, U.S. Dept. of Defense. Munitions Board Aircraft Committee. Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria. ANC-18. U.S. Government Printing Office: Washington, DC. 234pp.

Wood Aircraft Inspection and Fabrication, April 1951 ed. 1951. U.S. Dept. of Defense. Munitions Board Aircraft Committee. Subcommittee on Air Force-Navy-Civil Aircraft Design Criteria. ANC-19. U.S. Government Printing Office: Washington, DC. 235pp.