Abstract

Title of Thesis: The Westinghouse Aviation Gas Turbine Division 1950-1960:
A Case Study in the Role of Failure in Technology and Business

Degree candidate: Paul D. Lagasse

Degree and year: Master of Arts in American History/Master of Library Science

Thesis directed by Professor Robert Friedel
Department of History

The Westinghouse Aviation Gas Turbine (AGT) Division pioneered the development of aircraft gas turbine engines in the United States. Despite the support of the Navy's Bureau of Aeronautics for most of its twenty-year existence, the Westinghouse AGT Division failed to maintain its position as a leader in the aircraft engine industry. Repeated failures to manufacture satisfactory engines led to the gradual withdrawal of Navy support. In 1960 the division disbanded and Westinghouse withdrew from the industry.

The failure of the Westinghouse AGT Division is shown to be the result of the inability of the engineers and managers to develop a suite of skills and resources — what Alfred Chandler terms "organizational capabilities" — sufficient for the manufacture and marketing of a new product that significantly affected the aircraft engine market. Chandler's concept is a powerful explanatory tool which is used to develop an analytical framework around the history of the Westinghouse AGT Division. The case study demonstrates that success in the aircraft gas turbine engine industry in 1950-1960 depended on the engine manufacturer's ability to adapt certain of its Chandlerian organizational capabilities to keep pace with rapid changes within the industry, namely: 1) financial investment in research, development, and production; 2) initiative in developing new engines and customers; and 3) adaptive management and engineering practices. This case study demonstrates the importance of organizational capabilities by demonstrating how the absence of certain skills, management practices, and organizational routines negatively affects the outcome of an attempt at technological innovation.

The Westinghouse Aviation Gas Turbine Division 1950-1960:
A Case Study in the Role of Failure in Technology and Business

by
Paul D. Lagasse

Thesis submitted to the Faculty of the Graduate School of
the University of Maryland at College Park
in partial fulfillment of the requirements for the degree of
Master of Arts in American History
1997

Advisory Committee:

Professor Robert Friedel, Chair
Professor David Sicilia
Professor John Anderson

Acknowledgements and Note

Over the many years I have been researching the history of the Westinghouse AGT Division, I have incurred the debt of many people; I here formally express my gratitude. The thesis originated as a research paper for Dr. Anne Millbrooke, who has over the years steadfastly encouraged my efforts as an historian-in-training and who provided invaluable editorial suggestions right up to the final draft. Staff at the various museums, archives, and libraries that contain material related to the history of the AGT Division all helped me work with their priceless collections; Barry Zerby and Sandy Smith of the Military Reference Branch of the National Archives; Marjorie G. McNinch of the Archives & Manuscipts Department, Hagley Museum and Library; Betsy Hall of the Historical Electronics Museum, Inc.; Rick Leyes, Propulsion Curator in the Aeronautics Department, National Air and Space Museum, Smithsonian Institution; Lauren Lyon, Research Librarian at the Kansas City Star Information Store; Dave Lindsey, International Gas Turbine Institute; Charles Ruch, Westinghouse Electric historian; Ed Reis of the George Westinghouse Museum; and Frank A. Zabrosky of the Archives of Industrial Society, University of Pittsburgh.

Former Westinghouse AGT Division employees Reinout P. Kroon, Oliver Rodgers, Robert L. Wells, Chet Kelley, Dr. Stewart Way, and Harold L. Hildestad kindly answered my questions, provided documents from their personal collections, and helped me develop the human side of the AGT Division story. I know they would disagree with many of my arguments and conclusions, which are solely my own. Mary Jo Lazun provided editorial assistance, offered valuable suggestions for every aspect of the final product, and kept me on track throughout the writing process. I would also like to thank my thesis advisory committee, Dr. Robert Friedel, Dr. David Sicilia, and Dr. John Anderson for their help, support, and interest throughout the entire thesis project.

Throughout the thesis I refer to aircraft gas turbine engines of United States manufacture, and those of foreign manufacture that were used by the United States military, by their United States military designations. For the sake of c1arity, I chose this consistent and comparatively straightforward identification method over the unique designations used by the different engine manufacturers. For an explanation of this designation system, and a comparative listing of engines with their manufacturer designations, see Appendix I, Aircraft Gas Turbine Engine Designation Standards, following the text.

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Introduction: Determinants of Success and Failure in the Aircraft Gas Turbine Engine Industry

Nothing that Westinghouse did in its entire war history has had such far-reaching influence upon [its] future engineering as the successful gas turbine which resulted from this splendid challenge.[1]

"Westinghouse pioneers something and then lets G.E. walk in and take the market away. And the credit for pioneering it, too." [2]

In the decade and a half following the end of World War II, the aircraft gas turbine — "jet" — engine rose to dominance over the traditional aircraft piston engine. Westinghouse Electric was one of the first major manufacturing firms to enter the nascent jet engine industry. In 1941, Westinghouse's jet engine program appeared to have all the elements to ensure success: the economic support of a large and well-established firm, a ready customer in the United States Navy, and experience derived from the design and manufacture of an apparently closely-related technology, the steam turbine engine. However, Westinghouse failed to keep pace with the rapid growth of the jet engine industry and withdrew in 1960. This thesis identifies the reasons for the failure of Westinghouse in the industry, and explains the significance of those reasons in terms of how Alfred Chandler's concept of "organizational capabilities" can be used to understand the role of innovation in successful business operations.

There has been no analysis in the literature of aviation history as to why the Westinghouse AGT Division failed to maintain its position as a major aircraft gas turbine engine manufacturer. Most sources, if they discuss Westinghouse at all, simply mention the fact that Westinghouse engines suffered developmental problems which caused them to be unreliable and underpowered.[3] Historians of aviation agree that Westinghouse engines were consistently less powerful — that is, they provided fewer pounds of propulsive thrust obtained from the combustion of compressed air and vaporized fuel — than the contemporary engines of its rivals, General Electric and Pratt & Whitney Aircraft.[4] It is necessary but insufficient to say that Westinghouse Electric failed to maintain its position as a leader in the aircraft gas turbine engine industry because its engines failed to be competitive. The reasons why Westinghouse engines were consistently inferior in reliability and performance, and why those reasons are important to historians who study failure in technology-oriented businesses, are the topic of this thesis.

Historiographical Grounding: the Aircraft Gas Turbine Engine as Disruptive Technology

Historians of business and technology are increasingly interested in the mechanisms by which innovation, traditionally defined as the introduction of an invention into the commercial market,[5] appear to directly affect the success or failure of manufacturers in an industry. The successful introduction of the gas turbine engine into the aircraft engine market required new approaches by companies to project funding, marketing, and engineering in order to market the engine successfully and competitively. Historian and business analyst Clayton Christensen has labeled an innovation that requires such changes in business practices a "disruptive technology."[6]. I posit that the Westinghouse AGT Division failed to maintain its position as a major manufacturer of such engines because it was too slow in recognizing the need for the financial, marketing, and engineering changes required by the disruptive technology of the aircraft gas turbine engine.

The ability — or inability – of a company to deploy its skills and resources successfully in order to maximize its chances for success in the manufacture of a technological product is determined by what historian Alfred Chandler has termed the "organizational capabilities" of that company. In his book *Scale and Scope*, Chandler broadly defines organizational capabilities as a combination of the skills and resources possessed by a company.

> The combined capabilities of top and middle management can be considered the skills of the organization itself. These skills were the most valuable of all those that made up the *organizational capabilities* of the new modern industrial enterprise ... . These organizational capabilities included, in addition to the skills of middle and top management, those of lower management and the work force. They also included the facilities for production and distribution acquired to exploit fully the economies of scale and scope. [emphasis in original][7]

Chandler does not break his broad concept of organizational capabilities down into specific skills and facilities. Nor was Chandler the first business historian to recognize the key roles played by knowledge, skills, and resources in the successful manufacture of new technologies.[8] Chandler did, however, explicitly treat organizational capabilities as a quantifiable and manageable resource, and located them specifically within individual companies rather than attaching them to the larger industries or technologies. This treatment has the effect of placing the responsibility for the development and maintenance of organizational capabilities on the companies themselves.

Chandler considers organizational capabilities to be a *static* resource. He claims that once the organizational capabilities of a company are created and established, they must be maintained. However, he warns, the advent of new technologies, and accompanying new markets, constantly threaten to make organizational capabilities obsolete.[9] According to this model, the ability of a company to successfully diversify into new or disruptive technology markets is therefore limited, determined by whether the new market is "based on [existing] organizational capabilities, that is, product-specific facilities and skills."[10]

Other historians who have expanded on the idea of firm-specific organizational capabilities have discussed the ability of companies to learn to adapt their organizational capabilities to disruptive technology markets. Chandler's concept of organizational capabilities is essentially similar to the concept of "competence," which is defined by Dosi, Teece, and Winter as "a set of differentiated technological skills, complementary assets, and organizational routines and capacities that provide the basis for a firm's competitive capacities in a particular business ... . In essence, competence is a measure of a firm's ability to solve both technical and organizational problems."[11] According to Dosi, *et al.*, the presence of competences, both organizational and technical in nature, is necessary for the competitive success of a firm. Like Chandler, they do not identify specific organizational capabilities/competences that a company can employ to solve its problems. The authors present the theory of competence as part of a larger theoretical model which was at the time still being developed and evolved by the authors.

The competences identified by Dosi, *et al.* differ from Chandler's organizational capabilities in that capabilities are seen to be *dynamic*; the result is an inversion of the relationship between organizational capabilities and technologies as identified by Chandler. According to Dosi, *et al.*, the importance of *learning* is central to the development or adaptation of successful organizational capabilities. Learning, they contend, can be affected by "differences in the human skill base as well as differences in managerial and organizational systems."[12] The role of learning in a firm is demonstrated by the development of successful "organizational routines," defined as "patterns of interactions which represent successful solutions to particular problems," and by advantages taken by the firm of opportunities represented by new technologies."[13] The presence of such routines and opportunities are necessary for the development of what the authors term "corporate coherence" for a firm, which occurs "when its lines of business are related, in the sense that there are certain technological and market characteristics common to each."[14] The expansion of a company into a new technology market, therefore, is not dependent on whether the product fits with the existing organizational capabilities of the company, as Chandler would have it, but on whether those organizational capabilities can be adapted to accommodate the new technology. The historical events presented in this case study favor the latter interpretation of the central role played by organizational capabilities in determining the success or failure of an attempt at technological innovation.

A case study of a failed attempt to manufacture a disruptive technology offers historians an opportunity to elaborate on the concept of organizational capabilities by demonstrating how the *absence* of certain skills, management practices, and organizational routines affects the outcome of an attempt at technological innovation. Chandler, Dosi, Teece, and Winter all recognize the importance of the role played by organizational capabilities in successful diversification by companies into disruptive technology markets. However, though Dosi, *et al.* go some distance toward elaborating broadly-distinguished categories of competences,[15] other historians appear not to have placed specific business activities and decision-making strategies under the umbrella concept of organizational capabilities. This case study suggests that, for the Westinghouse AGT Division, the absence of a defined set of particular business activities and decision-making strategies, which can be classified as part of the organizational capabilities of the Division, directly affected its efforts to manufacture aircraft gas turbine engines.

Thesis Statement

Success in the aircraft gas turbine engine industry in 1950-1960 depended on the engine manufacturer's ability to adapt certain of its Chandlerian organizational capabilities to keep pace with rapid changes within the developing industry, namely: 1) financial investment in facilities for research and development and for production; 2) initiative in developing new engines and customers; and 3) adaptive management and engineering practices. Failure by Westinghouse to adapt these capabilities to the changing demands of the industry resulted in the company being unable to maintain its position as one of the major aircraft gas turbine engine manufacturers in the United States.

To varying degrees, the three organizational capabilities outlined above have already been individually recognized as distinct and significant concepts by historians of business and technology. They have not, however, been treated collectively as specific organizational capabilities. This case study suggests that at least under certain circumstances they may be so treated, at least in part because of their contribution to the failure, rather than to the success, of the Westinghouse AGT Division. Specific organizational capabilities are harder to isolate using only case studies of successful development and manufacture of disruptive technologies because such case studies provide little opportunity to compare the relative contributions of specific capabilities to the overall success of the company. In this case study, where the failure of the Westinghouse AGT Division can be compared to the successes of its competitors General Electric and Pratt & Whitney, the roles played by financial support of R&D, initiative in the development by companies of new engine designs, and adaptation of engineering and management practices can be comparatively tested between the three firms.

Financial support for facilities, staff, and products demonstrated that a company had a stake in the long-term success of its engine program and desired to keep abreast of the latest technological developments in the field. In their analysis of the interplay of technology and economics, Richard Nelson, Merton Peck and Edward Kalachek observe that "new technology often needs new capital."[16] The aircraft gas turbine engine required significant amounts of financial investment in the 1941-1960 period in support of research and development

(R&D), and since the primary customer for that product was the military services, during those years the Air Force and the Navy provided most of the R&D funding. In the years following World War II, the federal government, especially the military, became the biggest financial sponsor of industrial R&D.[17] Over 65% of government R&D support went specifically to the development of new technologies for production.[18]

Nevertheless, historians of economics and business agree that if a company does not ultimately invest a significant amount of its own funding in support of a new technological product, that product may fail to compete successfully.[19] In the case of aircraft gas turbine engines, the military services expected that engine manufacturers would invest company funds for the development of long-term infrastructure in support of future R&D and production, as well as continue to accept development contracts funded by the military. Christensen's research into disruptive technologies led him to conclude that "[i]nnovation proposals that get the funding and manpower they require may succeed; those given lower priority, whether formally or de facto, will starve for lack of resources and have little chance of success."[20]

A successful aircraft gas turbine engine manufacturer demonstrated its growing confidence in the technology by introducing improved engines on its own initiative, inverting the manufacturer-customer relationship of the early years of the industry, and in so doing broadening its customer base. Until the early and mid-1950s, aircraft gas turbine engine technology was tightly controlled by the military services, which required engine manufacturers to wait for the military to issue production contracts for engines with specific performance criteria. However, Herman Stekler noted in his 1965 analysis of the aerospace industry, beginning in the late 1950s the military services turned increasingly to design competitions for new aircraft and engines, requiring the firms to put forward designs of their own rather than simply manufacture products that slavishly copied military specifications.[21] Richard Nelson equated initiative with the importance of in-house R&D. "In an industry where innovation is an important aspect of competition, the ability of a firm to survive depends on the effectiveness of its [own] research and development laboratories, on its ability to exploit its innovations and protect them, or to quickly match anything that its competitors do."[22]

An adaptive corporate culture permitted the management and engineering staff of a successful engine manufacturer to keep or discard customs and practices based on whether or not they provided for the most efficient and effective development and production of the engine. Historian Walter Vincenti succinctly observed that "what engineers do ... depends on what they know."[23] For Vincenti, the generation of new engineering knowledge can be generated through a wide variety of interactions with existing scientific and engineering knowledge, and through research, production, and experimentation; in other words, through learning. Dosi, *et al.* also identify learning as a key component for a successful company.[24] In his analysis of inter-firm sharing of R&D knowledge, David C. Mowery cautions that, without the development of knowledge about new technologies, companies can develop institutional "blinders" that eventually prevent them from identifying and seizing opportunities presented by new or disruptive technologies.[25]

The Case Study

This thesis examines the ten years the Westinghouse Aviation Gas Turbine (AGT) Division manufactured aircraft gas turbine engines in Kansas City, Missouri during a period of rapid change and growth within the aircraft gas turbine engine industry. The case study illustrates the consequences of Westinghouse's attempt to enter and maintain its presence in the industry without the dedicated financial support, the gradual development of a broad product and customer base, and the willingness to adapt engineering and management practices that would permit the company to best respond to the changing needs of the industry.

Westinghouse management preferred to rely almost solely on large subsidies provided by the Navy for facilities, equipment, and engine development, and made little effort to invest company funds in the engine program. Customer requirements of the jet engine industry in the 1950s necessitated that companies develop new engine designs to a level of production readiness in a short time, which in turn required lavish financial support, which Westinghouse did not provide. Consequently, when the Navy began to withdraw financial support in the mid-1950s the AGT Division did not receive adequate financial resources from its parent, Westinghouse Electric, to compensate for the lost R&D funding. In early 1955 one aircraft gas turbine engine industry observer noted:

> Considering its technological headstart, Westinghouse should have become the No. 1 or No. 2 producer, whereas today it is only about fifth in size. The company dragged its heels after the war and waited for the government to guarantee orders instead of plunging into production with its own money as G.E. and other makers did. Westinghouse finally did pour millions into jet engines, but too late. Its engines were not mechanical failures; they were, as a Defense Department official comments, five years too late.[26]

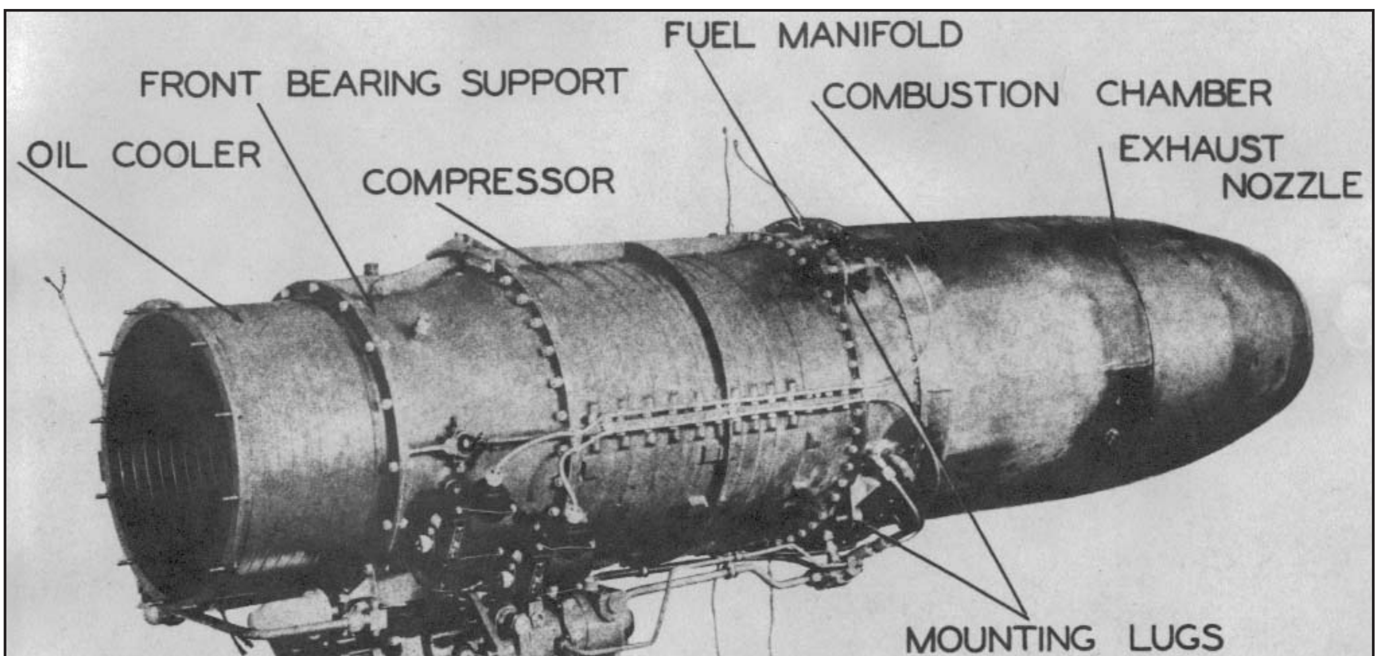
The Navy Bureau of Aeronautics' monopsony falsely encouraged the Westinghouse AGT Division to build engines solely to Navy specifications, rather than to develop new engines for a wider variety of airframe applications. The main rivals of the Westinghouse AGT Division, General Electric and Pratt & Whitney Aircraft, succeeded not just in developing significant R&D facilities and resources but in using those facilities and resources to produce products which were one step ahead of the requirements of its customers. This action permitted the military services to go forward with the development of a wider range of airframe applications for these new engines; it also helped spur the development of nonmilitary gas turbine engine-powered aircraft, thus broadening the customer base of the engine manufacturers. The Westinghouse AGT Division displayed little initiative in developing its own engine designs, and missed the resulting opportunities to broaden its market coverage.

Westinghouse management and engineering staff were loath to establish a separate aircraft gas turbine engine division or develop engineering practices suitable for the new and disruptive technology, but instead stubbornly persisted in manufacturing aircraft gas turbine engines with the same engineering approach used for industrial steam turbine engines. Westinghouse management, encouraged by its past engineering experience, considered the aircraft gas turbine engine to be an evolution of existing technology, but not a disruptive one; the company believed that the techniques for successfully manufacturing and marketing jet engines, therefore, could be drawn from the company's past engineering experience, especially from steam turbine engineering. Westinghouse failed to realize that the engineering requirements for the successful manufacturing of aircraft gas turbine engines differed from those required for steam turbine manufacturing by requiring experience with mass-production instead of individual production, interchangeability and uniformity of component parts rather than customized, hand-crafted components, and exponential improvement of performance derived from theoretical research, instead of incremental improvement arrived at through hands-on "tweaking."

Historical Significance

This historical case study provides an analytical elaboration of Alfred Chandler's concept of organizational capabilities suggested in his book *Scale and Scope* and suggests an analytical methodology applicable to other cases of success and failure in industries where disruptive technologies are introduced. The three particular organizational capabilities identified in this case study might be directly applicable to other case studies of both successes and failures in other technology-oriented industries. More broadly, by identifying specific organizational capabilities possessed by successful manufacturing firms which were *not* possessed by those firms which failed, a historian has an opportunity to thereby identify, and test the relative significance of, certain organizational capabilities for companies involved in the manufacture of a specific disruptive technology.

This thesis is also the first historical study of the Westinghouse Aviation Gas Turbine Division. It should not, however, be interpreted as a comprehensive history of the Division. This thesis is rather a selective history, cast in the mold of the specific interpretive and analytical framework outlined above. Events and personalities are discussed to the extent that they furnish the reader with a general understanding of the Division's history, while at the same time demonstrating the validity of the thesis statement. Specific events were excluded from discussion due to constraints such as immediate relevance, redundancy, and space. Though a definitive history of the Westinghouse AGT Division has yet to be written, it is sincerely hoped that this thesis might serve to suggest the broader scope such a history might embody.



Westinghouse Model 19XB-2B Turbojet Engine (Air Force Historical Research Agency)

Development of the Westinghouse Aircraft Gas Turbine Engine to 1950

The early history of aircraft gas turbine engines in the United States is a story of constant adaptation by manufacturers to rapidly changing business and technological environments. Success and failure in the nascent industry during this time was determined primarily by the organizational capabilities of the manufacturers — an imprecise cocktail in which is combined, added, and changed the skills and responsibilities of both the management and the work force, and also the available R&D and production facilities of the firm.[27] According to Alfred Chandler, who first suggested the term "organizational capabilities" in his book *Scale and Scope*, a successful manufacturing firm is one that dominates a market by optimizing its practices and infrastructure — its organizational capabilities — to the needs and demands of that market.

In 1941 there was no definition of what constituted satisfactory organizational capabilities for an aircraft gas turbine engine manufacturer. That year, the United States government asked Westinghouse Electric and General Electric to undertake R&D studies of aircraft gas turbine engine designs; the government considered the organizational capabilities of industrial steam turbine manufacturers would be adequate for the task. By 1950, the successful aircraft gas turbine engine manufacturers turned out be those which possessed two kinds of organizational capabilities. Pratt & Whitney Aircraft already possessed organizational capabilities that were especially suited to the aircraft engine *industry*, but not the *technology* of aircraft gas turbine engines. The company's knowledge of the needs of commercial and military aviation customers allowed the company to survive its late start in the aircraft gas turbine industry. General Electric possessed an understanding of aircraft gas turbine *technology*, through its own experience with turbine engines and the help of British engine technology, and quickly learned to understand the needs of a *market* with which it had no prior experience. Between 1941 and 1950 Westinghouse Electric demonstrated that it possessed organizational capabilities suited to neither the technology nor the market of the aviation gas turbine engine, and as a result by 1950 the pioneering firm had already become a follower in the industry.

Before the mid-1930s, few military organizations thought that the gas turbine engine held much promise for aircraft propulsion; however, two practical successes with such engines quickly changed prevailing opinions.[28] In 1936, Frank Whittle, a Flying Officer in the Royal Air Force, founded Power Jets, Ltd. to develop an engine of his design that provided a jet of high-speed exhaust through a gas turbine engine equipped with a centrifugal compressor.[29] That same year in Germany, Hans von Ohain, a young physics and aerodynamics student, joined the Heinkel aircraft factory to develop a similar turbine engine design.[30] By the outbreak of war in 1939 both Whittle and von Ohain, working separately, were able to produce working engines. The Heinkel He 178, powered by von Ohain's HeS-3 b engine capable of 1,200 pounds of thrust, made the world's first jet-powered flight on August 27, 1939; the Gloster E.28/39, powered by a Power Jets W.l capable of 860 pounds of thrust, first flew on May 15, 1941.[31]

In early 1941 the United States government decided to approach both Westinghouse Electric and General Electric with a proposal to investigate the possibilities of adapting turbine engines for aircraft propulsion, and both companies accepted the offer. American military intelligence reports regarding German developments in reaction propulsion — particularly with the rocket engine — had reached General Henry H. Arnold, the Chief of the United States Army Air Corps. General Arnold, concerned about the comparative lag in American rocket engine development, contacted the National Advisory Council for Aeronautics (NACA)[32], the premier aviation research organization in the United States, and requested that NACA undertake a study on rocket propulsion. In March 1941, the NACA convened its Special Committee on Jet Propulsion to investigate forms of non-traditional aircraft prime movers. Representatives of the United States Army Air Forces and the Navy joined the Special Committee because of their interest in the engine for military aircraft. The chair of the Special Committee, Dr. Robert F. Durand, also invited General Electric and Westinghouse Electric, long-time rivals in the electrical utility and appliance industry, to participate, and representatives from both companies attended the first meeting in April 1941.[33]

Though inviting electrical manufacturing companies to study aircraft engine design might seem unusual, the Army and Navy perceived several advantages to be gained from inviting Westinghouse Electric and General Electric to participate in the study. In particular, three advantages — the availability of company financial support for R&D, the ability of the military to dictate product specifications to the manufacturers, and the advantage of having companies with long experience working with a similar technology — made Westinghouse Electric and General Electric ideal choices to participate in the NACA Special Committee.

Both companies, by virtue of their broad range of industrial and consumer products, had significant financial assets to support research and development (R&D). Both firms manufactured and sold a wide variety of products, including appliances, radios, and even x-ray equipment.[34] Between them, Westinghouse Electric and General Electric virtually controlled the electrical utility manufacturing industry; the relative market positions of the two firms stabilized at around 60% General Electric to 30% Westinghouse.[35] The military believed that both Westinghouse Electric and General Electric would be willing to devote some of their profit back into researching a promising new product.

The armed services, by dictating to the manufacturers the desired engine characteristics, would not be limited to purchasing engine designs conceived by the manufacturer. The military typically purchased aircraft piston engines from established manufacturers such as Pratt & Whitney Aircraft, Curtiss-Wright, or Allison based on already-existing designs offered by the manufacturer, this new type of engine would allow the Army Air Forces and the Navy to issue specific engine requirements to manufacturers with no pre-established engine product lines. Throughout its existence the NACA Special Committee never invited representatives from the aircraft piston engine manufacturing companies. Schlaifer claims that General Arnold feared that the aircraft piston engine manufacturers would be opposed to undertaking research on unorthodox engines, a claim Schlaifer himself undermines by acknowledging that Pratt & Whitney Aircraft conducted its own in-house aircraft turbine engine research before the war.[36] Some business historians claim that the piston engine manufacturers were risk-averse, an explanation which fails to take into account the military's role in selecting the recipients of the technology.[37] The most likely explanation is that, at a time that the United States was engaged in its "Arsenal of Democracy" military production expansion, Arnold saw the need to keep the aircraft piston engine manufacturers focused on producing as many engines as possible and not diverting resources to research on unproven designs.[38]

The military believed that both companies' prior engineering experience with the design and manufacture of steam turbine engines for the electrical utility industry could be successfully extrapolated into aircraft gas turbine engine design, and the companies certainly believed likewise. Air- and land-based steam and gas turbine engines were technologically very similar, though gas turbine engine required more components — compressors to squeeze the gas to a certain density, fuel atomizers to inject a spray of fuel into the compressed air, and burners to ignite the fuel/air mixture — the engine still used the basic mechanical principles of the steam turbine. During the early 1920s the steam turbine engine became an important product for both Westinghouse Electric and General Electric. Westinghouse sold $14.5 million worth of engines in 1924, representing nearly 10% of its total domestic business. General Electric sold nearly $30 million worth of turbines the same year, which similarly represented just over 10% of its sales. As Sultan summarizes, "in about 20 years the turbine generator business had become crucial to each company."[39] General Electric had installed its first production steam turbine engine in an electrical utility plant in 1903 and in addition had several years' experience manufacturing gas turbine superchargers for airplane engines.[40] Westinghouse had begun building steam turbine engines in 1898 after securing the patent rights to the turbine designs of Charles A Parsons of England, and in March 1940 announced a design for an "internally fired closed system gas turbine power plant," created by engineer Winston New, that promised to provide power comparable to steam turbines while taking up less space."[41] An internal Westinghouse report noted that the Navy's request to undertake aircraft gas turbine research "fitted in with our prior engineering considerations of gas turbines."[42]

In late 1941 the Navy's Bureau of Aeronautics decided to sponsor Westinghouse Electric's research, in large part because the Army had approached General Electric first. In October 1942, the Army issued separate research contracts to both General Electric's turbosupercharger and steam turbine divisions.[43] The following month, the Bureau of Aeronautics offered a similar contract to the Westinghouse Steam Turbine Division for "a design study of internal combustion turbines utilizing only jet energy for the propulsion of aircraft" based on the axial-flow design of Dr. Stewart Way, which was in turn based on New's earlier "closed-cycle" gas turbine design.[44]

The Bureau of Aeronautics likely also decided to select Westinghouse due to the Navy's prior experience with the Steam Turbine Division, in much the same way as the Army Air Forces selected General Electric because of its prior contractual experience with that firm's turbosupercharger group.[45] During and following the First World War, Westinghouse succeeded in winning orders for a few turbine engines to be installed on Navy ships, based on engines the company had already built for commercial cargo ships.[46] As a result of these and subsequent marine steam turbine installations, the Navy developed and maintained a working relationship with the Steam Turbine Division of Westinghouse Electric through the interwar years. The Navy's familiarity with the Steam Turbine Division's capabilities as a propulsion turbine manufacturer influenced the Navy's Bureau of Aeronautics to ask them to undertake research in aircraft gas turbine engines.

However, the Bureau of Aeronautics, with which Westinghouse had almost no prior experience, was atypical of other customers of Westinghouse industrial products; the monopsonistic relationship of the Bureau with Westinghouse became a major factor in determining the success or failure of the Westinghouse jet engine program. The Bureau had been formally created as a separate agency within the Navy in July 1921; its mission was to coordinate the Navy's various aeronautical activities under one authority, and to develop, implement, and support Naval aviation policy. The Bureau controlled the Navy's aviation appropriations and had the authority to issue contracts for aircraft, engines, and equipment.[47] The Bureau had a long tradition of supporting engine development in the private sector, for use on Navy aircraft and even actively supported the founding of one company, Pratt & Whitney Aircraft, by promising it orders for its anticipated engines.[48] The Bureau also had a darker tradition of somewhat ruthless and impatient relationships with the private sector, frequently being "determined not to await the pleasure of large companies for the development" of better engines.[49] For example, in 1922 the Bureau of Aeronautics forced Wright Aeronautical to develop an engine that it wanted by not renewing contracts for another engine produced by Wright, figuratively starving the company into submission.[50] Unlike the Navy's own Bureau of Ships, which was responsible for ordering steam turbines for naval vessels, the Bureau of Aeronautics frequently appeared to have had little patience for incremental, gradual increases in engine performance, or tolerance for companies that did not provide the desired results in short order.

The research and development phase of the aircraft gas turbine engine at the Westinghouse Electric Steam Turbine Division did not suggest that the engineering and management methods of Westinghouse Electric were either unsuitable or incompatible with the requirements of the Navy's Bureau of Aeronautics. The steam turbine engineers in 1941 did not foresee that the jet engine would ultimately require different manufacturing methods and would ultimately prove to fall outside of the Division's traditional engineering experience with large, one-of-a-kind steam and gas turbines. The early research and design experience with the aircraft gas turbine engine at the Westinghouse Steam Turbine Division, in fact, seemed at first to affirm the Navy's choice to consult with an electrical manufacturing firm which possessed organizational capabilities apparently related to the final product.

Prior to December 1941, the Bureau of Aeronautics provided the necessary research funding, and Westinghouse considered the aircraft gas turbine engine project to be a relatively low-priority, long-term research program requiring little of its own financial or staff support. The Navy approved $100,000 for "research and design studies" to be conducted by the Steam Turbine Division, stipulating that "[t]he subject project does not involve any delivery of jet-propulsion units."[51] Reinout Kroon, who as manager of development engineering in the Steam Turbine Division was responsible for research projects, believed that research into the axial-flow compressors, combustion principles, and turbine efficiencies of aircraft gas turbine engines would primarily benefit the Division's other gas turbine development efforts then underway. Nor did Kroon see the research proposal as demanding haste or priority on the part of the Steam Division. "In view of the novelty of this work," Kroon commented, "I hesitate to give a time limit on this work, but with simultaneous study by two or three men, we should know a lot in a year."

> Summarizing, it is my recommendation that as long as the research program does not divert us from gas turbine applications for large capacity, and as long as it promises to yield us the type of information which we will need for the larger apparatus anyway; and further, since any possible production would not be started until about two years from now, we offer to cooperate with the N.A.C.A. Committee in entering a reasonable contract. Since we are the only large company not now participating in any high temperature-light weight turbine applications for defense, this would seem a good opportunity to cash in on the experience the others have obtained.[52]

Thus both the Bureau of Aeronautics and the Westinghouse Steam Turbine Division approached the project with the compatible intentions of undertaking a research and development effort primarily oriented towards providing broadly useful research results.

The Bureau of Aeronautics contracted with the Steam Turbine Division to develop an engine to a specific set of requirements which the Westinghouse engineers agreed to be a feasible goal for a research project. In addition to determining a price for the project, the Bureau specified that the engine must be able to "turn out the equivalent of 600 horsepower at 500 miles per hour at 25,000 feet" — broad criteria that were originally developed by the NACA Special Committee and agreed to by all the participants as an equitable first goal for an as-yet untried engine design.[53] Because the Bureau of Aeronautics had specified the required performance, Reinout Kroon and the Steam Turbine Division engineers were placed in a position not of promising something they would be unable to deliver, but rather of making a good-faith effort to design an engine against hitherto-untested requirements.

The Steam Turbine Division demonstrated its engineering expertise by developing an axial-flow compressor, which proved to be more efficient and possessed more growth potential than centrifugal compressors, which were used by General Electric.[54] The axial-flow compressor differed from the centrifugal compressor in that the intake air was compressed along its line of flow axially through the engine; a series of alternating stationary and rotating disks with blades of ever smaller length — compressor stages — compressed the air as it streamed rearward into the combustion chamber. In a centrifugal compressor, the air is compressed by being forced against the outer wall of the engine at right angles to the line of flight, and then redirected through another right angle to the combustion stage behind the compressor. Aircraft gas turbine engines with centrifugal compressors were initially more fuel-efficient and lighter than those with axial-flow compressors. However, centrifugal compressors possessed an inherent maximum growth potential whereby an increase in thrust output was mitigated by an increase in the diameter of the compressor, to a point where aerodynamic drag would outweigh the gain in thrust output.[55] The axial-flow compressor thus possessed the advantage of permitting a narrower-diameter engine which allowed for better streamlining of an aircraft. However, Oliver Rodgers, a steam turbine engineer and later director of jet engine research at Westinghouse, later characterized the compressor design as "adventuresome" by steam turbine standards, but "stodgy" by aircraft standards.[56]

As a result of adequate funding by the Bureau of Aeronautics, customer-dictated performance requirements, and the selection of an axial-flow design for the engine's compressor, all indications during the relatively brief research phase of the project, from April to December 1941, were that the Westinghouse Steam Turbine Division was capable of designing an aircraft gas turbine engine to the Bureau of Aeronautics' specifications. However, the formal entry of the United States into the war on December 8, 1941 transformed the Westinghouse aircraft gas turbine engine project overnight from a research program into a production program, a transition for which the Westinghouse Steam Turbine Division ultimately was not prepared.

The production phase of the first Westinghouse aircraft gas turbine engine design spotlighted a series of problems that caused the final product, the Westinghouse J30 aircraft gas turbine engine, to be ill-suited for mass-production. The Bureau of Aeronautics would eventually be forced to contract with Pratt & Whitney Aircraft to build the J30 engine, an experience which highlighted for the Bureau of Aeronautics the differences between the design and production methods of steam turbine manufacturers and traditional aircraft engine manufacturers. Westinghouse senior management proved unwilling to support the development of a production-ready aircraft gas turbine engine or of a separate aircraft gas turbine engine division. The Steam Turbine Division proved unable to accommodate a rapid transition from research work to full-scale production. Finally, the J30 engine, which Westinghouse developed for the Bureau of Aeronautics from the research proposal submitted to the NACA Special Committee, represented an engine that one aeronautical engineer described as "radical in aerodynamic design, conservative in mechanical design."[57] This mechanical conservatism, well-suited for a steam turbine engine, proved to be unworkable in an engine designed for a radically different range of performance. As a result of these problems, pre-production development became unduly protracted and the Bureau of Aeronautics became evermore impatient.

Having completed the design of the various engine components, Kroon and his small team of a dozen engineers — known within the Division as the "12 Disciples" — began the overall design of the first American-designed aircraft gas turbine engine on August 10, 1942; the task the Westinghouse engineers faced was daunting.[58] Kroon recalled that there was some anxiety that an aircraft gas turbine engine might not even work, given their comparatively primitive state of knowledge.

> We were pretty well versed in turbine work, less so in compressor work. We were OK on bearings and structural things. We knew nothing about combustion, and neither did anyone else. [We feared that if] you pour in all this fuel in this small, small volume it would be a nightmare; we could [imagine] them blowing up.[59]

This first engine that the Steam Turbine Division designed for the Bureau of Aeronautics, which in time received the military designation J30, had a 19-inch intake diameter and an eight-foot overall length, weighed 850 pounds, and was originally intended to provide 850 pounds of thrust.[60] Early research and testing work on the engine's turbine, however, demonstrated that by increasing the air temperature at the point of the air inlet into the turbine, the engine could produce far more thrust than the original estimate of 850 pounds, and perhaps as much as 1,200 pounds, which approximated the thrust of General Electric's engine.[61] The J30 engine would have to operate under conditions that severely tested the experience and knowledge of both the Westinghouse engineers and their Navy customers. The compressor had six stages (that is, six rotating disks alternating between six static disks), and would rotate at 18,000 rpm, putting a centrifugal force of 50,000 times the force of gravity on each blade. The burner would operate at a temperature of 1,500 degrees Fahrenheit as it ignited the compressed fuel/air mixture and accelerated it past the turbine wheels.[62] These were performance parameters with which Kroon and his people had little experience.

Despite severe space limitations and a shortage of manpower, Kroon's team assembled the first prototype J30 engine, serial number 2-A-9100,[63] in just 16 months and began work on a second; the early indications suggested that a mass-production version of the engine would be feasible.[64] During this time, someone — exactly who is not recorded — dubbed the engine the Yankee, in recognition of both the pioneering nature of the engine and the ingenuity and hard work of its builders, and the name stuck. Kroon viewed the two J30 Yankee engines as test articles to determine what were the operational and performance characteristics of an aircraft gas turbine engine.

> It [the engine] was not supposed to work right from the beginning; we were supposed to build something and then start life-testing, finding out what goes wrong and fix it. That's what you have to do for that sort of thing. The fact that your power source [the engine] is so small, that things can go wrong. Then you can take care of it. So we had to get adapted to that kind of design philosophy.[65]

The construction of the first two J30 engines was indeed instructive for the Development Engineering team, but frequently in ways not entirely anticipated. The first pieces of the engine to arrive in the experimental laboratory, which were fabricated in other parts of the Steam Division, had dimensions and tolerances that were glaringly in error, requiring labor-intensive corrective effort. "'Old Carl' Deiner, a mechanic [who] had worked with Mr. George Westinghouse, using freely an expressive 'shop language' and a lot of his skill, finally made it correct," read one deadpan contemporary account.[66]

On March 19, 1943 — fifteen months after the start of the research project, seven months after the start of the design of the Yankee the engineers and mechanics who had worked on building the engine gathered to watch the first test. No one really knew what to expect. Author Grover Heiman recounted the event twenty years later:

> John Rivell, the test operator, began the final preparations before a hushed audience. Compressed air was channeled into the intake. The polished compressor blades began turning. When the gauges indicated starting rpm's had been attained, fuel was injected into the flow of air. Rivell thumbed the switch that sent a spark arcing into the volatile combination.

> The 19[-inch] engine ... took off with a thunderous roar. The weary lines in the faces of the staff melted away. Rivell, according to plan, advanced the throttle and the engine twirled to 8,000 rpm's. Holding it there for a brief moment, Rivell then eased off on the throttle and shut down the engine.[67]

The milestone test had not been without incident; the engine sprang an oil leak from the combustion chamber — a potentially dangerous event that Rivell averted by shutting down the engine.[68]

The second Yankee engine became the first Westinghouse jet engine to fly, though not as a primary powerplant. At the Philadelphia Naval Yard Naval engineers installed the engine underneath a Navy piston-engined FG-l Corsair fighter. The Bureau of Aeronautics then shipped the plane to the Patuxent River Naval Air Test Center in Maryland, where the plane made several test flights of the engine beginning in January 1944.[69] The first flight of a Westinghouse aircraft gas turbine engine thus came a full *three years* after the Steam Turbine Division began research on the basic design, and *fifteen months* after the first flight of a General Electric engine. The test flights were made to determine the performance of the engine in the air, they were not even test flights of the fighter as powered by the aircraft gas turbine engine. In fact, the Yankee did not power the airplane on takeoff or landing, and was only switched on for brief periods while in flight.

The Bureau of Aeronautics nevertheless rewarded the halting progress being made on the construction and testing of the prototype Yankees by the small team of Steam Turbine Division engineers with the awarding of additional contracts for further development and improvement of the basic design in preparation for production. In addition to the first two J30 engines, the Development Engineering group began the development of an improved "B" model of the basic J30 Yankee design, for which the Bureau of Aeronautics contracted.[70] In January 1943 the Bureau of Aeronautics also contracted with the McDonnell Aircraft Company of St. Louis, Missouri, to develop a carrier-based fighter aircraft that would use two J30 engines for power, the XFD-1 Phantom.[71] As a result of this contract, the Bureau of Aeronautics began to grow more interested in developing a production version of the Westinghouse engine, in order to begin testing it in service on actual aircraft. On May 24, 1943, the Navy amended Contract NO(a)s-503 to order 16 of the more powerful "B" model engine, with an additional four to be built for the Army Air Forces. Deliveries of the first of the "B" models were slated to begin in November 1943. Financial terms would be submitted by Westinghouse when determined.[72]

Westinghouse deliberately encouraged the Bureau of Aeronautics to continue supporting the development of the Yankee engine. When Reinout Kroon and other Westinghouse representatives met with Bureau of Aeronautics officials in mid-June 1943 to discuss the process of turning the Yankee into a mass-production item, they announced that they now had at their disposal around 70 draftsmen, 10-12 junior engineers, and 8 senior engineers to work on engine design throughout the Steam Turbine Division. Osborne proposed that if the Bureau of Aeronautics would sponsor the construction of a government-owned plant and purchase machinery for it, within 14 months Westinghouse would be able to achieve a production output of 100 engines per month.[73] Such a statement no doubt satisfied the Bureau that Westinghouse intended to expedite engine production when possible.

Westinghouse also reinforced the Bureau of Aeronautics' desire to purchase aircraft gas turbines from them by offering to build the engines for a great deal less money per engine than offered by other companies. "It should be pointed out," one Bureau memorandum read, that

> [Westinghouse] is making a definite financial contribution to the development in that they are doing a splendid development job at the least cost to the government of any contractors whether Air Force or Bureau of Aeronautics at a figure from 1/5 to 1/10 the cost of comparable work.[74]

The technique of underbidding potential or actual competitors was subsequently used frequently by the Westinghouse Aviation Gas Turbine Division to win other engine contracts. This helps to explain why the Bureau of Aeronautics remained a customer of the Division long past the time it perceived Westinghouse as doing a "splendid" job.

Neither Westinghouse's president, Andrew W. Robertson nor the Steam Turbine Division's vice-president, Latham E. Osborne believed that the aircraft gas turbine engine program required significant R&D support because they saw the engine as a natural extension of steam turbine technology, which traditionally had operated with minimal financial support. Because profit on steam turbine engines derived not from sales of turbines alone, but of turbines as part of a complete package of dynamos, transformers, and other electrical components to a utility customer, the Steam Division did not require much financial support from Westinghouse management to support product development. Historian Ralph Sultan correctly points out that the steam turbine business was very lucrative for both Westinghouse and General Electric. Profits from sales were not directly returned in full to the Steam Turbine Division, but only in amounts that enabled the Division to purchase new parts and equipment for the next set of turbines.[75] Because of this method of generating profit, the Steam Turbine Division was relatively self-sufficient and Division managers — and not the corporate executives — were left with the responsibility for making business decisions for the Division. Neither Steam Turbine Division managers nor corporate executives expected that aircraft gas turbine engines would have financial requirements any different from steam turbines.

Robertson and Osborne preferred that the Bureau of Aeronautics sponsor the construction of adequate facilities for the Westinghouse aircraft gas turbine engine program, rather than spend company money on it. Throughout the war the Bureau of Aeronautics continued to place more orders for aircraft gas turbine engine research, development, and production with Westinghouse, but the company did little to accommodate the increased work. When the Bureau of Aeronautics expressed concern over the lack of available space, staffing, and funding from Westinghouse for J30 development and manufacture, Robertson personally addressed a defense of Westinghouse's efforts to that time.

> The jet propulsion business has been unusually complicated and difficult because we have attempted to telescope production onto research and experimental activities. In ordinary times we do not even talk of producing something in quantity before we have an experimental model. But under the circumstances surrounding this case we did include quantity in our discussion, although the Bureau must have understood as well as we did that any discussion as to production depended upon all sorts of unknown elements arising out of the experimental nature of our work.

In the same letter, Robertson suggested that the Navy subsidize the building of a small facility — "which will cost the Government about $3,000,000 and the Westinghouse Company $500,000" — as an immediate solution prior to the expenditure of more on a large production plant.[76] The Bureau of Aeronautics countered Robertson's proposal by suggesting the relocation of the jet engine program to existing buildings in Westinghouse's South Philadelphia factory and culling 200 engineers and other employees from other contracts and projects that would soon be ending.[77] For the rest of the war the issue remained a stalemate.

The physical location of the aircraft gas turbine engine program within the Steam Turbine Division facilities prevented the aircraft gas turbine engineers from growing apart as a separate specialty. Reinout Kroon was only permitted to recruit as many of the engineers from his own Development Engineering group as he could spare from other Division projects to work on the engine.[78] From this group and from the East Pittsburgh research laboratory, Kroon was only able to recruit 12 engineers — whose devotion to the Yankee project earned them the nickname "The 12 Disciples" — and several mechanics, though this number did slowly grow during the war.[79] In addition, the working conditions at South Philadelphia for the construction of the J30 were far from ideal. The Steam Division's main building was "jammed to the rafters" with orders for steam turbines for warships, cargo ships, and other projects, requiring the J30's builders to use outside contractors to fabricate engine components which then had to be hand-assembled.[80] The engineers and mechanics working on the construction of the J30 were confined to the Steam Turbine Division's experimental laboratory, which in size was "about the same as that of a small modestly equipped tool room."[81] Because of the small number of engineers and cramped working conditions, Kroon's engine production team remained in close physical and therefore philosophical proximity to the steam turbine engineers.

Westinghouse management consistently resisted urging by the Bureau to create a separate aircraft gas turbine engine division because it believed it could not afford to split up the few turbine engineers it possessed. The short term solution to the problem of inadequate production space and staffing, in the view of the Chief of the Bureau of Aeronautics Dewitt C. Ramsey, was for Westinghouse "to establish a pilot line whereby Westinghouse can gain necessary production 'knowhow' so that either it *or another concern* can later go into volume production in the event the product turns out as successfully as the Bureau anticipates." [emphasis added][82] The Bureau noted that "[t]his proposed arrangement for semi-production manufacturing ... would give Westinghouse a division which might be classed as a separate aviation section but is not, of course, the ideal setup," but noted that a senior Westinghouse Steam Turbine Division manager, William Boyle, rejected the idea of a separate division on the grounds that turbine experts were too scarce to be spread out among different divisions.[83] Westinghouse management resisted the suggestion until almost the end of the war.

The requirements of the customer changed faster than Westinghouse could respond; when the Bureau of Aeronautics urged the Steam Turbine Division to turn their research design engine into a production engine, Westinghouse was not prepared for such an acceleration of their program. Even before the first test of the prototype J30 engine, Kroon's Development Engineering team received additional engine orders from the Bureau of Aeronautics. The Navy registered its approval with Westinghouse's progress by ordering more engines. On March 8, 1943, with the first test only days away, the Bureau issued to Westinghouse a letter of intent for Contract NO(a)s-503, for the construction of six more J30 engines similar to the prototype being built, which Westinghouse designated the "A" model, in addition to the two engines already being built under NO(a)s-97181. In addition, the Bureau ordered six of an improved version of the J30 engine, the "B" model, with deliveries of all twelve engines to be begin by Ju1y 1943.[84] The contract also requested design studies on potential further improvements to the still as-yet untested first two engines. It is likely that Vice President Lynde, who oversaw the Steam Turbine Division, or the engineers themselves, communicated to the Bureau of Aeronautics that additional work could in fact be undertaken; although there is no documentary evidence to directly bear this assumption out, similar events occurred several times in the history of the later Aviation Gas Turbine Division. Even at this early stage, the Bureau of Aeronautics placed some pressure on the Westinghouse aircraft gas turbine engine team to begin turning out engines in quantities that space and manpower did not easily permit. There were several reasons for the Bureau's decision.

The entry of the United States into the war in December 1941 resulted in the Bureau of Aeronautics suddenly making the aircraft gas turbine a high priority, without significant increases in resources from either the Navy or Westinghouse. Two days after the attack on Pearl Harbor, Steam Turbine Division manager William Boyle traveled to Washington, DC, to meet with representatives of the Bureau of Aeronautics. There, he received a verbal promise that the Division would receive in short order a letter of intent to undertake a design study for the engine design that became the J30.[85] A letter of intent is a promissory note for a contract, allowing a contractee to begin arranging for materiel and personnel requirements while the details of the formal contract are being worked out. The Bureau of Aeronautics formally issued its letter of intent for research contract NOa(s)-97181 to Westinghouse Electric on January 5, 1942, giving it an A-1 priority.[86] The Bureau of Aeronautics viewed the subsequent progress made by Kroon's Development Engineering team as so promising that on October 22, 1942, it amended contract NO(a)s-97181 , and called for the actual construction of two of the J30 engines.[87] Within a matter of ten months, aircraft gas turbine engine research at Westinghouse went from being a relatively low-priority, long-term program to a high-priority development program, and then to an actual production program, all with virtually no increase in funding, staffing, or space at Westinghouse, or with increased funding from the Bureau of Aeronautics.

The Bureau of Aeronautics tended to express its satisfaction with the progress being made at Westinghouse by heaping more research and production on the Development Engineering team working on the J30. However, the Bureau did not significantly increase its funding or its material support commensurate with its increased expectations. An officer in the Bureau noted this discrepancy in late 1943:

> [W]hat do we want Westinghouse to do next? While Westinghouse may not have put the energy of its organization behind the gas turbine project in proportion to the importance of the project *in the beginning*, this appears to be corrected. However, Westinghouse has never enjoyed anywhere near the degree of lavish support which the [Army Air Forces] has given [General Electric]. If Westinghouse is to be kept in the field of [aircraft gas turbine propulsion] as a real competitor to [General Electric] — and this I personally believe desirable — some definite commitments must be made by BuAer. [emphasis in original][88]

The Bureau of Aeronautics was in competition with the Army Air Forces, which supported the General Electric jet engine program. Because of this, the Bureau urged the Westinghouse Steam Turbine Division to accelerate its J30 development and manufacture program faster than it might have otherwise, lest it find itself behind the Army Air Forces and suffer disproportionately in postwar program funding cutbacks. The Navy did not ask Westinghouse to undertake production development of its engine until three months later, nor were there any other British jet engine firms that the Navy could approach for similar assistance.[89]

Because of inter-service rivalry, the Bureau of Aeronautics required that Westinghouse maintain secrecy about its jet engine program, which forced the engineers to work in relatively complete isolation, in terms of information exchange with other organizations. At a NACA Special Committee meeting of November 20, 1941, the Army Air Corps and the Navy Bureau of Aeronautics jointly decided that the various engine projects being undertaken were to be kept so secret that no inter-company collaboration would be permitted, and no one company was permitted to share information with any other company regarding their turbine engine projects. Neither would the Army and the Navy exchange information on their own level, except what could be learned at the NACA Special Committee meetings.[90] This stricture would occasionally be lifted for visiting British engine experts working in an advisory capacity (and for the importation of Power Jets engines and plans for General Electric), and eventually relaxed considerably more as the war continued. Nevertheless, the restrictions meant that, at a crucial time in the early design phase, the Westinghouse Steam Turbine Division engineers suddenly found themselves working very much in isolation, with no one to turn to if and when technical problems developed. The Bureau of Aeronautics was particularly explicit in instructing Westinghouse to not seek outside assistance; Schlaifer notes that "[t]he Navy … seems from the beginning of its gas-turbine development program not only to have done nothing to encourage collaboration, but actually to have ordered each company to keep its work secret from all other companies and even from other government agencies."[91]

The Bureau of Aeronautics asked Westinghouse to investigate concurrently several other aircraft gas turbine engine designs because propulsion experts within the Bureau were uncertain of the future direction of its aircraft gas turbine engine program as a whole. The technology of the aircraft gas turbine engine was still new and offered several radically different forms of application; no one in the Bureau of Aeronautics in the early 1940s could confidently predict what form of aircraft gas turbine engine would be best suited for future Navy aircraft until all forms of aircraft gas turbine engines had at least been studied. As a result, the Westinghouse development engineering team, at the behest of the Bureau, spent valuable time and staff resources investigating other possible types of aircraft gas turbine engines.

Beginning in late 1942, the Bureau of Aeronautics approached Rein Kroon and his aircraft gas turbine engine team with proposals to develop several new engine designs. The first was for a "baby" or "half-size" engine, half the size of the J30 and with one quarter of the J30's thrust output. The Bureau envisioned a fighter using a dozen of these small engines streamlined into the aircraft's wings to minimize aerodynamic drag.[92] The Bureau's propulsion branch changed its opinion about the usefulness of such an installation soon after, the Bureau shelved the idea until the following spring, when someone in the Bureau realized such an engine could be used to propel the new Gorgon air-to-air guided missile being developed by the Navy's new missile unit. The Bureau at first ordered six of these engines, designated J32, in June 1943.[93] Though Kroon's staff encountered problems during the development of the engine that eventually precluded its use in the Gorgon, the Bureau of Aeronautics ordered at least 20 more of the J32 engines.[94] The Westinghouse engineers had to build these engines along with the larger J30 in the limited space available. In addition to the J32, the Bureau of Aeronautics contracted with Westinghouse to undertake preliminary design studies of a larger, more-powerful jet engine and a turboprop engine.[95] This additional research work required the limited number of available engineers to spread their time among several projects at once.

Westinghouse's steam turbine engineering practices and traditions proved detrimental to the successful design of the J30 engine because they were ill-suited for aircraft engine manufacture. This factor, along with the difficulties caused by lack of support from Westinghouse senior management and the increased pressure from the Bureau of Aeronautics to begin producing large quantities of the J30 engine, contributed to the failure of the Westinghouse Steam Turbine Division engineers to develop the J30 engine for mass-production. Had Rein Kroon's Development Engineering team been able to work with adequate space and funding, it might have been able to develop suitable engineering practices for turning the J30 into the engine that the Bureau of Aeronautics wanted. Without adequate time, space, or money, Kroon and his staff had to use the knowledge and skills they had developed as steam turbine engineers in order to build the Yankee engine. The result was an engine built like a smaller version of a hand-crafted steam turbine engine, rather than like a mass-produced aircraft powerplant expected by the Bureau of Aeronautics.

The use of oil-lubricated sleeve bearings in the engine, long incorporated in steam turbines, proved unworkable on the smaller, lightweight aircraft gas turbine engine.[96] The design of the engine's bearings, which permitted the compressor and turbine to rotate freely, and which were critical to the successful operation of the engine, serve as an example of how the engine designers incorporated traditional steam turbine engineering techniques that were not ideally suited for use on an aviation gas turbine engine. The Westinghouse engineers selected the sleeve bearing for the engine design because of their long experience with them, rather than for their suitability in aircraft gas turbine engines; in the J30 engine, they repeatedly proved to be unsuitable. Sleeve bearings lined with babbitt metal were commonly used on steam turbine engines, whereas airplane engines commonly used ball or roller bearings.[97] General Electric's contemporary J31 engine (the American version of the imported Whittle engine), for example, used two ball bearings to support the centrifugal compressor and turbine stage.[98] Nor was the use of babbitt metal in bearings as regular a practice in the aircraft engine business as in the steam turbine industry, Pratt & Whitney Aircraft pioneered the use of silver-lead alloy-lined bearings in the 1930s, instead of the babbitt metal's tin alloy.[99] During tests of J30 engines in South Philadelphia and in the Bureau of Aeronautics' test laboratories, the bearings repeatedly failed.[100]

The Steam Turbine Division engineers working on the J30 aircraft gas turbine engine preferred to improvise and tinker with the engine design in order to improve the performance, rather than to "freeze" the design as required for mass-production. This practice, normal for industrial steam turbine engine manufacture, was anathema to efficient aircraft engine manufacture.[101] Turbine engineers preferred to increase the size, efficiency, and power output of steam turbine engines gradually and incrementally. Historian Richard F. Hirsh has characterized this style of manufacturing as "design by experience;" such gradual product development suited the needs of the utilities, which, according to Hirsh, "demanded reliable and well-tested equipment that would provide long-lasting value for their huge capital investments." Utilities insisted on reliability, economies of scale, and high thermal efficiencies, which required the manufacturers to be both cautious and conservative in their approach to the design and manufacture of steam engines.[102] The pattern that Westinghouse and General Electric developed to build, test, and supply engines became the standard way of doing business for the first half-century of turbine manufacture:

> Vendors would introduce innovations into a pioneering technology that was custom-made for a utility having unusual requirements. The design process took a few years, as did manufacturing. The machine would then be put into service and observed by the utility and manufacturer. Based on experience with the equipment, the vendor designed another version of an incrementally better one for other customers ... . Over the long run, the advances appeared large, but the manufacturers took modest incremental steps slowly enough so that they could develop experience and so that users could gain confidence in the new design.[103]

The "design by experience" approach resulted in repeated delays which frustrated the Bureau of Aeronautics; suitable perhaps for the initial, cautious, R&D phase of the J30 program, it proved detrimental for the second, mass-production phase.

The Steam Turbine Division had no experience with large-scale mass-production. Since most of its industrial steam turbines were hand-crafted to order, the Westinghouse Steam Turbine Division traditionally manufactured them individually. In early 1941, the Westinghouse Steam Turbine Division began receiving orders from the Navy for a new generation of marine propulsion turbines. Westinghouse first produced smaller turbines for destroyers, then larger engines for light cruisers, and finally massive units for aircraft carriers. In order to meet the hitherto-unprecedented demand, the Division had to "break a generation of precedent in turbine building" by adopting semi-production line methods, all in order to build just four identical turbine units *per month*.[104] There was clearly no precedent in the Steam Turbine Division for producing the hundreds or even thousands of aircraft gas turbine engines that would be necessary for the Navy's new jet-powered airplanes.

As a result of Westinghouse's reluctance to support full-scale manufacture by a staff of specialized engineers, of the unexpected and sudden transition of the aircraft gas turbine engine program at Westinghouse from research to production, and of Westinghouse's engineering practices being unsuited for the requirements of an aircraft gas turbine engine, Westinghouse proved unable to mass-produce the J30 Yankee as desired by the Bureau of Aeronautics. In need of large quantities of J30 engines quickly, the Bureau of Aeronautics encouraged the Westinghouse Development Engineering group to approach Pratt & Whitney Aircraft with a proposal to develop the engine for production. Pratt & Whitney Aircraft, a division of United Aircraft Corporation located in East Hartford, Connecticut, was a major manufacturer of air-cooled radial aircraft piston engines for the military, and a contractor with the Bureau of Aeronautics since the firm was founded in 1925. The firm had 20 years of experience manufacturing aircraft engines, and possessed a large factory that could accommodate an assembly line for aircraft gas turbine engines.

The Bureau hoped that the intervention of Pratt & Whitney Aircraft would not only finally provide urgently-needed quantities of aircraft gas turbine engines for Naval aircraft, but also aid Westinghouse in changing its policy and engineering traditions by observing the way Pratt & Whitney Aircraft produced engines. In mid-December 1944, United Aircraft management received an inquiry from Westinghouse as to the possibility of Pratt & Whitney being interested in producing a reduction gear for one of their turbine developments."[105] In considering the request, Leonard S. Hobbs, President of United Aircraft and former head of Pratt & Whitney, stated in an internal memorandum "I think it is obvious that from a strictly Pratt & Whitney viewpoint we want to have nothing to do with this whatsoever." As Hobbs saw it, the workload would be too heavy for the small engineering staff that was already working on turbines at Pratt & Whitney, the work would not be of immediate value to the war effort, and "we would be simply (with essentially no benefit to ourselves whatsoever) showing competitors in the aircraft power plant field how to more successfully compete with us."[106]

The Bureau of Aeronautics succeeded in persuading officials of Pratt & Whitney Aircraft and the parent United Aircraft to change their minds and undertake the manufacture of 500 J30 engines by offering them a contract as prime contractors, rather than licensees. The Navy issued a Procurement Directive to Pratt & Whitney on December 28, 1944, which stated in part:

> Since the (J30) engine is not yet a fully developed and proven engine, it is considered advisable to have production initially undertaken by an outstanding aircraft engineering, development, and production organization; Pratt & Whitney Aircraft is the Navy cognizant facility [*sic*] best able to meet this requirement.[107]

The Bureau of Aeronautics sought Pratt & Whitney for both the expertise of its engineering staff with regard to aircraft engines, and their experience with mass-production, both of which the Bureau had found wanting in the Westinghouse Steam Turbine Division Development Engineering staff.

On January 5, 1945, the Bureau of Aeronautics issued a letter of intent to Pratt & Whitney for 500 J30 engines, plus additional spare parts to the value of 25% of the cost of the engines.[108] The Westinghouse development engineering team were required to turn over to Pratt & Whitney all the information they needed for manufacturing. All decisions regarding design and modification of the basic engine design, however, remained with Westinghouse. The first quantity production order for Westinghouse aircraft gas turbine engines, then, was not to be filled at Westinghouse; the Bureau instead issued to Kroon's team a contract for only 50 of the J30 engines, which, Kroon was forced to admit, was all they were capable of building in the limited space available in the South Philadelphia plant.[109]

Pratt & Whitney Aircraft's organizational capabilities proved well-suited to the manufacture of aircraft gas turbine engines, and the company used the contract to gain a foothold in the nascent aircraft gas turbine engine industry. The firm, just entering the field, was uncertain as to what type of turbine engines to pursue — a situation similar to that of Westinghouse's Steam Turbine Division four years previously.[110] Like Westinghouse, Pratt & Whitney Aircraft management established a separate group of engineers, under the direction of Perry W. Pratt, to study exclusively the technological and market requirements for military jet engines. Unlike Westinghouse, Pratt & Whitney built a research laboratory for the group and provided Pratt's group with extensive personnel, engineering, and technical support.[111] Overcoming his initial reluctance to taking on the Westinghouse engine, United Aircraft's vice-president Hobbs stated that he believed Pratt's group would be able to "take over completely the engineering phase of the Westinghouse [J30] program. This will not only relieve the [piston] engine group of this burden but will also serve as an excellent starting point in getting the organization broken in and functioning."[112]

Hobbs also encouraged Pratt to not limit the focus of his engineering team to one kind of turbine project, but rather to take enough time to research the entire range of possible engine forms and aircraft applications.[113]

Pratt & Whitney Aircraft also demonstrated the appropriateness of its organizational capabilities for aircraft gas turbine engine development and manufacture by successfully resolving several engineering problems with the J30 engine. Like the Westinghouse engineers, the Pratt & Whitney Aircraft engineers experienced much trouble with the three oil-lubricated sleeve bearings used to support the compressor/turbine shaft in the engine. However, when it became evident that a technical solution from Kroon's Development Engineering team would not be forthcoming, the Pratt & Whitney Aircraft team went ahead and developed replacement bearing designs "in accordance with the best Pratt & Whitney high speed bearing practice" to solve the problem. The replacement design selected featured a more durable silver-lead bearing coating developed by Pratt & Whitney Aircraft in the 1930s instead of the babbitt metal preferred by the Westinghouse Steam Turbine Division engineers.[114]

The differences between the designing and manufacturing styles of Pratt & Whitney Aircraft and Westinghouse came into sharp focus as Pratt & Whitney Aircraft's engineers complained increasingly to the Bureau of Aeronautics. Pratt & Whitney Aircraft was frequently forced to wait on Westinghouse to deliver blueprints of design changes, thus holding up production. At the Steam Turbine Division production was still under the control of the development engineers, and thus the design of the J30 experienced frequent changes as the engineers introduced new features or tweaked performance. The engineers' informal procedures also meant that, once introduced, the changes took a long time to appear on paper in a form that Pratt & Whitney Aircraft could translate into work.[115] Pratt & Whitney Aircraft communicated its frustration to the Bureau of Aeronautics:

> The [J30] is far from being developed to the point where it has adequate reliability. Therefore, (Pratt & Whitney Aircraft] believe that either production will be set back pending development of the engine by Westinghouse with consequent disruption of production at (Pratt & Whitney Aircraft] or that they will have to pitch in and assist Westinghouse with the development of the engine which will directly interfere with their own gas turbine developments.

Trapped in this untenable situation, more than once Pratt & Whitney Aircraft asked to be released from producing the Westinghouse engine. The Bureau persuaded Pratt & Whitney Aircraft to continue trying to produce the J30, citing the needs of the Navy, the advantage of experience to be gained, and the fact that it represented work during a period of wholesale contract cancellations due to the end of the war.[116]

As a result of the contract with Pratt & Whitney Aircraft to manufacture Westinghouse J30 engines, the Bureau of Aeronautics had its first opportunity to compare Westinghouse's organizational capabilities with another firm, and as a result found Westinghouse lacking. In 1947 Pratt & Whitney delivered 75 J30 engines McDonnell for installation in the Phantom fighter or to the Navy for tests, and in 1948, a further 54; in contrast, during all of 1946 Westinghouse produced only 35 J30 engines, many of which proved unusable due to mechanical problems, mostly bearing failures.[1l7] The Pratt & Whitney Aircraft engineers under Perry Pratt had done all they could to provide the Navy with workable engines, but in service the J30 engine proved to have many significant problems which Rein Kroon's engineers at Westinghouse could not completely solve. Two of the more alarming problems was a tendency for the engine to produce a "chatter" sound at full power, and an irregular "blurping" or surging effect where the engine's thrust output would momentarily dip, causing the airplane to unpredictably decelerate in flight in sudden jolts.[118] In one flight test of a Phantom, three oil lines failed on one engine, coating the rear of the airplane in oil before the pilot could land the airplane.[119] The Bureau of Aeronautics had waited more than four years for the J30 engine, and in service it provided only marginally satisfactory service; the Bureau voiced its objections to Westinghouse.

Towards the end of World War II Westinghouse management, faced with the urging of the Bureau of Aeronautics and the negative feedback from Pratt & Whitney Aircraft, finally realized that the engineering effort required to work on the J30 and the other projects necessitated the establishment of a separate division within Westinghouse Electric. In late January 1945, Latham E. Osborne, Westinghouse Vice-President in charge of the Steam Turbine Division, addressed by letter some of the criticisms leveled against Westinghouse by the Bureau of Aeronautics, acknowledging "there are of course instances of errors, defective workmanship and mistakes of judgment on our part." However, "[h]ere and there I note a criticism which perhaps would be omitted or at least [be] less harsh if the causes beyond our ability to control were given their due weight. Also, I assure you we have an interest in the aviation gas turbine after the war." Osborne then elaborated on plans to accommodate future production needs:

> I know that you and other members of the Bureau have felt [aircraft gas turbine engine] development has been handicapped by being a part of the activity of the Steam Division ... . I am in agreement, however, that it has grown up to the place where more rapid progress should now be possible on 'its own.' Accordingly, we are taking steps immediately to institute the following program:
>
> 1. Set this work up as the Aviation Gas Turbine Division, entirely independent of the Steam Division.
>
> 2. Place this new division in charge of a competent manager, responsible for all phases of the project, and reporting only to the Vice President ... .

In addition, the new Aviation Gas Turbine Division would transfer people from other Westinghouse Divisions and hire "new talent" from the aviation field, and attempt to physically relocate the new Division away from the Steam Turbine Division and into a more spacious location.[120]

On February 1, 1945, Vice-President Osborne announced to the press the formation of the Westinghouse Aviation Gas Turbine (AGT) Division, to be located at the Westinghouse South Philadelphia works.[121] In a subsequent press conference, Osborne introduced George H. Woodard of Westinghouse's New Products Division, as the first manager of the AGT Division. Reinout Kroon was named as the AGT Division's Chief Engineer. Osborne also announced that the AGT Division would be continuing development work on its new J34 engine for Navy combat aircraft, and that the new engine was also a "prototype of commercial versions to follow" from the AGT Division in the near future. Predicting a bright future for the aircraft gas turbine engine, and also for the AGT Division, Woodard stated that "Westinghouse engineers, as do engineers in the aircraft industry generally, feel that the upper limits of aircraft performance using conventional reciprocating engines is near at hand." Osborne went on to state that Westinghouse management had decided to provide this "potentially large post-war business room and opportunity to develop in the best interests of the armed forces, the aviation industry, and our own Company."[122] Osborne clearly hoped that the creation of a separate jet engine division — as the Bureau of Aeronautics had long wished — would prevent the recurrence of problems like those that had dogged the development and design of the J30 Yankee.

Despite the establishment of the Aviation Gas Turbine Division, the situation at Westinghouse changed little, and the Bureau of Aeronautics remained dissatisfied with the progress being made at Westinghouse toward the development of mass-production of aircraft gas turbine engines. The Bureau of Aeronautics certainly expected that it could from now on expect willingness on the part of Westinghouse management to provide the support the Company showed to its other product lines. In addition, the Bureau expected that the new AGT Division would quickly develop engineering practices that accommodated the requirements for successful aircraft gas turbine engine design and manufacture, free from those steam turbine engineering practices that were not suited to the new technology.

The Bureau found that the AGT Division had done little to introduce needed changes. "It was the belief of [the Bureau of Aeronautics] that with a strong management, [and with] the capable individual engineers on hand coupled with specialized engineers from the aircraft industry, the Aviation Gas Turbine Division would be able to correct its organization[al] deficiencies and start the development and production of engines on a sound basis," read an insightful Bureau of Aeronautics report on the young AGT Division. However, six months after the establishment of the Division the Bureau still found "the trend of the new division ... has not been adequate to overcome still existing policies, methods and lines of thought that are causing delays in the Aircraft Gas Turbine Division."

The Bureau cited the persistence of the "job shop" mentality of producing single, large, custom-built engines which "leads to a trend of thought both engineering wise, shop wise and production wise that is almost opposite to that followed" by activities required to mass-produce large quantities of items. The Division's reliance on "lots of know how and few specifications" was to blame for the slow progress of improvements and changes in engine designs. Additionally, Division management continued to express a preference for decisions traveling from the "bottom up" from the engineers on the shop floor, rather than from the "top down" from Division management.

The Navy also found the senior Westinghouse management lacking a desire to financially support the new Division, since the Division was used to the self-sufficiency of the Steam Turbine Division. The results were three-pronged: the Division lacked sufficient funds for extensive product research and development, could not afford to hire experienced engineers from the aircraft industry at salaries competitive with other aircraft engine firms, and mirrored Westinghouse senior management's reluctance to spend money up front with the promise of recouping from profits on sales.[123]

Thus, even after the establishment of a separate AGT Division the persistence of old engineering traditions indicated that the Division had not begun to develop adequate organizational capabilities. Nor would the Division undergo such necessary changes for many years, or undertake them in a consistent and uniform manner. It must also be pointed out that the AGT Division could not have felt that the Navy's constant urging of the Division to improve its commitment to engine manufacture carried the force of threat, since the Navy did not initiate action to sever its ties with the AGT Division despite continued problems with quantity and quality of the Division's products.

In contrast to the dissatisfaction felt about the Westinghouse Aviation Gas Turbine Division, Pratt & Whitney received an increasingly large share of the Bureau of Aeronautics' business following the completion of the J30 production contract. As the Army Air Forces had done with General Electric, the Bureau of Aeronautics arranged for Pratt & Whitney to purchase the manufacturing rights to two Rolls-Royce centrifugal-compressor jet engines — the J42 and J48 — basically similar to the Whittle engine imported for the General Electric turbosupercharger division.[124] Following the delivery of the last of the 129 Westinghouse J30 engines from Pratt & Whitney Aircraft, Perry Pratt's aircraft gas turbine engineering group undertook production of the J42 engine, capable of 5,000 pounds of thrust, and the J48 engine, which produced 6,250 pounds of thrust. Collectively, the company called the two engines Turbo Wasps (all Pratt & Whitney's piston engines had been designated some variation of either Hornet or Wasp.) The Navy installed the J42 and J48 engines in the Grumman Panther and Cougar front-line carrier-based fighters beginning in 1948, soon after being imported. By way of further contrast with Westinghouse's production experience, Pratt & Whitney eventually turned out enough J48 engines alone to power over 650 Panthers and 1,985 Cougars, the latter of which remained in production until 1959.[125]

As with Pratt & Whitney Aircraft, General Electric had considerably more success with its early R&D and production efforts than did Westinghouse, and quickly developed a leadership position in the nascent industry. Pratt & Whitney did not begin producing its own engine designs until the mid-1950s and in the late 1940s was still feeling its way into the new aircraft gas turbine engine industry. Prior to 1950, therefore, General Electric remained Westinghouse's chief rival. The lavish support the General Electric turbosupercharger group received from the Army Air Forces amounted to substantially more than that received by Westinghouse from the Bureau of Aeronautics, and because of its successful engine designs General Electric received the lion's share of early military production orders.

General Electric received aid from the Army Air Forces, its sponsor, in the form of technical assistance and even aircraft gas turbine engines from England; the company's management in turn gave the Army Air Force's development and production contracts to a group of engineers experienced with mass-production of small turbosupercharger turbines. Though General Electric's Schenectady steam turbine works were represented on the NACA Special Committee, it was the company's Lynn turbosupercharger group which leapfrogged ahead of all other American manufacturers: first, they secured, through the intervention of the Army Air Forces, an exclusive license to manufacture a British aircraft gas turbine engine; second, *both* the Lynn and Schenectady groups received significant financial support from the Army Air Forces to develop the engine. Army Air Forces General "Hap" Arnold was responsible for encouraging the support of General Electric. Soon after Arnold had encouraged the NACA to research unorthodox propulsion systems in early 1941, he traveled to England where he was first made aware of the progress that Britain had made in jet engines through Whittle's work at Power Jets, Ltd. When he returned from England in April 1941, Arnold, convinced by what he had seen in England, eagerly intended for an American firm to manufacture engines based on the Whittle design. In September the Army Air Forces issued a contract to General Electric's Lynn turbosupercharger group to license-build Power Jets engines. Furthermore, in anticipation of test-flying the Whittle engine and others built by General Electric based on it, the Army Air Forces issued a contract with Bell Aircraft Corporation that same month to build an aircraft, the XP-59A, to use the new engines.[126]

After studying the Power Jets, Ltd. engine and designs provided through General Arnold, the General Electric aircraft gas turbine engineers in Lynn made rapid progress in the development and manufacture of ever-more powerful engines before the Westinghouse engineers even had a finalized design ready. On March 18, 1942, the Lynn engine group first test-ran their engine, which was a modification of the basic Whittle engine imported by General Arnold. By using a higher compression ratio and introducing several mechanical improvements over the original, the General Electric engineers were relatively quickly able to achieve 1,300 pounds of thrust from the engine, which was 450 pounds more than the proposed output of the Westinghouse J30 engine.[130] On October 1, 1942, a Bell XP-59A, powered by two General Electric centrifugal-compressor engines capable of 1,300 pounds of thrust each, flew four test flights at the Army Air Forces' station at Muroc, California. The following day, the plane made the first "official" flight for a gathered group of Army officers, General Electric and Bell personnel, and Dr. Durand of the NACA Special Committee on Jet Propulsion.[128] Three months later the General Electric team began the design of a larger engine, which the Army Air Forces designated the J31.[129] The General Electric engines provided the Army Air Forces with operational experience flying jet powered aircraft, and pointed out to the General Electric engineers areas that could be improved in subsequent engine designs.

The General Electric engineers quickly improved on the British engine designs and began offering the Army Air Forces engines of the company's own design. The Schenectady steam turbine group succeeded their turboprop design with the J35, capable of 4,000 pounds of thrust. This engine suffered similar developmental problems to the Westinghouse Yankee, partly due to the complicated nature of its 11-stage axial-flow compressor,[130] and also possibly due to similar problems of accommodating the aircraft gas turbine engine within traditional steam turbine engineering practice as at Westinghouse. Manufacture of the engine was ultimately taken over by the Allison engine firm of General Motors.[131] Allison also took over manufacture of the General Electric J33 engine, a centrifugal-flow engine developed by the Lynn turbosupercharger group from the original Whittle design, and like the J35 capable of 4,000 pounds of thrust. The Lockheed P-80/F-80 Shooting Star single-engined fighter used a J33; it became the first operational jet-powered fighter of the new United States Air Force formed in 1947, and remained in service long enough to be used in Korea.[132] General Electric decided to transfer the development of both the J33 and J35 engines to Allison because shortly after the war the company wanted to focus its development energies on a promising new engine design, the axial-flow J47 engine developed by the Lynn turbo supercharger group.[133] The various models of the J47 provided anywhere from 5,000 to 6,000 pounds of thrust. The engine's first test flight occurred in 1948, in the prototype of the famous North American F-86 Sabre fighter. General Electric was able to successfully mass-produce thousands of the J47 engine at the Lynn plant for the Air Force as well as the Navy. The Air Force installed J47 engines in several major aircraft, including production versions of the Sabre and in the six-engined Boeing B-47 Stratojet bomber, two mainstays of American postwar jet airpower in that period.[134]

During World War II, General Electric began combining the engineering staffs of its steam turbine and turbosupercharger groups who had been working on jet engines into a separate Aircraft Gas Turbine Division dedicated solely to the manufacture of jet engines, and provided the group with lavish financial, staff, and material support.[135] Soon after the war, the company began dispersing all manufacturing to a range of subcontractors but by 1949 had consolidated most assembly and testing at the Lynn, Massachusetts, plant and purchased a former Defense Plant Corporation facility in Lockland, Ohio.[136] The Lockland plant offered “just about 4 million sq. ft. of factory, office and administration space ... one of the largest jet engine areas in the world” capable of producing “trainloads” of engines for military and commercial applications.[137] General Electric also sponsored the construction at the Lynn plant of a 30,000 square foot engine component testing laboratory in 1949, dedicated to the late Sanford Moss.[138] By 1950 General Electric had the space, resources, product, and other organizational capabilities necessary to dominate the aircraft gas turbine engine industry in the United States. In 1941 the General Electric aircraft gas turbine engine program was dependent on British material aid and military financial support. By 1950, the situation had turned completely and dramatically around:

> GE has been approached on the proposition of manufacturing British engines, it is reported, but nothing has come of it. GE technicians say there is no need for the company to build under license a higher power British jet engine because they feel they have better stuff coming up.[139]

By 1950 not only had the relative market positions of the two major United States aircraft gas turbine engine manufacturers been established, but so had the needs and requirements of the young jet engine industry; General Electric became the leader, and Westinghouse assumed the role of follower. General Electric’s J47 aircraft gas turbine engine proved to be such a popular and reliable engine that it helped General Electric to become the major manufacturer of aircraft gas turbine engines in the United States.[140] Lacking the financial support from either the parent company or the Bureau of Aeronautics that would allow it to acquire new staff and facilities, Westinghouse Electric’s Aviation Gas Turbine Division by 1950 had been reduced to a distant and nonthreatening challenger.

The explanation for Westinghouse’s secondary market situation at the end of 1950 lies in an analysis of the organizational capabilities of the Westinghouse Steam Turbine Division and later the Aircraft Gas Turbine Division; the Division carried these same problems into its second — and last — ten-year period. Whereas Westinghouse continued to rely on financial subsidization from the Bureau of Aeronautics after the war, General Electric set up a separate division and increasingly supported its jet engine programs with its own money. As a result, General Electric’s business grew not only because of ample production space, but because the military saw that the company willingly stood behind its product. Because of continued financial and material investment from the Bureau of Aeronautics, Westinghouse only sought to produce jet engines that specifically met particular applications of the Bureau, whereas success in the aircraft engine industry during a period of rapid technological innovation demanded a wider range of airframe adaptability; General Electric continually improved its early designs and introduced new engines based on previous experience. General Electric, for example, developed a range of J47 variants to supply a wider variety of airframe and missile applications than could be met with a single engine. Most damaging of all, Westinghouse’s reliance on its past engineering traditions, management practices, and steam turbine market experience had caused the Aviation Gas Turbine Division to misread the needs of both the aircraft gas turbine engine market and its customers; General Electric realized that for its aircraft gas turbine program to succeed it must be able to develop its own traditions and respond to the market in a way different from how it would approach the industrial steam turbine market.

Because it failed to adapt these three key organizational capabilities, the Westinghouse Aviation Gas Turbine Division’s first ten years were far from successful. Unless it learned from this failure, the Westinghouse AGT Division — especially in comparison with the meteoric rise of General Electric and the emergence of Pratt & Whitney Aircraft — would likely continually lose a share of the aircraft gas turbine engine market. Westinghouse executives and steam turbine engineers thought that their executive and engineering experience would successfully accommodate the design and production of aircraft gas turbine engines due to many technical similarities between aircraft gas turbine engines and industrial steam and gas turbine engines. The experiences of 1941-1950 showed this assumption to be erroneous. Westinghouse Electric’s senior management and the AGT Division both needed to learn this lesson before it could successfully compete in the aircraft gas turbine market, and by the end of 1949 it was apparent at least to the Navy’s Bureau of Aeronautics that it had not. Part of the reason for slow delivery certainly lay the lack of adequate production space for the AGT Division, and the Navy hoped that with the relocation of the AGT Division to a large production facility at least this problem could be alleviated, and might suggest to the AGT Division that other improvements were necessary lest the AGT Division eventually fail in the aircraft gas turbine industry.

A Case Study of the Role of Failure in Technology and Business: Westinghouse Electric and Manufacturing Corporation, Aviation Gas Turbine Division, 1950-1960

Part 1: "Faster Than You Think": Expansion, 1950-1953

In late 1949 the young Westinghouse Aviation Gas Turbine Division began relocating its engine production line to a new facility, a sprawling aircraft piston engine plant built by the Defense Plant Corporation during World War II and leased to Westinghouse by the Navy. Despite the relocation, however, neither Westinghouse president Price nor the AGT Division's chief engineer Kroon learned or applied the important lessons from their experience with the production of the J30 Yankee engine, and problems continued to plague the Division after its relocation. Though the AGT Division had initial success in Kansas City with the production of its J34 engine, production of a newer and more powerful engine, the J40, resulted in a repetition — on a larger and more consequential scale — of serious shortcomings with the organizational capabilities of the Westinghouse AGT Division. As a result, by 1953 the reputation of the Westinghouse AGT Division in the nascent aviation gas turbine industry was almost destroyed.

Westinghouse president Gwylim A. Price provided the AGT Division with little financial support, proportional to the requirements of the rapidly-evolving aircraft gas turbine engine market. Price's reluctance certainly did not result from a lack of liquid assets; under Price, Westinghouse Electric amassed a greater reserve of cash than did General Electric, a company double the size of Westinghouse.[141] There were rather two main reasons for Price's decision not to provide Westinghouse funds for increased aircraft gas turbine R&D: first, Price's postwar expansion program for Westinghouse called for an emphasis on the production of consumer goods over industrial and military products; second, his adversarial relationship with the federal government made him loath to spend company money on government projects.

Price developed a plan for Westinghouse's postwar business that focused on the manufacture of consumer goods, resulting in the neglect of aircraft gas turbine engine production. When Price succeeded Andrew Robertson as president of the company in 1946, he inherited a company that had spread itself too thinly across too many product fields during the war.[142] Price developed a two-part master plan for Westinghouse's postwar direction. The first part of the plan, which ran from 1946 to 1950, concentrated on increasing the output of industrial products. The second part, which commenced in 1950, targeted the consumer market.[143] As a result of this plan, from 1949 to 1953 each year's sales were higher than those of the previous year.[144] During those same years, however, Price decreased the attention being paid to its defense-related product lines, and correspondingly to research and development. In 1950, defense-related orders represented 30% of Westinghouse's undelivered backlog; the following year, over 40%.[145] However, during those years the Defense Products Group, of which the AGT Division was a part, only accounted for only about 10% of total Westinghouse sales, the lowest of any Westinghouse product group.[146] Though Price publicly recognized this disparity and pledged to expend more effort on defense-related work in the future, Price had in mind Westinghouse's burgeoning nuclear power program rather than the AGT Division.[147]

Gwylim Price had strong opinions about the relationship between business and government, and his negative opinion of what he perceived as undue interference by the government through excessive profit control contributed to his neglect of the AGT Division. Price, who had a background in banking going back nearly thirty years, had joined Westinghouse to work on military contract negotiations.[148] This experience provided him with a detailed understanding of industry-government financial relations, and during his presidency Price more than once demonstrated a strong dislike of what he viewed as excessive tax burdens placed upon industry and private citizens by the federal government, once stating that the government was "throttling the incentive to invest in American industry" by excessively cutting into profits.[149] Price also criticized excessive federal spending, which resulted in higher personal and business taxes.[150] Price pointedly observed that in 1950 Westinghouse paid nearly as much in taxes as it had made in profits.[151] It is likely, given his vocal opposition to federal intervention in business, that Price did not want to commit Westinghouse funds to a program that was so closely controlled by the Bureau of Aeronautics and would likely not generate enough short-term profit to overcome the expenses incurred in building new facilities and supporting an expensive R&D program.

Despite the lack of financial support from the company, the Westinghouse AGT Division's relocation to Kansas City between 1949 and 1951 indicated that given the proper environment the AGT Division could successfully manufacture aircraft gas turbine engines in large quantities. Initially, Price was reluctant to sponsor a move to a new location. Beginning in the mid-1940s the Bureau of Aeronautics had encouraged Westinghouse to expand its jet engine production facilities, and the Bureau even financed the construction, at the South Philadelphia Westinghouse plant, of one of the first turbine research laboratories in the United States devoted to aircraft gas turbine engines.[152] Content to allow the Navy to continue funding the AGT Division, Westinghouse management remained reluctant to relocate the nascent AGT Division away from South Philadelphia[153]; by 1948, however, the portion of the building that the AGT Division occupied, which had only enough space to allow the manufacture of 100 engines a month, was not enough to meet the Navy's present and anticipated needs.[154]

The AGT Division needed room to expand, but

Westinghouse management needed a reason to permit the Division to do so. When the Bureau of Aeronautics announced that it planned to substantially increase its orders for the AGT Division's new 3,000-lb. thrust J34 engine, as well as other planned engines, Westinghouse president Gwylim Price finally felt encouraged enough to acquire a plant — one that was government-owned and thus requiring minimal company financial output. At first Price confined the search to the mid-Atlantic region[155] but eventually settled on a massive Navy-owned plant in Kansas City, Missouri. With such a facility, the Westinghouse AGT Division would finally have adequate space to meet the Navy's jet engine requirements. The Navy, the Army-Navy Munitions Board, and Westinghouse reached an agreement in mid-August 1948; the AGT Division leased the Kansas City plant effective January 1, 1949 and refurbished the plant for a stated production goal of 150 aircraft gas turbine engines a month.[156]

The facility, officially designated NIRAP (Naval Industrial Reserve Aircraft Plant) Kansas City, was one of the largest purpose-built engine manufacturing plants in the country, and possessed an interesting history. The Defense Plant Corporation began construction of the engine plant in June 1942, and Pratt & Whitney Aircraft leased it for aircraft piston engine manufacture.[157] The spacious facility occupied 85 acres, encompassing 3 million square feet,[158] with walls on the assembly line floor ranging from between 20 to 26 feet high with few supporting columns to break up the floor space. The nearly 1/2-mile-long main plant building included 32 test cells, a 14,000-car parking lot, a fully-equipped medical facility, and six cafeterias.[159] The government closed the plant on V-J Day, September 2, 1945, shortly after Pratt & Whitney Aircraft shut down operations. In 1947 the Internal Revenue Service leased a small portion of the plant's office area to house some of its regional offices,[160] but aside from that the plant lay abandoned, used by the Government primarily for storage, until the Navy signed the lease with Westinghouse.

The arrival of the AGT Division in Kansas City represented a potential industrial boom for the city and the region. After Pratt & Whitney Aircraft closed its operations there, the area had few jobs requiring industrial skills. The prospect of a large international corporation returning to the area to reopen a manufacturing facility in one of the largest production plants in the United States, to make a product in great demand and with a potentially unlimited future, and offering employment and training to thousands of local workers, represented an opportunity that local newspapers and city officials extolled with praise and anticipation. "The closer Kansas City gets to the reopening of its war-time Pratt & Whitney plant for jet engine production, the more broad-gauged the operation looks to be," stated one editorial, citing a report that Westinghouse ultimately planned to have 5,000 people working at the plant, perhaps even by the end of 1949.[161]

An early indication of potential success was the speed with which the Division established itself in the Kansas City plant and began producing new J34 engines. Westinghouse began sending key AGT Division engineering and management personnel to Kansas City early in 1949 in order to get the plant ready for production by 1950, a challenging prospect In January 1950 production of Westinghouse jet engines began in earnest at the Kansas City plant The Division began by building a single engine production line "starting with only walls and floors."[162] Getting the huge plant cleaned up, laid out, equipped, and ready for production during the year required many people from across Westinghouse and beyond.[163] New arrivals included W.B. Anderson, AGT Division Manager, Sam S. Stine, 35-year veteran of Westinghouse and manager of the Kansas City plant; and Rein Kroon, who became Director of Engineering in Kansas City.[l64] By the end of September the staff at Kansas City grew to 160.[165] In January 1950 the plant, by then 300 people strong, delivered to the Navy its first J34 engine, an evolution of the J30 Yankee capable of 3,000 pounds of thrust, off the new assembly line.[166] By late September 1951, a mere eighteen months later, plant manager Sam Stine announced that the plant had completed of the Kansas City plant's *3,000th* J34 engine, and the establishment of a second assembly line to build a new Westinghouse engine, the J40. Stine expected the plant, which had been averaging about 150 J34 engines per month, would soon double its output.[167] In addition to production facilities, in January 1953 the Westinghouse AGT Division acquired a flight test facility at the Olathe Naval Air Station, just over the border southwest of Kansas City, Kansas.[l68]

The mass-production of the J34 engine and its success in Navy service suggested that the AGT Division had come of age in its new location, and was ready to accept new and more challenging projects for the Bureau of Aeronautics. The Division's staff gained confidence from its early production success in Kansas City. After having struggled to get along in its cramped third-floor location in the South Philadelphia turbine plant, from 1949 to 1951 the AGT Division provided tangible indication to the Bureau of Aeronautics that it had assumed the responsibilities required to maintain its position as one of only a few major domestic manufacturers of aircraft gas turbine engines. During the 1950-1953 period Westinghouse advertisements reflected the AGT Division's enthusiasm and optimism, portraying the AGT Division as "ready to go to work for you NOW" by producing rugged engines that flew "sub-sonic, super-sonic ... Faster Than You Think," a Division with practically unlimited growth potential in the aviation gas turbine industry.[169] Due in great part to the AGT Division's success with the mass-production of the J34 engine, the Bureau of Aeronautics placed with the Division an order to develop the first of the Bureau's next generation of aircraft gas turbine engines, the J40.[170] The AGT Division believed it could use its prior experience with the J30 and J34 to deliver the J40 engine sooner and cheaper than any other manufacturer, the Bureau of Aeronautics, which agreed, hailed the Westinghouse J40 as "a most significant step forward in the technological field of turbojet development."[171] Since the Bureau expected that the J40 would power many of its front-line combat aircraft, the AGT Division's securing of the development contract and, eventually, production orders for the engine represented a potentially lucrative, relatively secure business deal.

Despite early optimism on the part of both the Westinghouse AGT Division and the Bureau of Aeronautics, however, the relocation of the AGT Division's production facilities to Kansas City ultimately had a negative impact on the Division's organizational capabilities, compounding the lack of company financial support. Despite adequate production space in the newly-acquired Kansas City engine plant, the move caused new problems and exacerbated old ones. In particular, problems arose. The relocation ran counter to the contemporary industrial trend towards facilities consolidation. Developmental engineers with little or no production experience retained control of the production lines. The AGT Division engineers, in addition, misinterpreted the lessons to be learned from their successful production of the J34 engine.

By physically separating the research and production facilities by half a continent, Westinghouse management hampered vital information exchange between the two departments at a time other engine manufacturers realized the advantages to be gained from facilities consolidation. Military aircraft production for the Korean War and the nascent demand for jet-powered commercial airliners dominated the aviation industry from 1950 to 1953 in the United States; military aircraft output more than tripled, while the number of civilian aircraft produced increased by a slower 15%.[172] To meet this demand, airframe and engine companies expanded; they did so, however, not by relocating to larger facilities but by enlarging existing facilities in order to consolidate production and R&D in one location and hiring more workers. Many large aviation manufacturers had relocated and consolidated primarily to the east and west coastal areas, often into the newer plants built during World War II.[173]

Facilities consolidation offered significant advantages of economy and efficiency to the aviation industry. For General Electric's jet engine program, for example, consolidation was undertaken in order to permit more efficient communication between R&D, production, management, and marketing staffs; to increase production space, with resulting increases in orders from parts subcontractors; and to increase R&D project development efforts and space to match the increase in demand for production-ready engines.[174] In contrast, when the Westinghouse AGT Division's production line moved to distant Kansas City, its R&D staff remained at the Navy-financed turbine testing laboratory in South Philadelphia. This split hindered rapid communication between the two teams, necessitated duplication of support staff, and limited not only changes to production engines but also introduction of new engines, because the research capacity of the small laboratory could not match the production capacity of the new plant.[175] These limitations increasingly affected Westinghouse engine development and production as new engine models were introduced and put into production. For example, limited laboratory space caused the AGT Division to consistently lag behind its competition in compressor design and development.[176]

Reinout Kroon remained in charge of engine production; from 1950 to 1953 his steam turbine research background dominated the production of aircraft gas turbine engines with increasingly detrimental results. Kroon and his staff of "12 Disciples" had been responsible for the research engine program prior to Pearl Harbor and took charge of aircraft gas turbine engine production at Westinghouse when the Navy accelerated the program after the American entry into the war. As the Division's "old-timers," Kroon and his team of development engineers were rewarded for their pioneering efforts with key senior production positions at the Kansas City plant. As Chief Engineer of the AGT Division's Kansas City production facility, Kroon set the tone for engineering standards and practices at the facility, under his leadership, steam turbine engineering practices persisted in the Division. For example, Kroon did not, or was not able to, address the AGT Division's R&D situation, which, compared to its rivals and its own production needs, was inadequate for successful large-scale production.[177] Steam turbine engineering practice, favoring the "design by experience" approach described by historian Richard F. Hirsh, required little or no R&D in support of product improvement. From 1950 to 1953 the AGT Division's management did not press Westinghouse management for either consolidation of the R&D facilities at Kansas City or for expansion of the existing facilities in South Philadelphia; this indicates that the Division's management believed that the R&D situation was not urgent or critical to current and future production, an assessment with which the engineers either agreed or did not significantly dispute. The decision regarding R&D support of production represented a significant misreading of the emerging aviation gas turbine engine industry, which after 1950 relied increasingly on R&D for both product improvement and new products.[178]

In addition to underestimating the need for R&D, the AGT Division engineers and management misinterpreted their success with producing the J34 engine to suggest that relocation to Kansas City had cured many of the shortcomings that had been experienced with the production of the J30 Yankee engine. The Bureau of Aeronautics ordered large quantities of J34 engines for its fighter fleet, and the AGT Division delivered them, encouraging the AGT Division — and the Bureau — to believe that the Division would be able to continue successfully mass-producing new aircraft gas turbine engines. At the time of the Korean War, one of the United States Navy's and Marine Corps' frontline fighter aircraft was the twin-engined McDonnell F2H Banshee series, which were powered by Westinghouse J34 engines. Throughout the war the Navy fielded over 280 Banshees in several variants, including night fighters, photographic reconnaissance planes, and a long-range all-weather version. All of these were powered by I34s; the Westinghouse AGT Division developed several J34 models ranging from 3,000 to 3,600 pounds of thrust to accommodate newer and heavier versions of the plane. McDonnell produced the Banshee, which could operate to a range of nearly 2,400 miles and had a maximum speed of 570 miles per hour, from 1949 until 1953.[179] As a result, the J34 became the best-selling Westinghouse jet engine of all time. The AGT Division manufactured over 4,500 of all models of the J34 by 1955.[180]

The J34 engine was easily mass-produced, not because the AGT Division had learned how to mass-produce jet engines *per se*, but because the J34 represented the zenith of Westinghouse AGT Division production engineering using steam turbine engineering traditions. The engine represented the kind of gradual, incremental increase in both size and thrust output over the previous J30 Yankee that the AGT Division engineers favored, and as a result presented almost no design or production problems to slow down the manufacture of the engine for the Navy. The J34 was slightly larger than the J30 in external dimensions; its thrust output in early models represented only a 44% increase over the J30's 1,680 pounds. General Electric, by contrast, produced engines that tended to improve on the performance of predecessor engines by a much greater margin. The difference between the thrust output of General Electric's centrifugal-flow J31 engine, 1,600 pounds, and the same company's centrifugal-flow J33, 4,000 pounds, for example, represented a 60% thrust increase. Incidentally, General Electric engineers obtained this improvement in thrust output over a shorter period of development time (one year) than the Westinghouse J30-to-J34 period (over three years). Another General Electric product, the axial-flow J47 engine introduced in 1949, produced 5,200 pounds of thrust without afterburning; while not as significant a thrust increase over its predecessor, the axial-flow J35 of 4,000 pounds of thrust, the J47 still provided more than 2,000 pounds more than the J34.[181]

When the AGT Division attempted to mass-produce its new J40 engine, the three major shortcomings in the Division's organizational capabilities became apparent, and as a result the production phase of the J40 was filled with even more frustrations than the Yankee, on a larger — and more consequential — scale. Confidence with the successful mass-production of the J34 led both the AGT Division and the Bureau of Aeronautics to expect similar success with the J40. That engine, however, enjoyed none of the success of the J34.

The J40 engine employed several advanced features with which the AGT Division's development engineers had little experience; consequently, they experienced considerable difficulty in making the J40 engine develop its expected thrust output. The engine, designed to provide 7,500 pounds of thrust, represented a significant advance in engine output over contemporary American axial-flow engines at a time when many competitive engines, such as the General Electric J47, operated in the range of 5,000 pounds of thrust.[182] The J40's anticipated thrust represented a 50%-60% increase over the various models of the J34 engine. The engine also featured a compressor that provided a higher air compression ratio than earlier Westinghouse designs, and also incorporated a two-stage turbine; the AGT Division had never tried either high-compression compressors or dual-stage turbines in an aircraft gas turbine engine before.[183]

Due to unanticipated technical problems with the compressor and other engine components, which proved too difficult for the limited R&D staff to handle, development and production milestone dated quickly began to slip. The Division reluctantly had to admit that it had "underestimated the magnitude of the task we had undertaken as a result of our earlier successes."[184] First, the successful completion of test runs in the laboratory at South Philadelphia took longer than anticipated, and a 150-hour Navy qualification test, required by the Bureau prior to acceptance of the design, was not successfully completed until January 1951.[185] Even after that, the engine still required subsequent modifications in order to improve on shortcomings made apparent during the test runs. These delays pushed back the date for the start of production at Kansas City. To the Bureau of Aeronautics, it became increasingly apparent that the J40 would be unable to fly at all by the end of 1950, and that the Bureau's airframe orders would have to be put on hold pending availability of engines.

The Bureau of Aeronautics placed constant pressure on the AGT Division to put the J40 into production despite the delays, despite significant changes in the Bureau's requirements for the engine which were instituted faster than the AGT Division could keep up, and despite the lack of financial support from the Bureau. At the start of the J40 program, the design evolved into two distinct engine models, one of lower- and one of higher-thrust ratings.[186] The high-thrust J40 version, which were expected to provide 11,600 pounds of thrust,[187] required more development time and therefore would not be available concurrently with the lower-thrust version. The AGT Division, however, told the Bureau that at least the low-thrust version of the engine would be ready to fly sometime during 1950; as a result, the Bureau planned a whole range of new high-performance aircraft taking advantage of the J40's "special features," to enter service as soon as the engine became available.[188] The AGT Division promised the Bureau of Aeronautics that it could develop the low-thrust version of the engine within 20 months of receiving a contract, and the high-thrust engine in 30.[189] Beginning in 1950 the Bureau placed orders with the AGT Division for 1,186 J40 engines.[190] This order eventually rose to nearly 2,000 engines; next to the several orders for various models of J34 engines, this was the largest order for aircraft gas turbine engines ever received by the AGT Division.[191]

The Bureau constantly exhorted the AGT Division to attempt greater production efforts. "The [J40] engine which you are building is of the greatest importance to the Naval aviation program," read one letter following a plant survey in October 1952. "Every effort must be made to meet the required delivery schedules, as any slippage may result in a deficiency in our support to fleet operating forces.[192] Another tour three months later, in January 1953, produced similar praise and encouragement from the Bureau; however, the Bureau's praise was measurably more conditional in tone. "The concerted effort of your AGT Division, which has resulted in ... generally improved progress in the development and production status of the [J40] engine programs at Kansas City, is most gratifying to the Bureau of Aeronautics and is highly commended." The letter continued:

> However, the previous slippages and delays in development progress of the Westinghouse engines has resulted in extremely critical situation which requires even greater improvement to meet the minimum Navy requirements. *No doubt the Westinghouse Corporation is also fully aware of the development progress of other competitive jet engines, and therefore certainly realizes the demand/or continued effective effort to remain abreast of this competitive field.*[193] [emphasis added]

In 1951, the Bureau of Aeronautics changed its requirements for the first plane to use the J40 engine; this decision had a devastating impact on the already-delayed engine production program. In 1949, when the J40 engine still existed only on paper, the Bureau of Aeronautics announced that the first plane to use the engine would be the McDonnell F3H Demon single-engined interceptor. Several months before the first flight of the prototype Demon in August 1951, powered by a pre-production low-thrust J40 engine, the Bureau of Aeronautics suddenly and unexpectedly altered the mission of the Demon aircraft in order to accommodate a shortage of fighter planes operating with the Navy. The Bureau found that the new Skyray interceptor performed its role so successfully that it made the Demon redundant. At the same time, however, a design for a general purpose all-weather fighter airplane had fallen far behind schedule. In order to fill the fighter gap the Bureau simply ordered McDonnell to redesign the Demon from a lightweight, short-range interceptor to a heavier, long-range fighter. The Bureau of Aeronautics decided that, in order to accommodate the increased size and weight of the redesigned Demon, the plane would now have to use the alternative high-thrust model of the J40, development of which the AGT Division had not expected so quickly. The Bureau did not cancel or reduce its orders for the low-thrust version of the J40; thus, in order to meet the Bureau's new order the Westinghouse AGT Division would have to divert what staff, resources and money it could scrounge from other projects — and from the low-thrust J40 development program.[194]

Following the change in the specifications of the Demon, the Bureau of Aeronautics placed large orders for airframes and increased the number of high-thrust engines on order, despite the fact that no high-thrust J40 engines had yet been completed. The high-thrust J40 design did not complete its ISO-hour Navy qualification test until August 1952.[195] Nevertheless, beginning in March 1951 the Bureau of Aeronautics issued contracts to McDonnell to build 150 airframes, and to Goodyear for another 100 airframes. At the same time, to supplement engine production at Kansas City, the Bureau contracted with the Lincoln-Mercury Division of Ford Motor Company to build high-thrust J40s under license and built for Ford a new government-owned manufacturing plant in which to build the engines.[196] At the same time, the Bureau announced that it would finance a $50-million Government-owned engine facility for Ford to use as an engine production line. The Bureau of Aeronautics clearly did not intend to let the change in the airplane's mission and structural weight alter its timetable for procurement of airframes and engines.

Within a short time, the Bureau of Aeronautics found itself with Demon airframes without J40 engines to put in them. As a temporary solution, the Bureau, which needed the aircraft as soon as they could be delivered for service in the Korean War, ordered McDonnell to install lower-thrust J40 engines in the first Demons off the assembly line, at least until the high-thrust J40s became available. The Westinghouse AGT Division, however, had not yet delivered *any* J40 engines; the demands of the high-thrust J40 program had considerably slowed production of the low-thrust version. McDonnell Aircraft engineers noted that use of the low-thrust J40 in the fighter version of the Demon would "seriously limit the combat effectiveness of the airplane and result in a disappointingly underpowered combination in comparison to the performance potential of the airplane" and instead recommended that the Bureau seek an alternative engine.[197] The Bureau, nevertheless, decided to wait, reasoning that the purchase of new engines would be more expensive than waiting. In late 1952 the Bureau finally placed an order for several Allison J71 engines to use as a substitute in the Demon fighter. However, like the J40, the J71 had not yet entered into production; the Demon airframes therefore had to sit idle.[198] The Allison engines ultimately became available in late 1952.

Delays with the J40 engine program partly stemmed from the lack of financial commitment to full-scale production on the part of the Bureau of Aeronautics. In 1950, the Bureau ordered J40 engines not by entering into a formal contract, but rather by issuing "letters of intent" to the AGT Division. Contracts established prices and other expenses, and permitted the Bureau to issue regular progress payments to the firm; letters of intent, on the other hand, required the firm to commit its own money to the project until the contract progress payments reimbursed the firm at a future date. "While [a] firm is operating under the authority of a letter of intent," notes Herman Stekler, "it must be self-financing."[199] Over the lifetime of the J40 program, the Bureau did provide $27 million to Westinghouse; however, by way of context this amount must be compared with the approximately *$300 million* spent by both Pratt & Whitney Aircraft and the United States Air Force for Pratt & Whitney's J57 engine, a contemporary of the J40; the J57 produced 10,000 pounds of thrust, 25% more than the J40 and 48% more than the General Electric J47 engine.[200] Thus, the J40 program relied primarily on available AGT Division funds, with minimal financial support of the Bureau of Aeronautics. At least partly due to the inadequate funding, of the nearly 2,000 engines ordered, the AGT Division delivered none by the end of 1953.

The slipping production dates caused increasing concern in the Bureau of Aeronautics, and inflamed the opinions of key officers against the AGT Division. Some saw the delays as evidence that the AGT Division still operated along the leisurely pace of steam turbine engineering practice; Michael Combeirate, a propulsion expert in the Power Plant Division of the Bureau of Aeronautics, believed that further urging of Westinghouse "would be like whipping a dead horse ... maximum possible pressure had already been brought to bear on Westinghouse, making it illogical to expect improvement in this manner unless Westinghouse were still laying down on the job." In addition, "strictly off the record, and as my own personal opinion," Combeirate added that

> [Block]the cause for the present situation is not so much Westinghouse's inability to produce, but their incapacity to produce [sic]. Development after development program had been heaped upon Westinghouse without full cognizance of their capacity to handle these programs ... . Further, I said I believed that relatively nothing had been done to increase Westinghouse's development capacity, i.e., test facilities, etc. compatible with the size of the engine development program which the Navy had contracted with them.[201] [Block/]

Combeirate suggested that the Navy possibly had overburdened the AGT Division with its expectations of J40 production by 1950; this observation mirrors similar concerns during the early years of J30 production. So too do his observations that Westinghouse had insufficiently supported R&D and production of jet engines, and that both Westinghouse and the AGT Division were unresponsive and slow-moving. Combeirate's observations indicate that the Westinghouse AGT Division, by repeating some of the same key mistakes made during the production phase of the J30 Yankee, had obviously not learned from that experience after all. As a result of production and delivery difficulties with the J40 engine, "AGT [Division] prestige reached a critically low point in 1953 with relation to the aviation industry" and also with the Bureau of Aeronautics.[202]

In June 1953 the Korean armistice brought to an end not only the war that had provided impetus for Westinghouse AGT Division engine manufacture, but also the sense of urgency behind the J40/Demon program; as a result the Bureau quickly began canceling orders for J40 engines. Following the Armistice, the Bureau of Aeronautics began wholesale cutbacks of engine and airframe orders beginning with 400 J40s in February and 400 more engines in April 1953. In September the Navy canceled not only 1,000 more J40 engines but also all contracts for developing the high-thrust version of the J40. This left only a paltry 217 low-thrust J40 engines on order, a mere 10% of the original order, none of which had yet been delivered to the Navy.[203] The AGT Division, in fact, did not deliver its first production low-thrust J40s to the Navy until November, 1953 — more than three years after the Bureau had first expected them — and never delivered any high-thrust engines.[204] The J40 engine program dragged on in this reduced fashion until for nearly two more years, still plagued by unresolved problems with the compressor and turbine blades and the afterburner, until finally being completely canceled in October 1955.[205] The many and significant failures surrounding the J40 aircraft gas turbine engine in the eight years of the program dramatically illustrated several shortcomings inherent in the organizational capabilities of the AGT Division.

The Westinghouse J40 aircraft gas turbine engine proved to be a failure primarily because the AGT Division had still not learned the important lessons resulting from the production of the J30 engine five years previously, and misinterpreted the success of its J34 engine to suggest that it could successfully manufacture jet engines. When called upon by the Navy to produce, quickly and in large quantities, an engine that represented a significant leap in engineering design experience, and then to develop an even more powerful version of that engine in response to a sudden change in the customer's needs, the AGT Division demonstrated that it could not respond in a timely fashion. The factors that brought about the failure of the J40 aircraft gas turbine engine program were essentially the same as those that had similarly affected the J30 Yankee program almost ten years before; lack of company financial support, a sudden change in engine requirements by the customer which left the AGT Division unable to respond quickly, and the persistence of steam-turbine engineering traditions which were incompatible with mass-produced engines.

Lack of in-house financial support from Westinghouse prevented the AGT Division from acquiring sufficient R&D, design, and production staff necessary to design a trouble-free engine or resolve problems as they arose. The relocation of the AGT Division's production line to the larger Kansas City facility was not accompanied by a commensurate increase in either the size of the R&D facilities or the number of employees working in R&D in support of production, both of which remained relatively stagnant. The limited facilities and staff proved unable to cope with the many technical problems encountered with the J40 engine, causing delays which seriously affected the Navy's procurement of aircraft. Lack of company financial support also limited the size of the AGT Division's production staff. In 1950, the AGT Division possessed an estimated 3,000 production workers; that same year, General Electric had between 7,000 and 8,000 production workers, and Pratt & Whitney Aircraft employed 14,000.[206] Aerospace industry analyst William Cunningham has suggested that, following World War II, employment replaced available floor space as the standard of measurement for company size and performance; measured against this criterion the General Electric Aircraft Gas Turbine Division — not to be confused with Westinghouse's Aviation Gas Turbine Division — was more productive than the Westinghouse AGT Division by 62% and Pratt & Whitney Aircraft by 79%.[207]

Because the low-thrust J40 engine was built strictly according to the requirements of the Bureau of Aeronautics, there was little prognostication on the part of the AGT Division about the engine's design; when the Bureau's requirements suddenly changed the AGT Division had almost no capability to make the required performance improvements. The Bureau dictated not only the engine specifications but the program timetable to the AGT Division.[208] Inadequate R&D facilities coupled with pressure from the customer prevented the AGT Division from having enough time to solve major problems with the low-thrust engine's compressor and turbine. As the AGT Division engineers attempted to work out these problems, the Bureau suddenly added the high-thrust version to its engine requirements without accounting for the resulting overload at the R&D facilities; under such a burden the J40 program inevitably staggered and fell even further behind. The Bureau of Aeronautics, by issuing airframe and engine letters of intent and subcontracts worth millions of dollars based on the performance of a single prototype engine on a test stand, and by not providing either progress payments or R&D funds to the AGT Division, may have expected too much too soon of the AGT Division and not have been willing to pay for it.

The design of the J40 was too much of a leap forward in performance for the AGT Division, which was still used to step-by-step, incremental increases with future improvement based on experience. The J34 was successful because it was essentially a slightly larger Yankee engine, representing modifications and improvements based not on theoretical research and experimentation but on practical experience with the smaller engine. The J40, in order to meet the performance requirements established by the Bureau of Aeronautics, required many features that were new and previously untried by the AGT Division.[209] These new features required that the engineers, in accordance with their traditional steam turbine engineering practice, take time to learn about how these new components worked by observing them in operation and then making on-the-spot corrections which then had to be retroactively applied to all other identical components already built. The AGT Division engineers had used this method with the J30 engine, but was able to dispense with much of it for the J34. The AGT Division's engineering staff started this time-consuming and haphazard practice anew for the J40 engine, and established a pace for the program that was ill-suited to the mass-production of a new engine design.

The relationship of the Bureau of Aeronautics and the AGT Division was such that the Bureau's dissatisfaction could seriously threaten the AGT Division's future as a manufacturer of aircraft gas turbine engines; in addition to the Division's failure to manufacture the J40 engine, other factors contributed to the Bureau's growing dissatisfaction with the Division. The J40 program, with its repeated and protracted delays, generated a great deal of animosity within the Bureau of Aeronautics toward the Westinghouse AGT Division, and the cancellation of the bulk of the engine orders represented a significant loss of potential production and revenue for the Division. The Bureau was both the main source of financial support for and the primary customer of the AGT Division. The Bureau's monopsony over the AGT Division meant that the Division was not in direct competition with other aircraft gas turbine engine firms; without the Bureau's support the Division would essentially be forced out of the aircraft gas turbine engine industry altogether or forced to find a new source of funding for R&D and a new customer willing to place orders. Since the Air Force could rely on the General Electric Aircraft Gas Turbine: Division, which was busy designing new engines on its own initiative, the Westinghouse AGT Division had virtually no alternative in the military-dominated market of the early 1950s should the Bureau of Aeronautics decide to withdraw support — which, in 1953, the Bureau very nearly did. In addition to the failure of the J40 engine program, a series of deceptive Westinghouse advertisements about the J40 and the entry of a new aircraft gas turbine engine manufacturer into the industry encouraged the Bureau to rethink its support for the Westinghouse AGT Division.

Throughout the J40 program, Westinghouse engaged in deceptive advertising regarding the progress being made with the J40 engine. The AGT Division misrepresented the J40 engine in the press, but ultimately served only to focus more criticism on the Division. For example, when the high-thrust J40 finally completed its 150-hour qualification test in August 1952, Westinghouse celebrated the achievement with "a blast of newspaper ads" that announced this new engine as the "most powerful jet engine qualified for production."[210] The publicity campaign critically backfired, however, when the critics figuratively read the fine print and tore the claims apart. Experts pointed out that the Westinghouse advertisements provided only the engine's total *horsepower* output, not a standard measure for a jet (as opposed to propeller) engine. In addition, the given horsepower calculations were based on measurements at flight speeds and altitudes, also not standard measurements for aircraft gas turbine engines. If more traditional measures were applied — the engine's *thrust* output measured at sea-level altitude at lower speed — the engine's performance was estimated to be somewhat more modest, in fact only marginally more powerful than the General Electric J47. Though this still left the J40 in the position of being the most powerful *qualified* jet engine, critics noted that Pratt & Whitney Aircraft had a more powerful engine — the J57 — in production and in service with the Air Force, though it had not yet passed a qualification test.[211] And, as for being "qualified for production," the AGT Division still had yet to actually produce or deliver any to the Navy at that time.

The Bureau of Aeronautics noticed the deceptive advertising and resented the AGT Division's attempts to generate positive press at the Bureau's expense. This did not prevent the AGT Division from attempting to find an exploitable "angle" to the J40 engine. In February 1953, for example, the AGT Division requested of the Bureau of Aeronautics permission to use J40 data and photographs in advertisements in newspapers and magazines. This decision demonstrated an almost surreal disregard on the AGT Division's part for the growing disaster surrounding J40 production in early 1953, and the Bureau took issue with the idea. The Bureau objected to the AGT Division's attempt to "make character in the public press" using government funds in paid advertising to publicize a government contract. Since the relationship of the Bureau of Aeronautics to the Westinghouse AGT Division was that of a monopsony, the advertising campaign would have little, if any, impact on AGT Division sales to its sole customer if advertised in a public arena. "Finally," the memorandum states with deliberate circumspection, "there are a number of statements in the text of the ads that are not palpably in error but are subtly misleading resulting in probable misconception by the reader as to the overall progress of Westinghouse engine development."[212] The Bureau resented being asked to condone a publicity campaign which, like the August 1952 advertisements, it knew to be untrue.

Westinghouse also angered the Bureau of Aeronautics by convincing the Bureau to subsidize the construction of a new facility for engine component manufacture, which Westinghouse ultimately used solely for the production of consumer goods. As part of Westinghouse's postwar expansion program, Westinghouse President Price announced in January 1951 plans to build a sprawling facility in Columbus, Ohio to supplement production of Westinghouse refrigerators. Though Westinghouse publicly claimed that the Columbus plant was funded by the company, Price in fact sought a Certificate of Necessity from the Navy whereby the government would subsidize 80% of the construction costs in exchange for which Price promised that the 45-acre, 2 million sq.ft. facility would be used to double the Kansas City plant's output of aircraft gas turbine engine components and sub-assemblies during the Korean War crisis, and then be changed over to civilian production afterwards.[213] The Bureau of Aeronautics agreed to the terms and provided the Certificate of Necessity and $20 million worth of government — owned manufacturing equipment; construction of the Columbus plant began in mid-October 1951.[214]

Because of changes in the requirements of the Bureau of Aeronautics, for fewer engines, and of Westinghouse, for more appliances, the Columbus plant ended up never being used for manufacturing engine components. In December 1952, following the decision by the Bureau of Aeronautics to substitute the Allison J71 for the high-thrust J40 in the Demon fighter, the Bureau notified Westinghouse that there would be no need for additional engine components from the as-yet unfinished Columbus plant after all, and that the company should cease procurement of tools and other equipment.[215] Westinghouse in turn sought reimbursement from the Bureau of Aeronautics for money spent during the pre-production phase — originally $6 million, eventually negotiated down to a more accurate $500 thousand — and in March 1953 the two parties entered into protracted negotiations over who should pay for the Columbus plant's deactivation as a quasi-military facility, and against what contracts.[216]

The Navy shouldered the burden of the $45 million already spent in construction of the plant. In mid-1953 the Bureau informed Westinghouse that the company's $500 thousand of incurred costs would be factored into]953 price projections and thus reimbursed.[217] Westinghouse, which owned the Columbus facility, finished construction of the plant and opened it in March 1954, and ultimately moved all of the company's refrigerator and freezer production there.[218] The Navy had subsidized the construction of the plant with the expectation that engine components would be manufactured there; the Bureau's own changing requirements, brought about by Westinghouse's failure to manufacture J40 engines, ultimately resulted in the Navy having no use for the plant — and effectively prevented the Bureau from claiming that Westinghouse had taken advantage of the Bureau to build a plant at government expense. Essentially, the failure of one Westinghouse Division helped the success of another, at significant financial expense to the Navy.

The Bureau's increasing experience with Pratt & Whitney Aircraft and General Electric caused the Bureau's senior officers to conclude that Westinghouse's performance with the J40 had been less than satisfactory. From 1950 to 1953, the Bureau witnessed General Electric gradually taking the initiative in the design and manufacture of its jet engines, instead of designing engines to match Air Force specifications, and begin offering a variety of different engines for a wide range of airframe applications. Pratt & Whitney Aircraft, which had successfully manufactured large numbers of jet engines under license for the Navy the firm, set out to make up for the company's late start in the aircraft gas turbine engine industry by "leap-frogging" both Westinghouse and General Electric and create "something far in advance of what they were thinking about."[219] Their first in-house design for a production jet engine, the J57, had a unique double-compressor and turbine arrangement that could provide an unprecedented 10,000 pounds of thrust; far above the rival Westinghouse J40 or General Electric J47 engines.[220] As a result of these developments in the jet engine industry, the Bureau of Aeronautics no longer had to rely exclusively on Westinghouse to supply aircraft gas turbine engines, as the Bureau had to do during and immediately after World War II.

In contrast to the significant progress being made by Pratt & Whitney Aircraft and General Electric in the development and production of new aircraft gas turbine engines, the Westinghouse AGT Division appeared, in the eyes of senior Bureau of Aeronautics officers, to be stagnant and unresponsive by comparison. Bureau officers had an opportunity to express their growing dissatisfaction with the AGT Division in May 1951, when the Navy's Contract Renegotiation Division asked them to submit reports describing the Westinghouse AGT Division's past performance. The respondents clearly thought that the Westinghouse AGT Division could have done better. "Westinghouse has *only* done a reasonable job of providing turbo-jet engines," one Bureau officer wrote. "The record to date would certainly not indicate an outstanding record" [emphasis added]. Candidly, the officer assessed Westinghouse's shortcomings:

> Westinghouse under the present gas turbine division leadership appears to be more interested in just "getting by" and producing engines rather than getting needed "fixes" incorporated. As a matter of fact Westinghouse has at times shown an attitude of being unwilling to take any action to correct known deficiencies. One reason for this condition is that management seems to be reluctant to employ enough engineers at reasonable pay to do the job. Other engine [companies] have successfully raided the best engineers away from Westinghouse. A couple of years ago the quality control was poor but this seems to be improving in recent months.

Another Bureau officer stated that he believed the AGT Division had done "a reasonably good job but not outstanding;" he stated that the Division had generally met its production schedules for the J34 engine "*with not hardship on the part of BuAer*" [emphasis added]. Regarding the J40 and other engines in the development stage, however, the AGT Division "fell down rather badly." "The contractor has made valuable contribution[s] to the Defense Program," the Bureau's final report noted dryly, "notwithstanding the fact that their cooperation with the Government has in some instances not been of the highest degree."[221]

Because of its dissatisfaction with the AGT Division, in late 1953 the Bureau of Aeronautics threatened to cease further support of the AGT Division, which would have resulted in the Division having no customers for its engines and virtually no financial support for further R&D. In late 1953, the Bureau of Aeronautics undertook a survey of the aircraft gas turbine engine industry in the United States, with an eye towards deciding which of the manufacturers would in the future receive Navy funding for R&D and production of jet engines. The Bureau of Aeronautics, in person and in letter, intimated to the Westinghouse AGT Division that "the status of the Westinghouse Electric Corporation in the aircraft jet engine program is in a state of uncertainty."

> In view of this situation, ... the approval for extending additional funds for facilities for Westinghouse could not be justified until such time as a decision is made by higher authority relative to the continuance of Westinghouse in the overall aircraft jet engine research, development, and production program.[222]

Unless the Westinghouse AGT Division demonstrated that it could indeed learn from its mistakes, it faced the prospect of having to abandon an industry which it helped create.

In three crucial years the AGT Division went from the promise of success to the realization of failure. In 1950, the Westinghouse AGT Division moved its production line to a new facility in Kansas City, Missouri, with enough room to expand into full-scale mass production of aircraft gas turbine engines. The Bureau of Aeronautics, impressed by the AGT Division's successful production of J34 engines there, sponsored the development of a powerful new engine, the J40, and promised to order thousands of them if the engines could be brought successfully to the production stage. By 1953, however, the AGT Division failed to bring the J40 into production and faced the humiliating cancellation of almost all of the orders for the engine, due in large part to inadequate R&D funding and engineering practices that were ill-suited for the manufacture of the engine — a situation for which the earlier production of the J30 Yankee had served as a warning. The Bureau of Aeronautics grew displeased with the AGT Division over the failure to produce the J40 engine, the Division's deceptive advertising campaigns, and the construction of the Columbus, Ohio, plant. In addition, the Bureau recognized the inadequacy of the AGT Division in comparison to its rivals in the industry. All these factors contributed to the failure of the AGT Division between 1950 and 1953 to achieve little of what had been expected of it by either the Navy or the AGT Division itself, and as a result in 1953 the fate of the AGT Division's future hung in the balance.

Part 2; "If You're Not In Trouble, You're Not In Aviation": Transitions, Scandals and Cancellations, 1954-1956

At the end of 1953, the Westinghouse AGT Division occupied a weakened and increasingly vulnerable position in the aircraft gas turbine engine industry in the United States. The failure to mass-produce the J40 engine highlighted serious shortcomings in the organizational capabilities of both Westinghouse Electric and its AGT Division. Westinghouse management only grudgingly invested a minimum amount of company funds in the AGT Division, resulting in inadequate R&D facilities and underpaid staff. Unlike its competition, the Division's engineers preferred not to seize the initiative by developing new or improved jet engines which would draw new customers and further push the state of the technological art, preferring to build only according to specifications from its sole customer. Finally, the Division preferred to rely on its steam-turbine engineering philosophy, which minimized R&D support of production and maximized gradual, incremental design progress; this caused the Division's designs to lag behind the growth potential of the technology, unlike its major rivals. As a result, the Bureau of Aeronautics threatened to withdraw its support for the AGT Division unless those engineering practices, and their condonation by the Division's management, changed. Beginning in 1954, a series of changes in key personnel in both the AGT Division and the top management at Westinghouse signaled acknowledgement that the shortcomings in the Division's organizational capabilities had at least been acknowledged; however, the remedies came too late to affect the AGT Division's relative position in the industry, which was further diminished by the introduction by Pratt & Whitney Aircraft and General Electric of new and more powerful aircraft gas turbine engines.

On December 30, 1953, Westinghouse announced that Latham E. Osborne, who had overseen the creation of the Westinghouse AGT Division in 1945 as manager of the Defense Products Group, was promoted to the position of Executive Vice-President in charge of all Westinghouse divisions and placed on the Westinghouse Board of Directors. Leslie E. Lynde, until then the vice-president in charge of the AGT Division, replaced Osborne in charge of the Westinghouse Defense Products Group, which included not only the AGT Division, but also the Atomic Power Division, and the "Baltimore Divisions" which manufactured avionics and radar for military aircraft.[223]

Eight days later, Vice President Lynde introduced W. Waits Smith as the new AGT Division manager, whom Price hired to "implement a more aggressive program" of jet engine development and manufacture.[224] Smith, who replaced F.L. Snyder, a veteran Westinghouse engineer, had nearly thirty years' of engineering experience including the development and mass-production of aircraft engines. Smith had started his career as an engineer at Studebaker where he was promoted to chief engineer in charge of Studebaker's defense-related aircraft production. After a tour in the Army Air Forces as a captain involved in defense production, where he concentrated on development and manufacture of engines for bombers, he returned to Studebaker; several years later Smith assumed control of the car builder's license-manufacturing of General Electric's J47 aircraft gas turbine engine design.[225] The Westinghouse AGT Division sorely needed Smith's extensive knowledge of R&D and mass-production, which included not only automobiles but also aircraft piston and gas turbine engines.

"This [job] presents a definite challenge to me," Smith told a Kansas City reporter. "I am looking forward to being a part of these developments."[226]

Smith's appointment was followed by major changes in the senior staff of the AGT Division's research and manufacturing departments. In late 1953 the AGT Division's Research Director, Oliver ("Ollie") Rodgers, one of the original "12 Disciples" who had worked on the Yankee engine during World War IT, left Westinghouse for a better-salaried position at the Packard Motor Company, the first of that group to leave the AGT Division.[227] When Rodgers departed, Reinout Kroon relinquished his position as Chief Engineer, which he had held since the establishment of the Westinghouse AGT Division, to take over the position vacated by his old friend. The Division in turn hired Allan Chilton, an engineer with over 25 years' aviation engineering experience, to take over as the new Chief Engineer.[228]

Kroon's transition to the post of Research Director, and his replacement as Chief Engineer by someone from the aviation industry, represented a break with past AGT Division traditions. Kroon's new job did not simply represent a lateral move between equal positions. In the organizational structure of the AGT Division, the position of Chief Engineer was second only to the Division Manager. The Director of Research position, however, was below both the Chief and Assistant Chief Engineers, and co-equal with the Director of Development (see Appendix III, Organizational Structure of the Westinghouse Aviation Gas Turbine Division). Kroon went from the single second-tier slot, with control of all engineering aspects of the Division including R&D and production, to a shared fourth-tier position that did not include engine production. Kroon's move, and the hiring of Smith as his superior, represented a definite transition away from the old engineering traditions of the Steam Turbine Division — the hand-crafted engine built by intuition and know-how — towards an engineering leadership more suited for the product and the industry — the mass-produced engine supported by R&D experience.

From 1954-1956, despite changes in the AGT Division's senior staff, the Westinghouse AGT Division came under attack and scrutiny from within and without the company, forcing the Division to make significant changes in order to remain in the aircraft gas turbine engine field. Changes in Westinghouse senior management resulted in increasing scrutiny of the AGT Division's failures by the senior management to secure and maintain a dominant position in the growing aviation gas turbine engine industry. The Bureau of Aeronautics demanded significant changes in the AGT Division in order to merit continued financial support and future business with the Division. Finally, the United States House of Representatives held hearings into the procurement of the J40 engine and Demon fighter by the Bureau of Aeronautics; the hearings brought to a head the acrimony long felt towards the Division by the Bureau of Aeronautics, but which the Bureau's representatives rarely expressed overtly.

Westinghouse Electric's senior vice-president Mark Cresap began to take interest in the AGT Division, not by increasing support for the Division but demanding that it begin showing more profit. Despite consistently strong sales and profits from 1950 through most of 1954, beginning in late 1954 Westinghouse experienced a rash of business setbacks including lower-than-anticipated sales of consumer goods, a large-scale strike that not only closed Westinghouse appliance plants across the country but also shattered the company's record sales growth trend, and a price war over heavy industrial machinery with its main competitor, General Electric.[229] In order to counter these setbacks, Westinghouse president Price decided to reform the company's management practices and gave Mark W. Cresap, Jr., Executive Vice-President and special assistant to Price, responsibility for developing the reform program.[230] Cresap instituted a policy of holding managers accountable for the profitability of their divisions. In July 1954 he brought all the Westinghouse division managers together in Pittsburgh and gave a speech explaining his new plan. "Each division manager has been given a profit bogey to meet along with a free hand to cut costs and expenses wherever necessary to produce that profit," explained Cresap. "With profits sliding and costs rising, the requirement is strongly upon us to get our expense house in order."[231] Though the AGT Division showed a consistent return on investment due to the extensive subsidization by the Bureau of Aeronautics, defense-related products accounted for the lowest percentage of sales of any Westinghouse product group, and consequently exhibited small profit margins.[232]

Chief of the Bureau of Aeronautics Apollo Soucek threatened to cancel further aircraft gas turbine engine business with Westinghouse unless it demonstrated that the company was willing to invest in the future of its AGT Division in order to prevent a repetition of the J40 debacle. The chief of the Bureau, Admiral Soucek, announced in late 1953 that the AGT Division faced the prospect of being denied future Bureau funds pending a review of the engine manufacturing industry.[233] In March, 1954, Westinghouse president Price wrote to Admiral Soucek pledging to commit company funds to resolving deficiencies in the AGT Division, which the Bureau acknowledged as a positive indication of Westinghouse's willingness to remain in the jet engine industry. However, Price also asked of Admiral Soucek that the Bureau of Aeronautics pay for 50% of the new facilities once approval to undertake the move had been granted by the Bureau.[234] Not until July did the Bureau notify Westinghouse of its final decision, which was to conditionally support the expenditure of Westinghouse funds for improvements at the Kansas City plant. In his letter of approval, Soucek stipulated that by giving the go-ahead the Bureau was not committing itself to financially supporting the undertaking, as Price had asked.[235]

The heaviest scrutiny came in late 1955 from a House of Representatives subcommittee hearing investigating the J40 engine and Demon fighter cancellations. The investigation, and the acrimonious fallout which resulted, damaged what remained of the AGT Division's credibility as one of the country's major manufacturers of jet engines. The investigation into the trouble-plagued development and protracted production of the J40 engine resulted in a public airing of the Westinghouse AGT Division's shortcomings and of the Bureau of Aeronautics' frustrations with the Division. It also resulted in stiff financial penalties for the cash-strapped Division as a consequence, not because of production delays, but because of its public attempt to avoid responsibility for its share of the J40/Demon fiasco.

The investigation resulted from a tour of the McDonnell plant in St. Louis by Rep. Frank Karsten of Missouri in September 1955, during which Karsten saw 50 Demon airframes parked on the company's ramp awaiting engines. McDonnell officials told him that the planes were originally designed for Westinghouse engines that were not powerful enough for the plane, and hence unsafe to fly. Karsten was told that the Navy had calculated that it would be cost-effective to refit only 29 of those planes with more powerful Allison J71 engines, which had only recently entered production, and planned to ship the remaining 21 by barge to a Navy mechanics' school in Tennessee as maintenance trainers.[236] While visiting the McDonnell plant, Karsten also heard that several Demons fitted with low-thrust J40 engines had crashed during test flights, some of which resulted in pilot fatalities. These planes had been fitted with low-thrust J40s in order to provide pilots with some flight experience with the aircraft pending the arrival of more powerful Allison engines. Newspaper reports of the accidents inflamed suspicion that the aircraft were grounded because they were unsuitable or unsafe for flying.[237]

Karsten wrote to the Chairman of the House Committee on Government Operations, William L. Dawson, and reported (inaccurately) that "[i]nformation has come to me that approximately *50* Demon jet fighter planes produced at the McDonnell Aircraft Corp. plant ... have been found unsuitable by the Navy Department" and requested Dawson to "consider the advisability of ordering a full congressional investigation ... in order to study the procurement practices of the Navy Department and assess responsibility in this matter" [emphasis added].[238] On September 27, 1955, Rep. Chet Holifield, chair of the Committee's Subcommittee on Military Operations, publicly ordered a preliminary fact-finding investigation "into the basis of published reports that the Navy has expended large sums of money on fighter aircraft that won't fly."[239] Between Karsten's visit and Holifield's announcement, therefore, the subject of the J40/Demon investigation quickly ballooned from a handful of airplanes to the entire development, manufacture, and testing programs of both the Demon fighter and the J40 engine, and the procurement directives of the Bureau of Aeronautics.

In late September and early October, a team of investigators visited the McDonnell Aircraft plant in St. Louis, Westinghouse offices in both Kansas City and Washington, DC, and Bureau of Aeronautics branches in all three locations. They interviewed senior staff in order to obtain their accounts about what had happened to the J40 engine and the Demon. The investigators found discrepancies in the accounts of the Bureau of Aeronautics and the Westinghouse AGT Division regarding the causes of the test aircraft crashes.[240] The Bureau of Aeronautics told the investigators that they considered the low-thrust J40 "unsatisfactory due to lack of reliability."[241] The Westinghouse AGT Division's presentation to the House investigators included a presentation on the increase in airframe weight, rather than engine problems, as a major factor in the crashes.[242]

As a result of "apparently conflicting statements made by Navy and Westinghouse spokesmen [to the investigators] and incomplete or inaccurate information reported in the press," Holifield decided that the situation warranted more than just a preliminary investigation and announced that the Subcommittee on Military Operations would hold public hearings from October 24 to October 27, 1955, in order to sort out the contradictions and establish responsibility for the failure of the Westinghouse-powered Demon to satisfy the requirements of the Navy.[243] Altogether 25 people from Westinghouse, McDonnell and the Bureau of Aeronautics traveled to the New House Office Building in Washington, DC, to appear as witnesses during the four days of hearings. W. Waits Smith appeared on behalf of the Westinghouse AGT Division; with him were Robert L. Wells, his administrative assistant; John L. Howland, Westinghouse assistant general counsel; and Russell Mathias, the project engineer in charge of the J40 engine development and production.[244]

The Subcommittee's investigation team testified that the Westinghouse AGT Division's lack of support for R&D caused many of the delays in the J40 program. "It was indicated to us by Navy officials that Westinghouse was the least aggressive [of the major engine manufacturers] in investing in development facilities," they reported.[245] The subcommittee investigators estimated that the total cost of the failed J40-powered Demon program, including facilities, equipment, and cancellation compensation, cost the Navy over $200 million.[246] Admiral James Russell, who succeeded Apollo Soucek as Chief of the Bureau of Aeronautics in early 1955, agreed that the Westinghouse AGT Division's R&D program was "rather poor." "Facilities, staff, something along the line is certainly inadequate [if] the engine did not come out properly," he asserted.[247]

The investigation suggested that the decision by the Bureau of Aeronautics to pursue development of the high-thrust J40 engine despite the inadequate R&D also contributed to the problem. Rear Admiral R. E. Dixon, Assistant Chief of the Bureau of Aeronautics, testified that the Bureau increased the design weight of the Demon airframe only after assurances from the Westinghouse AGT Division that the high-thrust version would be available in time to power it:

> The concept of the airplane changed due to the prospective availability of the [high-thrust] engine which we required for the heavier airplane ... . Westinghouse said that he [sic] could deliver us the ... engines ... . We therefore revised our concept of the airplane and gave it more capabilities, which resulted in increasing its weight approximately 10,000 pounds.[248]

Yet, Admiral Russell testified that the Bureau of Aeronautics had originally come to the decision first on its own, and then had consulted with Westinghouse on the availability of the high-thrust version; not surprisingly, Westinghouse concurred with this version of the sequence of events.[249] The exact sequence of events will likely never be determined, but considering how closely the Bureau monitored the AGT Division's progress during the J40 program, the Bureau held more responsibility than Admiral Dixon ascribed.

Testimony from test pilots and questions from the Subcommittee focused attention away from the Bureau's procurement policy and toward mechanical problems with the J40 as an explanation for the problems with the program. Test pilot Commander Nicholas Smith spoke about his narrow escape from an accident during a test flight of an F3H Demon, which appeared to have been caused by the failure of the plane's J40 engine. Chairman Holifield read into the record a dramatic transcript of communications between Smith and his chase plane that chronicled how the engine suffered repeated malfunctions and finally burst into flames, causing the plane to break up and forcing Smith to parachute to safety. Subcommittee member R. Walter Riehlman asked the Commander "[i]n your experience in the service have you ever known of any other jet plane that has ... caused as much trouble as this model?" Smith replied that he had not, but pointed out that it was not unusual for test planes to be dangerous. Riehlman pressed the issue: " I am asking you if you know from your best knowledge of any plane with this type of engine, a jet engine, that has caused as many failures ... and the loss of lives that this one particular plane has? Commander Smith admitted that he did not. "The F3H is grounded for more engine trouble than any other planes that I have ever worked with," he stated.[250]

W. W. Smith and the other AGT Division personnel did not testify until the third day, after both the Bureau of Aeronautics and McDonnell presented their cases, explicitly and implicitly placing most of the blame for the failure of the J40-powered Demon upon the Westinghouse AGT Division. Smith's testimony took the defensive. Smith began with a brief prepared statement summarizing the history of the AGT Division and the J40 engine development and production program, conceding that the failure of the J40 production program highlighted several serious shortcomings in the AGT Division:

> It is true, and we are certainly willing to admit it, that this engine program moved slowly in face of [*sic*] the urgent Korean war emergency when the emphasis was on speed, and this slowness was delaying the Navy's program. Five factors contributed to the problems we encountered in successfully developing the J40 engine, all of which have since been corrected:
>
> 1. A lack of technical manpower on jet-engine work. We did not expand our engineering staff fast enough.
>
> 2. We lacked experimental parts development facilities and manpower which we know now are vitally important to successful development work in jet engines.

3. We had placed inadequate emphasis on the basic aerodynamic aspects of research, no doubt because of some complacency resulting from our almost immediate success with the J30 and J34 engines.

4. We had too few "house," or experimental, engines for test work.

5. Our operations were too widely scattered for most effective performance. Our development facilities were at South Philadelphia, Pa., and our production facilities at Kansas City, Mo. Our flight-test facilities were in three wide-apart locations — Delaware, Texas, and California.[251]

Smith pointed out that all these deficiencies had been recognized by the AGT Division and addressed through the $12.5 million consolidation program, though they had not yet fully rectified because the consolidation had not yet been completed.

Following the prepared statement, Smith answered questions from the Subcommittee; his replies were evasive and defensive. Herbert Roback, director of investigations and counsel for the Subcommittee, asked Smith directly whether there was any basis for a judgment that the J40 engine was mechanically unreliable. Smith replied that neither the Navy nor McDonnell had claimed that the low-thrust J40 engine by itself had proven unsound, only the combination of that engine with the heavier Demon airframe. Roback countered Smith by reading a statement made to the investigators by Bureau of Aeronautics officers that the low-thrust J40 was unreliable, and repeated the question.[252] Smith evaded answering by arguing over the question's semantics. Roback then asked Smith about Navy funding for the consolidation move; Smith responded that Westinghouse did not *solicit* financial assistance from the Navy to finance the move. Neither Smith nor Admiral Russell volunteered the fact that funding — solicited or otherwise — had nonetheless been *received* by the AGT Division from the Bureau of Aeronautics. Representative Glenard Lipscomb of California asked Smith whether or not the government should increase its spending for jet engine R&D in general. "The more money that is spent on the research and development in any line," Smith replied, "the more results we will get."[253] Smith did not specify, however, who he thought should provide R&D money to Westinghouse.

Smith's performance at the Congressional hearings provides a revealing glimpse into the AGT Division's own attitude towards the pressing need to address and correct the engineering and management shortcomings made apparent by the J40 program. The transcripts suggest that the AGT Division did not accord the hearings much import or consequence. The AGT Division sent only four people to testify at the hearings, only one of whom (Smith) represented management of the Division. In contrast, McDonnell sent eight people including the company president and two vice-presidents, while the Bureau of Aeronautics sent 14, including the Assistant Secretary of the Navy, the Bureau chief, two assistant chiefs, and an acting chief.[254] Likewise, Smith's brief testimony was atypical of the participation of the witnesses from McDonnell and the Bureau of Aeronautics. Smith alone testified, and only for part of the afternoon of one day; aside from reading his short prepared statement and answering the subcommittee's questions, neither he nor any of the other Westinghouse representatives — including Russell Mathias, the J40 project's chief and therefore one of the most knowledgeable people on the subject — volunteered more. Smith declined several invitations from Chairman Holifield to make further statements on behalf of Westinghouse. In contrast, many representatives of the Bureau of Aeronautics testified extensively over all four days of the hearings, and McDonnell representatives did likewise throughout the final three days.

The House Subcommittee on Military Operations ultimately concluded that while the expenditures on Demon fighters and J40 engines by the Bureau of Aeronautics were excessive, there was no evidence of "dishonesty or improper influence in the awarding or termination of the airframe and engine contracts." The subcommittee also noted that the Bureau of Aeronautics' "prevailing attitude ... of resignation to the inevitability of frequent failures in development and 'slippages' in production" had led the Bureau to be more tolerant of problems in those areas than it should have been. Likewise, the subcommittee criticized the Bureau's failure to consider the AGT Division in default on its J40 deliveries despite repeated delays. Altogether the subcommittee made nine recommendations ranging from procurement and contract incentive practices to hiring of retired military officers.[255] Except for the issuance of its final report on the subject in March 1956, the subcommittee considered the matter closed following the hearings.

For the AGT Division, however, the testimony offered by Division manager Smith met with hostility from the Bureau of Aeronautics. The unrepentant tone of W. W. Smith's prepared statement and the evasive nature of his answers to questions did not please the Bureau. Smith had listed five factors he saw as contributing to the failure to produce the J40: too little manpower, lack of parts and facilities; lack of R&D; too few test engines; and scattered facilities. Read one way, this statement served as an admission of shortcomings at the AGT Division. Read another way — the way the Bureau of Aeronautics read it — the statement appeared to indicate that the AGT Division had not received all the necessary financial support for development and manufacture of the J40 engine that it had required.

When called on by Bureau representatives to explain and clarify his implication that the AGT Division had not received adequate support, Smith suggested that the Bureau had misinterpreted his statement but repeated that the AGT Division had not received enough R&D funding — from either Westinghouse or the Bureau.[256] The Bureau representatives who met with Smith were nonplussed by his response:

> In spite of the fact that the contractor will, as of the end of the calendar year 1955, have been paid over $1,600,000.00 in profit, and in view of the fact that in the past few years the Government has made available to the contractor approximately $75,000,000.00 for research and development, the contractor, in the same meeting, declined to admit any responsibility or obligation.[257]

While the statement fails to address the question of whether or not $75 million was, in fact, adequate for R&D support for the AGT Division, the Bureau certainly had the right to expect from the AGT Division recognition and acknowledgement of the Bureau's considerable financial contributions over many years.

Many senior officers within the Bureau believed that the AGT Division's ingratitude warranted a punitive response from the Bureau. Captain J. D. Arnold, director of the Bureau's contracting office, strongly recommended to Admiral Russell that the Bureau of Aeronautics respond to the AGT Division's "uncooperative position" by undertaking a review "of the entire field of operations of the contractor and of the bureau's present and prospective policy thereto."[258] Arnold suggested the imposition of a stiff $2.5 million price reduction on the AGT Division, consisting of the estimated $600,000 in AGT Division profits from 1954, plus $1.9 million for "misdirected or inadequate engineering emphasis." Arnold further suggested taking a similar "bite" from 1955 profits.[259]

Admiral Russell noted that financially punitive measures "may determine whether or not Westinghouse can stay in the engine business" and asked for the recommendations of his senior staff before making his decision.[260] Rear Admiral R. E. Dixon, Assistant Chief of the Bureau of Aeronautics, expressed his belief that "[u]nder the circumstances we are fighting for a principle," and suggested levying only the $600,000 penalty on 1954 profit.[261] The other senior Bureau officers concurred with Dixon's recommendation, noting that "WECO is ... down and should not be killed but spanked."[262] Again, the Bureau of Aeronautics gave the AGT Division an opportunity to learn from its mistakes, rather than simply withdrawing further support. Nevertheless, after 1955, though the Bureau repeatedly maintained that it harbored no particular resentment against them, the AGT Division never again received an order for large quantities of a new engine design from the Bureau of Aeronautics. In January 1955 the Bureau of Aeronautics slashed over 60% of the AGT Division's budget, reducing it from nearly $6.5 million to just over $2 million, forcing the Division to restructure its programs and drastically reduce its manpower.[263]

The appearance of new and more powerful aircraft gas turbine engines by General Electric and Pratt & Whitney Aircraft in the mid-1950s further diminished Westinghouse's share of the market. During those years both companies demonstrated that they possessed organizational capabilities more suited to manufacturing aircraft gas turbine engines according to the needs of the market. Both firms possessed extensive financial support for facilities and staff for both R&D and production. Both companies put their R&D staff to work designing and manufacturing new and ever more powerful engines on their own initiative, gradually seizing the development initiative away from the military. Both Pratt & Whitney Aircraft and General Electric were able to achieve these successes through the adaptability of their engineering practices to the evolving requirements of the market. Unable to match these accomplishments, between 1954 and 1956 the Westinghouse AGT Division played a decreasingly significant role in the American aircraft gas turbine engine manufacturing industry.

Because Pratt & Whitney's expertise traditionally lay in the development and manufacture of aircraft engines, the company already had in place excellent financial and facilities support; likewise, General Electric continued to provide significant financial support to its Aircraft Gas Turbine Division. Evidence for the success resulting from this support comes from an *Aviation Week* editorial written in early 1955 entitled "Our Engine Development Problem." In the editorial the journal's executive editor, Robert Hotz, echoed a recent statement made by Secretary of Defense Charles Wilson: "there have been too many engine development projects that have failed completely or have seriously delayed aircraft production." Hotz blasted the military for stifling competition by imposing specific requirements and standards upon the engine manufacturers, and stated

> [t]he record is clear that the hundreds of millions of taxpayers' dollars invested in jet engine development since 1946 have not yielded the dividends anticipated. However solid the engine builders' production record, the development picture has not been bright. *Of the five large engine builders, only General Electric and Pratt & Whitney have avoided major development fiascos.* [emphasis added][264]

As examples of General Electric's commitment, in 1954 the company initiated a "demonstrator engine" program, distinct from its production engine programs, to test new engine component designs free from the pressures of customer requirements.[265] Two years later it funded the construction of a wind tunnel capable of testing aircraft gas turbine engines to speeds in excess of Mach 3.[266]

Both Pratt & Whitney Aircraft and General Electric extrapolated new and more powerful engines from their previous designs, without limiting themselves to the specific military requirements that Hotz claimed were so detrimental to the industry. In 1954, due to radical organizational and managerial changes within its parent company, General Electric's Aircraft Gas Turbine Division pledged that it would strive to cut down future development lead-time by a year or more, and also promised "more advancement per dollar spent on development."[267] From 1954 to 1956 General Electric's jet engine division developed its J47 engine into a series of ever more-powerful versions that ranged from 5,425 pounds of thrust up to 6,000 pounds, all while reducing total weight by nearly 1,000 pounds. General Electric also evolved a new engine out of its workhorse J47, the J73. This new engine had the same external dimensions as its predecessor but produced 9,200 pounds of thrust, a 35% increase over the J47.[268] Further rapid design and development progress allowed the General Electric AGT Division to phase the J73 and the venerable J47 engine out of production in 1956 in order to concentrate on its powerful new J79, capable of 18,000 pounds of thrust, nearly twice the thrust output of the J73.[269]

Pratt & Whitney Aircraft likewise created a new design based on experience gained with its mainstay engine, the J57. Pratt & Whitney's new engine, the J75, used the same style of twin-compressor arrangement as the J57, with separate low-and high-pressure compressors lined up on concentric shafts, each connected to a separate turbine. The J75, which Pratt & Whitney introduced in 1954, was only slightly larger than the J57, but produced 17,200 pounds of thrust, 42% more than its predecessor.[270] Pratt & Whitney built nearly 3,500 J75 engines; the production run lasted until 1974, twenty years after it was first introduced.[271] Many mainstay military aircraft used the J75 engine, including the Republic F-105 Thunderchief fighter-bomber and the supersonic Convair F-106 Delta Dart interceptor.[272]

The engineering traditions and practices of both Pratt & Whitney Aircraft and the General Electric Aircraft Gas Turbine Division proved adaptable to meeting the requirements of the customers. Pratt & Whitney's management believed its organizational capabilities as an aircraft piston engine manufacturer were suitably compatible to the aircraft gas turbine engine industry; soon after the advent of the aircraft gas turbine engine, Pratt & Whitney Aircraft's management correctly assessed that, though jet engine technology was different from piston engine technology, the structure of the new industry would remain fundamentally the same as that of the old.[273] General Electric's jet engine division, like Pratt & Whitney, relied heavily on its improved R&D facilities to provide a steady stream of new and improved engines and engine components and demonstrated its ability to consistently mass-produce new engine designs.[274]

Faced with the possibility of having to withdraw from the aircraft gas turbine engine industry, the AGT Division attempted to address the shortcomings made evident by the Congressional investigation; despite taking significant steps in the right direction, between 1954 and 1956 the Division did not succeed in correcting those problems. In late 1953 the Bureau of Aeronautics threatened to withdraw funding support for the AGT Division; in response, Price attempted to demonstrate conclusively to the Bureau that he supported the AGT Division by providing the Division with millions of dollars in order to relocate its R&D facilities to new, enlarged quarters at the Kansas City plant, and promised that the Division would undertake the development of a new engine at its own expense. However, for a variety of reasons, these steps failed to bring about the significant changes to enable the AGT Division to reverse its fortunes.

In 1954 the AGT Division's new manager, W. W. Smith, announced that the AGT Division would specialize in developing engines in lower thrust ranges, a category overlooked by Pratt & Whitney Aircraft and General Electric; however, problems with funding and facilities prevented the Division from successfully exploiting this engine design niche. Smith's plan was to transition the AGT Division's organizational capabilities away from those required in steam turbine engine manufacturing, and towards those required in aircraft gas turbine engine manufacturing, through the increased use of R&D support of production.

> Future [design and production] emphasis will be on optimum-size aircraft engines rather than simply the highest power output. Westinghouse engineers are planning to work in the 2,000-8,000-lb.-thrust range — aiming at optimum combinations of weight-power ratios, low frontal area and [fuel consumption] rather than shooting for the highest possible power regardless of its cost in weight, drag and fuel ... .
>
> Westinghouse engineers believe the present complexity of jet engines and their controls make it ex1remely difficult and costly to produce large quantities fast enough to meet military combat requirements. They are devoting a major effort to simplifying designs to make engines easier to manufacture in quantity and to increase their operational reliability in the field.[275]

Smith's decision to abandon the race to build ever more powerful engines reflected the opinions of many industry observers who believed that the American jet industry had been neglecting to develop a "complete spectrum" of engines as had the British and French. Because of that neglect, few engine firms in the United States were manufacturing powerplants for trainers, helicopters, drones, missiles, and other low-and mid-thrust applications.[276] If the Westinghouse AGT Division could successfully fill that niche, then it could likely become a major aircraft gas turbine engine supplier once again. By radically reorienting the AGT Division's approach to engine design and marketing, Smith tried to move the Division into a market where its limited engineering resources, lack of mass-production experience, and preference for incremental increases in engine output would be assets, not liabilities.

President Price allocated $12.5 million for the relocation of the AGT Division's R&D facilities to Kansas City, though this took so long to accomplish that the Division began to suffer significant staff attrition and morale problems. From an organizational standpoint consolidation made eminent sense: by 1954 the AGT Division's senior staff, the bulk of its employees, and the majority of its engine production capacity were located in Kansas City, and the R&D facility in South Philadelphia was both too small and too distant for effective operations between the two plants.[277] "Westinghouse has every intention of staying in the jet engine business," Gwylim Price, Westinghouse president, told *Aviation Week* magazine, noting that the consolidation would put the AGT Division in "a far better position to do the development and production work necessary to insure our position as a major participant in this fast moving business."[278]

In order to consolidate the Westinghouse AGT Division Smith had to first close down R&D operations at the Navy-owned turbine laboratory in South Philadelphia, a decision which proved unpopular with the local community since the plant provided more than 2,500 jobs. Local civic groups and businessmen's associations cabled and wrote Congress and the Navy to ask Westinghouse to reconsider.[279] Senator Wayne Morse of Oregon objected to the move on the floor on the Senate.[280] James B. Carey, President of the International Union of Electrical Workers (IUE), pleaded with the Bureau of Aeronautics that "the workers and their families who are so concerned should be given assurances that they will not be thrown onto the streets."[281] The Bureau of Aeronautics repeatedly responded to the many objections by stating that Westinghouse had made its own decision, and the Navy could not dictate where Westinghouse should locate its plants.[282]

The Kansas City business community, on the other hand, received news of the consolidation move with pleasure and anticipation of the 2,500 people at the South Philadelphia plant, only 1,000 would be transferred from South Philadelphia; the AGT Division intended to hire the balance of 1,500 from the Kansas City area, a move which represented a payroll increase of $5 million.[283] One local editorial enthused that the move would "bring into existence the nation's largest jet aircraft development center."[284] Many local observers anticipated that the consolidation of all the Westinghouse AGT Division's R&D, production, and testing at one location might encourage other high-tech industries to relocate or expand to the Kansas City area. Concerned about the opposition to the move being expressed in Philadelphia, the editor of the *Kansas City Star* opined that "Kansas City has its big concern with the issue and it had better be prepared to fight for its own interest."[285] In the end, no fight proved necessary; the objections did not prevent Westinghouse from awarding contracts for the design and construction of the new R&D facilities in late 1954.[286] Nevertheless, when construction began in March 1955, Westinghouse president Price told the AGT Division staff "there shall be no fanfare and no publicity relative to this ground breaking and no official statements should be made."[287]

Despite the importance of the consolidation to future engine development and production at the Westinghouse AGT Division, the move took all of 1955 and 1956 to completely accomplish, which dealt a costly blow to the AGT Division's plans. At first, the staff reductions and transfers occurred swiftly, but in early 1955 the dates for the South Philadelphia plant shutdown quickly began to slip because the new R&D facilities were not completed.[288] Completion of the facilities in Kansas City depended on the approval of the Bureau of Yards and Docks, the Navy branch responsible for plant construction, approved the design drawings and plans for the new R&D facilities, and the AGT Division experienced significant delays in getting the approval from the Bureau.[289] In addition, the Bureau of Aeronautics found that the AGT Division had not satisfactorily kept up maintenance on part of the plant, which was owned by the Navy, and insisted that the Division first fix the damage.[290] Two major Westinghouse strikes in 1955 also contributed to the delay. The first, at the Kansas City plant from June to August 1955, slowed construction of one of the R&D buildings. The second, a major Westinghouse strike that began in October 1955 and closed plants across the country, kept the South Philadelphia plant closed despite a court injunction to open it.[291] Originally, AGT Division management expected to have South Philadelphia closed out by the middle of February, 1955; as a result of these delays the date quickly slipped to March, May, and then December 1955, and then to March 1956.[292] Not until the spring of 1957 — nearly *three years* after Price began the process of acquiring them — were the facilities finally ready.[293] In the meantime, in 1954, 1955, and 1956 development engineers could not test new engine and component designs, or else send them back to the understaffed South Philadelphia plant.

The multitude of frustrating problems that the engineering, research, and production staffs of the AGT Division faced during the many transitions of 1954 and 1955 resulted in a variety of morale problems throughout the plant, including alarming rates of attrition. The topic came up in a meeting of the senior Engineering staff in May, 1955:

> In general, the cut backs that we have had in our Engineering Department ... has [*sic*] resulted in a general lowering of the morale in the Engineering Department. This has also been combined with the recent concerted efforts made by our competitors in local hiring campaigns. In general, we feel that our situation as far as our engineers are concerned is much more encouraging than the feeling that they themselves have. Steps should be taken as soon as possible to correct this undesirable situation.[294]

Rein Kroon pointed that out one way to alleviate the morale problem might be for the senior engineering supervisors to spend more time talking with and getting to know the junior engineering staff. Kroon, who with members of the Industrial Relations Department formed an outreach program to recruit promising local engineering talent, also suggested that hiring engineers from area schools might decrease attrition because they would find themselves less homesick than people hired from farther away.[295] Nevertheless, despite such half-hearted measures, engineering and other staff continued to leave the AGT Division, many of them senior staff; for example, two senior engineering staff members left for the new Westinghouse Atomic Power Division within a month of each other, and one engineer even defected to a rival aircraft engine firm.[296]

In addition to money to build R&D facilities at the Kansas City plant, Price provided the AGT Division with an additional $8 million for the development and testing of a new aircraft gas turbine engine — the J54 — solely on the company's own initiative; without the completion of the R&D consolidation little could be accomplished until several crucial years slipped past. Following the final cancellation of the J40, the AGT Division at first turned its attention to developing another major engine design, the J46. This engine, which represented the AGT Division's preference for conservative, progressive engineering improvements over radical development, was essentially a redesign of the AGT Division's most successful engine, the workhorse J34.[297] First introduced in 1950, it produced 4,500 pounds of thrust, a modest 20% increase over contemporary models of the J34.[298] Though the engine received generally favorable reviews in service in the Vought F7U Cutlass tailless fighter during the early 1950s, the Navy did not order large quantities of the engine, partly due to the poor performance of the Cutlass.[299] The AGT Division next placed its hopes for continued jet engine production in the in-house design promised by Price, the J54.

The AGT Division intended that the J54 engine should reflect all the best features of its recently-adopted engineering philosophy of rugged, lightweight, mechanically simple, mid-sized aircraft gas turbine engines. Accordingly, the Division proudly characterized the J54 as "the Westinghouse answer" to military and civilian powerplants with those requirements.[300] Gwylim Price told a *Wall Street Journal* reporter, "We think we've got a fine engine ... . The Navy knows about [the J54], and I think in a year or two we'll be back in the jet engine business full blast."[301]

Inauspiciously, the AGT Division J54 project engineers began designing the engine on April 1, 1954. The design called for the engine to be capable of just over 6,000 pounds of thrust (10,000 pounds for brief periods with the optional afterburner) to a maximum operational altitude of 85,000 feet. The engine's basic design featured a combination of tried-and-true Westinghouse engineering practice with some radical innovations. The J54 had a 16-stage axial-flow compressor and a two-stage turbine arranged on three bearings, like all previous Westinghouse aircraft gas turbine engines except the J40, which had only two bearings.[302] On the other hand, the engine featured several novel innovations for a Westinghouse engine. The design made extensive use of titanium, aluminum, and magnesium alloys to keep the weight down.[303] The design called for making blades on ten of the compressor stages, and the entire compressor/turbine shaft, out of titanium — a relatively new and exotic metal with which the AGT Division had little or no prior experience. The compressor had to be able to operate in the transonic speed range, which Westinghouse aircraft gas turbine engines had not previously done.[304] In order to increase fuel efficiency and power output, the engine's compressor had a compression ratio of 9:1, considerably higher than the 4.35:1 ratio of the contemporary version of the J34 engine.[305]

AGT Division engineers first test-ran the prototype J54 — which did not include the titanium compressor blades or shaft — on March 19, 1955. The same engine completed a 50-hour endurance test four months later, validating the basic mechanical design of the engine and satisfying one of the Bureau of Aeronautics' criteria for considering the purchase of the engine.[306] The Westinghouse AGT Division put into motion a large-scale marketing and sales campaign to promote the J54 engine. The Sales and Engineering departments worked together closely to create brochures that would be both appealing to potential customers and effective in generating interest in the engine's potential. Beginning in May 1955, AGT engineering staff visited 37 airframe manufacturers and government agencies, making presentations about the J54 engine and attempting to generate interest in production orders.[307] The West Coast sales campaign returned results that were only "good with a touch of indifference at various locations." For the most part, commercial aircraft manufacturers expressed little interest in the J54, while several manufacturers of military aircraft thought they might have a use for it at some later date but made no firm commitments.[308] The engineers marketed the J54 as a jack-of-all-trades engine, pitching it for use in bombers, attack aircraft, drones, commercial aircraft, helicopters, transport, and missile applications — anything that would generate sales.[309] Chief Engineer Allan Chilton himself made a series of J54 presentations to representatives of the Air Force and Bureau of Aeronautics, and described the results only as "good."[310]

Chief Engineer Chilton stressed that the favorable attitude of the military was due in large part to successful tests with the all-steel first engine. He urged the J54 project engineers to proceed carefully with the tests of the second engine, which contained the titanium compressor blades and main shaft. Success in acquiring J54 engine production contracts depended heavily on the tests of the titanium engine. Within a month of the first test of the all-steel J54, however, project engineers were already reporting problems with the first batch of forged titanium blades received from the shops. The time necessary to correct the problems immediately began slowing up the engine's development timetable.[311] As a result of delays with the titanium forgings (and complicated by the U.A.W. strike at the Kansas City plant), the second J54 engine, which was originally scheduled to go to the test stand in June 1955, did not reach the stand until late August.[312]

The J54 ultimately had a very short existence. The second, titanium engine successfully completed its 50-hour qualification test in late October or early November 1955. The following month, the Bureau of Aeronautics accepted the first two J54 prototypes for a symbolic price of one dollar, in order to evaluate them in ground tests.[313] The AGT Division began testing one of the engines in flight in November 1956, underneath a B-45 flying testbed aircraft at the Division's Olathe, Kansas flight test center.[314] But the two engines purchased by the Bureau of Aeronautics were the only two that the AGT Division ever delivered.[315] The AGT Division had a total of six J54 engines in various stages of completion by the end of 1955 and kept some aspects of the J54 program alive through at least the middle of 1956 but without evidence of a large order from the Navy to get

J54 production underway, the AGT Division could not drum up sales to other customers.[316] As a result, the J54 program quickly and unexpectedly collapsed after three years of hard engineering and sales work on the part of the AGT Division. Nevertheless, the AGT Division had one fall-back option left — creating new outlets for its engines by broadening its customer base, especially in the emerging commercial aviation market.

The AGT Division had grown so dependent on the monopsony of the Bureau of Aeronautics that it neglected to broaden its customer base; in 1954-1956 the Division tried to break into the emerging commercial market, but lack of funds, facilities, and experience prevented success. In the mid-1950s, the new, more powerful, and more reliable engines that kept emerging from General Electric and Pratt & Whitney Aircraft permitted these two engine firms to cultivate new customers with broader ranges of applications, especially in commercial aviation, where, during that time, airframe firms were increasingly incorporating aircraft gas turbine engines into their new aircraft designs.[317]

The Westinghouse AGT Division, however, did not follow suit. The AGT Division tried to branch out into the development and manufacture of aircraft gas turbine engines for commercial applications, but lacked the R&D and production engineering expertise to break into the market competitively. The AGT Division desperately needed access to this market to compensate for its dwindling military business, but lethargy on the part of the Division and the parent company doomed these efforts. For example, in April 1955 Westinghouse formally asked the Bureau of Aeronautics for permission to use the Kansas City plant, which the Navy owned, for the production of non-military engines. The Bureau offered to lease the plant and its equipment to Westinghouse for such production; company management, displaying the kind of stinginess that had long riled the Bureau of Aeronautics, countered with a proposal whereby the Westinghouse AGT Division be allowed to build commercial engines without paying a lease. Negotiations over the lease issue in Washington and Pittsburgh dragged out through most of the year without resolution.[318]

The AGT Division attempted to exploit develop a better understanding of the needs of the commercial airline market, but its efforts were half-heated and the attempt quickly failed. "In view of our continued interest in the commercial end of our business," suggested Westinghouse engineer Arnold Redding at a staff meeting of the Engineering Department, "it might be well to appoint a man in Engineering as 'Mr. Airlines' who would be fully up-to-date on all phases of this activity."[319] Having one person in the Division who would establish and maintain contact with the airlines and commercial airplane manufacturers contrasts with the other firms, which each maintained a large staff devoted to product marketing. Even this limited effort does not appear to have been followed up to any extent; the AGT Division's contacts with airlines appear to have been very limited, and its contacts with airframe manufacturers were limited to sales pitches for particular engines.

The AGT Division attempted to develop commercial variants out of existing engines, but failed to sell any. The United States civilian jetliner market in the mid-to late 1950s was still in its infancy; airframe manufacturers preferred to utilize military designs, such as the Pratt & Whitney J57, which had already been developed to the point of reliability.[320] The AGT Division's lack of R&D infrastructure prevented the Division from creating engines with the reliability and growth potential needed by the industry. The Division did secure rights from Rolls-Royce to manufacture the English firm's already-developed Dart turboprop engine; despite an increase in the number of turboprop-powered civilian aircraft in the United States in the mid-1950s, the Division failed to sell Darts that were either license-built by Westinghouse or built in England and shipped into the United States.[321] (The Dart, like other turboprops, was an aviation gas turbine engine which derived most of its propulsive power from a propeller geared to the turbine, rather than solely from jet thrust output.)[322] In 1956 the AGT Division also obtained commercial certification for its venerable J34 engine from the Civil Aeronautics Administration, after having ended production of the military version of the engine the previous year.[323] However, no civil aircraft appear to have ever used J34 engines, and there are no indications that the Division actively marketed the engine. Despite these halting efforts, and more sales trips by AGT Division engineers to various airframe manufacturers, the Division obtained no orders for commercial J34 engines.

Finally, the AGT Division tried to develop new engine designs but failed to secure production contracts, which were vitally necessary if the Division was to remain in the aircraft gas turbine engine industry, Beginning in 1954, solely on the AGT Division's own initiative — and with only the inadequate and shrinking R&D facilities in South Philadelphia — the research engineering staff in Kansas City under Reinout Kroon embarked on a series of engines they called "PDs," for "Preliminary Designs," These engine designs quickly became the primary focus of the Division's R&D program.[324] The AGT Division engineers hoped that the most promising designs would receive development funding and eventually production orders from the military and commercial users, The PDs, which were mostly derived from Rolls-Royce engines obtained through a technical-exchange agreement with that company, were so essential to the future of the Division that the Bureau of Aeronautics recognized "it is of the utmost necessity that this type of development be continued if the contractor is to stay abreast of development and in the jet engine business."[325] The Division offered many varied PD proposals, often straining their dwindling engineering and drafting department manpower in doing so.

Though Kroon and his staff fielded several PD engine designs, none of them sparked interest in military or civilian airframe firms. The PD-29, the Westinghouse version of the Rolls-Royce Soar engine, served as the testbed for the J54 compressor. The Soar was a small powerplants designed for use in drones or helicopters. Though the AGT Division built one engine, it suffered repeated compressor and turbine blade failures.[326] The PD-42 was to be a turbofan engine capable of 15,000 pounds of thrust capable of operating at speeds up to Mach 3. Initial sales pitches to West Coast airframe manufacturers resulted in only lukewarm responses.[327] The PD-34 was not a complete engine, but rather a compressor designed to operate in the transonic range.[328] In response to an industry-wide design study competition for a "research engine," the AGT Division offered the PD-41, which secured a contract for a preliminary study in July 1955 but nothing else.[329] The AGT Division also instituted a study of the possibility of developing nuclear powered aircraft engines, along similar lines to programs underway at GE and Pratt & Whitney.[330] None of these PD engine designs, however, were put into production; many were not even developed past the preliminary design stage.

Between 1954 and 1956, the Westinghouse AGT Division engineering and design staffs made the maximum effort to design, build, and sell engines in order to reclaim a share of the military aircraft gas turbine engine business. Failing that, the Division tried to break into the civil engine market; for a variety of reasons — failure to obtain Navy permission to use the plant for commercial production, inability to obtain orders, and an almost total lack of experience with the commercial aircraft gas turbine market — the AGT Division did not obtain a foothold there.

By 1956 the AGT Division's reorganization and consolidation plan, on which W. W. Smith had pinned the Division's success, had completely lost its momentum. The halt was the result of the demoralizing effects of the delayed R&D program, lack of more than token company financial support, cutbacks in Navy financial support in the wake of the Congressional investigation into the J40, staff attrition, and the Division's failure to develop a broader customer base. Having finally taken steps to abandon steam-turbine engineering traditions in favor of reliance on a more systematic research and development program, delays in implementing that R&D support left the Division bereft of chances to develop successful products in an increasingly-competitive industry. The AGT Division's fortunes were at such a low in 1956 ebb that even the Division's penchant for legerdemain in public relations could not completely hide the fact.

> We have problems — plenty of them. However, a creed in the industry is "If you're not in trouble, you're not in aviation." During the past few years we have been replaced as No.1 in the industry. We are now in the midst of an ambitious, aggressive program to regain this position.[331]

By the end of 1956 Smith's "ambitious, aggressive program," first announced publicly in 1954, had failed to alter the Division's fortunes. With that failure ended the last major effort — and chance — to turn around the Westinghouse AGT Division's fortunes in the aviation gas turbine engine field. The AGT Division's situation had deteriorated so far by 1956 that Leonard S. Hobbs of United Aircraft, in an internal memorandum surveying the aircraft gas turbine industry in 1956, uncharitably — but essentially accurately — opined that "it does seem ridiculous for Westinghouse to be squatting there [in Kansas City] with only a vague fighter to look ahead to."[332]

Part 3: "Dreaming Over the Lunch Table": Withdrawal, 1957-1960

By the end of 1956, the Westinghouse AGT Division had ceased to be a major manufacturer of aircraft gas turbine engines. The Division failed to interest the Navy Bureau of Aeronautics or any other potential customers in its developed products — the medium-sized J46 and J54 aircraft gas turbine engines — or in its "PD" series of prototypes. The period of 1957-1960 represents little more than a postscript to the Westinghouse AGT Division story. During that time, the Division, gradually shrinking in manpower and budget, eked out a little business for itself only through occasional contracts from the Bureau of Aeronautics for improved versions of its venerable J34 engine, and through small contracts for spare parts and overhaul of Westinghouse engines already in service. With the departure of Westinghouse president Price in 1957 and the reorganization of the Bureau of Aeronautics in 1959, the AGT Division lost what little support it still enjoyed and dwindled in size and impact until its remnants were finally dismembered shortly thereafter.

By 1960, the Westinghouse AGT Division had failed to adapt its organizational capabilities to the demands of the new technological industry. It had failed to generate sufficient financial support from company management, failed to aggressively pursue a broader customer base with new engine designs developed solely on the company's own initiative, and to develop engineering practices suited to the successful mass-production of aircraft gas turbine engines. As a result, in 1960 Westinghouse abandoned the industry which it had helped pioneer. In its final three years, the AGT Division was constantly forced to reduce its manpower and expenditures to reflect a gradual reduction in budgetary allocation from the company and from the Bureau of Aeronautics and its successor, the Bureau of Naval Weapons. The engineers and staff that remained, unable to look forward to meaningful projects and faced with the daily threat of the loss of their jobs, became interested in little else than day-to-day survival. Their fatalism only accelerated the downward spiral in which the AGT Division became inextricably trapped from 1957 to 1960. One former AGT Division engineer characterized the few plans to revive the Division that sprouted up during this time as little more than "dreaming over the lunch table," powerless fantasies about lost opportunities.[333]

The AGT Division's dependence on the Bureau of Aeronautics for financial support and orders left the Division with a narrowing range of options after 1957 as this support gradually dried up. Because of its failure to develop a new customer base from 1954 to 1956, the Division had almost no other choice than to turn back to the Bureau in search of development and production contracts. The Bureau, however, clearly demonstrated to the Division that it had little intention of providing further succor. Ever since the failure of the J40 program conclusively demonstrated to the Bureau of Aeronautics the unrepentant attitude of the Westinghouse AGT Division toward its own failures, the Bureau's attitude towards the Division had hardened considerably. This hardening is evidenced by the fact that the Bureau did not support the promising J46 or the struggling J54 engines as it once had done the equally problematic J30 Yankee and J40 engines. The Bureau did have requirements for Westinghouse J34 engines, but they were minimal. The Bureau also had a self-interest in maintaining the AGT Division as a provider of maintenance and support for engines it had already delivered, but evinced no interest after 1956 of supporting the development of another engine. Following the reorganization of the Bureau of Aeronautics in 1959 as the Bureau of Naval Weapons, the new agency discontinued the policy of its predecessor of supporting contractors in government-owned facilities, a decision which effectively threw the AGT Division out onto the street.

Between 1957 and 1960 the Bureau of Aeronautics placed several orders with the AGT Division for uprated versions of the J34 engine and for spare parts and maintenance of 34s in service, but these orders were not enough to keep the AGT Division operating at more than minimum engineering and production staffing levels. In 1956, the AGT Division successfully campaigned for a contract to build a new, slightly more powerful version of the J34 for the Bureau of Aeronautics, and put the engine back into production after having completed contracts for the previous version in 1955.[334] In March 1957, the Bureau awarded the Division an additional $2 million contract to implement modifications to the turbine blades and various small components on the new J34 version, which provided some additional work.[335] Eight months later, the Bureau awarded the AGT Division a more substantial $26 million contract for an even more powerful version of the J34 which the Division had developed; the Bureau of Aeronautics announced that it planned to use the engines on its new North American T2J-l Buckeye trainer, and accepted the first J34s in June 1958.[336] On Christmas Day 1958, the Bureau of Naval Weapons placed an additional $15 million order for more J34 engines to be used in the Buckeye trainer. Though these two production contracts considerably aided the AGT Division, the new orders did not require the Division to increase its engineering or production manpower, which remained at about 2,500 employees.[337]

In addition to the production of new engines, the AGT Division also provided spare parts and maintenance for J34 engines already in service with Navy; contracts for these services provided some additional, but limited work and money for the AGT Division. One contract, in November 1958, was for $6 million is spare parts for J34 engines, was described as "the largest single [parts] order received by the jet plant here in four years.[338] Most others were for far less — $1.5 million in one case[339] — but provided a steady trickle of money into the AGT Division to tide the Division over between larger engine production contracts. As Bright points out in his study of the aerospace industry to 1972, in the late 1950s the military services drastically cut back on orders for spare parts as part of austerity drives in the wake of appropriations cutbacks.[340]

Commensurate with the decline in new R&D and production orders at the AGT Division, the Division's budget shrank considerably and the Division was forced to reduce its staff accordingly. As early as 1957, faced with no new orders and reduced financial support from the Bureau of Aeronautics and the company, the AGT Division, under instructions from management of the Westinghouse Defense Products Group, began reducing its engineering manpower and allowable expenses in earnest, and despite hopes to the contrary did not stop the reduction until both had reached zero. The reduction began as a result of the loss of a bid for an engine research contract. In 1956 the Westinghouse AGT Division, Pratt & Whitney Aircraft, and other engine manufacturers all bid to develop a new engine, the J58, for the Navy. The Bureau of Aeronautics awarded the development contract to Pratt & Whitney Aircraft in mid-1956.[341] In early 1957, Westinghouse president Gwylim Price wrote to the Secretary of the Navy, Neil H. McElroy, regarding the failure of the AGT Division to receive the J58 contract. Price's unusually candid letter illustrates the desperate situation the AGT Division faced as a result:

> We have received production contracts which will meet minimum requirements for production for a period of 11 to 18 months to enable us to maintain a moderate production organization. However, we have not received adequate research and development contracts effectively to utilize the preliminary design and development groups in our engineering department. Since we cannot continue to support these groups with our own funds, we plan to disband these groups (approximately 500 engineers and supporting technicians) ... in the absence of governmental support for them. This action will eliminate Westinghouse as a source of research and development work in the jet engine field.[342]

The Bureau of Aeronautics did not subsequently provide the AGT Division with large R&D contracts; as a result, the Preliminary Design staff — one of three R&D teams under Director of Research Reinout Kroon — disbanded in February 1957.[343]

The PD staff represented only the first round of personnel losses. One month later, the AGT Division laid off 60 hourly engineering personnel to compensate for budget shortfalls, in addition to "a proper percentage" of salaried staff let go at the same time.[344] In late 1958 the Division began a steady engineering staff drawdown in earnest; the securing of J34 production contracts, for which little new design engineering work was required, did little to keep the engineering staff productively busy. Chronicled in monthly reports by the Engineering Department to W. Waits Smith, the statistics read like a death watch on the Division. Staff and expenditures declined drastically beginning in late 1958. In December of that year, the Engineering Department had a total of 821 employees (316 of which were engineers) and spent $1.073 million on its projects.[345] Within six months, the department had been reduced by 87 people but spent only $846 thousand, a reduction of 22%.[346] Financial reductions continued along the same gradual incline, with occasional surges upward in expenditures due to various new projects, but the number of staff dropped more precipitously.

In January 1959, amid contract cancellations and wholesale reductions in expenditures and staff, the AGT Division celebrated its tenth anniversary in Kansas City. At what was no doubt a bittersweet event, the Division dug into its dwindling reserves to buy enough birthday cake to serve the remaining production-line employees and engineering staff, and W. W. Smith awarded gold 10-year service pins to 32 men who were the first Kansas Citians hired by Westinghouse to work in the plant.[347] But the end was already looming in sight. Ten months later, in October 1959, Westinghouse Electric announced to the AGT Division a plan for further reduced personnel requirements and program goals for the Division in 1960; this announcement resulted in an accelerated decrease in engineering employees in late 1959, by 235 in December alone. That month, the Engineering Department spent $1.028 million, mostly due to a series of J34 turbine tests contracted for by the Navy, but the number of employees in the department had dropped to a total of 440 — a decline of 41% since May of that year.[348]

In February 1960, the Division's engineering staff had been reduced to 423 people, and its engineering expenditures to $663 thousand.[349] Between February and March, 1960, the AGT Division received three severe blows in quick succession, as a result of which Westinghouse Electric completely disbanded the AGT Division at the end of that year. In the span of two months, the Bureau of Naval Weapons canceled a vital J34 production contract which left the AGT Division with no engines to build, the Bureau suddenly announced that the AGT Division would soon have to move out of the Kansas City plant, and Westinghouse Electric's senior management decided that the AGT Division's profit ratio was too small to justify continued support as an operating division of the Company. As a result of these three events, the fate of the Westinghouse AGT Division had finally been sealed.

The surprise cancellation in late February 1960 of a large production contract signaled the definitive end of aircraft gas turbine engine manufacturing at the Westinghouse AGT Division in Kansas City. The $11.4 million contract dated from late September 1959, when the Bureau ordered a version of the J34 engine that incorporated a new single-stage turbine in place of the original two-stage turbine. At the time the contract was awarded, he AGT Division's manager, W. W. Smith, announced that the J34 contract would permit the Division to halt the layoffs and maintain its current employment level until August 1961.[350] However, on February 19, 1960, the Bureau of Naval Weapons suddenly and unexpectedly issued an announcement canceling the vital contract.

> The Navy announced today termination of the uncompleted portion of its contract with Westinghouse for [J34] jet engines, a power plant for its T2J-1 jet trainer. This termination follows a decision to phase out the T2J-l program with the fiscal year 1959 procurement ... . With delivery of aircraft contracted for in the fiscal year 1959, the needs of the training command will have been met. Procurement previously planned in the fiscal year 1960 budget is no longer required.[351]

The cancellation of the T2J-l version of the Buckeye, however, did not actually signal the end of production of the aircraft, as the press release suggested. While the Bureau purchased only 217 of the T2J-l, over the next several years it purchased over 300 more Buckeyes, improved versions designated T-2A through T-2C — all powered by engines built by Pratt & Whitney Aircraft or General Electric.[352]

One Bureau of Naval Weapons officer commented that the staff of the Westinghouse AGT Division would likely be "reduced to zero" by the J34 contract cancellation.[353] However, the announcement of the contract termination did not immediately hasten the staff and expenditure reductions at the Kansas City plant. Engineering Manager D. W. Berry reported to Waits Smith that the cancellation, "although leading to [the] ultimate cessation of engineering activity" at the AGT Division, would not have much of an effect on spending until after March at the earliest. Beginning in April, however, the pace of staff and expenditure reduction increased significantly. Between February and March, the AGT Division's Engineering Department let 20 people go; in April, that number jumped to 63 and thereafter averaged almost 50 people per month until August; in November 1960, there were only 93 people left in the Engineering Department. Expenditures during that time dropped to just over $200 thousand a month, less than 20% of what Engineering had spent two years previously.[354]

The effects of the contract cancellation on the Kansas City area were more immediate than they were at the AGT Division. One editorial called the cancellation "a finishing punch" to defense-related work in the region.[355] The AGT Division, as surprised as the community, at first could offer little additional information about future employment prospects. "We'll have to sit down with [Bureau of Naval Weapons officers], review the contracts and their requirements before we know just where we are," an AGT Division spokesman said the day after the announcement.[356] Throughout the rest of February, city, state, and labor officials mobilized in an attempt to forestall the increased unemployment resulting from the predicted shutdown, but to no avail. Senator Stuart Symington of Missouri sent a telegram to the Secretary of the Navy, William B. Franke, stating he was "deeply disturbed" by the loss of jobs as a result of the cancellation.[357] Officers of United Auto Workers local 324, which represented the plant employees, met the day after the announcement to discuss the situation; the Kansas City Chamber of Commerce met with Westinghouse employees and then with company executives; the mayor called for the formation of a jobs committee.[358]

The efforts of Kansas City citizens and organizations to keep the plant in operation, however, proved to be in vain because of another, more fundamentally important, decision by the Bureau of Naval Weapons made at roughly the same time as the contract cancellation. In 1960, as part of a comprehensive reorganization, the Bureau of Naval Weapons decided that it would no longer operate Naval Industrial Reserve Plants, preferring to let commercial firms operate their own plants; as a result, the AGT Division suddenly found that soon it would be without a home base. Both General Electric's Aircraft Gas Turbine Division and Pratt & Whitney Aircraft possessed their own R&D and production facilities; the Westinghouse AGT Division, located in the Naval Industrial Reserve Plant in Kansas City, had not occupied Westinghouse property since moving its production and engineering personnel out of the Steam Turbine building in 1949.

The Bureau's decision to cease supporting government-owned plants was in keeping with contemporary military thinking regarding sponsorship of contractors and is an example of how, during the 1950s, the initiative for new product development in the aviation gas turbine engine industry gradually devolved from the customers onto the manufacturers. During the late 1950s, military procurement trends changed as a result of the growth of the missile industry and a reduced level of aircraft gas turbine engine production. Missile manufacturers tended to build their own testing and production facilities, instead of renting government plants. Increasingly, jet engine manufacturers tended to do likewise. "By the late 1950s a broad mobilization base was no longer required, and high-volume production ceased," wrote Herman O. Stekler, in his analysis of the aerospace industry and its relationship to the government during the 1950s and 1960s. "The government, therefore, directed that, wherever possible, procurement awards be made to privately financed plants."[359] In the late 1950s the military recognized that a growing number of aviation gas turbine manufacturers — Westinghouse excepted — had developed or were developing in house R&D and production to a level sufficient to take on an increasing share of support from the government.

Not all of the AGT Division's setbacks in February and March 1960 were caused by the Navy. Because the AGT Division failed to generate new contracts and hence sufficient profit, it finally succumbed to the fiscal axe of Mark Cresap, who succeeded Gwylim Price as president of Westinghouse Electric in 1957. Since being brought into the Westinghouse senior management in 1951 by Price, Cresap monitored the health of Westinghouse in terms of the profitability of its component divisions. When Cresap succeeded Price as president of the company in December 1957 amid dramatic changes in the company's management and organizational structure, Cresap's focus on profitability became a paramount concern. As Ronald Schatz pointed out, both Mark Cresap and his rivals at General Electric embarked on reorganization plans that strove to "reinvigorate the electrical corporations as profit-making enterprises by forcing their diverse component parts to act as aggressively as if they were competitive, medium-sized businesses."[360] The AGT Division traditionally generated little profit for Westinghouse, and thus became a prime target for scrutiny. As president, Cresap established a "profit detractor's club," which singled out Westinghouse divisions for "special attention from headquarters" if they consistently lost money, or if they provided a 5% or less return on investment.[361] By the end of 1955, more than ten years after introducing its first production aircraft gas turbine engine, the AGT Division had realized only $1.6 million in profit for the company, despite the infusion since 1954 of over $20 million of company funds, representing at the most a dangerously low 8% return on Westinghouse money.[362] While a low return on investment was not unusual for aviation engine manufacturers during the late 1950s and early 1960s, the percentage was lower than other Westinghouse product divisions during that time and far lower than returns being achieved by airframe manufacturers.[363]

Changes in the management of the Westinghouse Defense Products Group also resulted in increased critical scrutiny of the AGT Division. Under Cresap, the Defense Products Group came under the control of Edwin V. Huggins, whose job was to "shake up" the Group. In turn, Huggins named as his vice-president an energetic, 50-year-old retired Air Force General, Albert Boyd, to help Huggins "put new vigor into the company's defense business."[364] Despite assurances by Huggins and Boyd that the AGT Division would continue to play a "key role ... in the company's long range defense product planning," the shrinking budget and small contracts provided to the AGT Division by the Bureaus of Aeronautics and Naval Weapons after 1957, and the failure to secure new customers, suggested to Huggins and Boyd that they could expect only diminishing returns from the Division in the future.[365] The announcement by the new Bureau of Naval Weapons would no longer maintain NIRAP facilities for contractors probably only hastened the decision to dismantle the AGT Division, since the costs to the company of constructing a new facility for the Division would likely be out of all proportion to its potential profitability once installed there. The broader, industry-wide view was no more reassuring to Westinghouse management. Beginning in the mid 1950s, the military intensified its support of rocket-powered ballistic missiles, which resulted in a decline in orders for jet engines; the intensified competition for fewer contracts would have correspondingly decreased the AGT Division's chances for securing new orders.[366] Between 1957 and 1960, the Navy, the AGT Division's primary customer, increasingly invested in missile technology.[367]

Based on the lack of present or future business for the Division, and its impending removal from the Kansas City plant, Cresap, Huggins, and Boyd saw no alternative except to disband the fifteen-year-old AGT Division. The company formally announced its decision on March 22, 1960. The announcement stated that the decision to disband the Division was due solely to "steadily declining requirements for jet engines and the increasing emphasis on missiles and rockets."[368] The announcement did not declare when the disbanding would take place, but shortly thereafter AGT Division manager Smith ordered Division Engineering Manager D.W. Berry to further decrease expenditures after April 1960 and implement plans for the future reduction in engineering expenditures and personnel throughout the rest of 1960 until all remaining work had been completed.[369] By December only four supervisors and one clerical staff member remained in the Engineering Department. Winston R. New, whose closed-cycle gas turbine engine was the inspiration for the Westinghouse J30 Yankee in 1941, was one of those who remained until the very end.[370]

Despite the announcement of disbanding of the AGT Division, the Bureau of Naval Weapons still desired to maintain in operational service the Westinghouse J34 engines that it already had. As the Bureau of Aeronautics had once done fifteen years previously, in November 1960 the Bureau of Naval Weapons turned to Pratt & Whitney Aircraft for help. This time, the Bureau asked the engine manufacturer to take over "responsibility for servicing, engineering, and spare parts" for the Westinghouse J34 engines still in service.[371] The last Navy contract the engineering staff of the AGT Division completed was the packing up of all the necessary technical material — plans, drawings, reports, and manuals — into filing cabinets for shipment to Pratt & Whitney Aircraft.[372] Under the J34 Product Support Program, the Bureau of Naval Weapons shipped J34 engines to East Hartford where Pratt & Whitney engineers subjected whole engines and components to a variety of endurance tests as well as maintained them in flight-ready conditions for the Navy.[373] The Product Support Program continued until late 1973, when Pratt & Whitney Aircraft engineers requested of the Navy that, since the number of repairs and tests had gradually dwindled to zero, the program be discontinued.[374] The Navy agreed, but continued to operate J34 engines in dwindling numbers until, by 1977, thirty years after the Westinghouse AGT Division introduced the original version of the design — and seventeen years after the organization which built them had disbanded — the Navy still had 432 of the J34 engines in its inventory, 40 in active Lockheed P-2 Neptune maritime reconnaissance aircraft as auxiliary power plants, seven in drones, and the rest in storage and repairable for service. The long service life of the Westinghouse J34 aircraft gas turbine engine with the Navy thus serves as both paradox and irony to historians of technology; the J34 had such a long service life because it best exemplified the Westinghouse AGT Division's engineering philosophy of gradual, incremental development and *ad hoc* modification — the same philosophy which contributed significantly to the ultimate failure of the AGT Division in the aviation gas turbine engine industry.

From 1957 to 1960 the senior officers of the Bureau of Naval Weapons and the management of the Westinghouse Electric Corporation increasingly viewed the Westinghouse AGT Division as an economically non-viable entity. The sequence of events in February and March 1960 — which were made virtually inevitable by the many critical failures of 1953 through 1956 — happened with a rapidity which suggests the collapse of a house of cards. The analogy is borne out by the treatment the closure received in the press. The passing of the Westinghouse Aviation Gas Turbine Division generated scarcely any attention in the aircraft gas turbine engine industry, which it had helped found, but in which it had become an increasingly insignificant member. The March 28, 1960, issue of *Aviation Week* carried the AGT Division's obituary on page 37, in a brief, one-paragraph announcement in their "News Digest" column, in which the actual event of the disbanding is confined to one sentence:

> Westinghouse Electric Corp. announced last week that it is withdrawing from the jet engine business and plans to return to the Navy the Kansas City, Mo., facilities that house the firm's Aviation Gas Turbine Division. Westinghouse shares the Navy-owned Kansas City facilities with Bendix Corp., which occupies approximately one-third of the floor space, and with a regional office of the Internal Revenue Service. Bendix is considering expanding into at least a portion of the plant space now occupied by Westinghouse, but the Navy said late last week that no final decision on this has yet been made.[375]

Neither then nor in January 1961, when the AGT Division formally ceased to exist as a division of Westinghouse Electric Corporation, did *Aviation Week* or any other major American aviation journal analyze the Division's disbanding — no retrospectives commemorating the pioneering spirit behind the Yankee engine; no editorials about the impact of its passing on the aviation gas turbine engine industry. In an industry where leadership made success and followership made failure, the death of a follower was not newsworthy.

Conclusion

Between 1950 and 1960, the young aircraft gas turbine engine industry underwent dramatic growth and development. Decisions made by aircraft gas turbine engine manufacturers in the early 1950s to adapt their skills and resources — their organizational capabilities — follow these changes determined their success or failure in the industry, This case study examined the design and manufacture of jet engines at the Westinghouse Aviation Gas Turbine Division in Kansas City, Missouri, from 1950 to 1960. The case study illustrated how, during those ten years, the AGT Division and its parent company repeatedly failed to recognize that the aircraft gas turbine engine represented a disruptive technology, that is, a technology that required a company to change its traditional methods of project funding, product marketing, and development engineering in order to manufacture and sell the technology successfully and competitively. The Westinghouse AGT Division and its parent company failed to recognize the importance of adapting and reallocating key company skills and resources — in particular, making financial investments in facilities for R&D and for production, exercising initiative in order to develop new engines and to attract a broader customer base, and developing suitable management and engineering practices — in order to facilitate successful innovation of the disruptive technology represented by the aircraft gas turbine engine. The AGT Division's competitors, the Aircraft Gas Turbine Division of General Electric and Pratt & Whitney Aircraft, quickly and correctly learned the requirements of the new industry and adapted their skills and organization to meet those requirements.

The aircraft gas turbine engine required the availability of substantial company financial support for R&D and production, Both General Electric and Pratt & Whitney Aircraft recognized that successful jet engine innovation required strong financial support for research and development of new engine designs, and the consolidation of R&D and production facilities in a single location for the sake of economy and efficiency. Both companies received heavy financial support from the military for the development of new engine designs, from the Army and later the Air Force for the former, and from the Navy and Air Force for the latter. However, both firms also invested heavily in the success of their respective aircraft gas turbine engine programs; General Electric consolidated its Schenectady and Lynn development teams under one roof in Lockland, Ohio, and Pratt & Whitney constructed a new R&D laboratory especially for aircraft gas turbine engines at its main East Hartford, Connecticut, plant.[376] Actions like these convinced the military and airframe manufacturers alike that both companies were committed to staying in the aircraft gas turbine engine manufacturing business for the long term.

Westinghouse provided almost no financial support from its own funds from the founding of the AGT Division until 1954, preferring to let the Bureau of Aeronautics subsidize development and production; thus the company thus did not develop a financial stake in the survival of the AGT Division until the Bureau threatened to withdraw its support and even then only provided a comparative trickle of funds. The Bureau tried repeatedly to encourage the company to take over an increasing share of the financial burden of supporting the research, development, and production of jet engines, but to no avail. The AGT Division was housed in a government facility for which it paid minimal rent, built engines using government-furnished equipment, and when it finally decided to consolidate its R&D staff at its production facility, still called on the Bureau to fund at least half of the new facility's construction and fitting-out costs. Westinghouse's actions only served to convince the Bureau of Aeronautics that the company was paying little more than lip service to the idea of long-term investment when Westinghouse president Price repeatedly countered criticisms from the Bureau of Aeronautics by claiming — but never showing — that he was fully committed to keeping Westinghouse in the aircraft gas turbine engine business.

Over time, successful manufacturers were able to seize the initiative by developing their own new engine designs ahead of military requirements, which in turn led to a broadening of the customer base and increased business. From 1950 to 1960, the relationship between the manufacturers and customers in the aircraft gas turbine engine industry inverted, so that by 1960 General Electric and Pratt & Whitney Aircraft offered engines of their own specifications to both the military and airframe manufacturers. Early on, General Electric relied on the Army Air Forces to import centrifugal-flow compressor aircraft gas turbine engine designs from England while it worked on the development of its own axial-flow compressor engine designs, and later built engines to match the Air Force's particular engine requirements. However, thanks to its Lockland R&D laboratories General Electric began to offer in the mid-1950s a new family of ever-more-powerful engines, and even sold its engines to the Navy's Bureau of Aeronautics. Similarly, Pratt & Whitney license-built Westinghouse and Rolls-Royce engines for the Navy, then on the company's own initiative developed its J57 engine, originally designed to a Navy specification, into an engine that was far more powerful than anything General Electric had in production; this allowed Pratt & Whitney to achieve a significant share of military engine business and to virtually corner the commercial airliner engine market by the early 1960s.

By relying on the Navy Bureau of Aeronautics' monopsonistic patronage, the AGT Division abdicated any responsibility to develop a broader customer base for its products, either as a means of increasing sales and profits or providing a fallback option should the Bureau cease its support. The AGT Division displayed little inclination to develop jet engines that were anything other than strictly what its customer had ordered. Not that its limited company-sponsored funding and material resources would have permitted otherwise had they voiced such a desire to the Navy. Not until the AGT Division attempted to manufacture the J54 engine in the mid-1950s did the Division develop an engine that did not first have a specific military requirement. Since its engines had little use beyond the specific applications for which they were designed, and since the AGT Division lacked the ability to develop more powerful versions of any of its engines, it was unable to attract other customers, civil or military, when the pool of Navy contracts began drying up in the early 1950s.

In order to successfully mass-produce aircraft gas turbine engines, manufacturers had to learn new management and engineering skills, or adapt existing ones, that were suited to the peculiar needs of the disruptive technology. For General Electric, previous experience in the steam turbine industry provided little preparation for the manufacture of aircraft engines, and the company's jet engine division staff learned to adapt to the different requirements. The turbosupercharger division at Lynn, while it lacked experience with axial-flow compressors, possessed mass-production and R&D experience, both with turbosuperchargers and with the Whittle engine; by combining the two divisions, and providing them with facilities and funding, General Electric obtained an Aircraft Gas Turbine Division that proved capable, within a short time, of producing large quantities of powerful and reliable aircraft gas turbine engines. Pratt & Whitney Aircraft's engineers found that their experience with the aircraft engine industry compensated them for their lack of expertise with gas turbine engines. They were late starters in the industry, having been kept out of the initial military research program in April 1941. Nevertheless, Pratt & Whitney's senior management applied its twenty years' experience in the aircraft engine industry to prognosticate the military's future requirements and then set out to allocate the resources and train the staff necessary to design an engine capable of fulfilling those requirements. The result, the J57, was an engine that, like Pratt & Whitney's first Wasp piston engine introduced in 1926, proved better than anything being offered by its contemporaries.

The AGT Division derived its engineering traditions and management practices directly from previous experience with steam turbine engineering, and these proved ill-suited to the mass-production of reliable jet engines. When in 1954 AGT Division manager Smith attempted to move the traditions and practices more in line with the aircraft gas turbine engine industry, the changes proved too little and too late. Steam turbine engineering tradition at Westinghouse (as well as General Electric) favored the improvement of a design through observation by engineers of the engine in operation, followed by incremental improvements through modification and replacement of component parts. Steam turbines were unique, hand-crafted items, custom-built one at a time and tailored for individual customer needs. The requirements for aircraft gas turbine engines, on the other hand, quickly evolved into a need for large quantities of identical and reliable engines, supported by a comprehensive research and development program capable of systematic, comprehensive testing and guaranteed product improvement.

The management of the Westinghouse AGT Division, for a long time made up of engineers from the Steam Turbine Division, persisted in manufacturing aircraft gas turbine engines using the engineering practices in which they had been trained, with the result that their engines possessed neither uniform reliability from engine to engine nor significant performance improvement from design to design. As its competitors adapted their skills and resources to master the disruptive technology of the aircraft gas turbine engine, the Westinghouse AGT Division persisted in its traditional pattern of behavior and the industry quickly passed it by, driven by the progress of its competitors. By misinterpreting the disruptive nature of the aircraft gas turbine as simply an extension of existing technology, the AGT Division underestimated the requirements of that new technology and failed to learn how to better respond to those requirements.

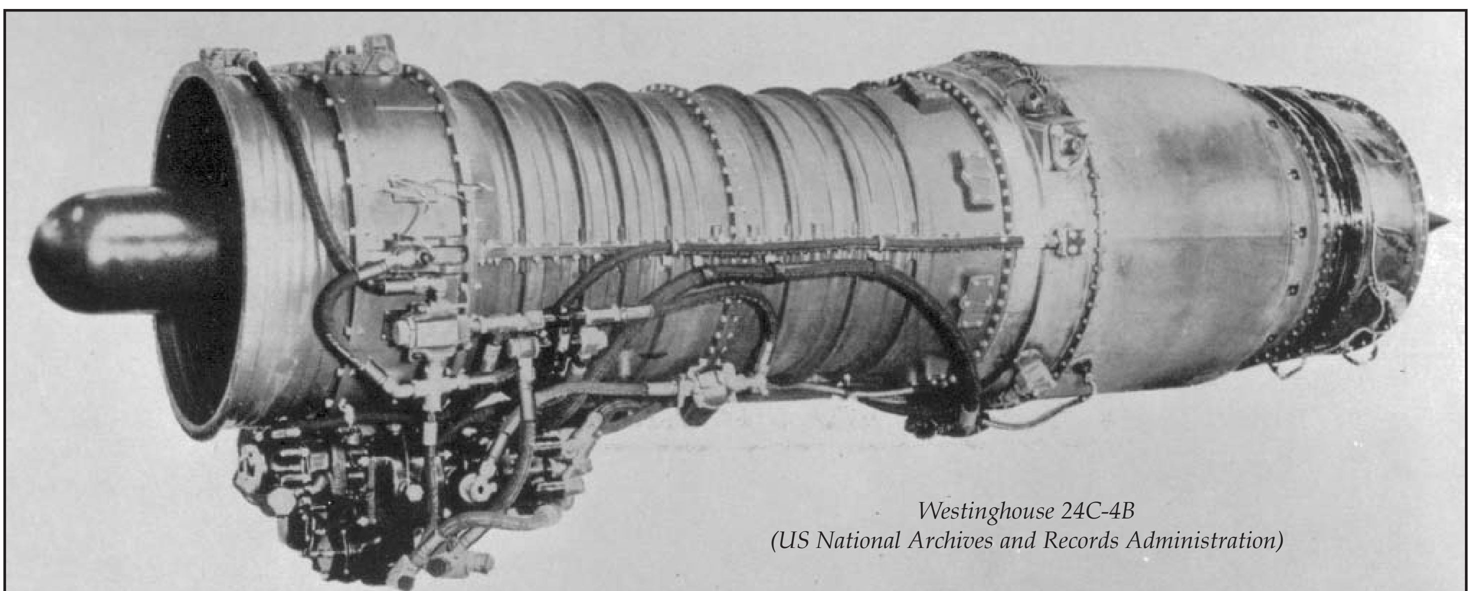
The significance of this case study of the Westinghouse Aviation Gas Turbine Engine Division lies in its demonstration, by example, of the key role played by Alfred Chandler's concept of organizational capabilities in the success or failure of manufacturing firms attempting to market a disruptive technology. Chandler's broad concept is a powerful explanatory tool which facilitates the development of an instructive analytical framework around the history of the Westinghouse AGT Division. The skills and resources that Westinghouse, General Electric, and Pratt & Whitney Aircraft each utilized in their respective attempts to turn the aircraft gas turbine engine into a successful innovation, more than any other apparent factor, were directly responsible for the success or failure of those firms in the industry. Any explanations of the failure of the Westinghouse AGT Division based on the technical shortcomings of its products — technical reviews of various Westinghouse engines cite conservatively low inlet temperatures and compression ratios, use of oil-lubricated sleeve bearings instead of ball bearings, and inefficient combustion chamber design — all fail to account for why those performance criteria were deemed acceptable by the engineers. Furthermore, since each firm responded to the challenge of the disruptive technology of the aircraft gas turbine engine in unique ways, the behavior of the managements and engineers at the three companies examined also bears out Chandler's attribution of organizational capabilities to individual companies rather than them to the industries or technologies in which the companies operated.

This thesis proposes that Chandler's broad concept of organizational capabilities be defined further to include three particular capabilities: company financial support, a broad customer base and suitable product lines, and suitable management and engineering practices and philosophy. The Westinghouse AGT Division lacked these skills and resources, which the case study demonstrated were vitally important for the successful manufacture and marketing of aircraft gas turbine engines. The case for considering these three skills and resources as particular organizational capabilities, as conceived by Chandler, is strengthened by their inclusion in the closely related concept of competence, in which Dosi, Teece, and Winter specifically address expertise in resource allocation, market knowledge, administrative capabilities, ability to develop new or improved products, and the ability to learn as components.[377]

The evidence presented in this thesis supports the contention of Dosi, Teece, and Winter that organizational capabilities can be *learned* and *improved upon*. In Chandler's interpretation of static organizational capabilities, the decision by a company to broaden out into a new technology market should be dependent on whether the new technology can be fit within the organizational capabilities of the company. For Dosi, Teece, and Winter, the decision should rather depend on whether the company can learn to adapt its organizational capabilities to the requirements of the new technology. The engineering and management practices presented in this case strongly support the contention of Dosi, Teece, and Winter that the success of a company, when branching out into a new technology market, is partly based on the ability of the company's staff to *learn*.

This historical case study suggests an analytical methodology applicable to the identification of key organizational capabilities in industries where disruptive technologies are introduced. The result of the analysis is the identification of a set of particular skills and resources that were to a large degree necessary for success in the industry following the introduction of the disruptive technology. The analytical process begins with historical research of a company or (preferably) companies which succeeded in turning a disruptive technology into a successful innovation, in order to identify a range of engineering and business skills and resources — organizational capabilities — particularly well-suited to the requirements of the company's customer, to the manufacture of the product, or perhaps to the performance of the overall industry. In order to isolate the *particular* skills and resources that were critical to the success of companies in the industry during and following the period of innovation, a comparative analysis is then made against a set of approximately the same skills and resources of a contemporary company that *failed* in the same industry. The skills and resources that the failed company lacked, once identified, can then be subjected by the historian to further historical research and analysis to ascertain the relative importance of the development or adaptation of those organizational capabilities within the broader context of the overall industry. The relative success or failure of a firm, and the reasons for that success or failure, can thus be established retrospectively by determining the extent to which a company adapted its organizational capabilities to successfully manufacture and market the particular disruptive technology.

Westinghouse Electric was an early leader in the field of jet engines by virtue of its pioneering status; ten years after helping found the industry in the United States, its AGT Division was an industry follower, behind its competitor and chief rival General Electric. Ten years after *that*, the Westinghouse AGT Division earned little more attention following its unceremonious dismantling than a brief obituary in the trade literature. The story of the AGT Division is ultimately a story about people, not technology; it was the decisions, biases, instincts, and habits of engineers and managers that caused the AGT Division to fail. In historical case studies where the learning process of a failed firm is studied alongside the learning process of a successful firm, therefore, a correct business decision is not implicitly treated as a foregone conclusion, and engineers and managers are shown as they really were: as talented men and women trying to both make something new and market it successfully, using all their collected knowledge, experience, and instinct, guessing right or wrong, and learning — or not — from their mistakes.



Westinghouse 24C-4B
(US National Archives and Records Administration)

Appendix I: Aircraft Gas Turbine Engine Designation Standards

Military Designations

The military services developed a uniform designation system for aircraft engines that consisted of a series of numbers and letters that indicated the type and model of engine, the manufacturer, and the specific version. For the sake of clarity, this thesis consistently uses only the broadest type and model designation for each engine, for example *J30*. However, the full designation of that particular engine can be expanded to include the particular manufacturer and specific versions, for example *J30-WE-20* or *J30-PW-20A*.

Engines are prefixed T for turboprop or J for jet, followed by a model number which roughly signifies the engine's sequence in military procurement. From 1941 to the early 1950s, even numbers were assigned to the Navy and odd to the Army Air Forces, which became the Air Force in 1947. Beginning in the mid-1950s, as the services increasingly bought engines interchangably, the services abandoned the odd/even system. According to military standards, there is no hyphen between the initial letter and the model number in military designations, despite the tendency of the press and casual observers to use one. The numerical sequence appears to have been assigned at the time of the issuance of the original requirement for the engine; therefore the numbers do not necessarily reflect the order in which the engines entered service.

The group of letters which follow the type and model number refers to the manufacturer (including licensee manufacturers), such as P (later PW) for Pratt & Whitney Aircraft, WE for the Westinghouse Aviation Gas Turbine Division, GE for General Electric's Aircraft Gas Turbine Division, A for Allison, W for Wright Aeronautical, and F for Ford. The letters specifically indicate the *manufacturer*, not the designer, of a particular engine; though the two are frequently the same, such a system allows for the identification of license-built engines for quality-control and maintenance purposes.

The final group of numbers and letters refers to particular variants of the engine, depending on ancillary or modified equipment such as additional turbine stages, afterburners, or starting motors. Major variants are designated with numbers which are not necessarily assigned sequentially; modifications of those variants are designated with a subsequent letter.

Company In-House Designations

Company-specific aircraft engine designations are confusing at first glance, but once the system has been explained its logic usually makes sense. However, the logic itself can change over time, and there may even be more than one logical order; military and commercial versions of a single engine design, or versions of a single engine design modified for different applications, may receive different company designations. For the sake of clarity this thesis almost entirely avoids the use of company in-house designations. Nevertheless, readers should be aware of them as they will likely be encountered when reading scholarly and popular aviation history literature.

Westinghouse usually classified its production engines with a number-and-letter system. The number indicated the internal diameter of the engine's air intake in inches, and the letter which followed originally indicated the version of the particular engine. Accordingly, the 19A — the Yankee — had a 19-inch air intake at the front and was the first Westinghouse aircraft gas turbine. The 19B was a major revision of the 19A, that externally resembled the 19A but contained fundamental modifications to the compressor and combustion stages. Likewise, the two versions of the "half-size" engine built by Westinghouse were designated 9.5A and 9.5B. The 19XB was a further improvement, but not a major one, over the 19B. The 19XB followed the 19MA and 19MB, two designs that Westinghouse proposed but never built.

In the mid-1940s Westinghouse modified this designation system and began using the letter to indicate the chronological order in which a particular engine design appeared. After the 19B and 19XB, therefore, the next Westinghouse engines were designated 24C (the J34), 25D (a never-built turboprop based on the J34), and 40E (the J40). No references indicating the in-house designation for the Westinghouse engine that the military designated the J46 have been found. The commercial version of the 24C engine received the company designation W-340 when the Civil Aeronautics Administration certified it for commercial applications.

Following the reorganization of the AGT Division's engineering, R&D, and management personnel in 1953-54, the AGT Division created a new designation system, using the prefix "PD" followed by a number. "PD" stood for "preliminary design," and the number referred to a particular design. The PD-33 received the military designation J54.

Other aircraft gas turbine engine companies used different designation standards. Pratt & Whitney Aircraft used both letter-number systems and names. Pratt & Whitney's first gas turbine engine designs, the first of which was only a bench-test model, were designated the PT-1 and PT-2, for the first and second "propeller turbine" models. When Pratt & Whitney Aircraft received a license to manufacture the Rolls-Royce Tay and Nene engines (named according to Rolls-Royce custom for rivers in England), it designated the two engines, collectively, as the Turbo-Wasp, in keeping with Pratt & Whitney's tradition of naming its reciprocating engines with some variation of either Hornet or Wasp. For its subsequent in-house aircraft gas turbine engine designs, however, Pratt & Whitney returned to the number-and-letter system and added the letters JT ("jet turbine") for turbojets and JTD for turbofans. Engines for ground-based electrical power applications received the designation GG, for "gas generator" (or "gas gooser") when used on pipelines.

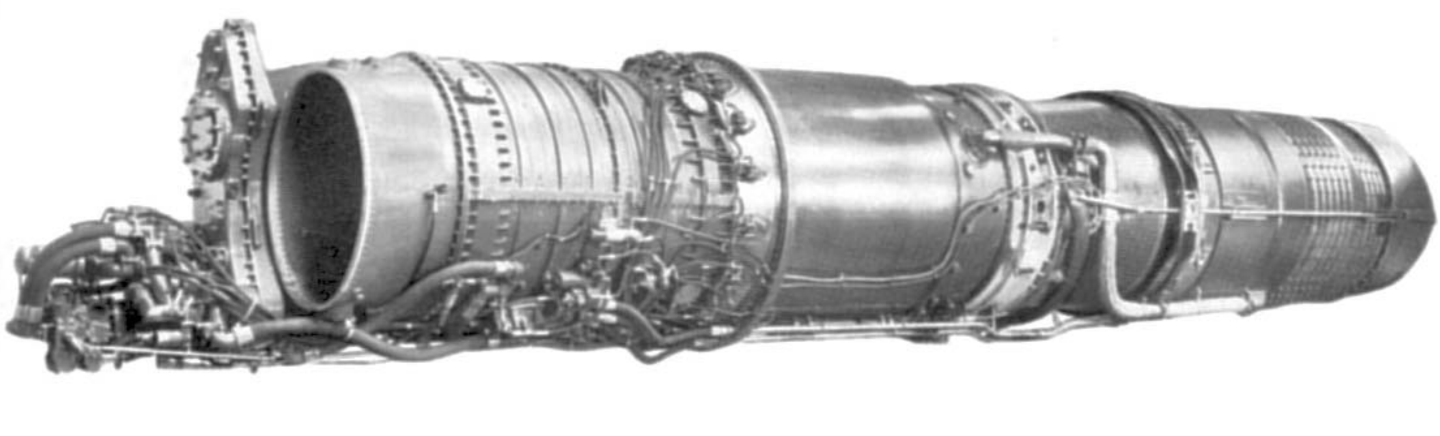
During World War II General Electric established two designation systems, one for the West Lynn plant, which produced an axial-compressor design of its own, and the other for the Schenectady plant, which produced engines based on the Whittle centrifugal-compressor design. The West Lynn designation used the prefix TG, for "turbine, gas" followed by a number. The Schenectady plant, which had manufactured superchargers prior to and during World War II, used the prefix "I" followed by a number. This prefix appeared, to the casual observer, to follow logically the supercharger designations used at that time; Schenectady was currently up to "H" for its superchargers.

In this way, wartime secrecy could be maintained by implying that the engine was merely the next series of supercharger development.

Appendix II: List of Aircraft Gas Turbine Engines[378]

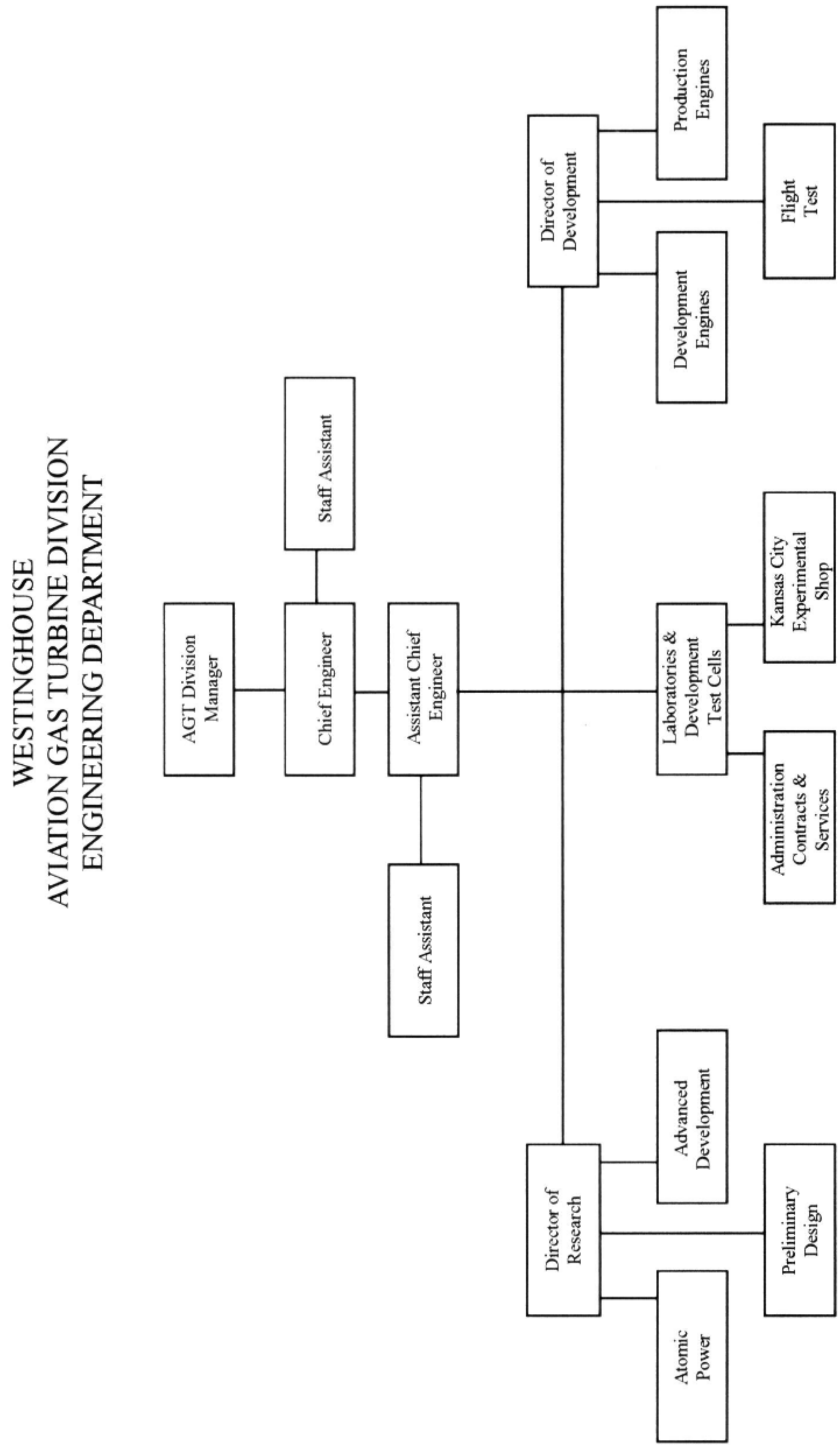
This Appendix includes comparative data for aircraft gas turbine engines used by the United States military discussed in this thesis, listed in numerical order according to their military designations. Only the broadest military engine model designations are used; therefore the range of thrust for each engine model.

Engine Model	Manufacturer	Manufacturer's Designation	Year Introduced	Thrust (lb)
J30	Westinghouse	19B/XB	1943	1,300-1,680
J31	General Electric	I-16	1943	1,300-1,400
J32	Westinghouse	9.5A/B	1943	260-275
J33	General Electric	I-40	1944	
J34	Westinghouse	24C	1947	3,000-3,400
J35	General Electric	TG-180	1944	4,000
J40	Westinghouse	40E	1951	7,500-11,600
J42	Pratt & Whitney	Turbo-Wasp	1948	5,000
J46	Westinghouse		1950	4,000-4,500
J47	General Electric		1948	5,200-6,100
J48	Pratt & Whitney	Turbo-Wasp	1948	6,250-8,300
J54	Westinghouse	PD-33	1955	6,500
J57	Pratt & Whitney	JT-3	1951	9,200-10,000+
J58	Pratt & Whitney		ca. 1957	22,000
J71	Allison		1953	9,700
J73	General Electric		ca. 1954	8,900-9,200
J75	Pratt & Whitney		1956	15,500
J79	General Electric		1956	9,600



Westinghouse J40 with Afterburner
(US National Archives and Records Administration)

Appendix III: Organizational Structure of the Engineering Department of the Westinghouse Aviation Gas Turbine Division, 1955



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HML - Westinghouse Electric Corporation Collection, Aviation Gas Turbine Division "A" Reports and Files of the Research Director, Accession #1459, Hagley Museum and Library, Wilmington, DE.

NA - from the personal collection of Michael Combeirate, formerly of the Navy Bureau of Aeronautics Power Plant Branch, copies provided to the author in 1992.

NA - United States Navy, Bureau of Aeronautics, Unclassified General Correspondence (unless otherwise specified), Series 1950 through Series 1959 (box numbering restarts at "1" for each series), Record Group 72, National Archives, College Park, MD.

NASMA - Various cited collections in the National Air and Space Museum Archives, Washington, DC.

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UTC-Perry W. Pratt Reading Files, Leonard S. Hobbs Papers, and Westinghouse Collection, United Technologies Archive and Historical Resource Center, East Hartford, CT [defunct].

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1. Woodbury, David O. *Battlefronts of Industry: Westinghouse in World War II* (New York: John Wiley & Sons, 1948), 278.
2. Unnamed "former Westinghouse public-relations executive," quoted in Rieser, Carl. "The Changes at Westinghouse." *Fortune*, August 1958, 88.
3. See, for example, Green, William and Roy Cross. *The Jet Aircraft of the World* (Garden City, NY: Hanover House, 1955; reprint ed. 1980 by Arno Press Inc), 26; Wooldridge, E.T. *Into the Jet Age: Conflict and Change in Naval Aviation 1945-1975, an Oral History* (Annapolis: Naval Institute Press, 1995), 58.
4. See Appendix II, List of Aircraft Gas Turbine Engines.
5. Nelson, Richard R., Merton J. Peck and Roy Cross. *Technology, Economic Growth, and Public Policy* (Washington. DC: The Brookings Institution, 1967),95-6; Dosi, Giovanni. *Technical Change and Industrial Transformation* (New York: St. Martin's Press, 1984), 73n2.
6. Christensen, Clayton M. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Boston: Harvard Business School Press, 1997), xiii, 207-210.
7. Chandler, Alfred D., Jr. *Scale and Scope: the Dynamics of Industrial Capitalism* (Cambridge: Belknap Press, 1990), 36.
8. Giovanni Dosi's concept of the "technological paradigm," put forward in his 1984 study, is broadly similar; however, Dosi does not ascribe paradigms to individual companies, but rather to the set of normative practices for an entire industry. See Dosi, Giovanni. *Technical Change and Industrial Transformation*, 14-16, and especially 166-7. Nelson, Peck, and Kalachek, in *Technology, Economic Growth, and Public Policy*, discuss the importance of the possession by companies of technologically knowledgeable employees.
9. Chandler, *Scale and Scope*, 594.
10. Chandler, *Scale and Scope*, 342.
11. Dosi, Giovanni, David J. Teece, and Sidney Winter. "Toward a Theory of Corporate Coherence: Preliminary Remarks," in Dosi, Giovanni, Renato Gianetti, and Pier Angelo Tuninelli, eds., *Technology and Enterprise in a Historical Perspective* (Oxford: Clarendon Press, 1992), 197.
12. Dosi, Teece, and Winter, "Toward a Theory of Corporate Coherence," *Technology and Enterprise*, 193.
13. Dosi, Teece, and Winter, "Toward a Theory of Corporate Coherence," *Technology and Enterprise*, 191-2.
14. Dosi, Teece, and Winter, "Toward a Theory of Corporate Coherence," *Technology and Enterprise*, 188, 191, 192.
15. According to Dosi, et al., "[a] core competence will typically have both an organizational/economic and a technical dimension." The former includes allocative, transactional, and administrative competences; the latter includes product-specific design, developmental, and learning competences. Dosi, Teece, and Winter, "Toward a Theory of Corporate Coherence," *Technology and Enterprise*, 198.
16. Nelson, Peck, and Kalachek, Technology, Economic Growth, and Public Policy. 17-8.
17. Mowery, David C. "The Boundaries of the U.S. Firm in R&D," paper presented at the Micro History Conference: The Coordination of Economic Activity Within and Between Firms," October 23,1992, 33-4.
18. Rosenberg, Nathan, *Technology and American Economic Growth* (New York: Harper & Row, 1972), 177.
19. Chandler, *Scale and Scope*. 622; Nelson, Richard R. Understanding Technical Change as an Evolutionary Process (New York: North-Holland, 1987), 99-101,108.
20. Christensen, *Innovator's Dilemma*, 208.
21. Stekler, Hem1an O. *Structure and Performance of the Aerospace Industry* (Berkeley: University of California Press, 1965), 72.
22. Nelson, *Understanding Technical Change*," 11.
23. Vincenti, Walter G. *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History* (Baltimore: Johns Hopkins University Press, 1990), 3.
24. Dosi, Teece, and Winter, "Toward a Theory of Corporate Coherence," *Technology and Enterprise*, 191.
25. Mowery, "The Boundaries of the U.S. Firm in R&D," 9.
26. Rieser, Carl. "The Changes at Westinghouse." *Fortune*, August 1958, 146.
27. Chandler, *Scale and Scope*, 36, 594. See particularly the Conclusion, "The Dynamics of Industrial Capitalism.." for a summary analysis of the role played by organizational capabilities in the success or failure of industrial manufacturers.
28. See for example Schlaifer, Robert. *Development of Aircraft Engines* [and] S.D. Heron, *Development of Aviation Fuels: Two Studies of Relations Between Government and Business* (Boston: Harvard University Press, 1950), 330. Schlaifer gives an excellent and detailed summary of the pre-history of the aircraft gas turbine engine, obviating the need for detailed analysis here. Schlaifer points out that calculations based on experience with steam and gas turbine engines indicated that gas turbines would weigh far too much for the potential output, especially when compared to contemporary piston aircraft engines.
29. Schlaifer, *Development of Aircraft Engines*, 333-334. Centrifugal compressors use a rotating impeller to deflect intake air at right angles to the direction that it entered the engine, and compresses it by centrifugal force in much the same way as a washing machine wrings clothes by spinning them against the tub walls. The air is then ducted into a ring of burners where it is mixed with atomized fuel and ignited by spark plugs. The heated gas then expands and exhausts at great velocity out the engine's tail providing forward thrust. On its way out it spins a turbine hooked up to the intake impeller in order to maintain the intake and compression cycle.
30. Schlaifer, *Development of Aircraft Engines*, 377-178.
31. Taylor, *Jane's Encyclopedia of Aircraft*, 420, 505.
32. The term "NACA" was traditionally pronounced as an abbreviation, not as an acronym.
33. [Westinghouse Electric Corporation, Aviation Gas Turbine Division], "History of Westinghouse in the War, Aviation Gas Turbine Division, Engineering Department," unpublished typescript ca. 1946, in Engine Vertgical Files, NASM, 3.
34. Chandler, Alfred. "The Structure of American Industry in the 20th Century: A Historical Overview." *Business History Review*, vol. XLIII no. 3, Autumn 1969, 275.
35. Sultan, Ralph G.M. *Pricing m the Electrical Oligopoly* vol. 1 *Competition or Collusion* (Cambridge: Harvard University Press, 1974), 9-10. Sultan's research into the electrical oligopoly led him to attribute Westinghouse's secondary position in the electrical utility manufacturing industry to the events of the early years of steam turbine engine technology. According to Sultan, General Electric took advantage of "access to technology, product superiority, marketing aggressiveness, ownership ties with key customers, intense attention to the electric power business, and timing" of entry into the market, as means of attaining and maintaining primacy.
36. Schlaifer, *Development of Aircraft Engines*, 452-3, 458. See also White, Eric. "The PT-1: An Adaptation of Corporate Research to an Era of Rapid Technological Change," 1984, Rensselaer Polytechnic Institute. A typescript research paper, on file at UTC.
37. Nelson, Peck, and Kalachek. *Technology, Economic Growth, and Public Policy*, 71.
38. Rae, John B. *Climb to Greatness: The American Aircraft Industry, 1920-1960* (Cambridge: Masachussetts Institute of Technology Press, 1968), 165.
39. Sultan, *Pricing In the Electrical Oligopoly*, vol. 1, 9.
40. Sultan, *Pricing in the Electrical Oligopoly*, vol. 1, 7-8; Schlaifer, *Development of Aircraft Engines*, 440. Passer, Harold C. *The Electrical Manufacturers, 1875-1900: A Study in Competition, Entrepreneurship, Technical Change, and Economic Growth* (Cambridge: Harvard University Press, 1953), 311, agrees on the year of the first General Electric turbine installation but states that the company's first commercial turbine installation was in Chicago, at the Commonwealth Edison Company. Sultan, Ralph G.M. *Pricing in the Electrical Oligopoly,* vol. 2, *Business Strategy* (Cambridge: Harvard University Press, 1975), xxi, in the List of Charts, refers to the GE turbine division as the Turbine Generator Division.
41. Schlaifer, *Development of Aircraft Engines*, 326-327; "History of Westinghouse in the War," [1]; American Society of Mechanical Engineers, *George Westinghouse Commemoration* (New York: the Society, 1937), 30; Passer, *Electrical Manufacturers*, 310-311.
42. "History of Westinghouse in the War," 5.
43. Schlaifer, *Development of Aircraft Engines*, 461-462.

44. Schlaifer, *Development of Aircraft Engines*, 460; “History of Westinghouse in the War,” 5.
45. Schlaifer, *Development of Aircraft Engines*, 102,325, 328-9, 440-441. General Electric’s turbosupercharger group, under the direction of Sanford Moss and located in Lynn. Massachusetts, worked briefly on gas turbine engines from 1903 until 1907. During the First World War, the United States Army acquired a turbosupercharger of French design and passed it on to Moss, remembering his pre-war experience with gas turbine engines. In 1917, Moss succeeded in developing a similar device for American airplane engines and as a result the Army sponsored all General Electric’s turbosupercharger work between the wars.
46. Woodbury, *Battlefronts of Industry*, 48-9.
47. Trimble, William F. *Admiral William A. Moffett: Architect of Naval Aviation* (Washington, DC: Smithsonian Institution, 1994), 80,83.
48. Schlaifer, *Development of Aircraft Engines*, 172-174, 186-187.
49. Schlaifer, *Development of Aircraft Engines*, 174.
50. Schlaifer, *Development of Aircraft Engines*, 174-175.
51. Power Plant Design Section to Head of Procurement Branch, “Westinghouse Jet Propulsion Project, Letter of Intent,” December 22, 1941, Box 1324, Contract General Correspondence, NA.
52. Kroon to F.T. Hague, cc L. W. Chubb, October 13, 1941, HML.
53. “History of Westinghouse in the War,” 7.
54. Schlaifer, *Development of Aircraft Engines*, 459-460. Schlaifer notes the general consensus reached by the NACA and other turbine manufacturers to this effect.
55. Kroon, Reinout P. “The Jet Engine Comes of Age.” *Westinghouse Engineer*, September 1950 [reprint], 3,5.
56. Interview by the author with Oliver Rodgers, March 13, 1992.
57. Foster, John, Jr. “Design Analysis of Westinghouse 19-B Yankee Turbojet.” *Aviation*, January 1946, 68.
58. “History of Westinghouse in the War,” 10.
59. Interview by the author with Rein Kroon, March 12, 1992.
60. [United States Navy], “History — Westinghouse,” unpaginated typescript ca. 1945, Propulsion Vertical Files, NASM, [1]; Woodbury, *Battlefronts of Industry*, 281, quotes the engine’s length at eight feet but quotes other performance statistics from the engine as built, not as originally designed.
61. “History — Westinghouse,”[1]; “History of Westinghouse in the War,” 10.
62. Woodbury, *Battlefronts of Industry*, 281.
63. Serial number listed in Reinout P. Kroon’s engine log book, HML.
64. Foster, John, Jr. “Design Analysis of Westinghouse 19-B Yankee Turbojet” *Aviation*, January 1946, 60.
65. Interview by the author with Reinout Kroon, March 21, 1992.
66. “History of Westinghouse in the War,” 14.
67. Heiman, Grover. *Jet Pioneers* (New York: Duell, Sloane & Pierce, 1963), 93-94.
68. “History of Westinghouse in the War,” 17.
69. “History of Westinghouse in the War,” 19; “History — Westinghouse,” [l].
70. The name Yankee was properly (if informally) applied only to the family of engines that was developed around the original 19-inch engine. Occasionally the name appears in print used in reference to other Westinghouse engine models, which is incorrect. The Navy referred to the engines using the formal military designation or Westinghouse’s internal designation.
71. Taylor, Michael 1. H. *Jane’s Encyclopedia of Aviation* (New York: Portland House, 1989), 641.
72. “Letter of Intent for Contract NO(a)s-503,” May 24,1943, Bureau of Aeronautics Contract Correspondence, Box 387, NA.
73. F.M. van Eck to L.K. Marshall, June 14, 1943, “Westinghouse Units,” and attached ““Notes on Conference on 14 June 1943 at Bureau of Aeronautics, Power Plant Design Section,” Bureau of Aeronautics Contract Correspondence, Box 387, NA.
74. [Bureau of Aeronautics] Power Plant Design Branch to [Bureau of Aeronautics] Plant Facilities, December 30,1943, “Westinghouse Electric and Mfg. Co Experimental Facilities, Contract NO(a)s-503 Jet Propulsion Units,” Contract NO(a)s-503, Box 388, NA.
75. [Bureau of Aeronautics} Power Plant Design Branch to Chief, Bureau of Aeronautics, July 24, 1945, “General Delays in WEC Development Contracts;

Analysis of,” Bureau of Aeronautics Contract Correspondence, Box 353, NA.
76. Robertson to Ramsey, April 3, 1944, Bureau of Aeronautics Contract Correspondence, Box 1324, NA.
77. Kraus to Chief of Bureau of Aeronautics Plant Facilities Section, April 10, 1944, “Westinghouse Electric & Mfg. Co., Essington, Pa., Additional Facilities For,” Bureau of Aeronautics Contract Correspondence, Box 1324, NA.
78. Interview by the author with Reinout P. Kroon, March 21, 1992.
79. Interview by the author with Oliver Rodgers, March 22, 1992; Power Plant Design Branch to Plant Facilities, “Westinghouse Electric and Mfg. Co. Experimental Facilities. Contract NOa(s)503 Jet Propulsion Units,” December 30,1943, Contract General Correspondence, Box 388, NA.
80. Woodbury, *Battlefronts of Industry*, 281.
81. “History of Westinghouse in the War,” 11.
82. Chief of the Bureau of Aeronautics to Secretary of the Navy and Director of Purchases, War Production Board, April 20, 1944, “Authority to Contract for additional facilities for Westinghouse Electric & Manufacturing Co., Lester, Pa., in the amount of $352,000,” Bureau of Aeronautics Contract Correspondence, Box 1324, NA.
83. S.M. Kraus to Chief of Bureau of Aeronautics Plant Facilities Section, Apri110, 1944, “Westinghouse Electric & Mfg. Co., Essington, Pa., Additional Facilities For,” Bureau of Aeronautics Contract Correspondence, Box 1324, NA.
84. “Letter of Intent for Contract NOa(s)-503,” March 8, 1943, Bureau of Aeronautics Contracts, Box 387, NA. The chronology of the first year of the Westinghouse aircraft gas turbine engine production program after December 7, 1941 is confusing. Primary and secondary sources further this confusion by offering various conflicting accounts, quantities of engines on order, and dates of key events.

Much of the confusion is no doubt due to the rapidly-changing situation following the attack on Pearl Harbor, to the rapid progress made on the engines themselves, and to the fact that many of the decisions made by Westinghouse and the Bureau of Aeronautics were communicated via telephone or in person, during a time of rapid progress on the design of the engine. As a result, the Navy frequently issued overlapping and possibly contradictory statements which appear in the contract documents. Historians must therefore take care when citing these documents, and consider the possibility that the documents are not actually representative of the final decision.
85. Chief of the Bureau of Aeronautics to the Chief of the Bureau of Supplies and Accounts, January 5, 1942, “Preliminary award of contract for development of Jet Propulsion Unit;” Power Plant Design Section to Head of Procurement Branch, December 22, 1941, “Westinghouse Jet Propulsion Project, Letter of Intent” both from Bureau of Aeronautics Contract General Correspondence, Box 1324, NA.
86. “History Westinghouse.” [1]; Chief of the Bureau of Aeronautics to Chief of Bureau of Supplies and Accounts, January 5, 1942, “Preliminary award of contract for development of Jet Propulsion Unit,” Bureau of Aeronautics Contract General Correspondence, Box 1324, NA Contract number listed in Reinout Kroon’s engine log book, HML.
87. “History of Westinghouse in the War,” 11.
88. Gavin to Pearson, December 31, 1943, “Notes for Capt. Pearson on Westinghouse Advanced Ratings,” Contract NO(a)s-503, Box 387, NA.
89. According to Schlaifer, *Development of Aircraft Engines*, 368-9, 371, 376, Rolls-Royce, the other major British aircraft gas turbine engine manufacturer, did not begin manufacturing their own designs until 1944, after completing licensee obligations with Power Jets, Ltd. Schlaifer points out that “[o]nly the Whittle-type centrifugal engine was ready for service before the end of the war.”
90. Schlaifer, *Development of Aircraft Engines*, 466-467.
91. Schlaifer, *Development of Aircraft Engines*, 491.
92. Kroon, “Engineer’s Trip Report, November 27, 1942,” November 30, 1942, folder BW400000-04, Propulsion Files, NASM; “History — Westinghouse,” 32.
93. “History — Westinghouse,” 30.

94. Trimble, William F. *Wings for the Navy: A History of the Naval Aircraft Factory, 1917-1956* (Annapolis: Naval Institute Press, 1990), 275.

95. "History of Westinghouse in the War," 22; Rossetto, "Redefinition of military and normal rated speeds of the X25D-2 for design and preliminary model specifications," September 24, 1946, Propulsion Files, NASM.

96. Foster, John., Jr., "Design Analysis of Westinghouse 19-B Yankee Turbojet," *Aviation*, January 1946, 60-68 *passim*. The design of the 19A's bearings were essentially similar to the 19B, for the sake of comparison here.

The J30 engine design incorporated a single rotating shaft running down the centerline of the engine from front to rear, upon which the compressor and turbine stages were mounted in the engine housing. The design called for supporting this shaft by using three bearings that would allow the shaft to rotate freely within the housing. The No. 1 bearing supported the front end of the shaft just in front of the first compressor stage; the No.2, or thrust, bearing held the middle of the shaft just behind the sixth and final stage of the compressor; and the No.3, or turbine, bearing supported the rear of the shaft just before the turbine stage.

The three bearings were of the oil-lubricated babbitt-lined sleeve type — in other words, each bearing consisted of a short cylinder (sleeve), with an interior diameter slightly larger than the compressor/turbine shaft, lined with a low-friction tin alloy (babbitt metal) and attached to the inside of the engine housing by mounting struts. With the engine assembled, the shaft was free to rotate inside the three sleeves because of the slightly narrower diameter of the shaft, and because of the smooth babbitt metal if and when the shaft came into contact with the sleeve as it rotated. In order to minimize such contact, the engine incorporated oil pumped through the narrow gap between the sleeve and the shaft, so that as the shaft rotated, it "floated" on a surrounding cushion of oil at the locations of the three bearings. The oil was pumped throughout the engine via a complicated network of pipes and grooved channels, and was also used to cool the engine while operating. The oil itself was cooled by being pumped into an air cooler after circulating through the engine, This arrangement is essentially the same as used on contemporary industrial steam and gas turbine engines.

97. Interview by the author with Oliver Rodgers, March 22, 1992.

98. See, for example, Carpenter, David M. *Flame Powered: The Bell XP.59A Airacomet and the General Electric I-A Engine* ([s.l.): Jet Pioneers of America., 1992), 68. The cutaway diagram of the compressor/turbine shaft is a reproduction from an Air Force instruction manual for the GE 1-16 centrifugal-compressor aircraft gas turbine engine and the Bell P.59 test aircraft that used the I-16.

99. Schlaifer, *Development of Aircraft Engines*, 33.

100. See, for example, "History of Westinghouse in the War," 17; Kroon, "Contract NO 97181, Progress Report from July 10-August 5, 1943," Contract NOa(s)-5340, Contract General Correspondence, Box 388, NA; Naval Air Material Center, Aeronautical Engine Laboratory Report on Altitude Calibration of Westinghouse XI9X13-3 Turbo-Jet Engine," Report AEL-992, November 12, 1947, Naval Air Propulsion Center Technical Publications Collection, Box 16, NASM-Garber.

101. [Bureau of Aeronautics] Power Plant Design Branch to Chief, Bureau of Aeronautics, July 24, 1945, "General Delays in WEC Development Contracts; Analysis of," Bureau of Aeronautics Contract Correspondence, Box 353, NA.

102. Hirsh, Richard F. *Technology and Transformation in the American Electric Utility Industry* (Cambridge: Cambridge University Press, 1989), 36-37.

103. Hirsh, *Technology and Transformation*, 39.

104. Woodbury, *Battlefronts of Industry*, 50-52.

105. Hobbs to Horner, December 15, 1944, Leonard S, Hobbs Papers, UTC. The details of the initial contact between Westinghouse and Pratt & Whitney Aircraft are sketchy and incomplete. The available documentation does not indicate under what circumstances the Navy "encouraged" Westinghouse to approach P&WA. A possible explanation for the circumspect phrasing used by Westinghouse is security restrictions which required Westinghouse to terms euphemistically, since at that time the Navy and Army Air Forces had yet to publicly announce that American firms had been engaged in aircraft turbine engine design, manufacture, and operation since before entry into the war. However, in the written correspondence considering the request, Pratt & Whitney gave every indication that they were aware of specific aircraft gas turbine engine projects that Westinghouse was working on.

106. Hobbs to Homer, December 15, 1944, Leonard S, Hobbs Papers, UTC.

107. [Bureau of Aeronautics], December 28, 1944, "Procurement Directive," Contract NO(a)s-5340, Box 1538, NA.

108. Bureau of Aeronautics, January 5, 1945, "Letter of Intent for Contract NO(a)s-5340," Contract NO(a)s-5340, Box 1538, NA.

109. Bureau of Aeronautics, January 2, 1945, "Request for Authority to Contract," Contract NO(a)s-3308, Box 1242, NA.

110. Hobbs to Horner, May 30, 1945, Leonard S, Hobbs Papers, UTC.

111. "Dictaphone record made by Mr. Hobbs," [n.d.], UTC.

112. Hobbs to Homer and J.F, McCarthy, January 1, 1945, Leonard S, Hobbs Papers, Series 2, Folder 15, UTC.

113. See, for example, Hobbs to Pratt, April 16, 1945, "Continuation of Study of Type of Turbine and Jet Power Plant to Build," Leonard S, Hobbs Paper Series 2, Folder 15, UTC.

114. [Pratt & Whitney Aircraft], "Navy Jet Unit," Engineering Order Supplement 12, February 12, 1947, Engineering Order Files, UTC.

115. See, for example, comments by van Eck and Schrnckrath, Bureau of Aeronautics route sheet dated May 16, 1945, Contract NO(a)s-5340, Box 1538, NA.

116. Director, [Bureau of Aeronautics] Production Division to Chief, BuAer, October 6,1945, "Model 19XB2B Turbo-jet engines — Manufacture of by Pratt & Whitney Aircraft Division," Contract NO(a)s-5340, Box J539, NA.

117. "Total Active and Inactive Jet Engines Produced by Pratt & Whitney Aircraft," [n.d.], on file at UTC; for data on contract NOa(s)-3308 (the Westinghouse contract for J30 manufacture), see for example Bureau of Aeronautics to BAR, Essington, Pennsylvania, July 3, 1946; Westinghouse Aviation Gas Turbine Division Semi-Monthly Report 428, August 22, 1946; both in Bureau of Aeronautics Contract Correspondence 1938-1945, NOa(s)-3308, NA.

118. [Bureau of Aeronautics] Engine Trouble Report, Engine P-400003, May 1, 1947, Contract NO(a)s-5340, Box 1539, NA.

119. Beach to Westinghouse AGT Division, September 15, 1947, Contract NO(a)s-5340, Box 1539, NA.

120. Osborne to Spangler, January 29, 1945, Bureau of Aeronautics Contract Correspondence, Box 353, NA.

121. Bridgman, *Jane's All the World's Aircraft*, 1947, 58d.

122. "Westinghouse Move Emphasizes importance of Gas Turbine Engines," *Aviation News*, April 9, 1945, 36.

123. [Bureau of Aeronautics] Power Plant Design Branch to Chief, Bureau of Aeronautics, July 24, 1945, "General Delays in WEC Development Contracts; Analysis of," Bureau of Aeronautics Contract Correspondence, Box 353, NA.

124. A Rolls-Royce representative, Pierson, visited Pratt & Whitney Aircraft in early December 1945 to discuss with Leonard S, Hobbs the licensing agreement for the J42 engine. The representative confided to Hobbs that "it was [Rolls-Royce's] strong opinion that in the end the aircraft engine manufacturers would win out in this country and that the GE's and Westinghouse's would fall by the wayside [*sic*]." Hobbs to Homer, "License from Rolls-Royce," December 5, 1945, Leonard S. Hobbs Papers, UTC.

125. Taylor, *Jane's Encyclopedia of Aviation*, 447.

126. Carpenter, *Flame Powered*, 14-15.

127. Schlaifer, *Development of Aircraft Engines*, 464.128. Carpenter, *Flame Powered*, 31.

129. Schlaifer, *Development of Aircraft Engines*, 465.

130. Schlaifer, *Development of Aircraft Engines*, 473.

131. Schlaifer, *Development of Aircraft Engines*, 478.

132. Taylor, *Jane's Encyclopedia of Aviation*, 593.

133. Anderton, David A. "GE Cuts Bottlenecks at New Jet Center," *Aviation Week*, April 14, 1950, 22.

134. Anderton, David A. "GE Cuts Bottlenecks at New Jet Center," *Aviation Week*, April 14, 1950, 22.

135. Division name taken from "GE Aims to Cut Jet Development Knots," *Aviation Week*, November 29, 1954, 22; see also entries from contemporary issues of *Jane's All the World's Aircraft*, which do not provide a formal date for the establishment of General Electric's AGT Division.

136. "How GE Subcontracts Its Jet Production." *Business Week*, November 4, 1950, 61.

137. Anderton, David A. "GE Cuts Bottlenecks at New Jet Center." *Aviation Week*, April 14, 1952, 21.
138. Stone, Irving. "New High-Thrust Turbojet Seen for GE," *Aviation Week*, December 4, 1950, 26.
139. Stone, Irving. "New High-Thrust Turbojet Seen for GE," *Aviation Week*, December 4, 1950, 22.
140. Harris, William B. "The Overhaul of General Electric," *Fortune*, December 1955, 116.
141. "The Problems at Westinghouse." *Time*, October 24, 1955, 99.
142. Fetridge, Robert H., "Along the Highways and Byways of Finance," *New York Times*, December 14, 1952, III, 3:3.
143. Smith., Edgar P. "The Recharging of Westinghouse." *Fortune*, December 1952, 122.
144. "Westinghouse Net Highest In History." *New York Times*, February 28, 1950, 37:5; "Westinghouse Net Up." *New York Times*, March 6, 1951, 37:5.; "Westinghouse Electric's Record of Sales Offset by Taxes in 1951." *New York Times*, February 26, 1952, 35:4; "Westinghouse Net Up 6% in 1952 to $68,581,000, or $4.25 a Share." *New York Times*, February 25, 1953, 35:6; see also Smith., Edgar P. "The Recharging of Westinghouse." *Business Week*, December 1952, 120.
145. "Westinghouse Electric's Record of Sales Offset by Taxes in 1951," *New York Times*, February 26, 1952, 35:4.
146. Smith., Edgar P., "The Recharging of Westinghouse," *Fortune*, December 1952, 121, 192. Within the Westinghouse Defense Products Group, only the AGT Division consistently showed a return on investment.
147. See, for example, Price's statements on the subject in "Westinghouse Electric's Record of Sales Offset by Taxes in 1951." *New York Times*, February 14, 1952, 35:4, 37:3; "Sales Record Seen by Westinghouse." *New York Times*, December 18, 1952, 47:3.
148. The highlights of Price's life are derived from Robert H. Fetridge's profile in "Along the Highways and Byways of Finance," *New York Times*, December 14 1952, III, 3:3, Price's obituary, "Gwilym Price, 89, Industrialist, Dies," *New York Times*, June 3, 1985, and the entry for "Westinghouse Electric Corporation" in Mirabile, Lisa, ed. *International Directory of Company Histories*, vol. II (Chicago: 81. James Press, 1988), 120-122.
149. "Westinghouse Net Highest in History." *New York Times*, February 28, 1950, 37:5.
150. "Westinghouse Net Highest in History." *New York Times*, February 28, 1950, 37:5.
151. "Westinghouse Electric's Record Of Sales Offset by Taxes in 1951," *New York Times*, February 26 1952, 35:, 37:3. According to Price, in 1950 Westinghouse paid $77 million in taxes and earned $77.9 million in income.
152. Power Plant Design Branch to Plant Facilities, "Westinghouse Electric and Mfg. Co. Experimental Facilities, Contract NOa(s) 503 Jet Propulsion Units," December 30, 1943, Box 338, NA; "Unique Laboratory Speeds Jet Engine Development" *Aviation Week*, December 1, 1947, 30-31; New, Winston R. "Turbojet Development Laboratory." *Aero Digest*, January 1948, 64-66, 94, 99-100.
153. Interview by author with Reinout P. Kroon, March 21, 1992.
154. McLarren, Robert. "USAF, Navy Step Up Jet Engine Buying." *Aviation Week*, July 12, 1948, 11.
155. McLarren, Robert. "USAF, Navy Step Up Jet Engine Buying." *Aviation Week*, July 12 1948, 11.
156. "Jet Start Soon." *Kansas City Star*, August 1, 1948; [History of the Bannister Federal Complex], Folder "General," Box 1, HEM; "A Giant in Field." *Kansas City Star*, October 16, 1949. Westinghouse in turn issued a sub-lease to the Bendix Corporation allowing them to use part of the facility for secret atomic power work for the government.
157. *Moody's Manual of Investments* (New York: Moody's Investor's Service, 1945), 2419.
158. "PD-33 Turbojet Engine," sales brochure, n.d., microfiche BO-071000, NASMA.
159. "Fast Construction for Fast Production." *Architectural Record*, February 1945, 66-73.
160. [History of the Bannister Federal Complex], Folder "General," Box 1, HEM.
161. "In a Big Production Job," *Kansas City Star*, November 18, 1949.
162. "Expand for More Jets." *Kansas City Star*, December 22, 1950; "Bigger Jet Plan." *Kansas City Star*, November 17, 1948.
163. "... in the Interest of National Defense.. ." pamphlet, Folder "Brochures," HEM.
164. Derived from *Jane's All the World's Aircraft* 1947, p. 58d; 1949-1950, p. 32d.
165. "Sure of Jet's Future," *Kansas City Star*, October 27 1949.
166. "... In the Interest of National Defense ... ," Westinghouse publicity brochure, [n.d.]. HEM.
167. "New Jet Phase," *Kansas City Star*, September 28 1951.
168. J.B. Graef to Chief, Bureau of Aeronautics, September 2 1953, "Test Pit and Taxiway for Westinghouse In-Flight Test Facility at NAS Olathe," Box 399, NA.
169. "Faster Than You Think, Westinghouse Aircraft Gas Turbine Division," undated illustrated brochure, WHC.
170. Harkleroad, Neil E. "Navy's New J40 Engine Approaches Flight Stage," *Naval Aviation Confidential Bulletin*, April 1949, 33.
171. House Subcommittee final report, 5; House Subcommittee hearings, 28.
172. Stekler, Herman O. *Structure and Performance of the Aerospace Industry* (Berkeley: University of California Press, 1965), 14; Cunningham, William Glenn. *The Aircraft Industry: A Study in Industrial Location* (Los Angeles: Lorrin L. Morrison, 1951), 185.
173. Cunningham, *Study in Industrial Location*, 161,171, 185.
174. "GE Jet Move," *Aviation Week*, January 15, 1951, 22.
175. Hotz, Robert, "Westinghouse Puts Millions in Jet Engine Program," *Aviation Week*, December 20, 1954, 16.
176. M. B. Combeirate to Director, Power Plant Division, December 28, 1950, "Informal conference between VF Design Branch and Turbo-jet Section; Individual report on," MC; "Navy Jet Procurement Program," 33.
177. Smith testimony, United States House of Representatives, Committee on Government Operations, Subcommittee on Military Operations, "Navy Jet Procurement Program," 84th Congress, 1st Session. October 24-27, 1955, 212-213.
178. Stekler, *Structure and Performance*, 96; Philips, *Technology and Market Structure*, 10-19, suggests that R&D plays a significant role in defining the market for a technological product by establishing a rate at which innovations which represent significant product improvements can be expected to appear.
179. Taylor, *Jane's Encyclopedia of Aviation*, 640. The McDonnell Banshee was featured in James Michener's 1953 Korean War novella *The Bridges at Toko-ri*, a fact which the Westinghouse AGT Division proudly advertised. In the 1954 Paramount Studios feature film of the book, however, the Banshees had been replaced by Grumman F9F Panthers, powered by Pratt & Whitney Turbo-Wasps.
180. United States House of Representatives, Committee on Government Operations, Subcommittee on Military Operations, House Report No. 1891, Tenth Intermediate Report, "Navy Jet Aircraft Procurement Program, 84th Congress, 2nd Session, March 15, 1956, 6.
181. St. Peter, James, ed., *Memoirs of Ernest C. Simpson, Aero Propulsion Pioneer* (Dayton: Special Staff Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, [n.d.]), 50.
182. Harkleroad, Neil E., "Navy's New J40 Engine Approaches Flight Stage," *Naval Aviation Confidential Bulletin*, April 1949, 33.
183. Harkleroad, "Navy's New J40 Engine Approaches Flight Stage," 33.
184. House Subcommittee hearings, 212.
185. Bridgman, Leonard, rd. *Jane's All the World's Aircraft*, 1954-1955 (London: Jane's All the World's Aircraft Publishing, [1954]), 343.
186. House Subcommittee Final Report, 6.
187. Green and Cross, *Jet Aircraft of the World*, 36.
188. "Harkleroad, Neil E., "Navy's New J40 Engine Approaches Flight Stage, Naval Aviation Confidential Bulletin, April 1949, 33.
189. House Subcommittee hearings, 28.
190. Director, Production Division to Director, Fiscal Division, January 22, 1953, "Estimated cost of J40 engines from Westinghouse Electric Corp.," Box 398, NA.

191. This number is derived from the estimated 1,800 engines canceled by the Bureau of Aeronautics in 1953, and verified by House Subcommittee Final Report, 10, which also notes that "[b]ecause of the numerous amendments to the Westinghouse contracts, which added or withdrew quantities of engines from time to time, it is difficult to get a clear picture of the J40 engines on contract at any given time."
192. Moss to Snyder, October 16, 1952, Box 309, NA.
193. Rear Admiral Thomas A. Combs to L.E. Osborne, January 13 1953, Box 398, NA.
194. House Committee Intermediate Report, 9, 10.
195. *Jane's All the World's Aircraft,* 1954-1955, 343.
196. Chief, Bureau of Aeronautics to Westinghouse Electric Corporation, March 9, 1951, "Westinghouse J-40-WE 10 [sic] Aircraft Engine Production by Ford Motor Co."; see also House Subcommittee Final Report, 9.
197. McDonnell to BuAer letter of April 25, 1952, as quoted in House Subcommittee Final Report, 11.
198. House Subcommittee Final Report, 13.
199. Stekler, *Structure and Performance*, 90.
200. Miller, Ronald and David Sawers. *The Technical Development of Modern Aviation* (New York: Praeger Publishers, 1970), 161-2. Miller and Sawers suggest this amount may have been excessively high due to limited experience with the requirements of designing a jet engine in those early years. Nonetheless Pratt & Whitney Aircraft — and the military — willingly lavished such funds on the J57 engine program and ultimately reaped significant rewards for their investment (see below).
201. Combeirate to Director, Power Plant Division, December 28, 1950, "Informal conference between VF Design Branch and Turbo-jet Section; Individual report on," MC.
202. "Sales School Talk," script for Westinghouse recruiting presentation, ca. 1956, WHC.
203. House Subcommittee Final Report, 16.
204. Testimony of W. Waits Smith in House Subcommittee hearings, 212, 225.
205. "Engineering Activity in Support of Production Engines:' from (inserted) "Westinghouse J40/C23 Turbojet," [n.d.], Report no. A1828, in folder "Brochures," HEM; "Engineering Staff Meeting, October 24, 1955, Minutes," 5, HEM.
206. Combeirate to Director, Power Plant Division, "Informal conference between VF Design Branch and Turbo-jet section; Individual report on," December 28,1950, MC.
207. Cunningham, *Study in Industrial Location*, 159.
208. At House subcommittee hearings in October 1955 regarding J40 procurement (see the following section), the Chief of the Bureau of Aeronautics, Admiral Russell, testified that the Bureau had established the performance criteria of the engine, and that the AGT Division won a bidding competition to build the engine because it had promised to design and build it sooner and for less cost than the competition.

Admiral Russell noted that no other American company started on an engine design of comparable thrust for another 18 months after the awarding of the first J40 development contract, but the Subcommittee shrewdly observed that "[o]f course, if another company had been awarded the contract to develop, with Government funds and facilities, a new higher powered engine, Admiral Russell's remark would have been equally applicable to it." House Subcommittee final report, 5; House Subcommittee hearings, 28.
209. Interview by the author with Robert Wells, March 21, 1991.
210. "Milestone for Westinghouse," *Time*, September 15, 1952, 98.
211. "Milestone for Westinghouse," *Time*, September 15, 1952, 98.
212. Route Sheet comments by Commander Cote, February 13 1953, Box 398, NA.
213. Harrod to Chief, Bureau of Aeronautics, "Westinghouse Jet Engine Feeder Plant, January 5, 1951, Box 398, NA; see also Smith, "Recharging of Westinghouse," 188; and " ... In the Interests of National Defense..." Folder "Brochures," HEM. The Columbus plant is not to be confused with the Government-owned plant built during the same period by the Navy in Romulus, Michigan, for Ford's planned production of J40 engines.
214. " ... In the Interests of National Defense ... ," brochure, HEM; Chief, Bureau of Aeronautics to National Security Resources Board, June 24, 1951, "Application for Necessity Certificate; Westinghouse Jet Engine Plant;" Wilson to Chief, Bureau of Aeronautics, October 15,1951, both Box 398, NA.

The Bureau rejected a subsequent Westinghouse request for $1.1 million in additional tools because the request "contains certain general purpose machine tools and related production equipment which have probable use in connection with your future consumer goods production." R.A Batz to Westinghouse Electric, March 13 1951, Box 398, NA.
215. Thomas A. Combs to Westinghouse Electric Corporation, December 12, 1952, Box 309, NA.
216. Lynde to Combs, "Westinghouse — Columbus Facility," February 19, 1953, with route sheet comments by Norton, March 23, 1953, attached to Lynde letter, Box 398, NA.
217. Chief, Bureau of Aeronautics to Westinghouse Electric Corporation, June 16, 1953, "Columbus pre-production costs," Box 399, NA; "Big Factory Opens," *New York Times*, March 20, 1954, 22:2.

For a detailed primary-source account of the negotiation process, see L.E. Lynde to Chief, Bureau of Aeronautics, February 19, 1953, "Westinghouse-Columbus Facility," Box 398; Director, Industrial Planning Division to Deputy and Assistant Chief of Bureau, March 18, 1953, "Westinghouse Electric Corporation Plant at Columbus Ohio; pursuit of mobilization plan for:" C.K. Quinn to Bureau of Aeronautics, April 8, 1953, "1952 Final Price Determination - 1952 Columbus Preproduction Costs;" C.K. Quinn to Bureau of Aeronautics, May 5, 1953, "1952 Final Price Redetermination-Columbus Preproduction Costs." all Box 399, NA.
218. "Big Factory Opens," *New York Times*, March 20 1954, 22:2.
219. American Institute of Aeronautics and Astronautics, Ninth Annual Meeting, Eleventh Aerospace Sciences Meeting Luncheon, *Elmer A. Sperry Award for 1972* (Washington, DC: the Institute, 1973), 14. The subsequent history of the J57 development is from this source.
220. Westinghouse and General Electric engines both used a single set of compressor rotors connected directly to the turbine by a shaft; this gave their engines an optimal range of performance at cruising speed, but thrust fell and fuel consumption rose when the engine operated above or below this range, as when accelerating for take-off or slowing down for landing. The J57 had *two* axial-flow compressor/turbine sets operating on concentric shafts, one tuned to a lower and one to a higher performance range. In this way, the J57 could provide more thrust across a wider speed and altitude range. In addition, the compressor ran at a higher compression ratio — air entering the engine was squeezed into a smaller space — also aiding fuel consumption. AIAA/ ASME, *The Elmer A. Sperry Award for 1972*, 15.
221. Kahn to Chief of Bureau of Aeronautics, "Westinghouse Electric Corporation Renegotiation Fiscal Year Ended 31 December 1949, Request for Performance Information," May 21, 1951, also route sheet comments appended to this letter dated June 19 and undated; Chief, Bureau of Aeronautics to Kahn, "Westinghouse Electric Corporation, renegotiation fiscal year ended 31 Dec 1949; performance information on," June 28, 1951, all Box 398, NA.
222. Chief, Bureau of Aeronautics to Secretary of the Navy, "Westinghouse Electric Corporation proposal to provide facilities at Contractor's expense to be located at the Naval industrial Reserve Aircraft Plant, Kansas City," March 29, 1954, Box 337, NA,
223. "Takes Over-All Charge of Westinghouse Units," *New York Times*, December 31, 1953, 23:2; *Westinghouse Electric Corporation Annual Report 1954*, RG72, Unclassified General Correspondence, Box 306, NA.
224. House Subcommittee hearings, 234.
225. "To Helm of a Jet Plant," *Kansas City Times*, January 8, 1954.
226. "To Helm of a Jet Plant," *Kansas City Times*, January 5, 1954.
227. Interview with Oliver Rodgers by the author, March 22, 1992. Rodgers said that he had decided to leave because he believed the Westinghouse AGT Division was by 1953 simply marking time; his reasons mirrored many of the concerns frequently expressed by the Bureau of Aeronautics. He cited lack of support — financial or otherwise — from Westinghouse senior management; inability to develop a strong in-house R&D program at Kansas City or expand the small South Philadelphia R&D facility; and the inability to hire more than a few entry-level engineers at a time, and only at non-competitive wages.

228. *Jane's All the World's Aircraft*, 1954-1955, 342; "Key Personnel," in "PD-41 Turbojet Research Engine Planning and Cost Report," January 25, 1956, 10, Vertical Propulsion Files, NASM.
229. "Sales and Net Up at Westinghouse," *New York Times*, February 24, 1955, 35:5; "Doctor to a Lagging Line," *Business Week*, December 10, 1955, 135; "Westinghouse Gets a Cuffing," *Business Week*, October 22, 1955, 43; Guilfoyle, Joseph M., "How Westinghouse, its Profits Down by 35%, Aims to Come Back," *Wall Street Journal*, September 14, 1955, 1.
230. Stryker, Perrin and Daniel Bell. "What's Wrong at Westinghouse?" *Fortune*, March 1956, 114.
231. Guilfoyle, Joseph M., "How Westinghouse, its Profits Down by 35%, Aims to Come Back," *Wall Street Journal*, September 14, 1955, 14.
232. Smith, Edgar P., "The Recharging of Westinghouse," *Fortune*, December 1952, 121, 192.
233. Chief, Bureau of Aeronautics to Secretary of the Navy, "Westinghouse Electric Corporation proposal to provide facilities at Contractor's expense to be located at the Naval Industrial Reserve Aircraft Plant, Kansas City," March 29, 1954, Box 337, NA.
234. Price to Soucek, March 12, 1954; Soucek to Westinghouse, April 12, 1954; both Box 337, NA.
235. Soucek to Price, July 2, 1954, Box 338, NA.
236. Russell, in Wooldridge, E. T. *Into the Jet Age: Conflict and Change in Naval Aviation 1945-1975, an Oral History* (Annapolis: Naval Institute Press, 1995), 58.
237. House Subcommittee hearings, 9-10.
238. Karsten letter, reproduced in House Subcommittee hearings, 2. The J40 investigation section draws heavily from this document.
239. Public announcement, reproduced in House Subcommittee hearings, 4.
240. House Subcommittee hearings, 10.
241. House Subcommittee hearings, 219.
242. "J-40 Top Statistics," September 27, 1955, Box 14, HML.
243. House Subcommittee final report, 2. The J40 investigation section draws heavily from this document. Appropriately, perhaps, the Westinghouse AGT Division was scheduled to deliver the last of the Navy's order for 107 low-thrust J40 engines that same month. "Engineering Staff Meeting, October 24, 1955, Minutes," 5, HEM; House Subcommittee Tenth Intermediate Report, 17; House Subcommittee hearings, 237.
244. House Subcommittee hearings, iii-v, 1.
245. House Subcommittee hearings, 19, 21.
246. House Subcommittee hearings, 17.
247. House Subcommittee hearings, 33.
248. House Subcommittee hearings, 48.
249. House Subcommittee hearings, 28.
250. House Subcommittee hearings, 107-109, 111.
251. House Subcommittee hearings, 212-213.
252. House Subcommittee hearings, 219, 221.
253. House Subcommittee hearings, 236.
254. House Subcommittee final report, 2-3.
255. House Subcommittee final report, 41-44.
256. The paragraph in which Smith discusses the five contributing factors does not include a specific reference to the engine version to which the factors applied. However, in the six preceding paragraphs, Smith almost exclusively discussed the J40-WE-22 engine — that is, the low-thrust model of the engine.
257. Director, Contracts Division to Chief, Bureau of Aeronautics, "Westinghouse Electric Corporation, Aviation Gas Turbine Division," February 21, 1956, Box 307, NA.
258. Director, Contracts Division to Chief, Bureau of Aeronautics, "Westinghouse Electric Corporation, Aviation Gas Turbine Division," February 21, 1956, Box 307, NA.
259. Director, Contracts Division to Chief, Bureau of Aeronautics, "Westinghouse Electric Corporation, Aircraft Gas Turbine Division; request for price reduction on J40-22 and 22A engines," March 5, 1956, Box 307, NA.
260. Bureau of Aeronautics Referral Slip, from Chief of Bureau of Aeronautics, appended to Director, Contracts Division to Chief, Bureau of Aeronautics, "Westinghouse Electric Corporation, Aviation Gas Turbine Division," February 21, 1956, Box 307, NA.
261. R. E. Dixon to AER-l [Chief of the Bureau of Aeronautics Admiral Russell], "Memorandum for AER-l," March 20, 1956, Box 307, NA. For a discussion of the role of financial incentives in cost-plus-fixed-fee contracts, see Scherer, Frederic M. *The Weapons Acquisition Process: Economic Incentives* (Boston: Harvard University School of Business Administration, 1964), 184-190.
262. Haley to Schoech, "Westinghouse," March 23, 1956, Box 307, NA.
263. "Engineering Staff Meeting, January 7, 1955, Minutes," 2, 4; Westinghouse Electric Corp., Kansas City Works to Chief, Bureau of Aeronautics, "Engineering Standard Development Program for 1955," April 19, 1955, Box 335, NA.
264. Hotz, Robert, "Our Engine Development Problem," *Aviation Week*, February 21, 1955,114.
265. "GE Aims to Cut Jet Development Knots." *Aviation Week*, November 29, 1954, 22-23.
266. "GE's Aircraft Turbine Division to Install Mach 3.5 Wind Tunnel." *Aviation Week*, February 20, 1956, 33.
267. "GE Aims to Cut Jet Development Knots," *Aviation Week*, November 29, 1954, 22-23; "GE Takes a Major Step Toward its Realignment Goal," *Business Week*, December 10, 1955, 128.
268. Bridgman, Leonard, ed. *Jane's All the World's Aircraft*, 1955-1956 (London: Jane's All the World's Aircraft Publishing, [1955]), 366.
269. Bridgman, Leonard, ed. *Jane's All the World's Aircraft*, 1958-59 (New York: McGraw-Hill, 1959), 482-483.
270. *Jane's All the World's Aircraft*, 1958-1959, 487-488.
271. "Total Active and Inactive Jet Engines Produced by Pratt & Whitney Aircraft," [ca. 1980], tabulation on file at UTC.
272. St. Peter, *Memoirs of Ernest J. Simpson*, 51.
273. As early as May 1947, Leonard Hobbs of United Aircraft, the parent company of Pratt & Whitney Aircraft, declared to the Bureau of Aeronautics that "what facts are available are overwhelmingly in favor of my conclusion that that the proper time the experienced aircraft power plant people had been called in, the United States program would have been much farther ahead." Hobbs to Lonnquest, "Personal and Very Confidential," May 20, 1947, Leonard S. Hobbs Papers, Series 2, Folder 17, UTC.
274. "GE's Aircraft Turbine Division to Install Mach 3.5 Wind Tunnel," *Aviation Week*, February 20, 1956, 33.
275. "Westinghouse Puts Millions in Jet Program." *Aviation Week*, December 20, 1954, 16.
276. Hotz, Robert, "Our Engine Development Problem," *Aviation Week*, February 21, 1955, 114.
277. See, for example, "Logical Westinghouse Move," *Kansas City Times*, January 9, 1954; Soucek to Senator Duff, November 25, 1953, Box 400, NA.
278. Hotz, Robert, "Westinghouse Puts Millions in Jet Program," *Aviation Week*, December 20, 1954, 16.
279. See, for example, Western Union Cable P.CY A453, Chester Business Men's Association to Duff, December 3, 1953, and Malone to Harrison, December 4, 1953, "Upper Darby Township Commissioners' Resolution to Keep Essington Plant in Delaware County," both Box 337, NA.
280. "Logical Westinghouse Move," *Kansas City Times*, January 9, 1954.
281. "Statement by James B. Carey, President of IUE-CIO on Contemplated Removal of Aviation Gas Turbine Division Westinghouse Corporation from Essington, Pennsylvania to Kansas City," appended to Chief of the Bureau of Aeronautics to Assistant Secretary of the Navy, January 28, 1954, "IUE-CIO Statement on proposed Westinghouse move from Lester-Essington, Pennsylvania, to Kansas City, Missouri," Box 337, NA.
282. Soucek to Duff, November 25, 1953, Box 400, NA; Soucek to Hillelson, January 9, 1954, both Box 337, NA.
283. "Gain in Pay Roll," *Kansas City Times*, November 21, 1953; "A Big Industrial Move," *Kansas City Times*, November 23, 1953.
284. "Expanding Jet Industry," *Kansas City Star*, November 21, 1953.
285. "Logical Westinghouse Move," *Kansas City Star*, January 9, 1954.
286. Hotz, Robert, "Westinghouse Puts Millions in Jet Program," *Aviation Week*, December 20, 1954, 16.
287. "Engineering Staff Meeting, May 11, 1955, Minutes," 7, HEM.
288. Bureau of Aeronautics Representative, Essington, Pa. to Chief. Bureau of Aeronautics, December 13. 1954, "Westinghouse Electric Corporation, Aviation Gas Turbine Division, Engine Program Support; information on," Box 338, NA.

289. “Engineering Staff Meeting, December 6, 1955, Minutes,” 4, HEM.
290. Chief, Bureau of Aeronautics to Westinghouse Electric Corporation, AGT Division, Lester, Pennsylvania, “WECO, AGT Div., Lester, Pa., Class III Property — Semi-annual inspection; report on,” May 4, 1955, Box 335, NA. The exact damages were not specified in the letter and no other references could be found.
291. “Engineering Staff Meeting Minutes,” for July 21, 1955, 6; October 24, 1955, 7; December 6, 1955, 4, HEM.
292. “Engineering Staff Meeting Minutes” for February 8, 1955, 5; March 3, 1955, 6; April 5, 1955, 2; August 1, 1955, 6, HEM.
293. “4,200 Have Jobs at Westinghouse,” *Kansas City Star*, October 25, 1956.
294. “Engineering Staff Meeting, May 11, 1955, Minutes,” 7. The Westinghouse Aviation Gas Turbine Division collection at the Historical Electronics Museum has a complete set of Engineering Division staff meeting minutes for 1955. As well as providing an excellent source of engine R&D and production information, these minutes provide a fascinating snapshot of the engineering staff during a key period in the AGT Division’s history. The “tone” of the discussions frequently suggest reticence and circumspection on the part of the engineers when discussing topics such as staff defections, low morale, funding cutbacks, and frequent rebuffing of sales representatives by airframe manufactures — topics that might otherwise be seen as distinct manifestations of overall systemic problems. I have relied heavily on the 1955 Engineering Department meeting minutes in my discussion of morale in Kansas City.
295. “Engineering Staff Meeting Minutes” for June 2, 1955, 7; October 24, 1955, 6, HEM.
296. “Engineering Staff Meeting Minutes” for February 8, 1955, 8; March 3, 1955, 2; April 5, 1955, 7, HEM.
297. Green and Cross, *Jet Aircraft of the World*, 36. The Westinghouse designation for the bulk of the J34 engine family was 24C-4; its designation for the J46 was 24C-10. See Appendix 1, Aircraft Gas Turbine Engine Designation Standards, for an explanation of Westinghouse’s in-house designation system.
298. United States Naval Air Propulsion Center. Report AEL-1520, “Altitude Calibration of WECO J46-WE-4B [*sic*] Engine,” July 17, 1957. United States Naval Air Propulsion Center Technical Publications Collection, Box 25, NASM. Very little statistical information could be found for the J46 engine, especially regarding its design lineage from the J34.
299. “Engineering Staff Meeting Minutes” for August 29, 2, and October 24, 1955, 1, HEM.
300. Westinghouse AGT Division Report No. A2047-A, “The New Westinghouse PD-33 Turbojet Engine,” [n.d.], [i], Propulsion File, microfiche BO-071 000, NASM-Garber.
301. Guilfoyle, Joseph M. “How Westinghouse, its Profits Down by 35%, Aims to Come Back,” *Wall Street Journal*, September 14, 1955, 14.
302. Interview by the author with Robert Wells, October 18, 1992.
303. Westinghouse AGT Division Report No. A2047-A, “The New Westinghouse PD-33 Turbojet Engine,” [n.d.], [I]-3, 8, 14. Propulsion File, microfiche BO-071000, NASM-Garber.
304. “Engineering Staff Meeting, February 8, 1955, Minutes,” 3, HEM.
305. Bridgman, Leonard, ed. *Jane’s All the World’s Aircraft*, 1957-58 (New York: McGraw-Hill, 1957), 447-448.
306. Westinghouse AGT Division Report No. A-2070, “PD-33 Turbojet Engine, Report of the 50-hour Endurance Test,” July 15, 1955, 1, Propulsion File, microfiche B0071010, NASM-Garber; “Engineering Staff Meeting, January 7, 1955, Meeting,” 1.
307. “Engineering Staff Meeting Minutes” for February 8, 1955, 2; March 3, 1955, 2; April 5, 1955, 5, HEM.
308. “Engineering Staff Meeting, May 11, 1955, Minutes,” 2-5, HEM.
309. “J54 Application Summary,” [ca. 1955], 1-2, HML.
310. “Engineering Staff Meeting, July 21, 1955, Minutes,” 1, HEM.
311. “Engineering Staff Meeting, April 5, 1955, Minutes,” 4, HEM.
312. “Engineering Staff Meeting Minutes,” for June 2, 1955, 5; July 21, 1955, 2; August 29, 1955, 3, HEM.
313. Engineering Staff Meeting, October 24, 1955, 1, HEM; “TL Aero, Jet Engines,” [photocopy of news wire report], November 18, 1955, Propulsion Files, NASM.
314. Bridgman, ed., *Jane’s All the World’s Aircraft*, 1957-58, 447.
315. St. Peter, *Memoirs of Ernest J Simpson, Aero Propulsion Pioneer*, 50.
316. “Engineering Staff Meeting Minutes” for January 16, 1956, 2; June 11, 1956, 2, HEM. The literature is very sketchy as to the reasons for the Navy’s lack of interest, but attest to its sudden and unexpected (at least to Westinghouse) nature.
317. Bright, Charles D. *The Jet Makers: the Aerospace Industry from 1945 to 1972* (Lawrence, KS: Regents Press of Kansas, 1975), 83-S5. According to Rae, *Climb to Greatness*, 202, between 1954 and 1956 the number of new military aircraft produced in the United States dropped dramatically. After a postwar peak of nearly 9,000 aircraft built in 1953 as a result of the Korean War buildup, production in 1956 dropped 57%, to just over 5,200 aircraft. The number of commercial aircraft manufactured during that same period, however, rose 57%, from approximately 4,100 to over 7,200, and an increasing number of those were powered by aircraft gas turbine engines.
318. Weber to Russell, “Commercial Production of Engines, “ April, 8, 1955, Box 335, NA; Henderson to Chief, Bureau of Aeronautics, “Commercial Use of Machine Tools at NIRAP, Kansas City, Missouri,” Box 306, NA.
319. Engineering Staff Meeting, October 24, 1955, Minutes,” 2, HEM.
320. Bright, *The Jet Makers*, 88; AIAA, *Elmer A. Sperry Award for 1972*, 18-20.
321. Bright, *The Jet Makers*, 91-92.
322. The Dart engine featured a centrifugal compressor, unlike all other AGT Division products which used axial-flow compressors, of which the Division had been a pioneer. In 1953 the Navy’s Bureau of Aeronautics arranged a technical-exchange agreement between Rolls-Royce and Westinghouse, in much the same way as the Bureau had arranged a license-building agreement between Rolls-Royce and Pratt & Whitney Aircraft in the late 1940s.
323. Bridgman, ed. *Jane’s All the World’s Aircraft*, 1957-58, 448.
324. The ill-fated J54 began as the Westinghouse PD-33.
325. Bureau of Aeronautics Representative, Essington, Pa. to Chief, Bureau of Aeronautics, “Westinghouse Electric Corporation, Aviation Gas Turbine Division, Engine Program Support; Information on,” December 13, 1954, Box 338, NA.
326. See, for example, “Engineering Staff Meeting Minutes” for April 5, 1955, 6; August 29, 1955, 3, HEM.
327. “Engineering Staff Meeting Minutes” for August 1, 1955, 3; October 24, 1955, 2, HEM.
328. “Engineering Staff Meeting Minutes,” August 29, 1955, 4, HEM.
329. “Engineering Staff Meeting Minutes” for February 8, 1955, 3; August 1, 1955, 4; December 6, 1955, 3, HEM.
330. “Engineering Staff Meeting, June 2, 1955, Minutes,” 8, HEM.
331. “Sales School Talk,” script for Westinghouse recruiting presentation, ca. 1956, WHC.
332. Hobbs to Homer, January 16, 1956, Leonard S. Hobbs Papers, Box 3, UTC.
333. Interview by the author with Oliver Rodgers, March 22, 1992.
334. Bridgman, *Jane’s All the World’s Aircraft*, 1958-59, 492.
335. “Jet Plant Gets Order.” *Kansas City Star*, March 13, 1957.
336. “Add to Big Jet Order.” *Kansas City Star*, November 18, 1957; “Approve a Jet Engine.” *Kansas City Star*, July 10, 1958.
337. “Big New Order for Jet Plant” *Kansas City Star*, December 25,1958; “Pay Increases for 1,300 Workers Here.” Kansas City Star, October 8, 1959.
338. “Big Jet Order to Plant Here.” *Kansas City Star*, November 21, 1959.
339. “Jet Engine Parts Order.” *Kansas City Star*, July 22, 1959.
340. Bright, *The Jet Makers*, 66.
341. St. Peter, *Memoirs of Ernest J. Simpson*, 51; Price to Secretary of the Navy, January 3, 1957, box 287, NA.
342. Price to Secretary of the Navy, January 3, 1957, box 287, NA.
343. Price, in Price to Secretary of the Navy, January 3, 1957, box 287, NA, stated that if no such contracts were received by mid-February he would disband the PD organization; there are no documents available to suggest this did not occur. In addition to Preliminary Design, the other teams under Director of Research Kroon were Advanced Design and Atomic Power. Preliminary Design consisted of five subdivisions: New Engines, Turbofan Engine Studies, Turbojet Engine Studies, Advisory Engineering, and Engine Application Studies. Westinghouse AGT Division organization chart, ca. 1957, folder “Brochures,” HEM.
344. “Engineering Staff Meeting, March 14, 1957, Minutes,” HEM.

345. Berry to Smith, “Engineering Operations Report, December 1958,” January 9, 1959, HEM.
346. Berry to Smith, “Engineering Operations Report, May 1958,” June 5, 1959, HEM.
347. “Jet Plant Here Decade.” *Kansas City Star*, January 1, 1959.
348. Berry to Smith, “Engineering Operations Report, December 1959,” January 7, 1960, HEM.
349. “Engineering Operations Report, February 1960,” March 9, 1960, 3,4; “Engineering Operations Report, March 1960,” April 6, 1960, 3.
350. “New Projects for Jet Plant.” *Kansas City Star*, September 24, 1959.
351. “Cancel Jet Pact Here.” *Kansas City Star*, February 19, 1960.
352. Taylor, *Jane’s Encyclopedia of Aviation*. 767.
353. “Cancel Jet Pact Here.” *Kansas City Star*, February 19, 1960.
354. Engineering Operations Reports for February through December, 1960, HEM.
355. “Pentagon Freezes Out This Area on Defense Jobs.” *Kansas City Star*, February 20, 1960.
356. “Workers Plead for Plant Use.” *Kansas City Star*, February 20, 1960.
357. “A Symington Message.” *Kansas City Star*, February 19, 1960.
358. “Workers Plead for Plant Use.” *Kansas City Star*, February 20, 1960; “A Drive to Save Plant Jobs.” *Kansas City Star*, February 23, 1960; “Begin Fight on Plant Use.” *Kansas City Star*, February 25, 1960; “Jet Plant Meeting Near.” *Kansas City Star*, February 25, 1960.
359. Stekler, *Structure and Performance*, 87-8.
360. Schatz, Ronal W. *The Electrical Workers: A History of Labor at General Electric and Westinghouse, 1923-1960* (Urbana: University of Chicago Press, 1983), 236.
361. “Tight Financial Controls Are Key.” Business Week, November 19, 1960, 105-106.
362. Director, Contracts Division to Chief, Bureau of Aeronautics, “Westinghouse Electric Corporation, Aviation Gas Turbine Division,” February 21, 1956, Box 307, NA. The estimate of Westinghouse funds comes from the $12.5 million provided for the expansion and relocation of the R&D program, the $8 million allocated for the development and production of the J54 engine, and other contributions that were likely made since 1941, but not specified in the available documentation.
363. In 1961, for example, United Aircraft’s earnings resulted in only a 0.9% profit margin on sales of over $1 billion. “United Aircraft 1961 Profit Cut Blamed on High R&D Expenses.” *Aviation Week and Space Technology*, March 26, 1962, 83-4. Profits-to-invested-capital returns in the early and mid-1950s for airframe manufacturers, by contrast, ranged from 79.9% for Martin to over 800% for North American Aviation. Stekler, *Structure and Performance*, 157.
364. Rieser, Carl. “The Changes at Westinghouse.” *Fortune*, August 1958, 90, 146. See also 87-90, 142, for details of the management changes before and after Cresap’s acceptance of the company presidency.
365. “Hopeful for Plant Here.” *Kansas City Star*, December 12, 1957.
366. Stekler, *Structure and Performance*, 16-18.
367. Bright, *The Jet Makers*, 52-53.
368. “Shutdown Set for Jet Plant.” *Kansas City Star*, March 22, 1960.
369. “Engineering Operations Report, April 1960,” May 6, 1960, 2.
370. “Engineering Operation Report, December 1960,” January 11, 1961.
371. Mallett to Fogg. “Pratt & Whitney’s Support for the Westinghouse J34 Engine,” November 14, 1960, Westinghouse Collection, UTC.
372. “Engineering Operations Report, December 1960,” January] 1, 1960.
373. See, for example, Hamm, ed., Report PW A-4031, “Technical Progress Report, J34 Product Support Program Review,” September 22, 1970, Westinghouse Collection, UTC.
374. Hamm, ed., Report PW A-4833, “Technical Progress Report, J34 Product Support Program Review,” October 3, 1973, Westinghouse Collection, UTC.
375. [No Title], *Aviation Week*, March 28, 1960, 37.
376. Anderton, David A GE Cuts Bottlenecks at New Jet Center.” *Aviation Week*, April 14, 1952, 21; *Elmer A. Sperry Award for 1972*, 13.
377. Dosi, Teece, and Winter, “Toward a Theory of Corporate Coherence,” *Technology and Enterprise*, 198.
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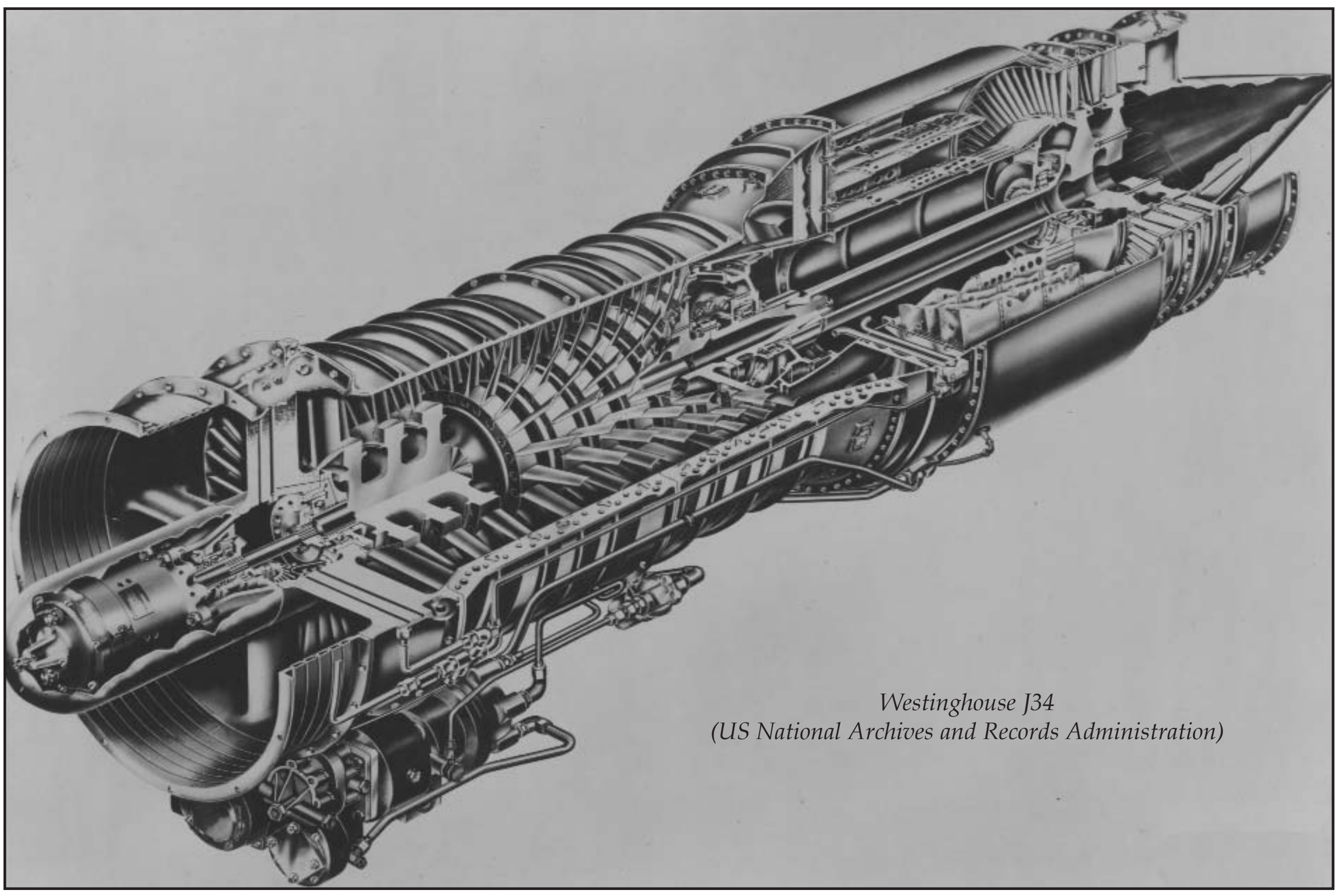

Westinghouse J34
(US National Archives and Records Administration)