1 Introduction

Acknowledgements

This article is possible only because of the kind assistance of Mr. Graham White, Aviation Historian, and the many current and former employees of Pratt & Whitney Aircraft. I would like to thank Mr. Richard C. Wellman and Mr. Jesse Hendershot, who made available archival material from which this article is drawn. Thanks are also due to the retired Pratt & Whitney engineers who took the time to undergo my telephone interrogation. In this category are Mr. Albert Crocker, Mr. Gordon Beckwith, Mr. Robert Gorton, Mr. George Meloy, Mr. Elton Sceggel, Mr. Frank Walker, and Mr. Dana Waring,

Dr. A. Gordon Emslie, Mr. James Howell, Ms. Margaret Jacobs, Dr. Greg Swanson, and my wife Shirley were among those who reviewed the early drafts and made many valuable comments. I am very grateful for their efforts.

Preface

All manufactured products, no matter how simple, are the result of considerable engineering effort. In a product as complex as an aircraft engine, there is an enormous amount of engineering, testing, and refinement before the engine meets the combined goals of being light, powerful, fuel-efficient, and reliable. Much of the credit for the success of a new engine goes to the test engineers who methodically and often with great ingenuity, identify and fix the problems with a new engine.

While the iterative work of engine designers may be lost in obscurity, the work of test engineers is nearly always recorded, and provides the best record available of the process of engine perfection. This is the story of a group of dedicated test engineers who took a design loaded with problems and refined it into one of the finest aircraft engines ever built - the Pratt & Whitney R-2800. This is not a criticism of the designers, but rather simply the nature of the engine development process itself. Contemporary engine designers make heavy use of computer simulation and they still rarely get it right the first time. Simulation only works when all of the unknowns are accounted for, and that is rarely the case when something truly revolutionary is being developed. Designers in the thirties had none of these tools, and had to depend on trial-and-error techniques of the test engineers to perfect revolutionary concepts. While this is hardly the complete account of R-2800 development, it does cover an important and historically significant story: the test engineers' efforts in perfection of the crankshaft and the triumph over vibration.

Gordon Beckwith is famous for leading the team that brought Pratt & Whitney's first commercial jet engine, the JT8D, to market. Despite the fact that Rolls Royce was already flying a competitive engine, Beckwith's team produced a better engine that met the customer's noise, bleed air purity, thrust, fuel consumption, weight, and interchangeability guarantees. The engine came through ahead of schedule and under budget.

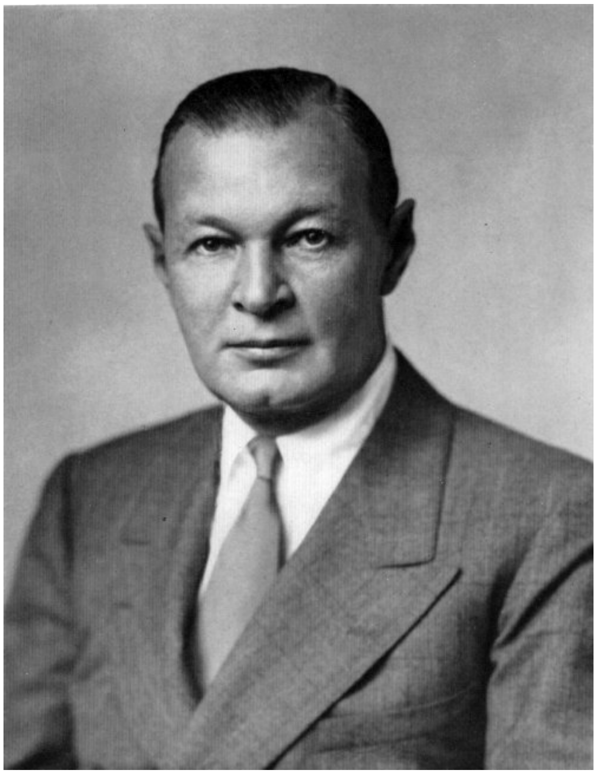
Beckwith came to Pratt & Whitney during the summer of 1939 before his senior year in college and worked in the stock room delivering parts to the engine assembly department. When he returned the next summer as a degreed engineer, he was told he would be working as a designer. The interviewer told him, "If you take this job, you will first become a draftsman. You will have a black oilcloth cover for your drafting table. At the end of the day, when the horn blows, your left hand will roll that cover across your board, you will get up from your stool, and you will go down the stairs and be done for the day." Beckwith objected, "Wait a minute, isn't there any place around here where I can work with the engines, you know, feel them and smell them?" "Oh, you wouldn't want to do that", said the interviewer, "that's the group of people they call test engineers and they don't even know when to go home at night - they stay here for all hours." Beckwith replied, "Hey, that sounds great! How do I get a job down there? So he let me go and talk to Joe Ballard, the head of the Experimental Test Department where I got a job actually working with engines."

Beckwith's story is typical of the many bright and innovative test engineers with abiding interests in aviation who brought the R-2800 to life.

Politics, Management, Corporate Culture, and Competition at the time the R-2800 project was begun

When development of the R-2800 began in March of 1937, Pratt & Whitney Aircraft was a company in trouble, both internally and externally. Pratt & Whitney badly needed a big success, and the R-2800 had to be it. In order to understand the motivations that drove test engineers to solve the complex problems of the R-2800 crankshaft, it is enlightening to review the political landscape of the times, as well as the corporate culture of Pratt & Whitney and the key engine architects' personalities.

The Formation and Spectacular Success of Pratt & Whitney Aircraft

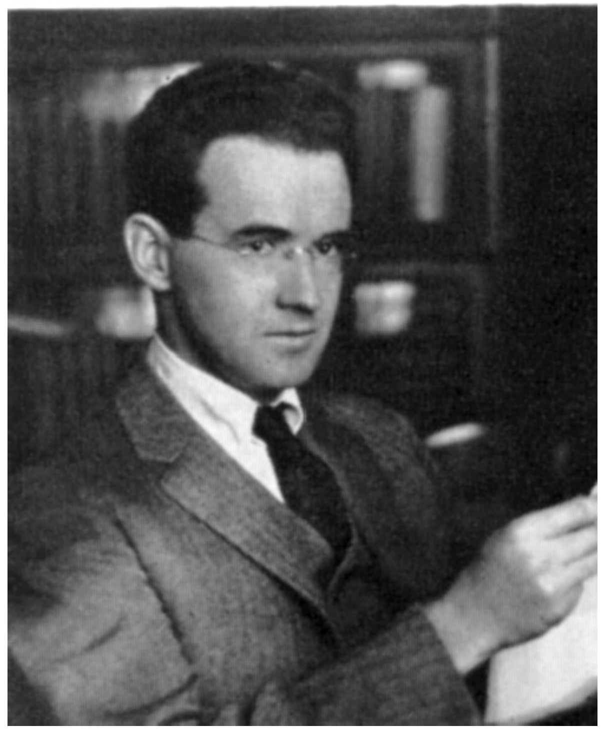


Frederick B. Rentschler, founder of Pratt & Whitney Aircraft (Pratt & Whitney)

Frederick Brant Rentschler turned his back on the family foundry business to become an Army engine inspector at the Wright-Martin Company during World War I. When the war ended, Wright-Martin was reorganized, and Rentschler stayed on to become President of Wright Aeronautical Corporation. But Rentschler was unable to convince the Wright Board of Directors, composed largely of investment bankers with little knowledge of aviation, to fund research necessary for continued improvement of air-cooled engines.[1] Such philosophical differences led Rentschler to resign from Wright on September 1, 1924[2].

By July 23, 1925[3], Rentschler had struck a deal with the Pratt & Whitney Tool Company of Hartford, Connecticut to fund the development of a high-powered air-cooled engine for the Navy.

He had secured the support of his old friend George Mead, the well-respected and highly capable chief engineer of Wright Aeronautical Corporation, as well as a promise from Admiral William A. Moffett to buy such an engine if it were successful. Thus, Rentschler and Mead obtained a controlling position in the Pratt & Whitney Aircraft Company. Other key people at Wright quickly joined forces with Rentschler and Mead. On December 28, 1925, the first Pratt & Whitney "Wasp" ran.[4] The Navy was overjoyed with the result, and, as promised, began to buy engines.



George J. Mead, Vice President of Engineering (Pratt & Whitney)

Bill Boeing also took note of the new engine and had his engineers design the Wasp-powered Model 40A mail plane. When the US Post Office privatized the carriage of airmail in 1927, Boeing won a large part of the transcontinental postal route by underbidding all others by nearly half. His competitors expected him to be bankrupt within months, but instead he made a sizeable profit and assured another market for Pratt & Whitney engines.

By the middle of 1929, Rentschler had organized the United Aircraft and Transport Corporation, a holding company for Boeing and Pratt & Whitney, as well as a number of other aircraft manufacturers, airlines, aviation schools, airports and export trading companies. In a series of stock transactions that were perfectly legal for the pre-crash "Roaring Twenties", Rentschler parlayed his and Mead's meager $500.00 investment into personal fortunes exceeding sixty million dollars. The other participants in United Aircraft also became fabulously wealthy.[5]

The Political Climate Turns Chilly

Healthy profits from exports made up for reduced military spending brought on by the Great Depression. But several factors were to present a real challenge during the 1930s. The McNary-Watres bill forced all airmail carriers to also provide seats for passengers after May 1, 1930. This was no major blow for United

Airlines, but it eroded the bottom line and started United Aircraft thinking of aircraft that could serve both roles. George Mead and Boeing engineers designed the Model 247,a sleek twelve-passenger all-metal monoplane that was to have been powered by two Pratt & Whitney Hornets. United pilots claimed the new design was too heavy and too powerful. In the end, Rentschler settled the dispute in favor of the pilots, and in doing so alienated Mead. To make matters worse, TWA commissioned Douglas Aircraft to build the DC-2 powered by Wright Cyclone engines of the same power class as Hornets. The DC-2 was superior to the 247 in all respects, and its successor, the DC-3 put Boeing out of the transport business for decades and Pratt & Whitney out of the transport engine business for a good part of the 1930s. Faced with lost transport sales, reduced military spending, and unused capacity, United Aircraft's bottom line began to reflect the deepening depression. Only the export picture remained highly profitable.

In 1934, real trouble began in the form of one Senator Hugo Black, a Democrat from Alabama. Black was troubled that in the middle of the depression, with rampant unemployment and hungry children, companies like United Aircraft were making huge profits on ventures originally funded by public money. Never mind that the government had deliberately tried to stimulate an American airmail and aviation transport industry through the Kelly Act of 1925 and McNary-Watres bill. Black thought everyone should suffer, even if they had done nothing illegal. Black publicly embarrassed Fred Rentschler and Bill Boeing on the floor of the U.S. Senate, and ultimately orchestrated the dissolution of United Aircraft. The Black-McKellar bill made it illegal for aviation manufacturers to be involved in air transport or the carriage of mail. Bill Boeing was so angry that he withdrew from aviation endeavors permanently.

Just as the feeding frenzy of the Black Committee was peaking, another grandstander, Representative John Delaney of New York, began investigating alleged profiteering on Navy contracts. Again, while nothing illegal was ever demonstrated, he singled out Pratt & Whitney's 1926 profit margins when research and development for the original Wasp and Hornet was being paid for by Navy contracts. In the end, Congress passed the Vinson-Trammel Act that limited profits to ten percent.

As if Black and Delaney were not bad enough, Congress authorized Senator Gerald Nye of North Dakota to investigate aircraft industry export policies. Again, Pratt & Whitney executives were roasted on the floor of the U. S. Senate, but no wrongdoing was proved. Still, a bill in the form of a neutrality act required exporters to obtain licenses before selling abroad.

To Pratt & Whitney owners and managers, all of this legislation seemed like a way for the Roosevelt New Deal to nationalize the aircraft industry. In Rentschler's view, their "only crime was earning a reasonable profit in a field where most others had lost their shirt"[6]

For the remainder of his life, Rentschler was haunted by accusations, largely by those unschooled in the intricacies of government contracting, of "profiteering" and "treason". The record, however, shows otherwise. Pratt & Whitney, under Rentschler's leadership, quite simply built the engines that won World War II. Pratt & Whitney and its licensees delivered 363,619 engines – fifty percent of all engines produced. Curtiss-Wright contributed thirty-five percent, with the balance coming from all other sources.[7]

While Curtiss-Wright had to be dragged kicking and screaming into subcontracting arrangements, Rentschler agreed to license Pratt & Whitney engines[8] for $1.00 each, and even this paltry fee was later waved[9]. While the papers accused the aircraft industry of "too little, too late", Pratt & Whitney, already producing **four million** horsepower per month from its East Hartford plant alone, was building a new plant in Kansas City, Missouri, and training 400 Missourians to produce aircraft engines.[10] While Curtiss-Wright President Guy Vaughn was defending the R-3350 before the U. S. Senate, aircraft powered by Pratt & Whitney R-2800s were dropping bombs on Europe. This was despite the fact that the R-3350 had almost a two-year development lead over the R-2800.

Rentschler was a shrewd, tough businessman. This attribute saved Pratt & Whitney from a fate like the post-war demise of Curtiss-Wright[11]. Rentschler was also a patriot who just wanted to make a fair profit building a product he believed in – air-cooled engines.

Internal Disharmony

In addition to external problems from the halls of Congress, Pratt & Whitney by 1935 was suffering internally as well. The key people had worked together for years, many having been handpicked by Frederick Rentschler during their previous time of service at Wright. They formed a very capable core group that shared a common philosophy about the superiority of air-cooled engines. When Rentschler focused on running United Aircraft, he appointed Don Brown, who had been with the company since August of 1925, to the Pratt & Whitney Presidency. This act, in conjunction with the Boeing 247 deal, had incensed George Mead to the point he was no longer providing suitable engineering leadership. An additional problem was that the engineering team was spread too thin by the myriad engines under development in the early-to-mid 1930s –the R-985 "Wasp Junior", the R-1340 "Wasp", the R-1535 "Twin Wasp Junior", the R-1690 "Hornet", the R-1830 "Twin Wasp", and the R-2180

"Twin Hornet". A further complication was Mead's fascination with high-speed liquid-cooled sleeve-valve engine, a complete departure from the air-cooled engine roots of Pratt & Whitney.

Stiff Competition from Curtiss-Wright

In the mean time, Curtiss-Wright had fully recovered from the hemorrhage of talent to Pratt & Whitney. Curtiss-Wright had introduced the very good R-1820 "Cyclone", and was progressing well with development of the R-2600 and R-3350, both of which were intended to produce more power than anything Pratt & Whitney had on the drawing boards. In order to restore some order to Pratt & Whitney engine development, Don Brown appointed Leonard S. "Luke" Hobbs to the position of Engineering Manager in 1935.

Technology Dictators: Army and Navy

On the technology front, both Army and Navy were convinced in 1937 that the only really high-powered engines on the horizon would be liquid-cooled. When R-2800 design began, the most powerful air-cooled engine in production was rated at just over 1000 HP. The biggest air-cooled engine even planned at that point was the Curtiss-Wright R-3350, initially rated at 2000 HP. In late 1936 or early 1937, the Navy had issued a request for an engine with a take-off rating of 2300 HP. Pratt & Whitney believed this rating would eventually be reached with an air-cooled engine[12], but knew it would take years to reach the 2300 HP mark.

Then in 1939, the entire Army Air Corps appropriation for fighter engine procurement was given to the Allison Division of General Motors for an order of V-1710s. This came as a devastating surprise to Pratt & Whitney. General Hap Arnold had given Pratt & Whitney a verbal contract, and operating solely on Arnold's word, Pratt & Whitney had started producing an order for R-1830s. Some months into the verbal order, Louis Johnson, the Assistant Secretary of War, actually awarded the order to Allison. According to Arnold, someone at Wright Field had made such a good case for Army support of liquid-cooled engines in fighters that the decision to buy from Pratt & Whitney had been reversed. Worse, it was anticipated that engine power for bombers would go the same route during the following fiscal year. Arnold advised Pratt & Whitney that if it wanted Army business, it had better develop a liquid-cooled engine of its own. Industry rumors attributed the reversal to a "procurement man who had never lost a game of poker to a General Motors representative". The bribery charge was never substantiated, but it made little difference to Pratt & Whitney, who laid off twenty percent of the work force and was seriously considering closing down the entire operation.[13]

Pratt & Whitney had been engaged in experimentation with large, high-powered liquid cooled engines under the direction of George Mead since about 1932. But Mead was disillusioned with Pratt & Whitney, and his health was failing. The liquid-cooled program languished to such an extent that no complete engine ran before testing began on the first experimental R-2800s. Ultimately, Pratt & Whitney would back out of all liquid-cooled contracts with both Army and Navy, freeing engineering resources to perfect air-cooled engines that would far exceed the original 2300 HP Navy liquid-cooled requirement.

The Architects of the R-2800: Hobbs, Parkins, and Willgoos

Hobbs

Leonard S. "Luke" Hobbs was born in Carbon, a Wyoming boom town that no longer exists. He spent his boyhood in Texas, graduated from Texas Agricultural and Mechanical College, and served as an engineering officer with the 42nd "Rainbow" Division in France. After WWI, Hobbs attended Kansas State College for further engineering studies before joining the Army Air Corp as a civilian experimental engineer at McCook Field, Ohio. In a later stint at Stromberg Carburetor, Hobbs' contributions to the modern aircraft carburetor established his reputation in aviation circles.

"Luke" Hobbs (Pratt & Whitney)

Hobbs came to Pratt & Whitney in 1927 where he rapidly gained the reputation as a brilliant engineer and capable manager. He proved his mettle by leading the team that solved the very serious master rod bearing problems that plagued the R-1535 and R-1830. When Pratt & Whitney's bearing vendors were unable to find a solution, Hobbs organized virtually the entire Pratt & Whitney engineering staff to solve the problem. Through much experimentation, hard work, and perseverance, the team invented the lead-silver-indium bearing that was so good it was even adopted by Pratt & Whitney's rival, Curtiss-Wright. After the Second World War, Hobbs would again lead a jet engine development team that would earn the prestigious Collier Trophy in 1953.

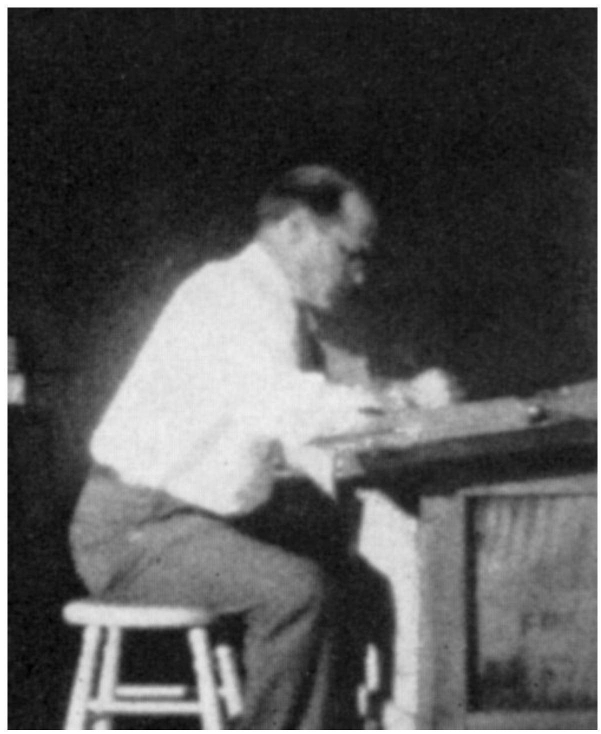
Parkins

Wright Parkins (Pratt & Whiney)

Wright A. Parkins was one of the development engineers who made his mark at Pratt & Whitney during Hobbs' master rod bearing campaign. Parkins, destined to eventually succeed Hobbs as engineering manager, was out of North Dakota by way of Manitoba and Seattle. He left high school to enlist and fight as a doughboy during the First World War. Afterward, he worked his way through engineering school at the University of Washington. Parkins met Hobbs while serving on the engineering staff at McCook Field, and followed him to Pratt & Whitney in 1928.[14] Without exception, those who worked for Parkins vividly remembered him nearly sixty years later. George Meloy described him as "a dynamo" who "made everyone cringe when you couldn't give him a [task completion] date he liked. He wanted two weeks work over a weekend"[15]. Both Frank Walker[16] and Elton Sceggel[17] said that Parkins "struck terror in the hearts of experimental engineers", but Sceggel continues "His bark was worse than his bite, he was strict but tough and that was what was needed". Gordon Beckwith remembers that Parkins was the "star of the show, with ideas, motivation, and leadership. You could leave the plant on Friday, and everyone would be down in the dumps with some terrible problem. Parkins would come in on Monday with eleven new things to try. One might not work, but another would. You didn't know until you tried."[18] One of Parkins' favorite targets was Joe Ballard, who ran the experimental assembly and machine shop. "Parkins made his life miserable", remembers Meloy. But it was Ballard's shop where the problems were and Parkins was a consummate problem-solver. It is no surprise that Parkins pushed Ballard hard to get results.

In addition to his energy, Parkins was well known for his wit. Parkins once guided a visitor on a tour of a test house. The visitor, while watching the blue exhaust flame of an engine under test, brightly remarked, "Actually, Mr. Parkins, you people simply are trying to contain and control fire, aren't you?" "Yes", said Parkins who was having his usual troubles, "and that's simply all the devil has to do in hell, too, as I understand it."[19]

Willgoos



Andy Willgoos in his garage during the summer of 1925 at work on drawings for the "Wasp" (Pratt & Whitney)

A. V. D. "Andy" Willgoos worked with Mead on the initial "Wasp" even before Pratt & Whitney Aircraft was incorporated. Willgoos left Wright Aeronautical Corporation in the summer of 1925 and worked without pay, enthralled by the task of creating a completely new engine in a new organization. [20] It is Willgoos' name in the title block of the first “Wasp” cylinder drawing dated July 25, 1925.[21]

It was Willgoos whose “calm and gentle”[22] nature moderated the high-strung Mead. And it is Willgoos who is copied on nearly all of the early R-2800 experimental test reports. It is likely, but not verifiable, that Willgoos was heavily involved in at least the initial R-2800 crankshaft designs.

Others

There were numerous other people who made significant contributions to high-level R-2800 design. Men like Earl Ryder and Val Cronstedt brought many skills from varied backgrounds. They were key to solution of problems regarding the crankshaft design and vibration issues. They were also unique in that they were consultants during R-2800 development. Unlike Wright, who used a large number of “hired guns” for their engine designs, Pratt & Whitney cultivated people from within who often made long careers of service to the company. Pratt & Whitney also had aggressive recruiting and work-study programs with numerous local colleges and universities. Pratt & Whitney recruited only the best, and summer internships allowed the company to identify those persons who were exceptional. Several of the test engineers came from these summer internships.

The Development Environment: Ideas into Metal

It took considerable fortitude to launch into a new engine development in such a political and corporate climate. New engine designs are always problematical endeavors. This is especially true of high-powered reciprocating engines, with literally thousands of moving, wearing, and vibrating parts. It seems simple to just add another couple of cylinders to each row of an already proven engine such as the R-2180 (a seven cylinder per row engine). In truth, this seemingly simple enlargement of seven to nine cylinders per row was to prove especially difficult for both Pratt & Whitney and Curtiss-Wright.

Luke Hobbs is usually credited with responsibility with the R-2800, and there can be little doubt that he led the team. Mead was almost certainly involved[23], especially in the early studies, but probably became absorbed with his passion for liquid-cooled sleeve-valve engines before the first R-2800 was actually built. Willgoos was heavily involved from conception through at least May of 1942, being copied on numerous reports from the experimental test department. According to George Meloy, who was closely involved with R-2800 development almost from the beginning, Hobbs had “overall responsibility, participated in the development of certain features, but primarily helped to develop solutions to problems”[24]. Hobbs would often show up unannounced to observe the results of an important test. When knotty problems were being solved, engineers would often report test results directly to Hobbs and get direction for the next phase of testing. But after the successful Type Test of the “A” model, Hobbs’ attention was diverted from R-2800 issues to more general management of a progressively larger engineering team.

In Hobbs’ place, Wright Parkins was the “idea man” with the tough job of achieving impossible schedules prior to and during World War II. He drove the team hard and though he was a fair and reasonable manager, the test engineers and personnel in the Experimental Department lived in constant fear of him.

Unlike engine development today, there was no modeling and very little analytical work at the time the R-2800 was developed. According to retired Pratt & Whitney Engineer Larry Carlson, engine designer L. Morgan Porter, using a 20-inch slide rule, did all of the analytical “high science” for the entire company.[25]

Instead, Pratt & Whitney used the time-honored “Run ‘um, bust ’um, and fix ’um” development philosophy. This technique, still an important part of today’s development practices, involves building a device using all available design tools and experience, running the device to destruction, analyzing what broke and why, designing a better part, and repeating the process until the desired level of reliability is achieved. Often, solutions would require the resolution of conflicting objectives. A fix to one part of an engine might introduce an unexpected problem elsewhere. But the ability of Joe Ballard’s experimental test and assembly department to rapidly produce and test new parts allowed these conflicting objectives to be sorted out with great rapidity.

Morgan Porter was instrumental in this process as well. George Meloy recalls Porter’s “unique ability to conceptualize engine configurations, sometimes using both hands as he drew illustrations on the blackboard”[26]. “Porter had a bachelor’s, master’s and professional degrees in mechanical engineering; had been professor of mechanical engineering and taught advanced college courses in aircraft engine design before joining Pratt & Whitney”[27]

The R-2800 crankshaft started out much simpler than it ended up. We can speculate that designers initially built the simplest engine that their vast experience dictated. With testing came problems, the solution of which necessitated complication of the design to include dynamic torsional vibration dampers, second-order counterbalances and the like.

As important as R-2800 development was, one must also bear in mind that other projects were under way which competed for the test engineers’ time. These included: R-1340 and R-1830 vibration tests; testing of the liquid-cooled X-1800 and H-3130 engines; and development and testing of the XR-4360, Also there were many miscellaneous studies and experiments of spark plugs, superchargers, valve mechanisms, and nose gear cases. The engineering and test team had just successfully completed an exhaustive program to eliminate master rod bearing failures, not to mention the R-2180, which was abandoned just prior to production.

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[1] See Ronald Fernandez, *Excess Profits* (Reading: Addison-Wesley, 1983), 27.
[2] See Robert Schlaifer, *Development of Aircraft Engines* (Boston: Harvard, 1950), 185.

[3] See Harvey Lippincott, "The Navy Gets an Engine", *American Aviation Historical Journal* (Winter, 1961), 258.
[4] *Ibid*.
[5] See Ronald Fernandez, 39 - 63.
[6] Ibid, 95.
[7] See*The Pratt & Whitney Aircraft Story*, 141-143.
[8] See Ronald Fernandez, 128.
[9] *The Pratt & Whitney Aircraft Story*, 132.
[10] See Ronald Fernandez, 144.
[11] At the end of World War II, Curtiss-Wright was the second richest company on earth. It never succeeded in gas turbines and ultimately sold the engine business to Deere in 1985.
[12]When work began on the R-2800, Pratt & Whitney had a 1400 HP engine, the R-2180, almost ready for production. Parts from R-2180s were used in early R-2800s.
[13] Ronald Fernandez, 113.
[14] See "The Pratt & Whitney Aircraft Story (East Hartford, CT: United Aircraft Corporation, August, 1950), 114-115.
[15] George E. Meloy, telephone interview by author, Huntsville, Alabama, December 14, 1998.
[16] Frank Walker, telephone interview by author, Huntsville, Alabama, March 29, 1999.
[17] Elton Sceggel, telephone interview by author, Huntsville, Alabama, March 22, 1999.
[18] Gordon Beckwith, telephone interview by author, Huntsville, Alabama, March 22, 1999.
[19] *The Pratt & Whitney Aircraft Story*, 115.
[20] Lippincott, 258.
[21] This drawing, on Willgoos' original drawing board, is on display along with his drafting tools at the New England Air Museum in Windsor Locks, CT.
[22] *The Pratt & Whitney Aircraft Story*, 95.
[23] See Cary Hoge Mead, *Wings Over the World, The Life of George Jackson Mead* (Wauwatosa: Swannet Press, 1971), 183.
[24] George Meloy, telephone conversation during meeting with R-2800 developers, East Hartford, CT, November 5, 1998.
[25] Larry Carlson, meeting with R-2800 developers, East Hartford, CT, November 5, 1998.
[26] George Meloy, electronic mail to the author, October 8, 1999.
[27] Albert R. Crocker, letter to the author, November 1, 1999.