PROBLEMS OF ACCELERATING AIRCRAFT PRODUCTION DURING WORLD WAR II

A REPORT BY

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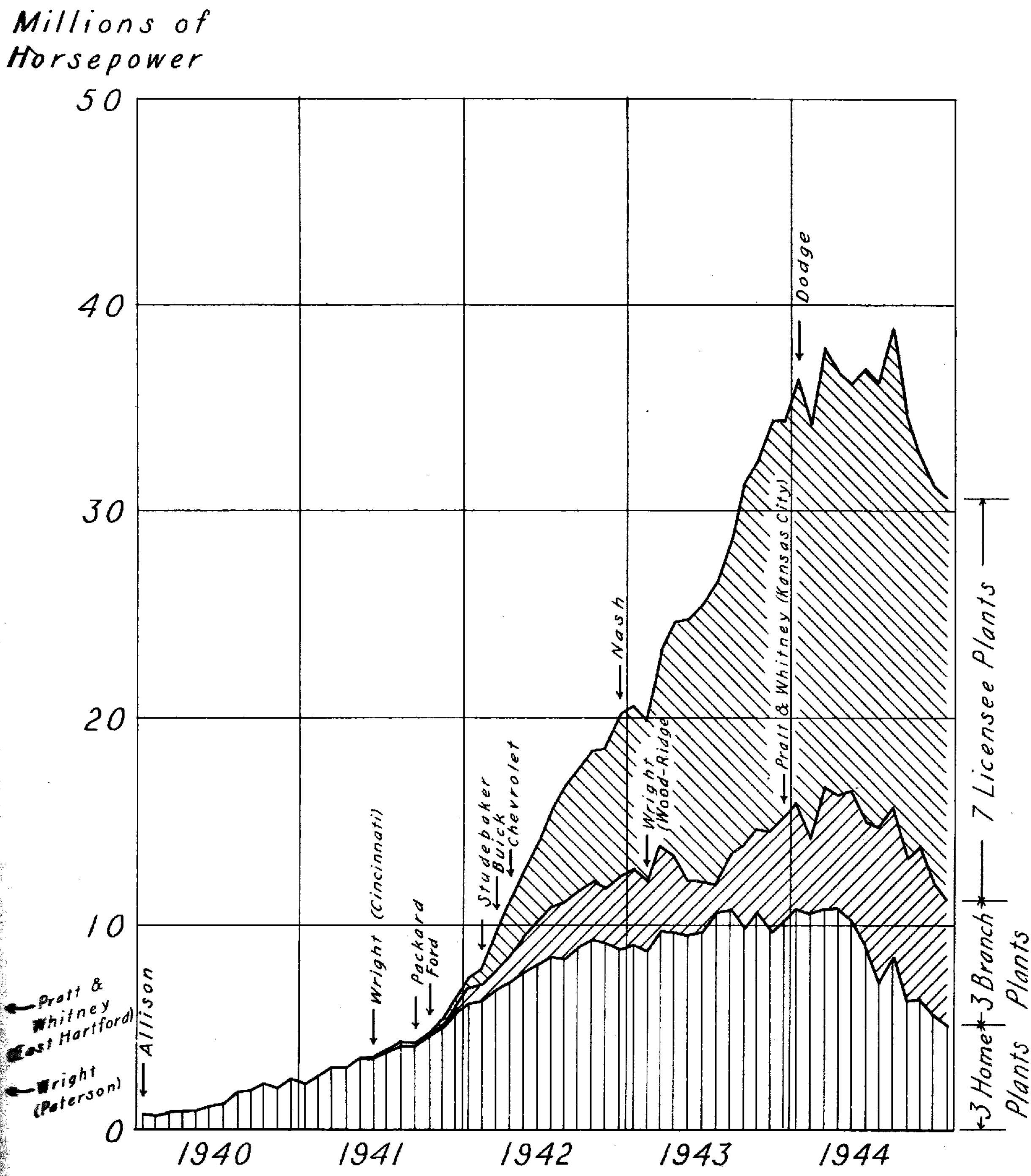
EXHIBIT 4. Horsepower of Engines Delivered: 13 Plants Producing Principal Models (Including Spares)



Source: Plotted from data appearing in Table 15, Appendix C.
Note: Names of plants shown indicate the month in which they first delivered an engine.

and 1941 aircraft production record are apparent. While certain models were produced in quantity during the pre-Pearl-Harbor period, most of these models were not of the types or of the advanced designs which proved essential for victory.

EXHIBIT 5. Measures of Annual Output of Airframes and Engines, 1940–1944

Years	Totals	Percentage of Five-Year Total, 1940–1944	Percentage Increase over Preceding Year
Number of Combat and Large Transport Aircraft Accepted			
1940	3,064	1.7%	......
1941	9,330	5.3	204.5%
1942	25,582	14.5	174.2
1943	57,544	32.6	124.9
1944	80,938	45.9	40.7
Total	176,458	100.0%	......
Pounds of Combat and Large Transport Aircraft Accepted*			
1940	17,176,700	0.9%	......
1941	62,117,000	3.4	261.6%
1942	233,136,300	12.7	275.3
1943	595,254,400	32.4	155.3
1944	930,593,400	50.6	56.3
Total	1,838,277,800	100.0%	......
Horsepower of Large Military Engines Delivered†			
1940	15,723,000	1.6%	......
1941	46,855,000	4.8	198.0%
1942	171,042,000	17.4	265.0
1943	326,789,000	33.2	91.1
1944	423,196,000	43.0	29.5
Total	983,605,000	100.0%	......

* Poundages shown are for complete airframes only and do not include spare parts produced.

† Deliveries from 18 plants producing engine models of 1,650 or more cubic inch displacement. Totals of two of these plants include the output of trainer engines. An allowance for spares is included.

Source: Airframe data compiled from unpublished data furnished by the Statistical Control Office, Air Technical Service Command, Wright Field. Engine data compiled from company sources and Aircraft Resources Control Office, Report 15.

Nineteen major models constituted about 87% of the total number of all combat and large transport aircraft produced in the years 1940–1944.[1] These models carried the major burden of American air warfare. Exhibit 6 shows the time spans between the acceptances of the 5th, the 500th, and the 1,000th airplane of each of these models. In June 1940 only three major models were in production for the services. At the time of Pearl Harbor, only two of the models had been produced in a volume of over 1,000 airplanes, the Douglas A-20 and the Curtiss-Wright P-40. The majority of the 19 models were not produced in a volume of 1,000 until the second half of 1942.

Before Pearl Harbor there were particularly acute shortages of the four-engine bombers and high-altitude Army fighters which were later to play such a vital role in winning the war. The total production of four-engine bombers in 1940 and 1941 was 380 airplanes (see Exhibit 7), mostly early versions of the Boeing B-17 and Consolidated B-24. In the fighter class, production was large in 1941 in comparison with most of the other types. As shown in Exhibit 7, however, output was concentrated on two Army fighters, the Curtiss-Wright P-40 and the Bell P-39, and on one Navy carrier-based model, the Grumman F4F. Neither of the two Army fighters was designed for high-altitude performance. The Army took steps in 1940 to obtain satisfactory high-altitude fighters, but none of these models was produced in significant quantities prior to Pearl Harbor. The first appreciable deliveries of fighters other than the above three models occurred in November 1941, when 111 of the new models were delivered.

In the two-engine bomber group, light bombers such as the Douglas A-20 and the Lockheed Hudson were produced in substantial quantities in 1940 and 1941, but few medium bombers were produced.[2] Single-engine bomber production was concentrated primarily on the Douglas dive bomber, the SBD; even for this model deliveries in 1940 and 1941 totaled only 395. Deliveries of transports to the services were negligible prior to Pearl Harbor because the services were concentrating all their efforts on obtaining combat aircraft and trainers.

Engine Production by Models

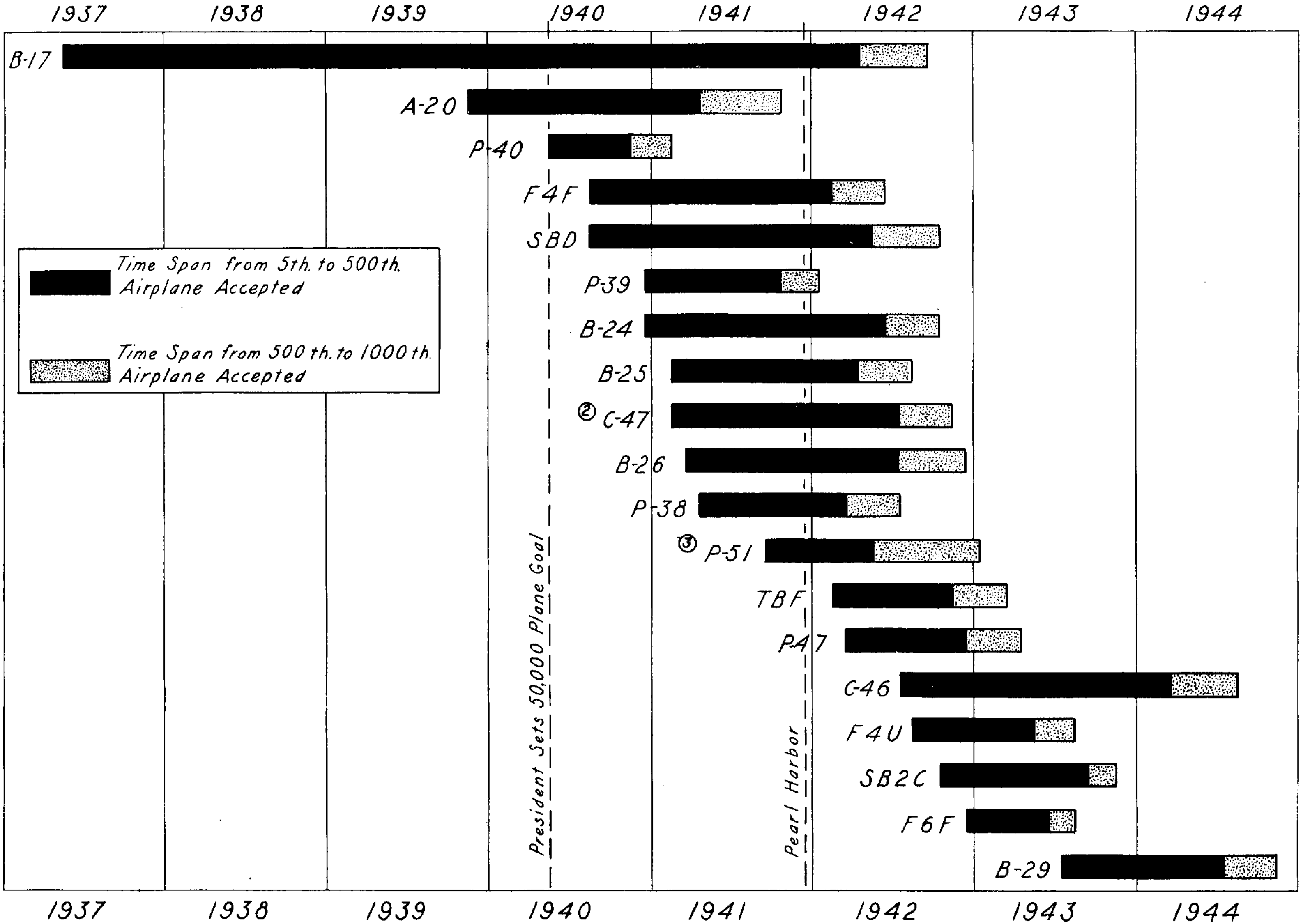
Eight principal models of engines were used to power combat and large transport aircraft during World War II. Most of the production prior to Pearl Harbor was concentrated on four of these models, each of which was in production in mid-1940 (see Exhibit 8). Two of these models, the Wright R-1820 and Pratt & Whitney R-1830, had been thoroughly service-tested for several years prior to 1940 in airline service and in military aircraft. The Wright R-2600 had been service-tested for only a few months, while the fourth model, the Allison V-1710, had not been in use at all prior to 1940.

The four models introduced later in the mobilization period included:

[1] See Appendix C for total production of each of these models.

[2] See Appendix C for a detailed statistical record of production of one- and two-engine bombers and transports.

EXHIBIT 6. Time Span Between 5th and 1,000th Acceptance of 19 Major Models of Combat and Large Transport Aircraft (1)



Source: Unpublished data furnished by Statistical Control Office, Air Technical Service Command, Wright Field.

Notes: (1) In determining the month in which the 5th, 500th and 1,000th airplane was accepted, consideration was given to the output of all plants manufacturing a model. All versions of basically similar design are included as one model, even though different military designations may be used for different versions.

(2) Acceptances by the armed services only. Commercial deliveries are excluded.

(3) Includes acceptances of A-36's, a version of the P-51.

EXHIBIT 7. Number of Acceptances of Major Models of Four-Engine Bombers and Fighters, 1940–1944*

Originator of Design	Military Designation	1940	1941	1942	1943	1944
FOUR-ENGINE BOMBERS						
THREE MAJOR MODELS						
Boeing	B-17	53	144	1,412	4,179	5,352
Consolidated	B-24	7	169	1,164	5,214	9,519
Boeing	B-29	....	....	3	92	1,161
Subtotal, Three Models		60	313	2,579	9,485	16,032
ALL OTHER MODELS	....	1	6	39	130	302
Total Four-Engine Bombers		61	319	2,618	9,615	16,334
FIGHTERS						
THREE EARLY MAJOR MODELS						
Curtiss-Wright	P-40	778	2,246	3,854	4,258	2,002
Bell	P-39	13	926	1,932	4,947	1,729
Grumman	F4F*	106	324	1,470	1,537	3,130
Subtotal, Three Models		897	3,496	7,256	10,742	6,861
FIVE LATE MAJOR MODELS						
Lockheed	P-38	1	207	1,479	2,497	4,186
North American	P-51	....	138	634	1,710	6,982
Republic	P-47	....	1	532	4,428	7,065
Chance Vought	F4U†	1	....	178	2,293	5,380
Grumman	F6F	....	....	10	2,547	6,140
Subtotal, Five Models		2	346	2,833	13,475	29,753
ALL OTHER MODELS	....	738	575	264	72	2,356
Total Fighters		1,637	4,417	10,353	24,289	38,970

* Includes acceptances of the FM, the version of the F4F produced by the Eastern Aircraft Division of General Motors Corporation.
† Includes acceptances of the FG and F3A versions of the F4U produced by Goodyear Tire & Rubber Company, Inc., and Brewster Aeronautical Corp.
§ Includes acceptances from all plants producing each of the models.
Source: Compiled from unpublished data furnished by the Statistical Control Office, Air Technical Service Command, Wright Field.

EXHIBIT 8. Deliveries of Aircraft Engines by Principal Military Models, 1939–1944*

Originator of Design	Military Designation	1939	1940	1941	1942	1943	1944
FOUR EARLY MODELS							
Wright	R-1820	2,056	2,272	4,593	15,925	32,804	35,199
Pratt & Whitney	R-1830	1,792	3,643	6,441	22,655	59,561	65,060
Wright	R-2600	163	1,925	7,395	18,116	22,112	29,014
Allison	V-1710†	....	1,149	6,402	14,904	21,064	20,191
Subtotal, Four Early Models		4,011	8,989	24,831	71,600	135,541	149,464
FOUR LATER MODELS							
Pratt & Whitney	R-2800	2	17	1,733	11,840	23,726	45,259
Rolls-Royce (British)	V-1650†	....	....	45	7,251	15,084	22,969
Pratt & Whitney	R-2000	....	....	9	406	1,449	3,164
Wright	R-3350	3	8	5	68	917	11,323
Subtotal, Four Later Models		5	25	1,792	19,565	41,176	82,715
Total, All Principal Models		4,016	9,014	26,623	91,165	176,717	232,179

* Includes deliveries from all plants producing each of the models.
† Liquid cooled engines. All other models shown are air cooled engines.
Source: Company data and Aircraft Resources Control Office, Report 15.

(1) *The Pratt & Whitney R-2800 and the Wright R-3350.* Both of these models developed greater horsepower than any of the previously used models. The R-2800 was used on a number of important Army and Navy models including the Republic P-47, the Grumman F6F, and the Martin B-26. The R-3350 was developed primarily to power the Boeing B-29.

(2) *The Rolls-Royce V-1650.* In mid-1940 the only American liquid-cooled engine, the Allison V-1710, had just been brought into production and was not considered a proved combat engine. The Rolls-Royce Merlin, developed and proved in combat in England, was put in production in this country by the Packard Motor Car Company to assure that England and the United States would have a proved liquid-cooled engine in production here. Use of this engine later made possible a great improvement in the altitude performance of several Army fighters.

(3) *The Pratt & Whitney R-2000.* This engine was generally similar to the R-1830 but developed greater horsepower. It was used primarily in the Douglas transport, the C-54, and was not produced in large volume.

Thus, several important engine models, including the two wartime models with the highest horsepower ratings, were not produced in appreciable quantity until after Pearl Harbor.

* * * * *

In summary, the total 1941 production of combat and large transport aircraft and engines expanded more than three-fold over the 1940 level. Nevertheless, total output in 1941 was only about one-tenth the output of the peak year, 1944. A breakdown of the totals reveals that most of the aircraft models used in large quantities during the war and several new engine models were not produced in significant quantities until after Pearl Harbor.

It would be a serious error to infer, however, that the years 1940 and 1941 were wasted. Even though there was little production of certain types during those years, the preparations made were instrumental in getting under way the volume output of the war-winning years. By late 1942 quantity production of most of the models which later were instrumental in winning air supremacy had started. By 1943 virtually all the new wartime plants were in volume production, their output equaling, and in the case of engines far exceeding, that of the home plants. The vast production peak of the program was achieved in 1944.

EXHIBIT 11. Dates of Start of Design, First Run, and First Acceptances: All Major Engine Models (Basic designs and major revisions)

Originator of Design	Military Designation	Design Work Started	Experimental Engine First Run	Fifth Engine Accepted	Approximate No. of Years between Start of Design and Fifth Acceptance
New Basic Designs					
Pratt & Whitney	R-1830	*	*	*	
Wright	R-1820	*	*	*	
Allison	V-1710	Mar 1930	Mar. 1932	Feb. 1940	10
Wright	R-2600-A	Dec. 1935	June 1936	Mar. 1938	2¼
Allison	V-3420	Jan. 1936	Mar. 1938	Feb. 1943	7
Wright	R-3350-BA	Jan. 1936	May 1937	Oct. 1939	3¾
Pratt & Whitney	R-2800-A	Mar. 1937	Sept. 1937	Mar. 1940	3
Pratt & Whitney	R-2000	Jan. 1939	May 1940	Dec. 1941	3
Pratt & Whitney	R-4360	Nov. 1940	April 1941	Nov. 1943	3
Major Revisions of Design					
Wright	R-1820 (C9HC)	Aug. 1935	Jan. 1942	April 1943	7¾
Wright	R-2600-BA	Nov. 1938	Nov. 1939	June 1941	2½
Pratt & Whitney	R-2800-B	May 1940	June 1940	Oct. 1941	1½
Pratt & Whitney	R-2800-C	May 1940	Sept. 1940	Aug. 1943	3¼
Packard	V-1650†	July 1940	May 1941	Oct. 1941	1¼
Wright	R-3350-BB	Aug. 1941	Jan. 1942‡	Aug. 1942	1
Pratt & Whitney	R-1830-C9G	Oct. 1941	Feb. 1942	Dec. 1943	2¼
Packard	V-1650Two Stage	Feb. 1942	May 1942	Dec. 1942	¾

* Basic designs for these models were made during such an early period that dates were not considered significant here.
† Classified as a major revision because of inadequacy of engineering data furnished to the company.
‡ Estimated.
Source: Company Records.

engineering work on 10 of the 19 major combat and large transport aircraft and all eight of the major engine types reaching combat was inaugurated by January 1939.[1] Design work on seven of the remaining nine aircraft models was commenced in 1939 and in the early months of 1940. Only for the Republic P-47 and Grumman F6F was design work initiated after June 1940. The P-47 was designed under pressure beginning in July 1940 in response to the urgent request of the Army for a satisfactory high-altitude fighter. The F6F superseded the F4F, also a Grumman model. In the engine field, the only major new models for which design work was begun after June 1940 were the Pratt & Whitney R-4360 and several jet engines. These models were being flown before V-J Day, but they were not used in combat to any appreciable extent.

This record is a dramatic illustration of the importance of developing in peacetime the weapons that are to be used during war, even a comparatively long war. Changes, many of them very important, were made in existing models throughout the years 1940–1945, but the basic design of almost all major models was started before mobilization began.

The experience with the Wright R-3350 engine, used in the B-29's, illustrates another point. Initial design work on this type began in January 1936, one month after the same company began the design of the R-2600. The military type test was passed in January 1938, but because of lack of interest on the part of the services, development was shelved in favor of the R-2600. Later, when the B-29 program needed the R-3350, the original design had become obsolescent, and the designers had much work to do in incorporating the latest engineering practices. Such an experience clearly illustrates the fact that a basic design must be followed by continuing developmental work if it is to be available for military use on short notice.

Readiness for Production

The World War II aircraft production program was delayed — not because of a lack of experimental models, but because an insufficient number of these models were at the advanced stage of development necessary for production. While 17 of the 19 major airframe models were being developed by mid-1940, manufacturing experience was

[1] The eight major engine models used in combat during the war include the V-1650. Historical information regarding the basic design of this model is not shown in Exhibit 11, but the original design work was begun in Great Britain well before January 1939. The V-3420 and the R-4360, shown in Exhibit 11, were not used in combat.

available on only four models.[1] The production records of 1940 and 1941 reflect the limited choice of fully developed models available. As shown in Exhibit 12, the only models with a combined 1940-1941 output of over 500 airplanes were two low-altitude fighters, two light bombers, and one Navy observation model. The ten models produced in excess of 300 airplanes did not include any four-engine bombers, high-altitude fighters, or medium bombers of the B-25 and B-26 class.

As later sections will explain, many factors contributed to the relatively small production achieved before Pearl Harbor. One of the most important single elements, however, was that few tactically useful combat models were developed to a stage where they could be put into immediate production.

The production of fairly large numbers of four different engines in 1940 and 1941 indicates a somewhat better situation in the engine field. It is important to recognize, however, that three of these models were rated only at the 1,000 horsepower level because of the previous importance given this level by the services. The fourth model, the larger R-2600, was not developed primarily at the request of the services but rather because of the need for it in large commercial flying boats. The lack of interest on the part of the services in large engines was also exemplified by the previously mentioned history of the R-3350. It was a retarding factor in the development of all models with potential outputs well over the 1,000 horsepower level.

[1] One of the four models, the Douglas transport whose military versions were usually designated as the C-47 or C-53, was not sold to the services in any significant numbers until 1941. The commercial version, the DC-3, had, however, been produced for commercial airlines ever since 1936; hence long production and service experience was available on the basic C-47 type.

Accelerated Development During the War

If World War II experience confirmed the necessity for continuing research and development before the war, it also emphasized the importance of such work during the war as well. Given a late start, the tremendous task of developing urgently needed airframes and engine models had to be undertaken currently with preparations for volume manufacture. The cost in terms of wasted resources and human energy was high, but the wartime telescoping of developmental and production processes made it possible to obtain quality and quantity of output more rapidly than could otherwise have been done. Nevertheless, the production record clearly indicates that wartime short cuts by no means eliminated the sizable time lags needed to perfect combat aircraft and engines.[2]

[2] The last columns of Exhibits 10 and 11 show the approximate elapsed time between the beginning of design work on major models and the acceptance of the fifth airplane and engine. While the more recently developed models were, on the average, put into production somewhat more quickly than earlier models, the indicated saving in time was not great in most instances. Actually, the time required to develop effective combat aircraft and engines is longer than Exhibits 10 and 11 indicate, since delivery of five airplanes or engines is no assurance whatever that a model is ready for tactical use. For instance, five B-29's were delivered by July 1943, but the B-29 was not used in combat until 11 months later, in June 1944, about four years after design work was initiated. Even then, the task was accomplished only by pouring unlimited funds and man-hours into the B-29 program.

EXHIBIT 12. Total Acceptances of Combat Aircraft by Models in the Two Years, 1940 and 1941

Originator of Design	Customary Designation	Type of Aircraft	Total Acceptances
MODELS WITH PRODUCTION OVER 500			
Curtiss-Wright	P-40 (and P-36)*	Fighter	3,535
Lockheed	Hudson	Light Bomber	1,434
Douglas	A-20	Light Bomber	1,308
Bell	P-39	Fighter	939
Chance Vought	OS2U	Observation	579
Subtotal, 5 Models			7,795
MODELS WITH PRODUCTION OF 300 TO 500			
Martin	A-22 and A-30	Light Bomber	499
Brewster	F2A	Fighter	471
Grumman	F4F	Fighter	430
Consolidated	PBY-5	Patrol Bomber	417
Douglas	SBD	Dive Bomber	395
Subtotal, 5 Models			2,212
MODELS WITH PRODUCTION LESS THAN 300. TOTAL			1,937
Grand Total, Combat Aircraft			11,944

* The P-36 was a predecessor of the P-40 developed previously by Curtiss-Wright.
Source: Compiled from unpublished data furnished by the Statistical Control Office, Air Technical Service Command, Wright Field.

SECTION IV

CONVERSION TO WARTIME PRODUCTION TECHNIQUES

When wartime mobilization was begun in 1940, industry as well as government had to create vast new organizations and, amid constant confusion and time pressures, to revolutionize methods of operation. In this section, problems involved in the change-over to wartime production techniques will be discussed, to be followed in the next section by analysis of the broader problems of providing the over-all company management to administer all phases of the wartime industrial task.

Analysis of the conversion to wartime production techniques will be divided into the following six chapters:

Chapter 1. The wartime production programs. A description of the types of companies selected by the government to produce airframes and engines during the war.

Chapter 2. Production processes. The nature of the processes used in the production of airframes and engines and the radical changes made in these processes during the war.

Chapter 3. Product design problems. The inappropriateness of job shop designs for line production processes.

Chapter 4. Airframe production problems. An analysis of the significance of certain aspects of production organization, production know-how, and manufacturing information to rapid acceleration of production.

Chapter 5. Engine production problems. An analysis of the same factors discussed in Chapter 4 but handled separately because of the differences in the product and in the source of the production processes used.

Chapter 6. Conclusions. A brief summary of the over-all conclusions of this Section.

CHAPTER 1: THE WARTIME PRODUCTION PROGRAMS

The decisions made in Washington during the latter half of 1940, just after the wartime mobilization began, set the basic pattern for the entire wartime expansion of the aircraft industry. Despite changes in detail, expansion in the later periods followed the broad outline of the original decisions. Before discussing technical methods of manufacture, the production programs resulting from these government decisions will be reviewed, first for engines and then for airframes.

The Manufacturing Plan for Engines

Early in 1940 there were three producers of engines suitable for military combat use. Two of them, the Wright Aeronautical Corporation, in Paterson, New Jersey, and the Pratt & Whitney Aircraft Division of United Aircraft Corporation, in East Hartford, Connecticut, had been aircraft engine makers for a period of years. Each was expanding its plant as a result of French and British orders. Although the early 1940 expansion seemed large at the time, it looks small in retrospect.

The Allison Division of the General Motors Corporation, long a builder of aircraft engines on special order, was carrying out the final production engineering on its 1,000 horsepower V-1710 engine based on an anticipated low rate of output. It also had under way a plant expansion, based on the size of orders foreseeable at the time.

None of these early expansions took the plants far in the direction of the line production methods that were ultimately used, but they gave invaluable preliminary experience with the problems of planning expansion; they furnished the machine tool makers with greater knowledge of the product and its production characteristics; and they brought some new suppliers into relationship with the engine companies.

At government-industry conferences held in Washington in 1940, a decision was made to encourage the development of military engine designs by other nonaircraft companies. With respect to this endeavor, certain companies, including automobile engine builders, promised great things in short periods, but none delivered a new engine in the periods allotted. Later, one company did deliver a promising engine, but the needs of the war had changed and it was not pushed.

Although new designs were solicited, the government decided that the production effort should be concentrated on proven engine models. For engines of military size, this meant the products of Wright and Pratt & Whitney. Allison's liquid-cooled engine had passed its type test; but it was not yet proven and had not been developed for high-altitude work. Consequently, the Allison engine was supplemented with the Rolls-Royce Merlin engine, a high-altitude, liquid-cooled engine urgently desired by the British Purchasing Commission.

It became clear in mid-1940 that the volumes needed would greatly exceed the expansions then under way at Allison, Pratt & Whitney, and Wright. Both within the government and in industry strong differences of opinion developed as to the proper program for expansion. The general principles decided on were to disperse centers of production and to bring into the program outside companies with a demonstrated competence in volume production involving similar processes. Nevertheless, in each instance these principles were modified to meet the wishes of company managements.

Allison, whose foreseeable expansion at the time was the least of the three, obtained approval of its plan to handle the expansion in or near its home plant in Indianapolis and to draw in men from other General Motors divisions as managerial help might be needed. The Wright management preferred to handle all the final assembly work itself. It was prepared to increase its subcontracting greatly, but hesitated to give to any other company the whole responsibility for producing a Wright engine, although it cooperated fully later when licensees were named. The Pratt & Whitney management offered to license its designs. It believed that there were definite limits to its ability to handle greatly increased manufacturing commitments and preferred to turn over the volume production of established models to others. The problem was complicated at Wright and Pratt & Whitney by the necessity of making early deliveries of trainer engines as well as the combat engines considered herein.

After some discussion, upon finding the Wright management firm in its preference to accept the responsibility for final assembly of its engines, the government authorized the company to build a large branch plant to make R-2600 engines but required that the plant be located in the inland area. Lockland, a suburb of Cincinnati, was chosen, although the company had suggested Philadelphia. In connection with this plant Wright proposed to use five major subcontractors, to be known as "cooperating companies," for the production of major subassemblies. These were: the Ohio Crankshaft Company (crankshafts), Otis Elevator Company (crankcases), Hudson Motor Car Company (pistons and rocker arms), Eaton Manufacturing Company (propeller shafts), and Graham-Paige Motors Corporation (master and articulated connecting rods). Wright retained for itself gear making, cylinder making, and magnesium casting — the processes which it considered the most difficult. Certain other production processes, together with assembly and testing, were also retained.

Shortly after this plan was formulated, the need for R-2600 engines increased. In November 1940 Mr. Knudsen's office brought the Studebaker Corporation into the R-2600 production program on a licensee basis. This decision was made over the objection of Wright, which proposed a further expansion at Cincinnati in order to avoid making the same engine in two plants. In June 1941, before Studebaker produced any R-2600 engines, its assignment was changed to the production of Wright R-1820 engines for the B-17 program. The government asked Studebaker to make this change instead of Wright because Studebaker was considered more able to change course in midstream.

The only other licensee for Wright aircraft engines ever named was the Dodge Division of the Chrysler Corporation. Wright itself made further expansions at Cincinnati and Paterson, and built a second large branch plant at Wood-Ridge, New Jersey. In addition, Continental Motors Corporation manufactured the Wright Whirlwind engine for use in tanks.

The production pattern for Pratt & Whitney engines was quite different. This company preferred to use licensees, although in 1942 it was required to assume the responsibility for a branch plant in Kansas City because no satisfactory licensees were available. The Pratt & Whitney R-2800 engine was licensed to Ford in August 1940 and the R-1830 to Buick in October 1940. Other licensees entered from time to time; ultimately Chevrolet, Nash, Continental Motors, and the Jacobs Aircraft Engine Company, in addition to Ford and Buick, each produced one or more Pratt & Whitney models as licensees. Concurrently, Pratt & Whitney expanded its East Hartford plant until, with its three smaller "feeder plants," it produced a peak output which was third largest in the industry. This plant manufactured a diversified group of models, whereas the two plants with larger peak outputs were new plants specializing on one or two models.

The contrasting policies of Pratt & Whitney and Wright are reflected by the following figures summarizing production, in horsepower, from 1940 through 1944:

	Pratt & Whitney		*Wright*	
Prewar Plants	162,163	35%	108,278	32%
Branch Plants	7,083	1	133,972	39[1]
Licensee Plants	298,976	64	96,998	29
	468,222	100%	339,248	100%

Looking at this history with the benefit of hindsight, most informed observers have concluded that the use of licensees was a wise choice (see Section V). The relative increase in the administrative burden of the Wright company was far greater than that of Pratt & Whitney, and the consequent dilution of Wright management, was probably one of the causes of the greater expansion in the use of Pratt & Whitney engines. For example, one reason that the Pratt & Whitney R-2800 displaced the Wright R-2600 in the C-46 transport model was to relieve the pressure on Wright; and the development of the Wright R-3350 was delayed by the concentration of the Wright management upon current production problems.

[1] Includes Wood-Ridge plant.

The licensee arrangement could, however, be used only to the extent that satisfactory licensees were available, and the supply was definitely limited. Pratt & Whitney's experience in 1942, when it was given the Kansas City branch, is evidence of this limitation. It is confirmed by the instances of refusal on the part of licensees to take over the responsibility for other models or plants.

The results of the engine production plan are shown in Exhibit 16. Perhaps the most emphatic way of stating the importance of the licensees is to point out that 48% of a five-year total horsepower output (1940–1944) was produced by licensee plants which were in production only a few months more than three years. In the peak

EXHIBIT 16. Total Horsepower Delivered, Principal Engine Plants, by Years:[1] 1939–1944
(Thousands of Horsepower)

Manufacturer	No of Plants	Years 1938	1939	1940	1941	1942	1943	1944	Total Five-Year Period 1940-194[illegible] Amount	%
Pre-War										
Allison	1	13	50	1,260	7,365	25,071	36,273	35,982	105,951	10.8[illegible]
Pratt & Whitney	1*	1,956	3,080	7,500	18,265	40,196	53,096	43,106	162,163	16.5
Wright	1	2,346	3,204	6,963	19,868	30,012	28,929	22,506	108,278	11.[illegible]
Total	3	4,315	6,334	15,723	45,498	95,279	118,298	101,594	376,392	38.[illegible]
Branch										
Pratt & Whitney	1	...	...	...	...	...	2	7,081	7,083	0.[illegible]
Wright ‡	2	...	...	...	757	24,557	41,640	67,018	133,972	13.[illegible]
Total	3	...	...	...	757	24,557	41,642	74,099	141,055	14.[illegible]
Licensee										
Packard	1*	...	...	...	61	11,056	20,661	38,406	70,184	7.[illegible]
Licensees of:										
Pratt & Whitney	4	...	...	...	539	31,610	111,680	155,147	298,976	30.[illegible]
Wright	2	...	...	...	...	8,540	34,508	53,950	96,998	9.[illegible]
Total	7	...	...	...	600	51,206	166,849	247,503	466,158	47.[illegible]
Total Output	...	4,315	6,334	15,723	46,855	171,042	326,789	423,196	983,605	

Percentage of Total Horsepower Delivered, by Years

	1938	1939	1940	1941	1942	1943	1944	Total Five-Year Amount	%
Pre-War Total	...	...	100.0%	97.1%	55.7%	36.2%	24.0%	38.3%	...
Branch Total	...	...	0.0	1.6	14.4	12.7	17.5	14.3	...
Licensee Total	...	...	0.0	1.3	29.9	51.1	58.5	47.4	...
% of Total Five-Year Output	...	...	1.6%	4.8%	17.4%	33.2%	43.0%	100.0%	...

[1] Includes an allowance for spare parts delivered.

*These plants had one or more "feeder" plants in nearby cities. ‡The Wright Wood-Ridge plant is classed as a branch because it was separately managed during most of the time it was in production.

Sources: Company data and Aircraft Resources Control Office, Report 15.

year, 1944, they delivered almost 60% of the horsepower output. In contrast, the three home plants accounted for 38% of the five-year output, while branch plants accounted for only 14%. It is significant, however, that the home plants produced all but a negligible quantity of the military engines delivered before Pearl Harbor, despite the fact that the licensee and branch plant program was originally set up in 1940.

EXHIBIT 17. Pounds of Airframe Accepted, by Plants: 1940–1944
(In thousands of pounds; spares excluded)

Plants	1940	1941	1942	1943	1944	Total 1940-1944	Rank[1]
MAJOR PRE-1940 PLANTS							
EAST COAST							
Bell - Buffalo	141	3,421	7,296	18,409	13,910	43,177	17
Chance Vought - Stratford	124	1,701	2,635	9,790	14,702	28,952	22
Curtiss - Buffalo	4,315	8,817	19,260	26,985	35,834	95,214	7
Grumman - Bethpage	514	1,382	10,257	26,259	35,355	73,767	11
Martin - Baltimore	1,723	6,040	19,402	36,583	32,909	96,657	5
Republic - Farmingdale	383	572	3,494	19,328	25,057	48,834	14
MID-WEST							
Curtiss - St. Louis	53	463	2,629	3,925	2,057	9,127	30
WEST COAST							
Boeing - Seattle	1,346	5,225	31,912	57,798	70,074	166,355	2
Consolidated-Vultee - San Diego	423	8,904	37,222	66,968	67,180	180,702	1
Douglas - Santa Monica	4,148	9,294	10,211	24,016	28,372	76,041	10
Douglas - El Segundo	507	1,431	4,335	13,423	4,485	24,184	25
Lockheed "B" - Burbank	3,013	11,595	20,303	25,660	35,977	96,548	6
North American - Inglewood	3,638	6,669	17,494	24,338	28,283	80,422	9
TOTAL MAJOR PRE-1940 PLANTS	20,336	65,514	186,453	353,482	394,195	1,019,980	
MAJOR NEW PLANTS - AIRCRAFT COMPANY MANAGED							
NEAR HOME PLANT, WEST COAST							
Boeing - Renton	...	...	...	...	6,686	6,686	31
Douglas - Long Beach	...	34	20,757	47,400	55,798	123,989	3
Lockheed "A" - Burbank	...	287	12,179	35,536	35,568	83,570	8
REMOTE FROM HOME PLANT, EASTERN							
Bell - Atlanta	...	...	...	192	9,668	9,860	29
Curtiss - Columbus	...	...	1,419	5,898	20,162	27,479	23
Curtiss - Louisville	...	...	...	164	4,107	4,271	33
Republic - Evansville	...	...	64	7,238	19,757	27,059	24
REMOTE FROM HOME PLANT, MID-WEST							
Boeing - Wichita #2	...	...	...	4,185	34,728	38,913	18
Consolidated-Vultee - Fort Worth	...	...	1,033	28,272	40,722	70,027	12
Douglas - Tulsa	...	...	186	11,908	17,669	29,763	21
Douglas - Chicago	...	...	...	239	6,038	6,277	32
Douglas - Oklahoma City	...	...	...	5,627	40,692	46,319	15
Martin - Omaha	...	...	1,376	19,639	9,298	30,313	20
North American - Kansas City	...	...	5,003	19,715	39,047	63,765	13
North American - Dallas "A"	...	1,920	9,982	11,661	20,752	44,315	16
North American - Dallas "B"	...	...	...	1,415	20,996	22,411	26
TOTAL MAJOR NEW PLANTS - AIRCRAFT COMPANY MANAGED	...	2,241	51,999	199,089	381,688	635,017	
MAJOR NEW PLANTS - NON-AIRCRAFT COMPANY MANAGED							
EAST COAST							
Eastern[2] - Linden	...	...	83	5,111	10,642	15,836	27
Eastern[2] - Trenton	...	...	20	7,652	24,361	32,033	19
MID-WEST							
Ford - Willow Run	...	...	557	29,951	92,568	123,076	4
Goodyear - Akron	...	...	...	2,074	11,594	13,668	28
TOTAL MAJOR NEW PLANTS - NON-AIRCRAFT COMPANY MANAGED	...	...	660	44,788	139,165	184,613	
TOTAL MAJOR NEW PLANTS	...	2,241	52,659	243,877	520,853	819,630	
TOTAL ALL MAJOR PLANTS	20,336	67,755	239,112	597,359	915,048	1,839,610	
TOTAL ALL OTHER PLANTS	2,775	13,609	36,717	56,829	46,073	156,003	
GRAND TOTAL - ALL PLANTS	23,111	81,364	275,829	654,188	961,121	1,995,613	

[1]The plants are ranked on the basis of the total poundage accepted in the five-year period, 1940-1944.
[2]Eastern Aircraft Divisions of General Motors Corporation.

Source: Compiled from unpublished data furnished by the Statistical Control Office, Air Technical Service Command, Wright Field.

The problem is one of building large, sheet-metal structures to close tolerances of weight, strength and curvature. Consequently, ordinary dimensioned drawings, suitable for the metal cutting industry, are not sufficient guides for building the necessary tooling.

Assembling the sheet-metal parts of an airframe is entirely different from assembling machined parts into a product. The tolerances established in designing machined parts are such that many parts are interchangeable, and assembly can usually take place by simply putting the parts together without the necessity of fitting or postassembly machining. Mating surfaces are characteristically large enough and parts are rigid enough so that they can be positioned satisfactorily without intricate holding devices. In the case of airframe manufacture, there are few such mating surfaces except at major joints such as the joint between wings and fuselage. In assembly, numerous large and frequently flexible parts must be held in proper relationship to each other as they are riveted together. It is the determination of the contours — the setting of jig-locating points in positions so that parts can be assembled properly — that introduces into the production of airframes elements that are peculiar to the industry.

In order to reproduce in physical form the curved surfaces designed into the airplane on paper, it is necessary to resort to the laying out of templates on metal sheets by means of a process known as "lofting" or "master layout." This technique has been adapted largely from the "lofts" of the shipbuilding industry where somewhat similar problems are encountered. "Loft lines" are obtained by passing sections through a portion of the airplane at uniform spacing in both horizontal and vertical planes so that a series of contours results. When these contours are cut out of sheet steel as templates and assembled in the same relationship as the sections passed through the structure, the result is a skeleton representation of the structure itself. If plaster is then filled in between the templates and, when set, worked down to the outside contours an accurate plaster "mock-up" is obtained from which tools can be made.

A related method consists, in effect, of building a mold surrounding the contour. If "female" templates are cut out of the steel sheets, laid out as above, and locating points in the form of wood or steel blocks are fastened in the proper positions, it is possible to develop a jig within which the desired structure can be assembled. In peacetime jigs built up in this fashion for the assembly of the first experimental units of a new model were frequently satisfactory for the small orders which sometimes followed, and were commonly referred to as experimental tooling.

The basic dimensions and reference points of specialized airframe tooling are established by this type of transition from engineering data into temporary jigs and other tools.[1] As the volume of production increased during the war, many changes were made in these tools. Temporary assembly jigs were broken down into smaller sections, strengthened through the use of heavy steel members, simplified by the removal of unnecessary portions of the template detail, and rendered more suitable for higher production through better location of control points and greater accessibility. These changes were, however, variations to meet the needs of increased volume. The translation of engineering data into tooling still followed the general pattern outlined above.

Engines

The aircraft engines of World War II had the common characteristics of being multicylinder, reciprocating engines designed to produce their rated output in a minimum of space and with a minimum weight. The manufacture of such products requires processes quite different from those used in making airframes.

Engine manufacturing processes are generally similar to those of the metal-cutting industries. Most of the parts are shaped and finished by the removal of metal from partially formed blanks. Thus the problems of engine manufacture are associated with processes calling for forges, foundries, and machine shops almost to the exclusion of such airframe problems as handling and forming sheets and making large structures. The assembly of engines is a relatively simple problem compared with airframe assembly. For engines, it is the design of tools, jigs, dies, and fixtures for the machining of parts which presents the chief difficulty.

Some conception of the multitude of closely fitted parts in a high-output aircraft engine is given by consideration of the R-2800, which was in the middle-size range at the end of the war and has about 13,000 pieces, many of which are alike. There are about 1,400 individual designs of parts, most of them moving parts or in contact with moving parts, and almost all calling for working

[1] Other airframe tooling, especially tooling used in the machining of certain parts, was much simpler and more closely allied to the tooling used in other industries (e.g., tooling used for machining forgings).

to close tolerances and extremely high finish.[1] The desire to achieve maximum performance with minimum weight accounts for some of the precision that is called for in the manufacture of engine parts and the assembly of the engine. Even the lowly stud that serves to hold together such parts as crankcase sections is especially designed for weight saving, and has "locator points" so that the goal of equal tension on each stud can be reached by measuring its stretch in tenths of thousandths of an inch. Some gears are ground so that under load conditions they will bend into the desired shape. Minute scratches in the finish of a part cause rejections because the high stress in operation may bring a failure, much in the way that a scratch on a sheet of glass enables it to be "cut" as desired.

Such examples emphasize the generally recognized fact that aircraft engines require very high standards of quality in manufacturing processes, compared with such mass production industries as the automobile industry. What is not generally recognized is the extent of the resulting difference in manufacturing methods. It is not alone a question of great care in conducting production operations. The number of operations is greatly increased, and inspections become more frequent and more severe. For instance, under conditions of volume production, the fork connecting rod of one of the military aircraft engines, weighing 4¾ pounds, requires 90 operations to machine the forging to final dimensions and surface finish. One hundred inspections take place. A conventional connecting rod for an automotive engine, weighing 2½ pounds, requires but 25 operations and 30 inspections.

One further result of the requirement of precision is the large proportion of manufacturing effort that is consumed by rejections. Such rejections occur at all the stages in the manufacturing process, even after assembly. The testing of a completed automobile engine is accomplished by a brief "run in." By contrast an aircraft engine as it leaves the so-called "green" assembly line, fully assembled, is connected to a bank of delicate measuring devices in a test cell and run for a period of hours on a schedule of outputs which taxes its capacities to the full. This is the "green run." Following this test, the engine is almost completely torn down and each part is inspected. Any defective part is replaced and the engine reassembled on the "final" assembly line. Even if its green run is perfect in all respects, the engine is put back into a test cell for a "final run." If a part is replaced, a "penalty run" is required. Furthermore, even after the experimental stage has been passed and regular production has gone on for some time, a significant percentage of parts is rejected after final assembly, thus wasting all the man-hours that have been expended to make the parts and to assemble them into engines. This loss is an indirect but inevitable result of the military necessity to get maximum reliability and maximum performance in combat.

Thus, in summary, engines as well as airframes are complex products, and, as a result, their manufacture is far more difficult an undertaking than the manufacture of most articles used in volume during peacetime. Although the production techniques used by the mass production industries can be more readily adapted to engines than to airframes, the differences between aircraft engines and such products as automobile engines are sufficiently great so that the production methods of the automobile and other similar industries had to be substantially modified before they could be used in engine manufacture.

Wartime Changes in Production Processes

The processes used in manufacturing any product depend not only on the product itself but also on the volume of output. The vast increase in airframe and engine output between 1940 and 1944 required far more than a mere duplication of the processes and tooling used in the earlier year. It required a revolutionary approach to the basic methods of production. In Chapters 3, 4, and 5, the problems encountered in this change-over will be analyzed in some detail. In order to make this analysis easier to follow, the method of producing airframes and engines in 1940 will first be contrasted with the very different processes in use when production reached its peak in 1944.

1940 Job Shops

Although they dealt with very different operations, the airframe and engine builders of 1940 were similar in that their processes were adjusted to the existing small-scale demand for their output. Their products were "handmade," parts were produced in "lots" (or "batches"), and the plant was a "job shop."

"Handmade" Products — By using the term "handmade," production men imply that parts are not interchangeable and hence a certain amount of finishing work is required in assembly

[1] The T-33 (I-40), a jet engine of about twice the power, has about 6,900 parts, of which about 800 are individually designed. The number of parts in a turbine type of engine of similar power would be between those in the reciprocating and in the jet engines.

negative. The negative was then projected through the same camera on sensitized metal sheets to reproduce accurate, full-size prints of the original template. Use was made of this reproduction process to produce full-size templates on plywood, heavy steel, and other types of material for various experimental tooling and other purposes. Blueprints could be reproduced to any desired scale by means of this technique.

Through the use of such techniques, changes in an original template can now be reproduced quickly and accurately. In some cases, the first step in introducing a change is to make the correction on the original template. Only the changed portion is photographed and then reproduced on a small piece of very thin sheet steel which can be cut out and fastened to outstanding copies of the templates. This method of keeping outstanding templates up-to-date represents an important step forward in ability to control manufacturing information.

Control over drawings and templates was strengthened as rapidly as possible, but close control had to wait until accurate parts lists and parts control files were set up. Each company worked on its own problems, and little industry-wide planned standardization of techniques or nomenclature took place during the war.

The second method of attacking manufacturing information problems was aimed at making possible an effective flow of information between cooperating manufacturers. Recognizing early in the war that steps would have to be taken to insure the availability of adequate manufacturing information, the Air Corps organized several intercompany committees. The first of these was the "BDV" Committee, made up of representatives of the Boeing, Douglas, and Vega (Lockheed) companies. It was organized in order to provide coordination for the joint manufacture of the B-17. One purpose was to provide an organized means of maintaining a satisfactory interchange of manufacturing information. Engineering and tooling subcommittees quickly found ways of speeding the flow of information between companies.

Two other large committees of this type were organized in connection with the B-24 and B-29 programs. The B-29 committee was established at the outset of the manufacturing program and was patterned largely after the B-17 committee. This committee was quite successful in helping to coordinate the flow of manufacturing information during the critical early months of the B-29 program. The B-24 liaison committee was not established until the program was further developed than it had been when the B-17 and B-29 committees were organized. The delay in establishing the B-24 committee was costly, but once it was established many manufacturing information problems were quickly settled.

* * *

In summary, World War II airframe production experience underscores the importance to production acceleration of sound production organizations that are strong in tool engineering and production control, specialized airframe production know-how, and adequate manufacturing information. Yet, in 1940, none of these factors existed to a satisfactory degree. Most tool engineering and production control organizations were either weak or nonexistent and had to be developed after the mid-1940 go-ahead. The nucleus of men possessing the required know-how was small, and there were no important sources of such know-how outside the airframe companies. Procedures for controlling and reproducing manufacturing information under conditions of rapid acceleration were inadequate in most airframe companies in 1940.

The fact that the production organizations, production know-how, and manufacturing information of the airframe manufacturers were not further developed in 1940 was due primarily to the lack of incentive during the years preceding the war. Such development was unnecessary for normal peacetime business. Most men in the armed services and in industry did not foresee the scope of the wartime expansion, and those who did foresee the need usually did not possess the funds with which to gamble on adequate preparations. Under the pressure of necessity, however, the industry created the new organizations and procedures needed for war volumes. The fact that most of the production engineering job had to be done after 1940 was a major factor in limiting the wartime acceleration of aircraft production.

CHAPTER 5: ENGINE PRODUCTION PROBLEMS

The production problems encountered by the engine manufacturers differed substantially from those of the airframe producers, although the fundamental prerequisites for line production were similar in both industries. The principal differences arose from the nature of the products and the peacetime experience of the companies producing them. In this chapter the production problems of the engine manufacturers are discussed under the headings of production know-how (where the differences were greatest), production organization, and manufacturing information.

Production Know-How

The wartime expansion of engine production did not require such radical changes in production techniques as did the expansion in airframe production. To a much greater degree the processes in use in 1940 were suitable to wartime production needs. Nevertheless, in spite of this greater carryover of existing manufacturing processes, substantial changes in process planning and production techniques had to be made before wartime levels of output could be achieved. In developing process plans suitable to wartime needs, the engine builders utilized (1) existing manufacturing processes, (2) the know-how of other industries, and (3) production processes not previously developed in peacetime. All three sources made substantial contributions.

Existing Manufacturing Processes

In the engine plants in 1940, some parts were being made with production techniques that without significant change were suitable for use in producing much greater quantities. Existing demands were high enough to call for some use of volume processes. Foreign orders had greatly expanded engine production. Moreover, in engine production, as distinct from airframe manufacture, the large number of identical parts in a single engine facilitated the use of volume processes. Also, many processes were basically the same for similar parts of different engine models, since the differences required only the resetting of tools for different dimensions.

The production techniques in use at the home plants of the prewar engine manufacturers were extensively utilized by the production engineers of licensee and branch plants. One licensee summarized the situation, as follows:

> We found that on some pieces which were standard on all engines built by Wright, and therefore manufactured in large volumes, Wright's operating procedure and tooling were adequate for our purpose. One such piece was the cylinder barrel. In the case of the cylinder head, however, the operation procedure that was designed for 1,000 a month was wholly inadequate for the production of 20,000 a month.

Another company indicated that its early program had gained impetus from the licensor, as follows:

> Operation sheets furnished by Pratt & Whitney were accurate and complete. They were useful in the beginning of the job. But as our schedules increased, changed tooling for high production rendered them obsolete to a large extent.

Evidence of this kind makes it clear that the prewar engine companies made invaluable contributions to the tooling up work of all engine plants, thereby saving much time.

Know-How of Other Manufacturers

The output of engines was also greatly accelerated by the contributions of the production engineers of the metal cutting industries, particularly the automobile builders, the machine tool companies, and the tool and die makers. The effectiveness of this source of know-how was far greater in the engine programs than in airframe production because of the greater similarity of engine production to the peacetime processes of the metal cutting industries.

The assistance was greatest in the plants of the licensees and major subcontractors. These companies contributed a fund of proved processes to transfer to the new product and, in addition, an organization that understood the importance of production engineering and that knew how to use it. Indeed, the contributions made by the licensees and major subcontractors in their own plants were so significant that the old-line engine companies also drew on this know-how in planning the tooling of their shops. They did so through the work of consultants and the engineers of machine tool companies and by the addition to their staffs of men with experience in volume production in other industries. Two of the three prewar producers gave top production engineering responsibility to such a man. The third producer had such men at important levels in the production engineering departments.

Utilization of New Production Processes

In spite of the rich background of production know-how brought to bear on the engine program, a number of manufacturing problems were solved only by developing new, untried processes. Many of the most lasting production bottlenecks arose from the need for new processes. For example, both Packard and Allison found inadequate the existing methods of casting the intricate aluminum cylinder heads and cylinder blocks of their liquid-cooled engines. Successful castings could be made, but only with large amounts of rejections and a process that required new plaster molds for each casting. Pending the development of better methods, a welding process was developed to enable the use of castings formerly rejected. Finally, after great effort, entirely new foundry techniques were developed; these techniques were used later by all engine builders in making large aluminum and magnesium castings.

Process Planning a Continuing Problem

From the three sources just described, the engine makers were able to design rapidly the volume processes which were needed for an efficient, balanced plan for line production at war quantities. As the war experience shows, the tooling up of a plant is never completed; it is a process of constant evolution through the elimination of "bugs" (often a source of delay) and the development of improved techniques. The great contribution of the above sources of know-how was that they shortened the time needed to jump the gap from small to large volumes.

The types of new processes used in the late war years can be pictured by a specific example which contrasts low-volume with high-volume methods of producing a part. The operations selected are the rough and semifinish boring, facing, and drilling of radial holes in a supercharger front section of a Wright engine. This is done by a special "Sixway Horizontal and Angular 14-Station Automatic Indexing Machine," of which the company says:

> At the first loading, this machine rough faces and bores 14 intake ports and 7 mounting pads, and rough bores 3 holes in the oil sump pad. This same machine is also used to semifinish face and bore the 14 intake ports, semifinish bore the 7 mounting pads, finish bore 3 holes in the oil sump pad, drill 2 holes in each of the 7 mounting pads, drill 7 holes in the oil sump pad, and drill 4 holes in each of 2 breather pads.[1]

In conjunction with a similar machine, the machine just described occupies 956 square feet and requires 17.4 man-hours per three-shift day. In contrast, using general-purpose machines to finish the part, there would be 5 radial drills, 1 radial tapper, and 1 vertical mill with rotary table. These would occupy 278 *more* square feet, and require 121.6 *more* man-hours per three-shift day. In general, special-purpose machines saved space, man-hours, and also capital investment. These savings simplified the attainment of volume production of engine parts and helped keep the management problem within the bounds of feasibility.

[1] Wright Aeronautical Corporation, *High Production Machine Tools*, pamphlet, undated, p. 15.

Variations in Process Planning at Individual Plants

From the foregoing discussion it is clear that the essential elements of process planning were ultimately provided in all the major wartime plants, but the details were varied to suit the particular circumstances of each individual organization. The process plans made in the various plants were conditioned by such factors as their layout, the availability of tools, the background of the production engineers, and the skill of workers. They were also influenced by the over-all war job outlined for the plant.

In particular, the process plans at the licensee and branch plants made much more use of special-purpose tooling than did the process plans at the prewar plants. The plants of licensees and the branch plants operated by the prewar manufacturers were highly specialized by engine model. Some of them produced but one model; none produced more than two at any one time.[2] Whether such plants were converted from other production to engines or were designed for such work from their inception, they made use of special-purpose tools and tooling almost to the ultimate degree known to production engineers at the time. Each plant had its own individuality, but high production tooling and line production plans were used throughout.

The organizations of the prewar plants, on the other hand, were influenced by the variety of models scheduled. They were further influenced by the background of the men and the type of tooling previously used. Consequently, these home plants used more general-purpose tooling and maintained a more definite departmental organization by type of process (e.g., a crankcase department). Layout and supervision followed these functional lines to a greater extent than in a plant designed for large volumes of one or two models. Functional organization was suitable for these plants. Pratt & Whitney experimented unsuccessfully at East Hartford with a plan which divided the plant into separate sections for each major engine model. Such specialization was found to be undesirable since it spread jobs out over the plant in such a way that they did not fit the skills of supervisory personnel.

Despite differing process plans, the prewar plants came more and more to use machine tools, as well as tooling, designed for specific operations on specific parts. At the end of the war, their tooling was almost as inappropriate for a return to a

[2] This statement ignores the many minor variations in product, so-called "dash numbers," which caused many problems in production planning and control.

period of small volumes and changing models as it was in the plants of the licensees.

Production Organization

The process plans and tooling problems discussed above were of great importance in the engine production program. But no sequence of operations to produce a particular part, no matter how cunningly designed, will fit into all the others in a plant without an over-all plan and the organization of people that makes and applies such a plan. The characteristics which must be possessed by such an organization were discussed at length in the preceding section on airframes. All the engine builders had in 1940 at least the beginnings of the necessary relationships.

In the home plants, Allison, Pratt & Whitney, and Wright successfully developed large manufacturing organizations, but only after a process of trial-and-error similar to that described for the airframe manufacturers. One of the problems particularly commented on by these companies was the difficulty of persuading foremen and other supervisors, who had grown up under job shop conditions, to accept the engineering discipline that large-scale production engineering required. For some time these men continued to "carry under their hats" changes which had been introduced into the process or even into the design of parts, since they felt that the paperwork systems that were being set up were unnecessary. Thus, unwittingly, these men tended to complicate their own problems.

Probably the greatest contributions of the licensee companies to the engine production program were their existing management organizations that knew how to carry out production engineering in all its phases. Allison shared directly in this contribution, for the General Motors organization provided the Allison division with a strong force of men, most of whom had had the experience of previously working together in one of the General Motors divisions.

In the branch plants under Pratt & Whitney and Wright, effective management organizations were also developed, although not quite so promptly. Production engineering departments were built up with personnel from the home plants and were augmented by men with experience in volume production industries.

Manufacturing Information

The third major component necessary for conversion to line production was adequate manufacturing information. Even within a plant there must be a large amount of manufacturing information available on paper when volume production is required. It is, of course, of far greater importance that information be available for transfer to licensees or branch plants if these organizations are to be asked to make a product.

The basic information for the manufacture of an engine is found in part and assembly drawings. These drawings should be accompanied by operation sheets that describe the manufacturing process and indicate the machine tools and tooling to be used. Although there are differences of opinion, it appears that engine manufacturers were given drawings which were reasonably satisfactory with two possible exceptions. The Packard Motor Car Company found itself in the unenviable position of being asked to make an engine which had incomplete and inadequate drawings. In the case of the R-3350 engine, Dodge was not always furnished drawings which reflected the latest engineering changes. This condition was not caused by inaccurate drawings, however, but rather it reflected poor follow-up and the intense pressure to get a newly developed engine into production.

In spite of the fact that the part drawings were generally satisfactory, all the licensees had some difficulty in interpreting the drawings furnished by the engine manufacturers. The accepted practices for part drawings in the engine industry caused automotive men, accustomed to different kinds of drawings, to have difficulty in understanding them. In the automotive industry, the practice was to include in a drawing all necessary dimensions, indications of finish, and other data describing the part. The practice of the engine makers was to combine some of this descriptive material with the description of manufacturing processes on the operation sheet. Thus, although all the information could be found, most of the licensees redrew a large number of the drawings which were furnished them in order to simplify the work of their foremen and others in the shop. In so doing they obtained drawings that satisfied their shop practice, although at the cost of some time and occasional clerical errors. Only one of the licensee companies, the Studebaker Corporation, adopted the policy of learning to use the drawings furnished by the engine manufacturers. It had a high degree of success with this policy and has, in fact, adopted some of the engine manufacturers' practices as a permanent part of its own operations.

In general, the situation can be summarized in the words of one of the licensees who stated:

Drawings and specifications were accurate and complete, this made it possible . . . to make part prints with only minor changes to fit our shop practice.

Several important reasons help to account for the general superiority of part and assembly drawings in the engine companies over those of the airframe manufacturers. First, the needs of the prewar industry required them. Interchangeability is a more critical matter when moving surfaces are involved and when parts are needed by the hundreds or thousands. Under such conditions, less can be left to men in the shop, and more must be done on the drawing boards. Also, since substantial portions of engines were normally acquired from vendors, accurate drawings had to be made available to them. Both Pratt & Whitney and Wright had licensed engines to foreign manufacturers and had had experience with the transfer of information at that time. Finally, engine drawings conformed to a more established set of practices, those generally used in the machining industries.

No mention has been made of the requirement of the Army and Navy that drawings be supplied for each part purchased by them. This requirement was treated so casually by both the services and the manufacturers that its effect was merely to give a false impression.

Unfortunately, the other essential paper records of the engine builders — operation sheets, tool drawings, bills of materials, and parts lists — were less adequate than the drawings. The needs of the peacetime engine manufacturers could be satisfied in many cases by such phrases as "lap to fit" or "make like sample." Minor changes were not reflected in the paperwork, for they could be remembered in the shop. Little care had been taken to consider the possibility of war volume and the need for transferring information to other plants. Gauging and inspection standards were very poorly expressed. Bills of materials and parts lists were often incomplete and inaccurate because the errors which they contained were not large enough to cause wasteful purchasing when it was scaled for a small quantity of engines.

When licensing arrangements were undertaken, the inadequacy of formal manufacturing information was overcome to some extent by the visits of groups of licensee personnel to the plants of the licensors. Whenever the engine to be licensed was already in production, groups of production men went to the licensor plant and observed the manufacturing processes used there. Both Pratt & Whitney and Wright gave the men sent by the licensees every opportunity to study the job. In the case of Chevrolet, the production and assembly planning teams stayed in East Hartford until their basic processes were fully written up. All other licensees also gained much by similar visits, though their first visit was not so long.

As in the development of manufacturing operations, the process of transferring information about a product from one plant to another was a continuous task. An enormous gap had to be filled at the outset, but a continuing flow of questions and answers always remained for which provision had to be made. The methods used by the Pratt & Whitney and Wright organizations to satisfy this need were quite different. The Wright Corporation arranged for teletype circuits with each licensee, thereby providing a constantly available information service. It could be supplemented, as necessary, by other means such as trips by engineers from one plant to another. Pratt & Whitney arranged for each licensee to have a "Resident Engineer" at the East Hartford plant. This arrangement was also supplemented by visits and other communications.

* * *

In summary, the engine makers, like the airframe builders, had to develop production know-how, production organizations, and manufacturing information, all to a degree that was far removed from the peacetime needs of the industry. Each of these three prerequisites, however, was somewhat easier for the engine builders to obtain. The metal cutting industries contributed know-how from their peacetime processes. The licensees and major subcontractors contributed production organizations that had worked on problems of similar magnitude. The prewar engine makers furnished reasonably satisfactory part and assembly drawings, although other manufacturing information was not as ready for use in a wartime program.

CHAPTER 6: CONCLUSIONS

The aircraft industry in general was not ready for the production job with which it was so suddenly confronted in 1940. The key element of this state of unpreparedness — lack of ability to convert quickly from job shop to line production methods — sprang from the fact that line production methods were neither needed nor could they be afforded under peacetime conditions.

The industry was not prepared because no one in authority in industry or government foresaw the production assignment, and too few understood what would be required. It had not been recognized that inability to change over quickly to line production techniques was a potential wartime bottleneck.

Conversion from job shop to line production methods, which was the essential prerequisite for the rates of production ultimately required to win World War II, was delayed by

(1) products that were not suitably designed for line production methods;

(2) the absence of production organization structures that could provide a better basis for expansion, particularly with reference to tool engineering;

(3) the lack of enough men possessing both aircraft production know-how and background in the use of line production techniques; and

(4) inadequate methods of handling manufacturing information, which failed to provide complete, accurate, and up-to-date descriptions of the product and of current manufacturing methods.

The government contributed to the delays in the change-over to line production methods by

(1) failing to plan carefully the introduction of design changes,

(2) not reducing the number of minor differences between models,

(3) setting the initial production goals of individual manufacturers at levels far below those ultimately required, and

(4) introducing an unnecessarily large number of schedule changes.

TABLE 16. Engines and Horsepower Delivered Allison Division, General Motors Corp.

	V-1710 -C-E-F -27-35-39-45-47-49 -51-53-55-57-63-65 -73-75-77-79-81-83 -85-87-89-91-93-95 -99-101-103-105-107 -109-111-113-115 -115A-117-121	V-3420 -2-11-13 -15-17-19 -21-23-29	Horsepower including Spare Parts[1] (000)
1940 Jan.	3		3
Feb.	7		8
Mar.	7		8
Apr.	7		8
May	14		13
June	30		32
July	73		80
Aug.	65		71
Sept.	223		243
Oct.	286		312
Nov.	175		191
Dec.	259		291
Total	1,149		1,260
1941 Jan.	130		134
Feb.	400		438
Mar.	317		339
Apr.	138		133
May	395		441
June	412		469
July	502		571
Aug.	671		764
Sept.	725		805
Oct.	765		952
Nov.	845		972
Dec.	1,102		1,347
Total	6,402		7,365
1942 Jan.	1,101		1,569
Feb.	1,039		1,587
Mar.	1,179		1,756
Apr.	1,151		1,706
May	1,203		1,868
June	1,252		2,021
July	1,265		2,160
Aug.	1,326		2,175
Sept.	1,330		2,672
Oct.	1,378		2,612
Nov.	1,301		2,515
Dec.	1,379		2,430
Total	14,904		25,071
1943 Jan.	1,430	2	2,398
Feb.	1,346	4	2,360
Mar.	1,452	4	2,511
Apr.	1,551	2	2,650
May	1,700	2	2,803
June	1,925	1	2,964
July	2,020		3,377
Aug.	2,105	5	3,593
Sept.	2,084	3	3,637
Oct.	1,936	3	3,511
Nov.	1,514	3	2,965
Dec.	2,001	2	3,504
Total	21,064	31	36,273
1944 Jan.	2,001	5	3,549
Feb.	2,008	2	3,636
Mar.	2,101	2	3,714
Apr.	2,101	6	3,908
May	2,101	1	3,775
June	1,900	2	3,192
July	1,702	11	2,806
Aug.	1,971	11	3,662
Sept.	1,190	13	2,179
Oct.	1,366	28	2,325
Nov.	1,073	17	2,021
Dec.	677	14	1,215
Total	20,191	112	35,982

[1] Figures for 1940 and 1941 exclude spare parts.

Source: Company figures through 1941. Later figures from Aircraft Resources Control Office, Report 15.

TABLE 17. Engines and Horsepower Delivered
Pratt & Whitney Aircraft Division, United Aircraft Corporation
East Hartford and Feeder Plants

	R-1830						R-2000-DG -1-3-7 -11	R-2800						R-4360 -4-5-7 -8-8A-9-9T -10-11-13-15 Stages		R-985 R-1340 R-1535 R-1690 R-2180	Horsepower including Spare Parts (000)
	-CG -SCG -S3CG	-C3G -35-49-53 -57-82-84 -84A-92	-C4G-C8G -33-39-41 -43-43A-55 -61-63-90 -90B-90C	-C5G-C7G -76-78-86 -88	-09G -94	Total		-A -1-2-4 -5-6-11 -13-15 -17-35-39	-B Single Stage -12-16-20 -21-27-31 -41-47-49 -59-63	-B Two Stage -8-8W-10 -10W-65	-C Single Stage -22-37-57 -61	-C Two Stage -18-18W -29-55	Total	Single	Two		
1938 Jan.		73				73										103	188
Feb.		65				65										95	159
Mar.		62				62										114	175
Apr.		34				34										97	140
May		38				38										96	136
June		67				67										106	190
July		59				59										97	175
Aug.		82				82										71	193
Sept.		54				54										62	125
Oct.		51				51										121	164
Nov.		36				36										101	138
Dec.		74				74										92	173
Total		695				695										1,155	1,956
1939 Jan.		83				83										99	194
Feb.		75				75										109	174
Mar.		96				96										108	218
Apr.		75				75										137	194
May		111				111		1					1			102	211
June		143				143										112	258
July		167				167										103	270
Aug.		167				167										90	272
Sept.		142				142										76	232
Oct.		245				245										65	330
Nov.		237				237		1					1			80	357
Dec.		251				251										103	370
Total		1,792				1,792		2					2			1,184	3,080
1940 Jan.	1	252				253		1					1			126	380
Feb.		139				139		1					1			134	266
Mar.		94				94		1					1			342	347
Apr.		117	2			119										287	354
May		96	23	4		123		1					1			272	369
June		56	113	1		170										388	544
July	3	80	220	1		304										359	678
Aug.		139	293	11		443		2					2			298	857
Sept.		94	281	33		408										305	834
Oct.		148	350	17		515		2					2			336	943
Nov.		227	245	14		486		1					1			328	888
Dec.	1	181	390	17		589		8					8			323	1,040
Total	5	1,623	1,917	98		3,643		17					17			3,498	7,500
1941 Jan.		267	251	16		534		13					13			391	971
Feb.		150	318	10		478		32					32			472	1,016
Mar.		189	356	11		556		64					64			551	1,189
Apr.		254	174	3		431		92					92			783	1,261
May	3	215	235	16		469		112					112			772	1,341
June		240	272	30		542		100					100			791	1,409
July		267	237	40		544	1	137		1			138			850	1,605
Aug.		229	264	54		547		117		1			118			1,005	1,696
Sept.		199	286	52		537		101		2			103			1,074	1,621
Oct.		226	267	96		589		160		1			161			1,106	1,827
Nov.		409	95	79		583		270	1	1			272			1,120	2,145
Dec.		424	107	100		631	8	263	1				264			1,123	2,184
Total	3	3,069	2,862	507		6,441	9	1,461	2	6			1,469			10,038	18,265
1942 Jan.		377	194	124		695	15	49	220				269			1,327	2,362
Feb.		434	147	118		699	14		359	5			364			1,303	2,343
Mar.		422	181	105		708	24		358	15			373			1,380	2,709
Apr.		415	255	146		816	22		382	24			406			1,400	2,913
May		385	277	166	4	832	30		432	26		1	459			1,425	3,271
June		432	243	125		800	60		468	47			515			1,525	3,492
July		517	210	150		877	38		400	100		1	501			1,525	3,617
Aug.		666	60	185		911	17		400	124	1		525			1,527	3,673
Sept.		689	60	199		948	44		381	68			449			1,527	3,554
Oct.		608	87	226		921	50		282	238			520			1,547	3,904
Nov.		630	99	265		994	50		312	213			525			1,676	4,102
Dec.		580	101	320		1,001	42		306	219			525			1,706	4,056
Total		6,155	1,914	2,129	4	10,202	406	49	4,300	1,079	1	2	5,431			17,868	40,196
1943 Jan.		440	100	460		1,000	75		268	257			525			1,815	4,041
Feb.		417	223	261		901	80		271	192		1	464			1,750	3,721
Mar.		568	168	364		1,100	118		179	455			634			1,828	4,481
Apr.		310	350	390		1,050	146		16	460			476			1,792	4,188
May		325	215	459		999	139		38	323			361			1,896	3,970
June		166	350	449		965	100		140	384			524			2,057	4,434
July		266	344	250		860	86		268	476			744			1,707	4,752
Aug.		341	432	179		952	114		358	491	1	1	851			1,600	5,193
Sept.		457	306	109		872	94		211	335			546	2		1,611	4,146
Oct.		517	494	5		1,016	106		209	620	2		831	2		1,581	4,827
Nov.		500	400			900	175		237	627	2		866	1		1,395	4,782
Dec.		503	400		5	908	216		227	645	1	1	874	3		1,337	4,561
Total		4,810	3,752	2,926	5	11,523	1,449		2,422	5,265	6	3	7,696	8		20,369	53,096
1944 Jan.		357	425		24	806	275		220	680	1		901	3		1,374	4,636
Feb.		200	425		132	757	318		200	745	1	1	947	4	1	1,561	4,591
Mar.		202	425		156	783	325		100	825		2	927	3		1,808	4,638
Apr.		212	425		173	810	265		102	803			905	2		1,539	4,691
May		5	405		302	712	200			808		1	809	5		1,195	4,062
June			391		331	722	194			799		1	800	3	1	992	3,807
July		4	262		265	531	114			532		3	535		1	756	2,397
Aug.		4	140		339	483	185			789		3	792	1	1	750	3,101
Sept.		4	162		254	420	179			518		22	540		1	626	2,557
Oct.			181		313	494	349			590		50	640			405	3,062
Nov.		2	69		265	336	243			406		86	492		1	453	2,481
Dec.		11	49		387	447	517			247		198	445			494	3,083
Total		1,001	3,359		2,941	7,301	3,164		622	7,742	2	367	8,733	21	6	11,953	43,106

Source: Company accounting records. In general, engines were counted as invoiced. In a very few instances, engines included in these totals were kept in the plant for experimental purposes. Information concerning the R-4360 was taken from Aircraft Resources Control Office, Report 15.

TABLE 18. Engines and Horsepower Delivered, Wright Aeronautical Corp., Paterson Plant[1]

	R-1820							R-2600			R-3350			R-760 R-975	Horsepower including Spare Parts (000)
	-C9HD -74	-C9F -30-75	-C9G -50-77	-C9G100 -52-57-79 -81-83-85 -89	-C9GC -40-40B-54 -60-65-71 -87-97-G200 -G202-G205A	-C9HC -56-56W -56WA-62-66 -70-70W -72WA-93	Total	-A -11-19-21 -23	-BA -8-10-12 -13-16	Total	-BA -5-13-18 -19-21-35 -37-39	-BB -8-10-14 -16-17-43	Total		
1938 Jan.							92	2		2				34	121
Feb.							101	2		2				29	165
Mar.							135	2		2				16	177
Apr.							162	3		3	1		1	20	212
May							168	3		3				18	181
June							152	9		9	1		1	13	201
July							140	5		5				34	223
Aug.							143	4		4				6	182
Sept.							153	2		2				9	186
Oct.							152	7		7				30	206
Nov.							170							6	197
Dec.							235							34	230
Total							1,803	39		39	2		2	249	2,346
1939 Jan.							198							8	250
Feb.							199	1		1				22	252
Mar.							219							19	295
Apr.							238	1		1				21	311
May							214	1		1				34	239
June							205	8		8	1		1	26	293
July							145	8		8				62	235
Aug.							116	4		4	1		1	47	163
Sept.							139	26		26				62	232
Oct.							103	29		29	1		1	87	255
Nov.							147	38		38				81	289
Dec.							133	47		47				94	340
Total							2,056	163		163	3		3	563	3,204
1940 Jan.			R-1820 DETAILS NOT OBTAINED PRIOR TO 1942				150	59		59				98	325
Feb.							204	50		50	2		2	51	356
Mar.							150	68		68				85	345
Apr.							177	66		66				93	365
May							165	66		66				118	388
June							195	96		96				86	471
July							122	168		163	2		2	55	508
Aug.							215	137		187	1		1	30	692
Sept.							184	234		234				55	718
Oct.							225	293		293	1		1	42	873
Nov.							215	287		287	2		2	55	863
Dec.							267	351		351				108	1,030
Total							2,272	1,925		1,925	8		8	874	6,963
1941 Jan.							236	438		438	3		3	97	1,156
Feb.							262	415		415	1		1	140	1,157
Mar.							365	515		515				116	1,451
Apr.							348	604		604				132	1,585
May							342	654		654				118	1,657
June							340	676		676				118	1,694
July							413	657		657				108	1,750
Aug.							423	675		675				134	1,802
Sept.							452	617		617				166	1,763
Oct.							454	644		644				146	1,879
Nov.							392	637		637				97	1,830
Dec.							525	651		651	1		1	188	2,144
Total							4,552	7,186		7,186	5		5	1,560	19,868
1942 Jan.			15	30	517		562	610	103	713	2		2	120	2,241
Feb.		2	19	43	490		554	596	37	633		1	1	172	2,093
Mar.		50	63	49	667		829	602	1	603	1	1	2	189	2,415
Apr.		2	45	125	566		738	638	5	643				134	2,513
May			35	114	654		803	579	1	580	1		1	150	2,577
June				146	672		818	540		540	7		7	152	2,561
July		2		122	652		776	600		600	6		6	95	2,724
Aug.		5	29	159	794		987	339		339	10	3	13	80	2,539
Sept.			3	170	711		884	566		566	4	1	5	177	2,685
Oct.		2	23	155	794		974	503		503	10	1	11	121	2,790
Nov.				183	809	1	993	378		378	11	1	12	167	2,527
Dec.				170	758		928	442		442	7		7	161	2,347
Total		63	232	1,466	8,034	1	9,846	6,393	147	6,540	59	8	67	1,721	30,012
1943 Jan.				211	656		867	425		425	19		19	122	2,587
Feb.				146	734	1	881	527		527	10	1	11	107	2,644
Mar.				212	794	1	1,007	582		582	8	1	9	160	2,779
Apr.				205	664	5	874	555		555	1		1	96	2,858
May				211	750	4	965	535		535		1	1	77	2,763
June		6		27	731		764	440		440				58	2,333
July					824	13	837	487		487				88	2,480
Aug.					467	70	537	346		346				81	1,906
Sept.					615	45	660	402		402				102	2,115
Oct.					656	184	840	371		371				103	2,280
Nov.					524	164	688	331		331				58	1,986
Dec.					372	404	776	358		358				20	2,198
Total		6		1,012	7,787	891	9,696	5,359		5,359	38	3	41	1,072	23,929
1944 Jan.					382	432	814	398		398				18	2,684
Feb.					259	571	830	402		402					2,304
Mar.					99	583	682	445		445				2	2,428
Apr.					8	608	616	380		380		1	1		2,201
May					20	824	844	442		442					2,306
June					38	577	615	495		495					2,166
July					42	606	648	298		298				9	2,024
Aug.					48	541	589	236		236		3	3		1,713
Sept.					30	571	601	140		140		6	6		1,586
Oct.					45	338	383	94		94		10	10		974
Nov.					41	285	326	4		4		17	17		1,177
Dec.	2				26	303	329					5	5		941
Total	2				1,038	6,239	7,277	3,334		3,334		42	42	29	22,506

[1] Wood-Ridge plant reported separately.

Sources: (1) Engine Units - Years 1938-1941, Wright Aeronautical Corporation. Years 1942-1944, Engine Shipments (RC-391) Power Plant Branch, Production Section, **Army Air Forces Materiel** Command. Wright Aeronautical Corporation furnished details permitting separation of R-3350-BA from R-3350-BB engine and of production of Paterson from production of Wood-Ridge plant.
(2) Horsepower - Company records.

TABLE 19. Engines and Horsepower Delivered, Pratt & Whitney, Kansas City Plant

		R-2800-C Single Stage -14-22-22W-34-34W-28-57-81	Horsepower including Spare Parts (000)
1943	Dec.	1	2
	Total	1	2
1944	Jan.	9	19
	Feb.	28	75
	Mar.	30	104
	April	80	203
	May	154	391
	June	301	699
	July	305	726
	Aug.	225	575
	Sept.	260	692
	Oct.	427	1,097
	Nov.	450	1,226
	Dec.	475	1,274
	Total	2,744	7,081

Note: In general, engines are counted as invoiced. In a very few instances, engines included in these totals were kept in the plant for experimental purposes.
Source: Company accounting records.

TABLE 20. Engines and Horsepower Delivered
Wright Aeronautical Corp., Cincinnati Plant

	R-2600			R-3350-BA -57	Horsepower including Spare Parts (000)
	-BA -8-12-13 -29-31	-BB -14-15 -20-22	Total		
1941 Jan.					
Feb.					
Mar.					
Apr.					
May					
June	6		6		14
July	12		12		20
Aug.	22		22		37
Sept.	17		17		29
Oct.	45		45		77
Nov.	135		135		230
Dec.	206		206		350
Total	443		443		757
1942 Jan.	57		57		642
Feb.	23		23		793
Mar.	138		138		995
Apr.	94		94		1,432
May	177		177		1,752
June	489	1	490		2,149
July	709		709		2,362
Aug.	588		588		2,714
Sept.	684		684		2,767
Oct.	1,018		1,018		2,575
Nov.	715		715		2,608
Dec.	1,289		1,289		3,468
Total	5,981	1	5,982		24,557
1943 Jan.	1,961		1,961		3,610
Feb.	1,892	1	1,893		3,230
Mar.	2,248	8	2,256		4,014
Apr.	1,957	5	1,962		3,692
May	1,558		1,558		2,452
June	1,177	2	1,179		2,292
July	574	10	584		1,292
Aug.	1,673	29	1,702		2,613
Sept.	1,984	84	2,068		3,707
Oct.	1,693	215	1,908		3,598
Nov.	2,214	248	2,462		4,097
Dec.	2,010	400	2,410		4,135
Total	20,941	1,002	21,943		38,792
1944 Jan.	1,867	346	2,213		4,232
Feb.	939	73	1,012		2,767
Mar.	2,551	168	2,719		4,831
Apr.	1,396	639	2,035		4,174
May	1,612	892	2,504		5,088
June	1,269	720	1,989		3,999
July	1,589	1,870	3,459		5,628
Aug.	1,433	463	1,896		5,596
Sept.	1,242	1,051	2,293		4,911
Oct.	1,492	1,018	2,510		5,087
Nov.	1,055	857	1,912		3,986
Dec.	365	773	1,138	1	3,125
Total	16,810	8,870	25,680	1	53,424

Sources: (1) Engine Units - Engine Shipments (AC-391) Power Plant Branch, Production Section, Army Air Forces Materiel Command.
(2) Horsepower - Company records.

TABLE 21. Engines and Horsepower Delivered Wright Aeronautical Corp., Wood-Ridge Plant

	R-3350 -BA 13-18-19-21 23-23A-35 35I-35A-35II 37-41-57-59	R-3350 -BB 8-14-43	R-3350 Total	Horsepower including Spare Parts (000)
1943 Jan.				55
Feb.	7*		7*	55
Mar.	14*		14*	73
April	9*		9*	31
May	20*		20*	65
June	13*		13*	41
July	22*		22*	67
Aug.	32*		32*	104
Sept.	101		101	312
Oct.	169	1	170	499
Nov.	230	2	232	736
Dec.	253	3	256	810
Total	870	6	876	2,848
1944 Jan.	283	8	291	792
Feb.	331	5	336	880
Mar.	360	7	367	1,020
April	381	8	389	1,144
May	330	4	334	974
June	415	2	417	1,077
July	452	2	454	1,127
Aug.	501		501	1,240
Sept.	551		551	1,357
Oct.	529	1	530	1,341
Nov.	405	2	407	1,079
Dec.	650		650	1,563
Total	5,188	39	5,227	13,594

* First 100 engines assembled from parts supplied by Paterson plant.
Source: Company records.

TABLE 22. Engines and Horsepower Delivered, Buick Division, General Motors Corporation, Licensee of Pratt & Whitney Aircraft

	R-1830 -C4G-C8G Single Stage -43-43A-65 -65A-906	R-1830 -C9G Single Stage -75	R-2000-9	Horsepower including Spare Parts (000)
1942 Jan.		None delivered before 1945	None delivered before 1945	
Feb.				3
Mar.	440			528
April	610			743
May	616			776
June	700			935
July	750			1,127
Aug.	879			1,341
Sept.	1,000			1,306
Oct.	1,000			1,337
Nov.	1,200			1,636
Dec.	1,200			1,828
Total	8,395			11,560
1943 Jan.	1,200			2,004
Feb.	1,200			1,261
Mar.	1,225			2,278
April	1,201			2,250
May	1,500			2,866
June	1,800			3,150
July	2,100			3,146
Aug.	2,501			3,605
Sept.	2,799			4,230
Oct.	3,099			4,930
Nov.	3,299			5,002
Dec.	2,700			4,309
Total	24,624			39,031
1944 Jan.	2,700			3,985
Feb.	2,544			3,967
Mar.	2,704			3,974
April	2,799			3,684
May	2,902			3,493
June	3,000			4,052
July	3,100			3,792
Aug.	3,100			3,757
Sept.	2,700			3,246
Oct.	1,800			2,189
Nov.	1,400			1,745
Dec.	1,800			2,244
Total	30,549			40,128

Sources: (1) Engine Units — Pratt & Whitney records.
(2) Horsepower — Aircraft Resources Control Office, Report 15.

TABLE 23. Engines and Horsepower Delivered, Chevrolet Division, General Motors Corporation, Licensee of Pratt & Whitney Aircraft

		R-1830				
		-C4G-C8G Single Stage -43-43A-65A-67	-C3G Single Stage -92	Total	R-2800-C Single Stage -57-73-77 -83	Horsepower including Spare Parts (000)
1942	April	4		4		5
	May	21		21		25
	June	183		183		219
	July	325		325		389
	Aug.	773		773		963
	Sept.	510		510		707
	Oct.	683		683		900
	Nov.	722		722		1,192
	Dec.	812	25	837		1,246
	Total	4,033	25	4,058		5,646
1943	Jan.	550	261	811		1,291
	Feb.	297	631	928		1,416
	Mar.	233	721	954		1,447
	April	371	724	1,095		1,726
	May	832	683	1,515		2,449
	June	902	907	1,809		2,734
	July	1,102	1,001	2,103		3,110
	Aug.	1,170	1,191	2,361		3,493
	Sept.	1,367	1,355	2,722		3,948
	Oct.	1,313	1,292	2,605		3,877
	Nov.	1,681	1,770	3,451		4,895
	Dec.	2,024	1,036	3,060		4,708
	Total	11,842	11,572	23,414		35,094
1944	Jan.	2,060	640	2,700		4,378
	Feb.	1,950	650	2,600		4,122
	Mar.	2,051	550	2,601		3,931
	April	2,002	601	2,603		3,900
	May	2,004	597	2,601		3,124
	June	2,290	311	2,601		3,151
	July	2,298	303	2,601		3,151
	Aug.	2,300	300	2,600	1	3,153
	Sept.	1,996	304	2,300	25	2,844
	Oct.	1,255	296	1,551	56	2,060
	Nov.	820	581	1,401	101	2,060
	Dec.	518	533	1,051	144	1,648
	Total	21,544	5,666	27,210	327	37,522

Sources: (1) Engine Units, Pratt & Whitney records.
(2) Horsepower, Aircraft Resources Control Office, Report 15.

TABLE 24. Engines and Horsepower Delivered Ford Motor Company Licensee of Pratt & Whitney Aircraft

		R-2800 -A Single Stage -5	R-2800 -B Single Stage -21-27-31-43-51-59 -63-71-75-79	Horsepower including Spare Parts (000)
1941	Oct.	1		2
	Nov.	99		202
	Dec.	162	2	335
	Total	262	2	539
1942	Jan.	229	36	546
	Feb.	238	63	651
	Mar.	225	150	818
	April		463	908
	May		526	1,097
	June		530	1,018
	July		570	1,147
	Aug.		572	1,123
	Sept.		640	1,317
	Oct.		672	1,464
	Nov.		691	1,568
	Dec.		798	2,114
	Total	692	5,711	14,392*
1943	Jan.		776	1,552
	Feb.		770	2,072
	Mar.		1,015	2,562
	April		1,091	2,527
	May		1,052	2,519
	June		1,048	2,575
	July		1,198	2,961
	Aug.		1,241	2,796
	Sept.		1,389	3,150
	Oct.		1,289	2,911
	Nov.		1,209	3,140
	Dec.		1,259	3,219
	Total		13,337	31,984
1944	Jan.		1,598	4,660
	Feb.		1,628	4,023
	Mar.		1,794	4,304
	April		1,820	3,999
	May		2,324	4,903
	June		2,419	5,163
	July		2,350	4,990
	Aug.		2,359	5,143
	Sept.		2,224	5,015
	Oct.		1,880	4,249
	Nov.		1,896	4,695
	Dec.		1,904	5,514
	Total		24,196	56,658

* The actual total of the monthly figures shown for 1942 is 13,771. The figure 14,392 is used here and in the summaries appearing as Exhibits 4 and 16 of the report as this total was published in the year-end summary by Aircraft Resources Control Office, Report 15, indicating a later revision of the monthly published figures. This revision was not obtained.

Sources: (1) Engine Units, Pratt & Whitney accounting records.
(2) Horsepower:
(a) October, 1941, through January, 1942, Pratt & Whitney records.
(b) February, 1942, through December, 1944, Aircraft Resources Control Office, Report 15.

TABLE 25. Engines and Horsepower Delivered, Nash-Kelvinator Licensee of Pratt & Whitney Aircraft

		R-2800B Two Stage -8-8W-10-10W-65	Horsepower including Spare Parts (000)
1942	Dec.	6	12
	Total	6	12
1943	Jan.	24	50
	Feb.	11	20
	Mar.	55	110
	April	83	166
	May	106	212
	June	158	316
	July	226	452
	Aug.	300	600
	Sept.	325	686
	Oct.	303	652
	Nov.	501	1,057
	Dec.	600	1,250
	Total	2,692	5,571
1944	Jan.	700	1,460
	Feb.	701	1,472
	Mar.	758	1,628
	April	800	1,721
	May	850	1,828
	June	850	1,870
	July	575	1,507
	Aug.	825	2,133
	Sept.	800	2,063
	Oct.	800	1,765
	Nov.	800	1,664
	Dec.	800	1,728
	Total	9,259	20,839

Sources: (1) Engine Units, Pratt & Whitney records.
(2) Horsepower, Aircraft Resources Control Office, Report 15.

TABLE 26. Engines and Horsepower Delivered, Dodge Division, Chrysler Corporation, Licensee of Wright Aeronautical Corporation

		R-3350-BA -23-23A-57	Horsepower including Spare Parts (000)
1944	Jan.	15	35
	Feb.	31	80
	Mar.	82	205
	April	136	343
	May	205	505
	June	344	842
	July	507	1,161
	Aug.	659	1,595
	Sept.	809	1,867
	Oct.	957	2,266
	Nov.	1,079	2,584
	Dec.	1,229	2,704
	Total	6,053	14,187

Source: Aircraft Resources Control Office, Report 15.

TABLE 27. Engines and Horsepower Delivered, Studebaker Corporation, Licensee of Wright Aeronautical Corporation

		R-1820 -G200-65-97	Horsepower including Spare Parts (000)
1942	Jan.		
	Feb.	4	5
	Mar.	7	9
	April	35	42
	May	168	251
	June	387	528
	July	600	830
	Aug.	804	1,066
	Sept.	1,016	1,366
	Oct.	1,008	1,390
	Nov.	1,011	1,476
	Dec.	1,051	1,577
	Total	6,091	8,540
1943	Jan.	1,212	1,854
	Feb.	1,403	1,970
	Mar.	1,608	2,216
	April	1,801	2,508
	May	2,000	2,767
	June	2,069	2,891
	July	2,160	3,089
	Aug.	2,092	3,184
	Sept.	2,002	3,206
	Oct.	2,217	3,645
	Nov.	2,198	3,675
	Dec.	2,304	3,503
	Total	23,066	34,508
1944	Jan.	2,298	3,449
	Feb.	2,266	3,519
	Mar.	2,479	3,573
	April	2,300	3,355
	May	2,300	3,340
	June	2,381	3,409
	July	2,387	3,322
	Aug.	2,314	3,178
	Sept.	2,314	3,221
	Oct.	2,322	3,231
	Nov.	2,313	3,110
	Dec.	2,246	3,056
	Total	27,920	39,763

Source: Aircraft Resources Control Office, Report 15.

TABLE 28. Engines and Horsepower Delivered, Packard Motor Car Company Licensee of Rolls-Royce, Ltd.

		Single Stage Merlin -28-29-31-33 -38-224-225-266P V-1650 -1-5-17	Two Stage Merlin -68-69 V-1650 -3-7	Horsepower including Spare Parts* (000)
1941	Sept.	4		5
	Oct.	5		7
	Nov.	10		14
	Dec.	26		35
	Total	45		61
1942	Jan.	109		142
	Feb.	149		237
	Mar.	333		537
	April	505		819
	May	602		930
	June	702		1,128
	July	801		1,248
	Aug.	800		1,249
	Sept.	800		1,262
	Oct.	800		1,269
	Nov.	800	4	1,040
	Dec.	850	1	1,195
	Total	7,251	5	11,056
1943	Jan.	850		1,209
	Feb.	864		1,182
	Mar.	615	3	858
	April	607	1	2,068
	May	1,222	16	1,849
	June	1,002	56	1,732
	July	1,142	184	2,006
	Aug.	964	371	1,684
	Sept.	1,203	475	2,140
	Oct.	1,290	450	1,677
	Nov.	1,268	547	2,084
	Dec.	1,265	689	2,172
	Total	12,292	2,792	20,661
1944	Jan.	610	954	2,662
	Feb.	631	859	2,747
	Mar.	780	1,220	3,581
	April	860	1,045	3,425
	May	522	753	2,378
	June	1,114	1,125	3,560
	July	811	1,457	3,578
	Aug.	737	2,017	4,153
	Sept.	528	1,499	3,163
	Oct.	428	1,522	3,149
	Nov.	132	1,729	3,452
	Dec.	18	1,618	2,558
	Total	7,171	15,798	38,406

* Figures for 1941 exclude spare parts.
Source: Aircraft Resources Control Office, Report 15.