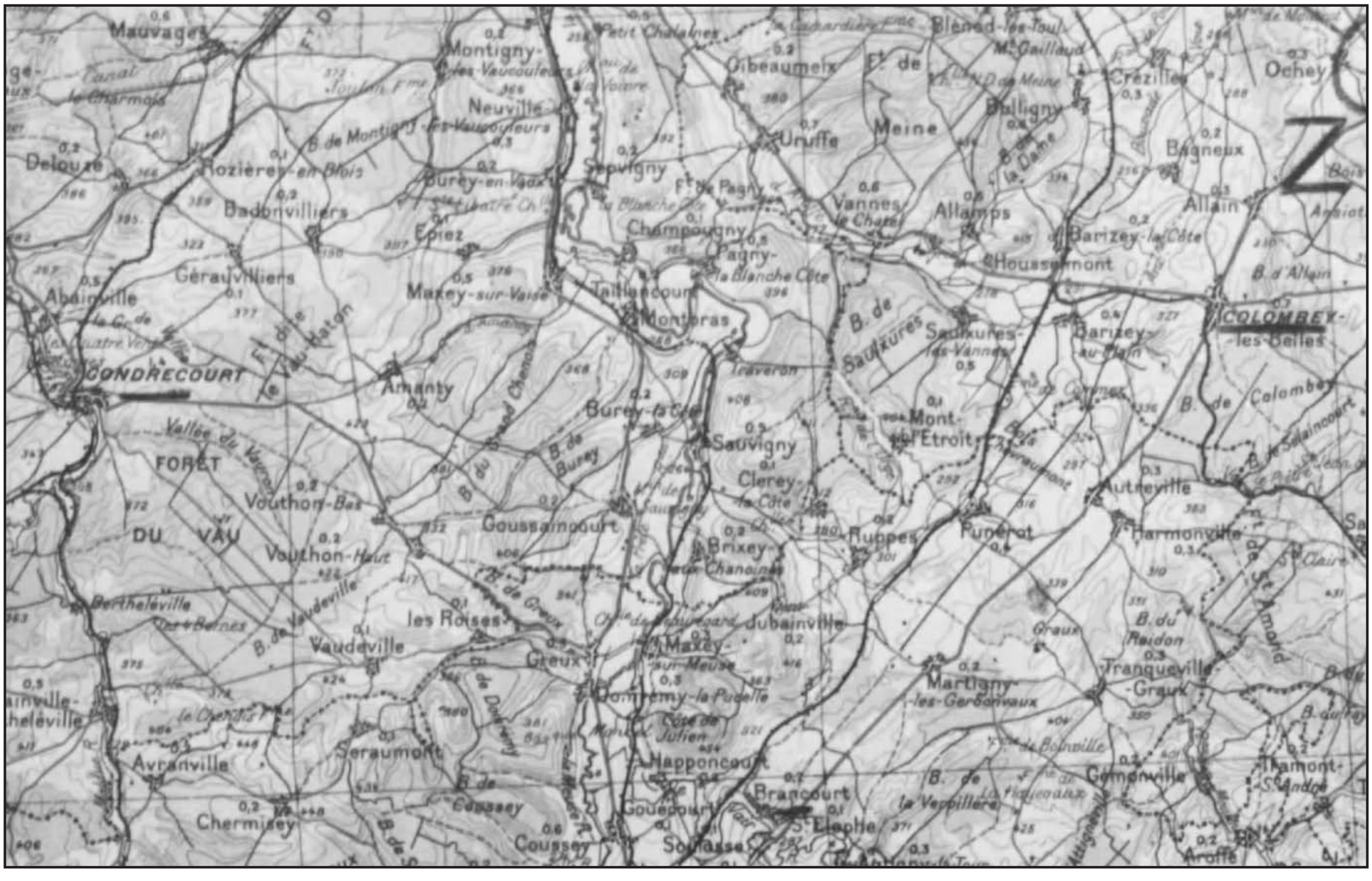
Aircraft Engines and Strategic Bombing in the First World War



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Title Page: NARA, RG 120, M990/10, B VII 124, Statistical Analysis of Aerial Bombardments, Report No. 110, Statistics Branch - General Staff, War Department, Nov. 7, 1918.

Historiography and Acknowledgments

The following avoids repeating much of the well known stories of the Liberty aircraft engine and the controversies surrounding American aviation in the First World War. It also avoids offering a definition of strategic bombing, save to suggest that economic warfare may be properly considered to be an element of that definition. The following adheres to the long established understanding that many of the aircraft engines successfully used during that war were derived from an engine designed before the war by Ferdinand Porsche. There is no attempt to revise the present understanding that strategic bombing operations had no significant effect upon the military course of that war, although the following does contain much to support the present understanding that those operations were the clear and proximate prelude to the strategic bombing operations of the Second World War.

The following is a synthesis of American and European primary and secondary source historical material that includes monographs, government documents, articles from scholarly journals and other periodical literature as well as essays and other material available on the website of the Aircraft Engine Historical Society. It may in part be read as a history of technology that is supplementary to the account of aircraft engines presented in John H. Morrow, Jr.'s *The Great War in the Air from 1909 to 1921* (1993) and in this regard it also takes advantage of some of the scholarship on this subject that has been published in this country and in Europe in the last twenty-five years. The extraordinary gift to the entire world made by some of the major libraries of this country, the Google company and the HathiTrust Digital Library as presented on the latter's website is to the following a sine qua non.

This is not a technical study, the common understanding of how an internal combustion engine works being sufficient to understand the descriptions of engine design and performance presented and in this regard the following is focused on the engine cylinder, the definitive heart of every internal combustion engine. In regards the descriptions of strategic bombing, focused as per American practice on daylight operations, the numbers presented are a simple arithmetic of weight, speed, time and distance. It is that arithmetic however which makes the following a revision of the thesis of Irving B. Holley, Jr.'s *Ideas and Weapons* (1953) that the American military aviation effort in the First World War failed due to a lack of airpower doctrine, a revision the need for which is pointed to in the second volume of Mauer Mauer's edition of *The U.S. Air Service in World War I* (1978.)

The continuing efforts to understand the world wars as a single historical event and to study them "from the middle" perspective of technology and engineering[1] are appropriate and admirable and thus the following is also intended to serve as a study of the American origins of the Second World War in Europe.

I am grateful to Mr. Kimble D. McCutcheon, president of the Aircraft Engine Historical Society, for his help and encouragement.

Introduction

One important aspect of the strategic bombing operations conducted during the First World War was the development and production of the aircraft engines used to power the bomber aircraft deployed in those operations. Engine design and performance directly determined the bombload and tactical radius and thus the strategic bombing capability of the respective bombers. Engine design and manufacturing process also determined what became in the last year of the war the critically important capability of mass producing a serviceable, high-power aircraft engine, the high rate of loss of men and machines in long range bombing operations, as well as the day bomber's limited bombload, requiring the deployment of large numbers of aircraft and engines if strategic bombing operations were to have significant effect. The most important realization of this latter capability was the Ford Motor Company's employment of a process to manufacture the cylinder of the Liberty aircraft engine.

While its effect upon the military events of the war was minimal, the Liberty was a successful international transfer of technology to this country that was an important part of our assumption of world leadership during the First World War, a leadership that we did not relinquish in the decade after the war. The technology of the Liberty cannot be separated from its geoeconomics and this fact makes that engine a focal point in the history of the 20th Century. Initially conceived and soon directed as a weapon of strategic bombing against Germany, the Liberty was turned during the war by the adept management of the Wilson Administration into an instrument of America's international economic expansion, a policy that during and after the war posited the post-war growth and prosperity of Germany. It was entirely appropriate that that engine and the famous war bonds that were used to finance it bore the same name, those bonds being the forecast of the flood of American finance and investment that entered Germany after the war. The bonds accompanied the bombs and the relation between the two was more than one of simple coincidence. Amidst the domestic and international propaganda of the war, this technological, military and geoeconomic significance of the Liberty engine was sometimes denied or ignored and this misunderstanding, reiterated by some British and American historians to the present day, constitutes a not insignificant distortion of the history of the United States.

Directly financed, supplied and guided by leading military, industrial and political interests and authorities of the major belligerent nations, the development and production of the respective wartime aircraft engines were an important means by which each country succeeded or failed to bring its economic and technological power to bear upon the course of the First World War, a war characterized by military failure and by economic and technological success. Every American is schooled from childhood in the fact that it is economic power as much as military prowess that wins the wars and throughout our history war for us has always been the continuation of business by other means. Our participation in the First World War was no exception, it being concerned with a number of important matters besides the military.

Notes

[1] John Keegan, *The First World War* (New York: Alfred A. Knopf, 1999), 359, 406; Niall Ferguson, *The War of the World Twentieth Century Conflict and the Descent of the West* (New York: The Penguin Press, 2006); Paul Kennedy, *Engineers of Victory The Problem Solvers Who Turned the Tide in the Second World War* (New York: Random House, 2013); Heinrich August Winkler, "Die Kontinuität der Kriegspartei," *Frankfurter Allgemeine Zeitung*, Aug. 25, 2014, www.faz.net.

Table I: Comparative Aircraft Engines

	Austro-Daimler 120	Rolls-Royce Eagle Mk VIII	Liberty 12A	Daimler-Mercedes D IVa	Renault 12Fe
Configuration	6 cyl in-line	12 cyl 60° V	12 cyl 45° V	6 cyl in-line	12 cyl 50° V
Normal Rating (bhp @ rpm)	120 @ 1,200	360 @ 1,800	400 @ 1,650	260 @ 1,400	315 @ 1,550
Compression Ratio	~	5.3:1	5.3:1	4.9:1	5.0:1
Bore x Stroke (inches)	5.1 x 6.9	4.5 x 6.5	5.0 x 7.0	6.3 x 7.1	4.9 x 5.9
Bore x Stroke, (mm)	130 x 175	114 x 165	127 x 178	160 x 180	125 x 150
Displacement (in^3)	850	1,241	1,649	1,326	1,347
Weight, direct drive, dry (lb)	419	836	844	936	794
Length, Width, Height (inches)	~	63¼, 32, 39	67½, 27, 41½	77½, - , 46	81, 44¼, 54
SpecificFuel Consumption (lb/bhp/hr)	~	0.50	0.51	0.54	0.52

All engines listed are separate-cylinder, liquid-cooled.

Sources:

Angle, ed., *Airplane Engine Encyclopedia*, 305-312, 343-345, 416-418, 429-434; Ludvigsen, *Ferdinand Porsche*, 243; Smith, *Aircraft Piston Engines*, 53-54. Renault: Angle, ed. *Aerosphere 1939*, 644-645.

Table II: Aircraft Engine Production, 1914-1918

	1914	1915	1916	1917	1918	Total
France	2,335	8,090	17,683	22,015	44,033	94,156
Germany	848	5,037	7,822	11,200	16,412	41,319
Britain	100	1,721	5,363	11,763	22,088	41,035
United States	20	59	134	9,431	34,109	44,053

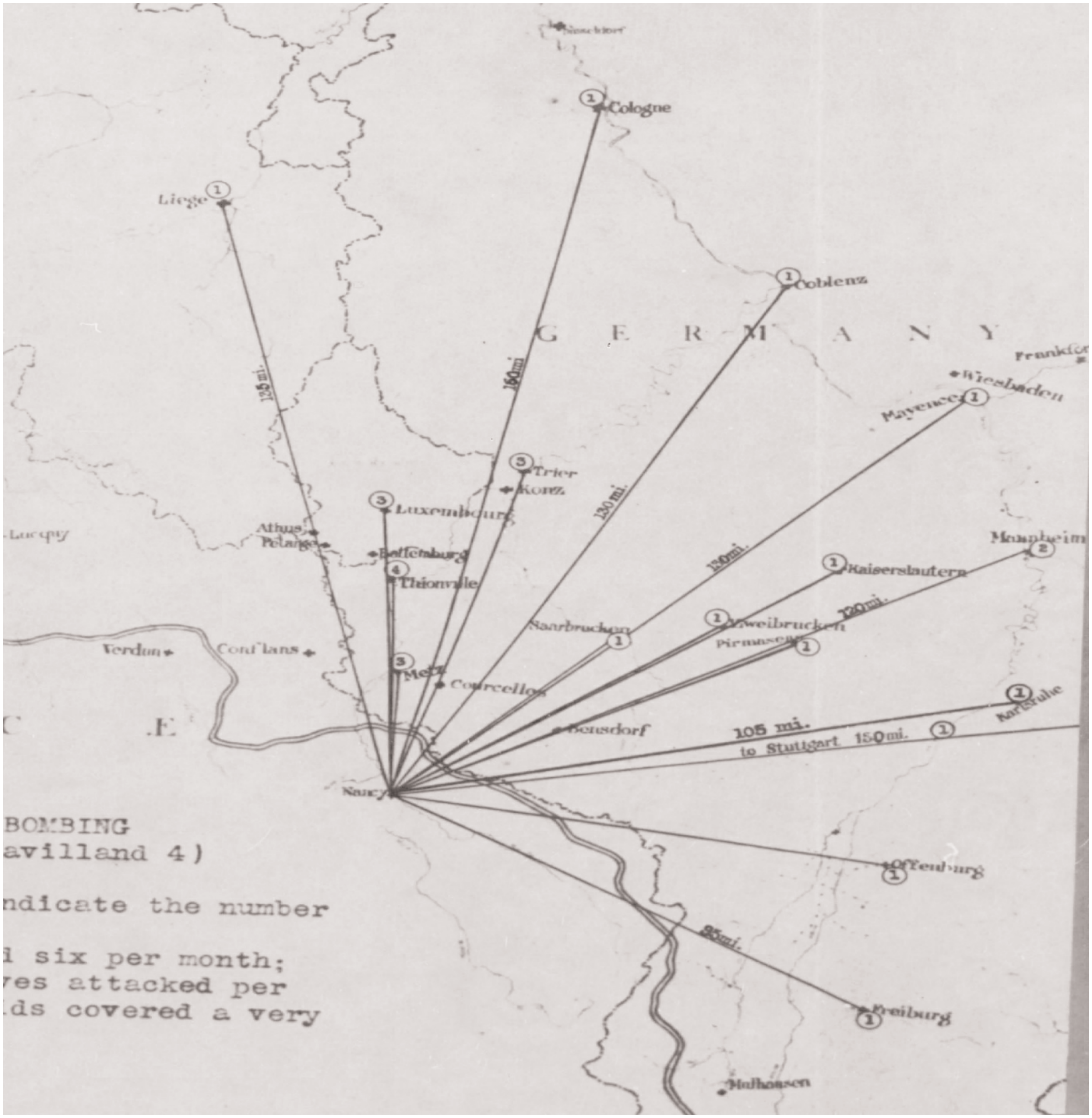
Sources:

France: Chadeau, *De Blériot à Dassault*, 435; Christienne and Lissargue, *History of French Military Aviation*, 148, 157.

Germany: [Aug. - Dec., 1914] Morrow, *German Air Power in World War I*, 209; Gilles, *Flugmotoren*, 185; http://www.theaerodrome.com/forum/showthread.php?t=44622.

Britain: *History of Ministry of Munitions*, 12: 174. Additional total procurement of foreign- built engines = 16,897.

United States: *House War Expenditures Hearings – Aviation*, 1919, 497, 503-504; *History of Ministry of Munitions*, 12: 174; NARA, RG 120, M990/4/1230, A XVII 53, July 11, 1918, No. 1696-R, AGWAR – GHQ AEF. U. S. shipments to U. S. Army. U. S. Navy wartime 1917-1918 aero-engine procurement was through U. S. Army. 1917 includes estimated production of 7,000 Curtiss Aeroplane and Motor Co./Willys-Overland/Willys-Morrow aircraft engines exported to Britain and Canada 1915-1918 not included in U.S. Army figures.



Map: British Independent Force Squadron No. 55 DH-4 Day Bombing Raids, Germany, January to June, 1918.

Source:
NARA, RG 120, M990/10/1074, B VII 87, Statistical Analysis of Aerial Bombardments, Report No. 110, Statistics Branch – General Staff, War Department, Nov. 7, 1918, 16.

Abbreviations

AEF	American Expeditionary Force
AEG	Allgemeine Elektrizität Gesellschaft
AEHS	Aircraft Engine Historical Society
AFHRA	U.S. Air Force Historical Research Agency
AG	Aktien Gesellschaft
AGWAR	Adjutant General, War Department
bmep	brake mean effective pressure
BMW	Bayerischen Motoren Werke
in^3	cubic inch
CSO	Chief Signal Officer
Delco	Dayton Engineering Laboratories Co., Inc.
DH	de Havilland
DZL	Deutsche Zeitschrift für Luftschifffahrt
F	Franc
faz	Frankfürter Allgemeine Zeitung
FIAT	Fabbrica Italiana Automobili Torino
FMCA-OHS, BFRC	Ford Motor Company Oral History Section, Benson Ford Research Center
FRUS	Foreign Relations of the United States
GHQ	General Headquarters
GmbH	Gesellschaft mit beschränkter Haftung
hp	horsepower
IF	Independent Force
JHB	Journal of Historical Biography
JSAE	Journal of the Society of Automotive Engineers
L	liter
lb	pound(s)
LoC	Library of Congress
M.A.	Military Attaché
mm	millimeter
NACA	National Advisory Committee on Aeronautics
NARA	National Archives and Records Administration
NASM	National Aeronautics and Space Museum
oclc	Online Computer Library Center
R	radial
RAF	Royal Air Force
RFC	Royal Flying Corps
RG	Record Group
RHA	Revue Historique des Armées
RNAS	Royal Naval Air Service
rpm	revolutions per minute
SAE	Society of Automotive Engineers
SOS	Service of Supply
ufv	University of Fraser Valley, Canada
USSBS	U.S. Strategic Bombing Survey
ZFM	Zeitschrift für Flugtechnik und Motorluftschiffbau

Part I: Aircraft Engines

1. Austria and Germany

Like so much else of the 20th Century, the origin of these engines may be traced to developments begun in the last years of the Austro-Hungarian empire and fin-de-siècle Vienna. In 1910, Ferdinand Porsche began designing and building airplane engines for the Österreichische Daimler-Motoren-Aktien-Gesellschaft (Austro-Daimler), the automotive manufacturing firm located approximately forty miles south of Vienna at Wiener-Neustadt in Austria and since 1906 independent of the Daimler Motorenwerke of Stuttgart in Germany. In 1911, Porsche built the engine from which were derived nearly all airplane engines successfully employed for the purpose of long-range, strategic bombing during the First World War.

Porsche's Austro-Daimler 120 horsepower aero-engine featured a water-cooled, vertical in-line, six cylinder configuration, a configuration that was characteristic of most of the aero-engines produced in Austria and Germany during the First World War. Porsche's engine had a speed of 1,200 revolutions per minute. The bore and stroke dimensions of its cast iron cylinders were 5.12 x 6.89 inches (130 x 175 millimeters.) These cylinders were screwed and bolted onto an aluminum crankcase which housed a six-throw, eight-bearing crankshaft. The pistons were thin-wall cast iron. Each cylinder included two spark plugs controlled by a hybrid magneto-coil ignition system. The camshaft using push rods to operate the overhead valve gear was located on one side of the engine within the crankcase. The cylinders were encased by sheet-metal water jackets.[1]

The cylinder head of the Porsche design included valve ports cast integrally on each side of the head and the single inlet and exhaust valves each had a diameter of 65 mm. The valves' large diameter improved the cylinder's intake distribution of the fuel-air mixture as well as the cylinder cooling. The design of a 130 mm diameter cylinder with two 65 mm diameter valves required that the cylinder head be dome shaped and that the valves each be inclined approximately 30° outward from the cylinder's vertical center line. Enclosed within the domed head was the critical feature of the Porsche cylinder, a spherical combustion chamber, a feature similar to that used in the cylinder design developed in that same year in France by Robert Esnault-Pelterie (REP) for his air-cooled aero-engines.[2] Another aero-engine of 1910 featuring a spherical combustion chamber was that produced for one of the Parseval airships by the Neue Automobil-Gesellschaft, AG (NAG) of Berlin. Unlike the Porsche cylinder with its integral head and barrel, the NAG's cylinders were made up of machined steel barrels onto which threaded, cast-iron heads were screwed and clamped. Porsche and Austro-Daimler were also at that time producing aero-engines for the Parseval airships.[3]

Porsche had previously used a spherical combustion chamber in his construction of automobile engines[4] and while it facilitated the use of large diameter valves and also subsequently the use of an overhead camshaft, the spherical shape itself was recognized in Germany in the pre-war years and later as the optimal combustion space.[5] By providing the geometry required for the most efficient and complete combustion of the fuel-air mixture, the spherical combustion chamber would prove fundamental to many of the future improvements of aero-engine technology. In the United States during the years following the First World War, it would be a decisive design feature in the development of the high-power, air-cooled, radial aero-engines that equipped our long range bomber and heavy transport aircraft.[6]

The Porsche cylinder's relatively long cylinder stroke dimension and its relatively low engine speed, though sacrificing something of the engine's output horsepower, maintained the brake mean effective pressure (bmep) within the engine's cylinders and thus also improved cooling as well as fuel efficiency. These features of the Porsche cylinder design were the basis for what at that time were reliable aero-engines capable of powering relatively long distance flight.[7] One pre-war customer for the Austro-Daimler was the U. S. Army Signal Corps Aviation Section.[8]

Porsche's first aero-engines had featured copper water jackets electrolitically deposited onto the cylinder. This was a feature similar to that of the some of the first successful French aero-engines of the pre-war era, the Antoinette and the Clerget-Blin.[9] It was a slow and expensive manufacturing process and would have hindered these engines from being put into any sort of large-scale production. This and other considerations, including a prominent German banker's characterization of Porsche as some mysterious creature in a veiled cage who might occasionally emit a page of design work, may have been instances of disagreement between Porsche and one of the owners of Austro-Daimler, the Viennese financier and industrialist Camillo Castiglioni. While an active and important patron of aviation and the fine arts, Castiglioni was also an entrepreneur who insisted on a business turnover derived from production. By the beginning of the First World War, he would acquire a near monopoly position in the Austro-Hungarian aviation industry.[10] With the war's increased demand, Porsche and Austro-Daimler would subsequently make changes to the Porsche engine that facilitated series production but the total Austro-Hungarian wartime output would nevertheless be just 4,426 aero-engines.[11]

During the war, Porsche and Austro-Daimler developed this design into a 200 hp engine. The pistons were aluminum, a feature that reduced engine weight and, with aluminum's better heat conductivity, improved cylinder cooling. The domed head enclosed a hemispherical combustion chamber.[12] In 1915, Austro-Daimler developed a 380 hp V-12 version of this engine which, though it featured an aluminum crankcase and aluminum pistons, weighed approximately 1,100 pounds.[13] In the following year, the Austro-Hungarian navy placed a large production order for the 380 hp Austro-Daimler at the Rapp Motorenwerke in Munich, an order negotiated by Camillo Castiglioni and placed in part due to lack of production capacity in Austria-Hungary.[14]

The German government's decision in 1917, consequent of the United States' entry into the war, to intervene at Rapp[15] led directly to Rapp's reorganization as the Bayerischen Motorenwerke GmbH (BMW,) a company of Austro-German ownership. Before completion of testing of a first prototype, an order was placed by the German government with the new firm for the production of several hundred new engines. Instead of the 380 hp Austro-Daimler, the BMW production in 1918 would be devoted primarily to the BMW IIIa, a 185 hp aero-engine, the cylinder design of which was derived directly from the Porsche engine as well as from similar engines then in production at the Daimler Motorenwerke in Stuttgart.[16] The BMW IIIa, the work of former Daimler engineer Max Friz, featured a system of three carburetors that permitted the use, with reduced throttle at take-off, of a high, 6.7:1 compression ratio in cylinders with the large dimensions of 5.9 x 7.1 inches (150 x 180 mm.) This "over-compressed, over-dimensioned" design was distinct from the Austro-Daimler design of Ferdinand Porsche and it also improved aircraft rate of climb and air speed at altitude. It was a principle that in post-war patent adjudication would be basically attributed to Hugo Junkers.

Using forged aluminum pistons, Max Friz was able to build his engine of larger dimensions[17] with a weight less than that of similar German aero-engines and it was the combination of these features that made the BMW IIIa particularly suitable for fighter aircraft. It would equip the Fokker D VIIF fighters that fought the Allied strategic bombing campaign conducted against industrial and transportation targets in western Germany in that last year of the First World War.[18] In January, 1918, a large, licensed production order for the BMW IIIa was placed at Adam-Opel, AG, Germany's largest automaker located at Rüsselsheim, a few miles east of Mainz (Mayence) near the confluence of the Main and Rhine rivers, a firm that would be acquired in 1929 by the General Motors Corporation. Opel had earlier been engaged in aero-engine production and was thus able to begin delivery of the BMW IIIa in June 1918. BMW's general manager, the Austrian engineer Franz-Josef Popp, would later recall in regards this production, production undeterred by Allied strategic bombing operations, that "Opel had actually in four months in a grand manner and with great success organized the serial production of the BMW IIIa engine. Had the war lasted another year, Opel by then would have become the largest German aero-engine factory."[19]

The Daimler Motorenwerke of Stuttgart, located approximately 50 miles east of the Rhine River in southwest Germany, produced aero-engines for German, Austrian and French airships in the late 19th and early 20th Centuries. These heavy, large-dimension engines, like the airship engines of other pre-war manufacturers, had relatively poor output power to weight ratios and were unsuitable for the contemporary airplanes. In 1909, Daimler began development of airplane engines and by the following year had produced a 50 hp, water-cooled, four cylinder aero-engine, its cast-iron cylinders cast in pairs. The single, vertical inlet and exhaust valves were arranged fore-and-aft on the cylinder head.[20] By 1912, however, the year after Porsche had built his 120 hp Austro-Daimler, the Daimler Motorenwerke had developed the DF 80, an 85 hp engine that featured forged steel cylinders according to the Porsche design and an overhead camshaft. It was noted at that time that, given the high failure rate of cast-iron cylinders, the serial production of forged steel cylinders could prove to be relatively economic. Also by 1912, Daimler-Mercedes had developed a similar, slightly larger 120 hp engine using the Porsche-type cylinder and described as being produced “not to attain greater speed but to power aircraft with increased useful load and extended radius of action.”[21] By the beginning of the First World War, Daimler would hold a dominant position in the German aero-engine industry, particularly in regards the equipment of German army aircraft, a position similar to that held in pre-war France by Gnôme with its air-cooled, rotary engines and one which, unlike Gnôme, Daimler would maintain throughout the war.[22] Daimler-Mercedes’ two principal, wartime aero-engines were the D III and D IVa.

With production started by the beginning of the war, the 160 hp D III accounted for approximately 12,000 of the 19,876 total Daimler-Mercedes aero-engine output of 1914-1918. The maximum diameter of the Porsche-type cylinder head was slightly enlarged, or “bumped,” beyond the outside diameter of the barrel thereby permitting the use of larger diameter valves. Unlike the earlier Porsche design, however, the D III’s forged steel cylinder featured screwed-on and welded valve ports as well as an overhead camshaft. Unlike the BMW IIIa, the D III featured a standard dual carburetor system, a low compression ratio of approximately 4.5:1 and moderate cylinder dimensions of 5.52 x 6.30 inches (140 x 160 mm.)

Each cylinder included two spark plugs positioned horizontally on opposite sides of the cylinder just above the piston’s top dead center position. This was the spark plug arrangement adopted in the cylinders of U. S. air-cooled radial aero-engines beginning in the mid-1920s and it was an arrangement that best utilized the spherical combustion chamber for the most efficient and complete combustion of the fuel-air mixture.

With a slightly increased compression ratio and an output of 180 hp at 1,500 rpm, the Daimler-Mercedes D IIIa also equipped many of the German fighter aircraft of the First World War, including the Fokker D VII. As in the BMW IIIa, its overhead camshaft, could be shifted to provide a low compression setting for starting.[23] Its continued production however may have been an example of the problem inherent in many wartime mass production efforts — the conflict between the need to standardize and the continuing need for development progress. As the war progressed, the German army complained repeatedly that Daimler’s aero-engine patent rights and the failure of Daimler and other aero-engine manufacturers to meet production goals were proving to be bottlenecks in the expansion of the German air forces. It was agreed that this production failure could not be attributed to an inadequate supply of machine tools. Daimler’s main plant at Stuttgart-Untertürkheim by 1915 had a floor-space of nearly 3 million square feet, half of which was covered. It had its own foundry that included nine ovens for smelting aluminum. It produced much of its own tools and tooling, including precision measuring instruments accurate to within 0.001 mm. As at the Ford Motor Company’s main plant at Highland Park near Detroit in 1915, the thousands of machine tools at the Untertürkheim factory were driven by overhead belts. Unlike Ford, however, where steam power was employed, the Daimler machine tool drive belts were powered by electric motors. Like Ford, Daimler continued its automotive production for the army during the war and would profit substantially from its war work. By 1917, Daimler would realize a net annual profit of 6.6 million M on a nominal capitalization of 8 million M, declaring a 25% dividend with its shares selling at 6.3 times their par value. Yet, despite all this, on at least three occasions in 1918, the German monthly production of airplanes would exceed that of aero-engines. The total German wartime production would be less than half the total French production of approximately 94,000 aero-engines.[24]

This failure of the German war economy has been attributed to a number of factors besides Daimler's refusal to agree to the licensed production of its engines and the issue of Daimler's patent rights.[25] One possible reason may have been the continued European emphasis on specialized workmanship in industrial manufacturing. As noted in early 1918 by American automotive engineer Henry M. Crane, whose Simplex Automobile Company had a pre-war agreement with Daimler-Mercedes, "an engine may have been developed in a factory in which certain machine tools were available and may even have been built depending on certain foremen who knew how to do their work extremely well. The Mercedes engine is an example of this."[26] It would be manufacturing process, not design patents or manufacturing licenses, that would prove to be the principal barrier to, or defense against, the international transfer of aviation technology to the United States in the First World War. The often stated American complaints, that the European sample airplanes and aero-engines sent to the United States on the basis of inter-government agreement were unaccompanied by drawings, materials lists and gauges, that many parts dimensions were not specified and those that were lacked tolerances and that there was a general lack of standardization in the European manufacturing, may have been referring to an apparent failure that may not always have been inadvertent.

Another of the most commonly cited factors pertaining to the relatively low German aero-engine output during the First World War has been an asserted lack of raw materials, specifically aluminum. Yet, while there certainly was a scarcity, it may not be accurate to simply posit a shortage of aviation aluminum in Germany during the First World War. Of the major components of all the major production aero-engines of that era, aluminum was commonly used only for the crankcase and pistons.[27] Skepticism in Germany before the war in regards the use of aluminum in aero-engines did not prevent the development in Germany of duralumin, one of the major advances in aluminum technology and one particularly important to the development of aviation.[28] One of Germany's most important industrial firms, the Allgemeine Elektrizität Gesellschaft (AEG), a firm throughout its history closely associated with the General Electric Company of Schenectady, New York, was interested in the pre-war supply of aluminum to Germany as well as in the wartime development of a German aluminum industry. AEG was also an important participant in the early development of aviation in Germany and its chairman, Walter Rathenau, headed the German government's early wartime effort to administer raw materials production and allocation. In this latter capacity, Rathenau would be an advocate of Germany's long range bombing of Britain.[29] Germany's development of an aluminum production capacity that by 1919 would be equivalent to the entire world output of a decade earlier, the increasing use of aluminum pistons at an increasing number of wartime German aero-engine manufacturers, the decision to standardize German fighter aircraft production on the BMW IIIa, an engine using an increased amount of aluminum[30] and the curtailment in 1917 of the German army's procurement and operation of the aluminum framework Zeppelin airships,[31] are indications that the wartime scarcity of aluminum in Germany may not have proved to have been an absolute limit to German aero-engine production.

The French aluminum industry, with its nearly ideal basis of rich bauxite deposits located near the hydropower resources of the French Alps and Pyrenees Mountains, would also be thoroughly integrated into the French war economy through the growth during the war of the Tréfileries et Laminoirs du Havre. One of this industry's contributions to the French war effort would be the construction of bomber aircraft featuring duralumin framework fuselages.[32]

The German government's push in 1917 to open the Daimler-Mercedes bottleneck on aero-engine production was preceded by Daimler's own effort begun in the spring of 1916 to develop an aero-engine suitable for long range bombing operations. The 260 hp Daimler-Mercedes D IVa ran at 1,400 rpm, the same speed as the less powerful D III and BMW IIIa and, except for the use of twin inlet and exhaust valves, it used the same, basic Porsche cylinder design, featuring a large cylinder of 6.3 x 7.1 inches (160 x 180 mm) set at a moderate compression ratio of 4.9:1. This combination allowed bomber aircraft to use the full throttle output of the D IVa at take-off.[33] The large bore diameter, however, pushed the upper limit of an aero-engine cylinder. Adequate cooling and fuel efficiency require a complete as possible combustion of the fuel-air mixture and this complete combustion requires that the flame fronts moving across the combustion chamber from their respective points of ignition be given time to meet. The speed of a four-stroke aero-engine with a large cylinder bore is thus actually limited by the rate of combustion of the fuel-air mixture which for a given cylinder and mixture is a constant and thus efforts to increase the output horsepower by increasing the speed of an engine with a large bore cylinder may result in incomplete combustion, over-heating and detonation.[34] This limit on the DIVa's ability to increase its engine speed coincided with a similar limitation on increased compression ratio, the latter limitation the result of the increased difficulty of cooling the valves, particularly the reduced diameter exhaust valves, of a four valve cylinder. One reason the BMW IIIa was able to use a high compression ratio of 6.7:1 to maintain output at altitude was that its cylinder featured single, large diameter inlet and exhaust valves.

Unlike the D III and D IIIa, the D IVa cylinder featured a drop-forged steel head manufactured separately from a barrel made of tubular steel, the ends of the head and barrel being threaded and then screwed and welded together. The forged steel, twin inlet and exhaust valve ports of the D IVa were welded onto the sides of the domed head which enclosed a spherical combustion chamber. The valves were inclined 15° outward from the cylinder's vertical center line. The top or "crown" of the cylinder head had a maximum thickness of 0.433 inch. The convex-head piston was of cast iron and forged steel. The steel barrel was machined to a minimum thickness of 0.138 inch. In contrast to the D III, the two spark plugs were placed on the same side of the cylinder head below the intake ports.

At well over 900 lbs, the D IVa was not a light weight engine and its fuel efficiency of 0.54 lb/hp/hr was not as good as that of the Liberty and Rolls-Royce Eagle Mark VIII.[35] The use of a section of forged steel tube for the barrel, a feature similar to that of the Liberty aero-engine, may have been for the purpose of facilitating mass production. And the decision to use, unlike the Liberty, a separate head may have been for the same purpose, the accurate machining of the interior dimensions of a cylinder with an integral barrel and head enclosing a spherical combustion chamber proving to be a difficult procedure.

This development of an open-ended cylinder barrel with a separate head was contemporaneous with similar work being done at the Royal Aeronautical Factory at Farnborough in Britain,[36] at the Siddeley-Deasy Motor Co., Ltd., in Coventry,[37] and in the United States at the Wright-Martin Aircraft Corporation's plant at New Brunswick, New Jersey.[38] All of these efforts to open up the aero-engine cylinder tended to improve the respective cylinder's fuel-air mixture distribution and cooling and thus the respective engine's fuel efficiency and potential for increased output horsepower.

In Stuttgart, Daimler development director Paul Daimler preferred to pursue supercharging as a means of maintaining aero-engine performance at altitude and it was thus that Daimler engineer Max Friz was available to pursue his own design work at Munich and BMW, the latter work facilitated by the German army's virtual expropriation of aviation patent rights in Germany by early 1917.[39] AEG, itself a manufacturer of bomber aircraft powered by the Daimler-Mercedes D IVa, built and successfully tested during the war a centrifugal supercharger for the D IVa. Also, the Swiss manufacturer Brown, Boveri & Cie. built a turbo-supercharger for the D IVa which underwent successful wartime static and flight testing aboard the giant Zeppelin-Staaken R VI four-engine bomber. This testing indicated that the D IVa, because of its moderate compression ratio, was amenable to supercharging to maintain output at altitude and that it could be overloaded at ground level thus making it particularly suitable for bomber aircraft.[40] The D IVa, the cylinder design of which was directly descended from the 1911 work of Ferdinand Porsche, would power many of the German multi-engine bombers of the First World War and it would be a squadron of these aircraft, flying from fields in Belgium, each aircraft powered by two Daimler-Mercedes DIVa aero-engines, that would make the first German daylight airplane group bombing raid on London on June 13, 1917, the same day that General Pershing arrived at Paris to take command of the American Expeditionary Forces.[41]

Notes

[1] Karl Ludvigsen, *Ferdinand Porsche Genesis of Genius* (Cambridge: Bentley Publishers, 2008), 228-233, 243-244, Aircraft Engine Historical Society [AEHS], www.enginehistory.org; Daimler-Motoren-Gesellschaft. *Zum 25 Jährigen Bestehen der Daimler-Motoren-Gesellschaft* (Untertürkheim, 1915), 115, 121, www.hathitrust.org; *Zeitschrift für Flugtechnik und Motorluftschiffbau* [*ZFM*] 1, 21 (Nov. 13, 1910): 278, www.hathitrust.org; *Deutsche Zeitschrift für Luftschifffahrt* [*DZL*] 15, 3 (Feb. 8, 1911): 13-16, www.hathitrust.org; John H. Morrow, Jr. *The Great War in the Air from 1909 to 1921* (Washington: Smithsonian Instiution Press, 1993), 23.

[2] *Aérophile*, Apr. 15, 1911, 177-179, www.hathitrust.org; Glenn D. Angle, ed. *Aerosphere 1939* (New York: Aircraft Publications, 1940), 660.

[3] *ZFM* 1, 10 (May 29, 1910): 123-124; J. A. Gilles, *Flugmotoren 1910 bis 1918*. Herausgegeben vom Militärgeschichtliche Forschungsamt. (E. S. Mittler & Sohn GmbH, 1971), 7; Angle, ed. *Aerosphere 1939*, 540-542.

[4] Ludvigsen, *Ferdinand Porsche*, 228-232, 243-244; Herschel Smith, *Aircraft Piston Engines* (New York: McGraw-Hill, 1981), 29; Gunston, *Development of Piston Aero Engines*, 117; Glenn D. Angle, ed. *Airplane Engine Encyclopedia* (Dayton: The Otterbein Press, 1921), 60-64.

[5] *ZFM* 1, 10 (May 29, 1910): 124; ibid, 4, 17 (Sept. 13, 1913): 236; Gilles, *Flugmotoren*, 6; Fritz Huth, "Luftfahrzeugmotoren," in Georg Paul Neumann, ed. *Deutschen Luftstreitkräfte im Weltkriege*. (Berlin: Ernst Siegried Mittler und Sohn, 1920), 149-150, www.hathitrust.org.

[6] E. T. Jones, "The Development of the Wright Whirlwind Type J-5 Aircraft-Engine," *Journal of the Society of Automotive Engineers* [*JSAE*], Sept. 1926, 303-306; S.D. Heron, "Aircraft-Engine Practice as Applied to Air-Cooled Passenger-Car Engines," *JSAE*, Jan. 1923, 34; George J. Mead, "Wasp and Hornet Radial Air-Cooled Aeronautic Engines," *JSAE*, December 1926, 613; Charles F. Marvin, Jr., "Combustion Time in the Engine Cylinder and Its Effect on Engine Performance," *National Advisory Committee for Aeronautics* [*NACA*] *Report No. 276* [1927] 393-394; S. D. Heron, *History of the Aircraft Piston Engine. A Brief Outline* (Detroit: Ethyl Corporation, 1961), 22; Martinot-Lagarde, "Les Moteurs D'Aviation Pendant La Guerre Mondiale 1914-1918," in Maurice de Brunoff, ed. *L'Aéronautique pendant la Guerre Mondiale* (Paris, 1919), 130, www.hathitrust.org; F. Gosslau, "Mathematical and Experimental Investigation of Heat Control and Power Increase in Air-cooled Aircraft Engines," trans. Dwight M. Miner, *NACA Technical Memorandum No. 540*, Nov. 1929, 4 [trans. from *Zeitschrift fuer Flugtechnik und Motorluftschiffbau*, Oct. 7, 1928]; Franz Merkle, *Handbuch für Flugmotorenkunde* (Berlin: C. J. E. Volckmann Nachf. GmbH, 1934), 44-45.

[7] Smith, *Aircraft Piston Engines*, 30; Gunston, *Development of Piston Aero Engines*, 117; Martinot-Lagarde, "Les Moteurs D'Aviation," 124-125; Gilles, *Flugmotoren*, 22.

[8] H. H. Arnold, *Global Mission* (New York: Harper & Brothers, Publishers, 1949), 38-39.

[9] Ludvigsen, *Ferdinand Porsche*, 233, 235; Angle, ed. *Aerosphere 1939*, 81, 113, 217; *Aérophile*, Apr. 15, 1909, 179; Bill Gunston, *The Development of Piston Aero Engines* (Sparkford: Patrick Stephens, Ltd., 1993), 106.

[10] John H. Morrow, Jr. *German Air Power in World War I* (Lincoln: Univ. of Nebraska Press, 1982), 6, 10-11, 169-181; Morrow, *Great War in Air*, 23; Ernst Heinkel, *Stürmisches Leben*, ed. Jürgen Thorwald (Stuttgart: Mundus Verlag, 1953), 102-103; René Del Fabbro, "Internationaler Markt und nationale Interesssen. Die BMW AG in der Aera Castiglioni," *Sozial Geschichte* 18, 2 (2003): 36-37; Horst Mönnich, *BMW Eine deutsche Geschichte* (Wien-Darmstadt: Paul Zsolny Verlag, 1989), 50-51; Ludvigsen, *Ferdinand Porsche*, 226; *Aerial Age*, Apr. 17, 1917, 152; *Living Age*, 323, 4192 (November 16, 1924): 309-310.

[11] Morrow, *German Air Power in World War I*, 213.

[12] C. G. Grey, ed. *All the World's Aircraft 1919* (London: Sampson Low, Marston & Co., 1919) [reprint, New York: Arco Publishing Co.], 14b-17b; Angle, ed. *Airplane Engine Encyclopedia*, 64-67; Smith, *Aircraft Piston Engines*, 53; Lionel S. Marks, *The Airplane Engine* (New York: McGraw-Hill Book Co., Inc., 1922), 68, www.hathitrust.org; Jesse G. Vincent, "The Liberty Aircraft Engine," *Transactions of the Society of Automotive Engineers* [*SAE Transactions*] 14, 1 (1919): 406-407, www.hathitrust.org; Henry M. Crane, "Possible Effect of Aircraft Engine Development on Automobile Practice," *SAE Transactions* 14, 1 (1919): 140, www.hathitrust.org.

[13] Ludvigsen, *Ferdinand Porsche*, 253-254; Angle, ed. *Airplane Engine Encyclopedia*, 67-68; Glenn D. Angle, ed. *Aerosphere 1939* (New York: Aircraft Publications, 1940), 115-116; Gilles, *Flugmotoren*, 77; "A Metallurgical Report on Materials Used in Foreign Aeronautical Engines," *Air Service Information Circular* 3, 222 (Apr. 30, 1921): 6, AEHS, www.enginehistory.org.

[14] Christian Pierer, *Die Bayerischen Motoren Werke bis 1933* (München: Oldenbourg Verlag, 2011), 18-19; Mönnich, *BMW*, 51-53; Fred Jakobs and Robert Kröschel and Christian Pierer, *BMW Flugbetriebwerke* (München: BMW Group Classic, 2009), 25; Morrow, *Great War in Air*, 46.

[15] Morrow, *German Air Power in World War I*, 95-96 120, 125; Morrow, *Great War in Air*, 227-228; Pierer, *Bayerischen Motoren Werke*, 21; Mönnich, *BMW*, 55-56.

[16] Pierer, *Bayerischen Motoren Werke*, 19, 22-24, 32, 44-50, 67; Mönnich, *BMW*, 64-65, 71-74; Kyrill v. Gersdorff and Kurt Grasmann, *Flugmotoren und Strahltriebwerke* (München: Bernard und Graefe, 1980), 36-37; [Otto] Schwager, "Zur Berechnung überverdichter und überbemessener Flugmotoren," *Technische Berichte*, 3, 5 (1918): 179-181, www.hathitrust.org; [Otto] Schwager, "Neuere Bestrebungen und Erfahrungen im Flugmotorenbau," *Technische Berichte*, 3, 5 (1918): 150; Martinot-Lagarde, "Les Moteurs D'Aviation," 142.

[17] Jakobs and Kröschel and Pierer, *BMW Flugbetriebwerke*, 51-57, 214; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 35-37; Marks, *Airplane Engine*, 78, 285-286, 392-394, 427; *Aviation*, March 21, 1921, 370-371; S.W. Sparrow, "Performance of B.M.W. 185-Horsepower Aeroplane-Engine," *NACA Report No. 135* [1923], 101-110; Mönnich, *BMW*, 57-58, 62-64; Till Lorenzen, *BMW als Flugmotorenhersteller 1926-1940* (München: Oldenbourg Wissenschaftsverlag, GmbH, 2008), 38-39; Del Fabbro, "Internationaler Markt," 40; Smith, *Aircraft Piston Engines*, 38, 53-54; Angle, ed. *Aerosphere 1939*, 152; *Automotive Industries*, July 21, 1921, 140; *JSAE*, June, 1926, 621-622.

Junkers: Lutz Budrass, *Flugzeugindustrie und Luftrüstung in Deutschland 1919-1945* (Düsseldorf: Dröste Verlag, 1998), 76; Pierer, *Bayerischen Motoren Werke*, 51; Mönnich, *BMW*, 105, 118; Morrow, *German Air Power in World War I*, 105; *Technische Berichte* 3, 5 (1918): 150; ibid, 3, 7 (1918): 339; Richard Byers, "An Unhappy Marriage: The Junkers-Fokker Merger," *Journal of Historical Biography* 3 (Spring 2008): 1-30, www.ufv.ca/jhb.

[18] Morrow, *German Air Power in World War I*, 113, 124-125, 134, 192; Jakobs and Kröschel and Pierer, *BMW Flugbetriebwerke*, 52, 59; Mönnich, *BMW*, 65-68; Grey, ed. *All the World's Aircraft 1919*, 291a; Alan Morris, *First of the Many The Story of Independent Force, R.A.F.* (London: Arrow Books, 1968), 97, 122; John W. R. Taylor, ed. *Combat Aircraft of the World From 1909 to the Present* (New York: G.P. Putnam's Sons, 1969), 157.

[19] Jakobs and Kröschel and Pierer, *BMW Flugbetriebwerke*, 60; U.S. Air Force Historical Research Agency, Maxwell Air Force Base, Montgomery, Alabama [AFHRA], K113.8231, vol. 1, Technik: Production Triebwerke, Popp - Udet, Sept. 5, 1938, transcript, 2 (quote); Mönnich, *BMW*, 65; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 37; Gilles, *Flugmotoren*, 97, 103; Martinot-Lagarde, "Les Moteurs D'Aviation," 142.

[20] *ZFM*, 1, 10 (May 29, 1910): 125; ibid, 1, 11 (June 11, 1910): 130-131; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 10, 16; Angle, ed. *Aerosphere 1939*, 517-518; *DZL* 15, 3 (Feb. 8, 1911): 11-13; Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 95-99; Gilles, *Flugmotoren*, 4-5; *Erinnerungen 1934-1984 Flugtriebwerkbau in München* (München: MTU Motoren-und Turbinen-Union GmbH, 1984), 36.

[21] Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 106, 108 (quote, 108); *ZFM* 4, 8 (Apr. 20, 1913): 102-103; Gilles, *Flugmotoren*, 25-26, 29, 36, 43; Derek S. Taulbet, *Eagle Henry Royce's First Aero Engine* (Derby: The Rolls Royce Heritage Trust, 2011), 41-44, 47, 268-274; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 17; Angle, ed. *Aerosphere 1939*, 518-519; Huth, "Luftfahrzeugmotoren," 151; Morrow, *Great War in Air*, 18.

[22] Morrow, *Great War in Air*, 16, 37; Morrow, *German Air Power in World War I*, 8, 189, 193; *ZFM*, 5,1 (Jan. 17, 1914): 8 ; ibid, 5, 12 (June 27, 1914): 191-192; Gilles, *Flugmotoren*, 22-23, 58; Gunston, *Development of Piston Aero Engines*, 110-112.

Gnôme: Emmanuel Chadeau, *De Blériot à Dassault: Histoire de l'industrie aéronautique en France 1900-1950* (Fayard, 1987), 53-64, 101; Marie-Catherine Dubreil-Villatoux, "L'Aéronautique Militaire dans la Grande Guerre: Vers L'Institutionalisation," in Francine de Auer-Véran, *Archives de L'Aéronautique Militaire dans la Première Guerre Mondiale* (Château de Vincennes: Service Historique de la Défense, 2008), 17, www.rha.revues.org.

[23] Angle, ed. *Aerosphere 1939*, 152, 519, 521; Neumann, ed. *Deutschen Luftstreitkräfte*, 82, 585; Marks, *Airplane Engine*, 73; *Aérophile*, May 15, 1916, 129-140; ibid, Dec. 15, 1916, 379-380; Morrow, *Great War in Air*, 369; Gilles, *Flugmotoren*, 65; Jakobs and Kröschel and Pierer, *BMW Flugbetriebwerke*, 54, 56; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 26; Heron, *History of the Aircraft Piston Engine*, 13; Herbert Chase, "Modern Aeronautic Engines," *SAE Transactions* 13, 2 (1918): 245; Smith, *Aircraft Piston Engines*, 36-38, 53; Grey, ed. *All the World's Aircraft 1919*, 344a.

[24] Morrow, *German Air Power in World War I*, 31, 51, 65, 71, 80, 96-97, 102, 108, 119, 125, 129, 209; Morrow, *Great War in Air*, 308; Martinot-Lagarde, "Les Moteurs D'Aviation," 147; Chadeau, *De Blériot à Dassault*, 435; Smith, *Aircraft Piston Engines*, 37-38 ; Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 114, 135-156; *Aeroplane*, 13, 1 (July 3, 1917): 30; J. M. Waggoner, "The Reminiscences of Mr. J. M. Waggoner," 12-15, Aug. 1955, Acc. 65, Ford Motor Company Archives, Oral History Section, Benson Ford Reseaarch Center [FMCA-OHS, BFRC] www.oclc.org.

[25] Morrow, *German Air Power in World War I*, 101-104; Hoeppner, *Deutschlands Krieg in der Luft,* 90-91; Gilles, *Flugmotoren*, 104, xviii.

[26] *SAE Transactions* 13, 1 (1918): 102 (quote); Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 124; James S. Flink, "Mass Production," in George S. May, ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920* (New York: Bruccoli, Clark, Layman, Inc. 1990,) 322-323; AFHRA, Microfilm A1127, 137.3041-5 to 137.3055B, U.S. Strategic Bombing Survey, European War, Summary Report, 1947. Equipment Division, Machine Tool Section, "Machine Tool Industry," 1.

[27] "Metallurgical Report on Materials Used in Foreign Aeronautical Engines," 4, 6; Martinot-Lagarde, "Les Moteurs D'Aviation," 130.

[28] Asbert Vorreiter, "Konstruktionsprinzipen der Motoren für Flugapparate," *ZFM* 1, 2 (1910): 13; *Technische Berichte* 3, 3 (1918): 93-94; George W. Stocking and Myron W. Watkins. *Cartels in Action. Studies in International Business Diplomacy* (New York: The Twentieth Century Fund, 1947), 217-219, www.hathitrust.org; E. Unger and E. Schmidt, "Duralumin," *Technische Berichte* 3, 6 (1918): 229-234; Budrass, *Flugzeugindustrie*, 30; Manfred Knauer, *Hundertjahre Aluminumindustrie in Deutschland (1886-1986)* (München: Oldenbourg Wissenschaftwissenschaft Verlag, GmbH, 2014), 52-53, www.books.google.com; *ZFM*, 11, 7-8 (Nov. 20, 1920): ii; Charles C. Carr, *Alcoa An American Enterprise* (New York: Rinehart & Co., 1952), 151.

[29] Harry Kessler, *Walter Rathenau His Life and Work*, trans. W.D. Robson-Scott and Lawrence Hyde (New York: Harcourt, Brace and Co., 1930), 118-119, 169-178; Morrow, *German Air Power in World War I*, 21; Morrow, *Great War in Air*, 72; Gerald D. Feldman, *Army Industry and Labor in Germany 1914-1918* (Princeton: Princeton Univ. Press, 1966), 45-51; Kenneth Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919* (New York: The MacMillan Co., 1968), 149-150; Guillame de Syon, "Faded Memories The Wright Brothers and Germany 1909-1913," http://corescholar.libraries.wright.edu; "Eine Moderne Flugzeugfabrik," Reel No. 3, U.S. Army Signals Corps Historical Film No. 1106 in "Munitionsanfertigung 1918," U S National Archives, www.youtube.com.

[30] *Engineering and Mining Journal*, 106, 20 (Nov. 16, 1918): 884; Junius David Edwards and Francis C. Frary and Zay Jeffries. *The Aluminum Industry*, vol. 1, *Aluminum and Its Production* (New York: McGraw-Hill Book Co., Inc., 1930), 37-41, 47-49, 52-54, www.hathitrust.org; Stocking and Watkins, *Cartels in Action*, 219-220, 227-228, 233-235, 245; Wilfried Kossmann, *Uber die wirtschaftliche Entwicklung der Aluminumindustrie* (Druckerei und Verlagsantalt, 1911), 30-31, 39, 62, 80, 90-97, www.hathitrust.org; A. Sander, „Luftschiffahrt und Metalltechnik,“ *ZFM* 1, 15 (Aug. 13, 1910): 197-200; Gérard Hartmann, "L'Aluminum Historique," 2004, 1-2, www.hydroretro.net; *Aerial Age*, 5, 21 (Aug. 6, 1917): 716; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 16, 25, 33, 37; Grey, ed. *All the World's Aircraft, 1919*, 16b, 26b-27b, 270a; *ZFM* 1, 3-4 (1910): 39-41, 47; ibid, 1, 5 (March 12, 1910): 55-57, 59; ibid, 1, 7 (April 6, 1910): 82-83; ibid, 1, 11 (June 11, 1910): 135-136; ibid, 3, 9 (March 11, 1912): 124-125; *Aérophile*, May 15, 1909, 224; ibid, July 15, 1909, 323; ibid, Oct. 1, 1909, 439; ibid, Aug. 15, 1916, 224-225; *DZL* 14, 3 (Feb. 9, 1910): 25-26; Gilles, *Flugmotoren*, 10, 21-22; Morrow, *German Air Power in World War I*, 71, 80-81, 134, 189, 193; Mönnich, *BMW*, 53-54, 64-65, 71-77; *BMW AG, Geschäfts-Bericht*, *1918*, 2, www.bmwgroup-classic.com; Angle, ed. *Airplane Engine Encyclopedia*, 71, 90; Martinot-Lagarde, "Les Moteurs D'Aviation," 141.

[31] *Aeroplane*, 13, 18 (Oct. 31, 1917): 1250; Grey, ed. *All the World's Aircraft, 1919*, 24c-27c; Neumann, ed. *Deutschen Luftstreitkräfte*, 23, 32, 40, 345, 361, 584; [Ernst W. H.] v. Hoeppner, *Deutschlands Krieg in der Luft,* (Leipzig: Verlag von K. F. Koehler, 1921), 95, 120-121, www.hathitrust.org.

[32] Edwards and Fray and Jeffries, *Aluminum and Its Production*, 39-41; Marc Lagana, "A propos de l'interdependence des mileux d'affaires et des mileux politiques: Le Cas des Tréfileries et Laminoirs du Havre de 1901 à 1918," *Revue Françise d'Histoire d'Outre-mer* 66, 242-243 (1979): 59-71, www.persee.fr; Hartmann, "L'Aluminum Historique," 7; Gérard Hartmann, "Les Premiers Appareils Breguet," 2005, 3-5, www.hydroretro.net.

[33] Angle, ed. *Aerosphere 1939*, 520-521; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 24; Smith, *Aircraft Piston Engines*, 37; K. Kutzbach, "Ergebnisse einige Höhenflugversuche mit Daimler-Benz- und Maybach Motoren," *Technische Berichte*, 3, 1 (1918): 17-18, www.hathitrust.org; Gilles, *Flugmotoren*, 65.

[34] Jack Connors, *The Engines of Pratt and Whitney: A Technical History* (Reston: American Institute of Aeronautics and Astronautics, 2010), 38-39; Marvin, "Combustion Time in the Engine Cylinder," 393-394; Marks, *Airplane Engine*, 231, 347-348.

[35] Grey, ed. *All the World's Aircraft 1919*, 103b-113b; Angle, ed. *Aerosphere 1939*, 520-521; *Aeroplane*, Dec. 5, 1917, 1655-1656, 1658, 1660; *Aerial Age*, 6, 1 (Sept. 17, 1917): 19; Gunston, *Development of Piston Aero Engines*, 119; Smith, *Aircraft Piston Engines*, 35-37; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 24; Chase, "Modern Aeronautic Engines," 245-246; Heron, *History of the Aircraft Piston Engine*, 13-14; Kutzbach, "Ergebnisse einige Höhenflugversuche," 18-19.

[36] A. H. Gibson, "Theories and Practices in the Air Cooling of Engines, Part II," *Automotive Industries* 42, 21 (May 20, 1920): 1155; A. H. Gibson, "Aero-engine Efficiencies," *Aviation*, Feb. 21, 1921, 238-240; Gunston, *Development of Piston Aero Engines*, 123-124; S.D. Heron, "Some Aspects of Air-Cooled Cylinder Design and Development," *JSAE*, April 1922, 231, 235, 241-242; Paul Dempsey, "The Great Transformation. Notes on Early Air-cooled Engine Design ," AEHS, www.enginehistory.org; Smith, *Aircraft Piston Engines*, 99-101; Kimble D. McCutcheon, "Wright J-5 'Whirlwind'," 2, AEHS, www.enginehistory.org.

[37] J. M. Bruce, "The De Haviland D.H. 9," *Flight*, 69, 2463 (April 6, 1956): 386, www.flightglobal.com/pdfarchive; *Flight*, Apr. 3, 1919, 429; Chase, "Modern Aeronautic Engines," 252; Smith, *Aircraft Piston Engines*, 71, 93, 102-103; Marks, *Airplane Engine*, 105-106, 108.

[38] Gibson, "Theories and Practices in the Air Cooling of Engines, Part II," 1155; Smith, *Aircraft Piston Engines*, 68; Paul Dempsey, "Notes on Hispano-Suiza WWI Engine," 2010, AEHS, www.enginehistory.org; Angle, ed. *Airplane Engine Encyclopedia*, 248-257; Angle, ed. *Aerosphere 1939*, 794; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515; Heron, *History of the Aircraft Piston Engine*, 16; C. Fayette Taylor, *Aircraft Propulsion A Review of the Evolution of Aircraft Piston Engine* (Washington: Smithsonian Institution Press, 1971), 34; H. O. C. Isenberg, "Hispano-Suiza Aircraft Engine Production Problems," *SAE Transactions* 13, 2 (1918): 487-490, www.hathitrust.org.

39 Pierer, *Bayerischen Motoren Werke*, 21; Jakobs and Kröschel and Pierer, *BMW Flugbetriebwerke*, 54; Heinz Nowarra, *Die Deutsche Luftrüstung 1933-1945*, 4 vols (Koblenz: Bernard & Graefe Verlag, 1993), 4: 97.

Patent rights: Morrow, *German Air Power in World War I*, 80-81; Morrow, *Great War in the Air*, 224; Neumann, ed. *Deutschen Luftstreitkräfte*, 140-141.

Paul Daimler: Daimler-Motoren-Gesellschaft. *Zum 25 Jährigen Bestehen*, 36, 116, 131; *Erinnerungen*, 37.

40 Dempsey, "Notes on WWI German Superchargers;" Gilles, *Flugmotoren*, 112-114; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 25, 40; W.G. Noack, "Tests of the Daimler IVa Engine at a High Altitude Test Bench," *NACA Technical Note No. 15*, October, 1920, 7-8, 13-16 [trans. *Technische Berichte* 3, 1 (1918): 1-9]; Schwager, "Neuere Bestrebungen und Erfahrungen im Flugmotorenbau," 148; Huth, "Luftfahrzeugmotoren," 157; Sanford Moss, "Superchargers for Airplane Engines," *American Machinist* 53, 1 (Aug. 19, 1920): 345-348; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 159.

41 C. M. White, *The Gotha Summer The German Air Raids on England May to August 1917* (London: Robert Hale, 1986), 112-124; H. A. Jones, *The War in the Air*, vol. 6 (Oxford: Clarendon Press, 1937), 6: 1-2, https://archive.org; Raymond H. Fredette, *The Sky on Fire The First Battle of Britain 1917-1918 and the Birth of the Royal Air Force* (Washington, D. C.: Smithsonian Institution Press, 1976), 57; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 24-27, 103-105, 158-160; Grey, ed. *All the World's Aircraft 1919*, 288a, 299a; Taylor, ed. *Combat Aircraft of the World*, 158-161, 195; Martinot-Lagarde, "Les Moteurs D'Aviation," 141-142; *Aeroplane*, 13, 2 (July 11, 1917): 79.

2. France

Immediately upon the outbreak of the war, on August 4, 1914, the French government seized Daimler and Benz engine patents registered by locomotive and automobile manufacturers located in France. Some of these patents were subsequently assigned by Colonel Edouard Auguste Hirschauer, head of the French war ministry's Direction de l'Aéronautique, to the French automaker Lorraine-Dietrich. This firm, located at Argenteuil in the northern suburbs of Paris, was controlled by an industrial trust and had no pre-war experience in aero-engine production. In the autumn of 1914, automotive engineer Marius Barbarou was hired to begin Lorraine-Dietrich's development and production of aero-engines based on the Daimler and Benz patents. Barbarou, like Max Friz of BMW, had previously been employed at the Daimler Motorenwerke in Stuttgart.[1]

One French automaker that did have pre-war experience in aero-engine development and production was the Renault firm located at Billancourt in the western suburbs of Paris. By 1907, Louis Renault had entered into aero-engine production and Renault himself would continue to lead this effort throughout the pre-war years during which his company also expanded to become France's leading automaker. In early 1909, he visited southern France and witnessed some of the exhibition and training flights being staged by Wilbur Wright at Pau. The pre-war Renault aero-engine developments included both water- and air-cooled engines some of which equipped aircraft which were awarded Michelin aviation prizes for achievements of distance and endurance. An air-cooled, 80 hp Renault V-8 featuring steel cylinders was one of the most widely used aero-engines in the pre-war French army air service and this engine was also licensed to a number of manufacturers in Britain. A pre-war license request made by AEG chairman Walter Rathenau was however rejected.[2]

The relative durability of these early, low-power Renault engines was due in part to the use of a moderate compression ratio. This design feature was necessitated by the engines' poor cooling, a failure resulting from the use of a cast-iron F-head clamped to the cylinder barrel. The interior angles and corners of the F-head hindered the even distribution of the fuel-air mixture within the combustion chamber and constituted points of carbon deposit and over-heating. In turn, these engines' poor cooling also required the use of a rich fuel-air mixture and that blowers be attached to the aft end of the air-cooled types. The use of a built-up cylinder with a separate head attached to the open-ended barrel was, however, a significant development, one which, along with Renault's early efforts to develop aluminum cylinders, influenced the Gibson and Heron development of air-cooled cylinders with separate aluminum head and steel barrel at the Royal Aircaft Factory in Britain during the war. Rolls-Royce would begin its aero-engine production history in 1914 with the licensed production of an air-cooled V-12 Renault.

The propeller of the early Renaults was driven by the camshaft and thus turned at half the speed of the crankshaft which itself ran at a relatively high 1,800 rpm. This reliance on high engine speed to obtain output horsepower was a characteristic of some high-power French aero-engines during and after the war, a practice that may have led to the over-speeding, and over-rating, of some French engines in the inter-war years.[3]

By the beginning of 1915, with the military deadlock on the western front, an understanding in France that the war had become an industrial struggle led to plans to build a large bomber force, part of which was to be directed at German industrial capacity.[4] This planning required the development and production of aero-engines of greater output horsepower. At Renault, French army demands for such engines were initially resisted and it was this resistance that prompted French army air service chief Colonel Édouard Barès to send two members of his staff in early 1915 to Barcelona to consult with Marc Birkigt and the Hispano-Suiza firm.[5] By the latter part of 1915, Renault had in production a water-cooled, 220 hp V-8 engine and in development a similar 280 hp V-12.

The cylinder design of both these engines was dissimilar to the earlier Renault designs and similar to the Porsche cylinder design then in development at Lorraine-Dietrich and in use in aero-engines in Austria and Germany. The Renault steel cylinders measured 4.92 x 5.91 inches (125 x 150 mm), pairs of barrels welded together and sharing a common head, each pair encased by a welded sheet-metal water jacket. The cylinders for the 220 hp V-8 were machined out of a hollow steel forging. Located on the sides of the head, the single inlet and exhaust valves each had a 61 mm diameter, were inclined 14° outward from the cylinder's vertical center line and were operated by an overhead camshaft. Both the V-8 and V-12 engines used aluminum pistons and both normally ran at a moderate speed of 1,550 rpm using a low compression ratio of approximately 4.5:1. These wartime Renaults were direct-drive engines with the propeller coupled to the crankshaft. Compared to the pre-war Renaults, the 280 hp Renault V-12 had a much improved fuel consumption of 0.52 lb/hp/hr. It was the design feature of a spherical combustion chamber in the wartime Renault aero-engines that improved these engines' cooling and fuel efficiency and thereby made possible subsequent increases of compression ratio and output horsepower. In this regard in early 1918, it would be Charles Kettering, one of the American automotive engineers who participated in the wartime development of the Liberty aero-engine, who would remark that "I think the Lord has tolerated this foolishness of throwing away 90 per cent of the power in fuel as long as he intends to, and we must act and help ourselves a little."

With an increase of compression ratio to 5.0:1, the Renault V-12 was put into series production at the end of 1916 as the 300 hp Renault 12Fe, a sturdy aero-engine, running at a moderate speed, built not for maximum output but for reliability. One factor preventing the development of a higher output from this engine was its use of castor oil as a lubricant. It equipped many of the Breguet 14B2 bomber aircraft put into combat service during the war, the Breguet 14B2, featuring an aluminum framework fuselage, being one of the aircraft upon which the French bomber program would be standardized in December, 1917.[7] One of the several wartime manufacturers of the Breguet 14 was Michelin.

The French tire and automotive manufacturer André Michelin was, like Walter Rathenau, a major European industrialist who advocated the use of long range bombing to wage economic warfare. Before the war, Michelin had awarded U.S. aviator Riley E. Scott 150,000 F in prize money for Scott's demonstrations of a bombsight during competitions held in France.[8] In August, 1914, before the stabilization and deadlock on the western front, Michelin had made a proposal to the French government offering to build and donate to the government 100 bomber aircraft. Supported by President Raymond Poincaré, receiving in November a government contract, Michelin entered into joint operations with Louis Breguet to produce a series of bombers with parts and sub-assembly production at the Michelin plant at Clermont-Ferrand in central France and final assembly and testing at the Breguet plant at Velizy-Villacoublay located immediately to the west of Paris, an arrangement that initiated the production of over 1,800 Breguet aircraft by Michelin during the war.[9]

The total wartime Renault output of 13,586 aero-engines made the firm France's leading producer and yet Renault was also France's leading manufacturer of artillery and tanks, the firm supplying most of the tanks used by the American Expeditionary Force (AEF) in 1918. Its production of 5,050 aero-engines in 1918 would account for less than one-third of its total sales for that year.[10] This enormous industrial output and its consequent profits provided the firm with significant political power. When in the spring and summer of 1917, U.S. Army Signals Corps Major William Mitchell objected to terms proposed by Renault to equip the AEF Air Service in France, Mitchell felt it necessary to seek the help of the French under-secretary of state for aviation. In Mitchell's opinion, Renault was capable of exerting an influence in the French parliament comparable to that of the government itself.[11] However, in the post-Dreyfus Affair politics of the French Third Republic, industrial capitalists like Renault and Michelin could also encounter significant opposition, opposition which could find expression not only in the Chambre des Députés but in the French war ministry as well. One such expression was the ministry's wartime preference for using a multiplicity of firms in its aviation procurement programs. While there would be continuing efforts to standardize airplane and aero-engine types, a number of the large-scale, French aviation production programs of the First World War would be characterized by a pervasive use of licensing and subcontracting, referred to as the *système globale*, employing several and in some cases a dozen or more different licensed manufacturers.[12] One prominent feature of this wartime system was the French government's decision to place no maximum limit of production quantity in regards its payments of royalties for airplanes and aero-engines. In the words of French historian Emmanuel Chadeau, a scholar familiar with the history of French public finance, the First World War in France was "*une guerre de luxe*."[13]

By early 1915, Colonel Barès and his staff had organized a force of four bomber groups, having prepared instructions for a bombardment mission that included ground support operations and that also designated industrial and transportation targets. In the spring of 1915, the French army air service began a limited series of daylight, long range bombing raids on German munitions factories located at the Rhine River cities of Freiburg, Mannheim-Ludwigshafen and Karlsruhe, as well as on various German coal, iron, steel and railway facilities located in Luxembourg, the Saar and occupied Lorraine. Single-engine, pusher Voisin 3 biplane bombers, some of which were equipped with pre-war design Renault V-8s of approximately 150 HP, were deployed against the Rhine River targets. Groups of up 60 aircraft were launched from fields near Nancy, located approximately 80 miles west of the Rhine, and from points further south. The under-powered, slow and vulnerable Voisins with their characteristic lattice-frame tail sections, though carrying light bombloads of approximately 115 lbs, were unable to climb to an altitude above the German anti-aircraft fire and they met increasing German fighter resistance. While the aircraft losses on these raids were relatively light, the aircrew casualties were considerable. Conducted as reprisals, these raids into Germany were halted in September 1915, a time of worsening flying conditions, a major French ground offensive in Champagne and the advent of the initial "Fokker scourge" when German fighter aircraft gained a temporary air superiority over Allied aircraft.[14] Throughout this time, discussions were held among officials of the French army, war ministry and aviation industry concerning a large-scale, bomber procurement program.

General Joseph Joffre, the French army commander-in-chief, was in favor of a program largely standardized on Breguet bombers equipped with Renault aero-engines. This Breguet-Renault bomber program was opposed by the war ministry's Col. Hirschauer, the officer who had assigned the Daimler and Benz patents to the Lorraine-Dietrich firm in 1914 and who favored acquisition of German and Italian aero-engine and airplane patents and licenses, as well as the bomber of French designer Paul Schmitt, as the bases of French bomber development and production. Louis Renault's demand in the latter part of 1915 that the French bomber program be standardized on his aero-engines in return for his promise to use production licensees and sub-contractors was rejected by other French manufacturers as well as by the war ministry. Besides government and industry opposition to Renault dominance, one objection raised was that the larger, heavier, more powerful Renault engines were unsuitable for fighter aircraft.[15] Another was the inability in 1915 of any aero-engine, Renault, French or otherwise, to lift a significant bombload and carry it at adequate speed and altitude over a long distance as was then being demonstrated by the Voisin raids on the Rhine. The termination of those raids also coincided with the failure of the French army's offensive in Champagne and consequent criticism in the French parliament. On September 13, 1915, Col. Hirschauer and the war ministry's Direction de l'Aéronautique were replaced by the office of under-secretary of state for military aeronautics, the first of a series of steps increasing parliamentary and ministry control over French wartime avaition and which eventually led to the dismissal of Colonel Barès in March 1917.[16]

Beginning in November 1915, orders for some 700 bombers were issued to a multiplicity of firms including Breguet, Breguet-Michelin, Voisin, Caudron, Schmitt and Caproni. These bombers were to be equipped with a multiplicity of aero-engines including those of Renault, Salmson, Bugatti and possibly Clerget-Blin and Panhard, inadequate engine performance thereby determining not only bombing operations but also bomber aircraft procurement. As characterized by Emmanuel Chadeau, "*L'affaire des bombardiers devenait l'affaire des moteurs*."[17]

In 1915, the French designer Paul Schmitt, backed by André Michelin and President Poincaré, had begun development of a heavy, large-dimension, twin-engine bomber. By 1917, however, Schmitt had acquired an order for 450 single-engine Breguet 14 aircraft and in November, backed by August Belmont, Jr., and a group of Lorraine political and business leaders associated with President Poincaré, Schmitt established Les Ateliers de Constructions Mécaniques et Aéronautiques Paul Schmitt, a firm located at Levellois-Perret in the northwestern industrial suburbs of Paris. Two months after the formation of the new Schmitt firm, and following French army air service commander Colonel Maurice Duval's final decision to standardize French bomber production on the Breguet 14B2 powered by the Renault 12Fe, designer Paul Schmitt sold his portion of Les Ateliers to the other owners, the company going on to produce, along with a number of other licensees including Michelin and Renault, thousands of Breguet 14s.[18]

In 1916, French long range bombing operations were mostly conducted at night and directed at railway and other transportation targets serving German troop movement and supply as well as the foundries of the Saar, Luxembourg and occupied Lorraine, the flaming blast furnaces, busy railroad yards and moonlit rails being readily identifiable on a fair night from reduced altitude. Two major French raids were however conducted in daytime. On June 22, 1916, the Feast of Corpus Christi, a squadron of twin-engine Caudron bombers using air-cooled rotary engines and lead by Captain Henri de Kérillis attacked the city of Karlsruhe on the Rhine River. The resulting deaths of over one hundred civilians was a massacre comparable to that inflicted one year later on London by the first daytime Gotha bomber raid. It was also effective as a reprisal raid in that it temporarily halted similar German bombing raids on French cities for the remainder of 1916. In the inter-war years, de Kérillis, as a parliamentarian and as an author writing under the the name of "Pertinax," would be one of France's leading opponents of the inter-war policy of appeasement vis-a-vis German rearmament and aggression. On October 12, 1916, the heavy losses suffered by a French bomber group during its raid on the Mauser small arms factory located east of the Rhine in Oberndorff caused the French general staff to also call a temporary halt to French daylight bomber group raids in Germany.[19]

Throughout this wartime history of French aero-engines and strategic bombing, Marius Barbarou had continued to lead the Lorraine-Dietrich development of aero-engines based on the Daimler and Benz patents. By March, 1915, a Lorraine aero-engine was undergoing type testing. Like the Porsche 120 hp aero-engine, this early 110 hp Lorraine was a water-cooled, vertical in-line, six cylinder configuration, the cylinder barrel integral with the head which included single inlet and exhaust valves inclined at the sides of the head, the valve ports integral with the head. The pistons were cast-iron. Like the wartime Renault engines, the 120 x 140 mm steel cylinders of this early Lorraine were manufactured in pairs, each pair encased by a common sheet-metal water jacket welded to the cylinders. Using this same cylinder design, Barbarou in 1915 also began development of water-cooled, V-8 engines and by 1917, using an increased cylinder stroke of 170 mm approximate to the early Porsche design, had in development a 250 HP, water-cooled V-8 running at 1,500 rpm.[20] It was this engine, the Lorraine 8B, a sample of which was shipped with spares to the United States in the summer of 1917, that was cited as the basis for the development of the Liberty aero-engine in the famous Vincent-Hall report delivered to a joint meeting of the Aircraft Production Board and the Joint Army Navy Technical Board in Washington, D. C., on May 31, 1917. Described as "the coming motor in Europe," it was the only foreign engine therein cited[21] and as such constitutes another continuation in the direct line of development between the cylinder design of the 1917 Liberty and the 1911 design of Ferdinand Porsche. And in 1917, the Lorraine 8B's principal place in the French wartime aviation procurement program would be to power the Farman F50, a twin-engine bomber, two of which were purchased by the AEF in March, 1918.[22]

Notes

1 Chadeau, *De Blériot à Dassault*, 87, 126; Gérard Hartmann, "Les Moteurs d'Aviation Lorraine," 2003, 1-2, www.hydroretro.net; Brunoff, ed. *L'Aéronautique pendant la Guerre Mondiale*, 631-632; Angle, ed. *Aerosphere 1939*, 472; W. F. Bradley, "The Lorraine-Dietrich Production of Airplane Engines," *Automotive Industries*, 42, 7 (Feb. 12, 1920): 449; Daimler-Motoren-Gesellschaft. *Zum 25 Jährigen Bestehen*, 15, 120-121; Gilles, *Flugmotoren*, 1; Hirschauer: Emmanuel Chadeau, "Le Général Edouard Hirschauer," *RHA* 192 (1993): 115-120.

2 Hartmann, "Les Moteurs d'Aviation Renault," 9, 12; *Aérophile*, Nov. 15, 1908, 462; ibid, March 15, 1911, 121-129; *ZFM* 1, 21 (Nov. 13, 1910): 279; Taulbet, *Eagle*, 28-31; Martinot-Lagarde, "Les Moteurs D'Aviation," 122; Heron, *History of the Aircraft Piston Engine*, 10-12; Dubreil-Villatoux, "L'Aéronautique Militaire dans la Grande Guerre," 17; Morrow, *Great War in Air*, 16.

3 Angle, ed. *Aerosphere 1939*, 643-644; Hartmann, "Les Moteurs d'Aviation Renault," 5-8, 12; *ZFM* 4, 4 (Feb. 22, 1913): 45; ibid, 5, 4 (Feb. 28, 1914): 68; Gunston, *Development of Piston Aero Engines*, 108; Smith, *Aircraft Piston Engines*, 22-23, 39; Martinot-Lagarde, "Les Moteurs D'Aviation," 123; George Genevro, "Air-Cooled Aircraft Engine Cylinders An Evolutionary Odyssey Part 1 - From the Past," AEHS, www.enginehistory.org; Brunoff, ed. *L'Aéronautique pendant la Guerre Mondiale*, 648; Taylor, ed. *Combat Aircraft*, 73. Influence on British: Heron, *History of the Aircraft Piston Engine*, 10-12; Taulbet, *Eagle*, 28-31, 36; Angle, ed. *Airplane Engine Encyclopedia*, 397; www.rolls-royce.com/about/our-story/the-rolls-royce-heritage-trust/articles/aero-engines.aspx;

Over-rating: National Aeronautics and Space Museum, Arthur Nutt Collection [NASM-Nutt], Box 2, File 2, "Comparison of European and American Aircraft Engines, [1935]" 2-3; NASM-Nutt, 2/3, "Report of European Trip October 8 to December 4, 1936," 70-71.

4 François Pernot, "Barès, 1914-1917 ou l'aviation à l'epreuve de la Grand Guerre," *Revue Historique des Armées* [*RHA*] 192 (1993): 4, www.rha.revues.org; *Aérophile*, Jan. 15, 1915, 365, ibid, March 15, 1916, 155; Féquant, "Aviation de chasse et de bombardement de jour," 38-40, 43; Patrick Facon, "Aperçus sur la doctrine d'emploi de l'aéronautique militaire française (1914-1918)," *RHA* 172 (1988): 83-84, www.rha.revues.org; Dubreil-Villatoux, "L'Aéronautique Militaire dans la Grande Guerre," 22; John R. Cuneo, *The Air Weapon 1914-1918* (Harrisburg: Military Service Publishing Co., 1947), 373-374.

5 Pernot, "Barès," 9-10; Paul Dempsey, "Notes on Hispano-Suiza WWI Engine," 2010, AEHS, www.enginehistory.org.

6 Gérard Hartmann, "Les Moteurs d'Aviation Renault," 2009, 13-14, www.hydroretro.net.

7 Angle, ed. *Aerosphere 1939*, 644-645; Hartmann, "Les Moteurs d'Aviation Renault," 14-16; Morrow, *Great War in the Air*, 214; Smith, *Aircraft Piston Engines*, 38-39; Martinot-Lagarde, "Les Moteurs D'Aviation," 130-132, 135; *Aerial Age*, 5, 11 (May 28, 1917): 356; E. H. Sherbondy, "Details of German Aviation Engines," 5, 16 *Aerial Age* (July 2, 1917): 524; Christienne and Lissargue, *History of French Military Aviation*, 150; Gilles, *Flugmotoren*, 80, 129; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 19, 98-99; Robert Neal, *Technical and Operational History Liberty Engine Tanks, Ships and Aircraft 1917-1960* (North Branch, MN: Specialty Press, 2009), 10; NARA, RG 120, M990/6/469, A XXI, Feb. 3, 1918, No. 568, HQ AEF – AGWAR;

Kettering quote: Charles Kettering, "The Future of the Airplane Business," *SAE Transactions* 13, 2 (1918): 368, 370, www.hathitrust.org.

8 Charles Christienne and Pierre Lissargue *A History of French Military Aviation* trans. by Francis Kianka (Washington, D. C.: Smithsonian Institution Press, 1986), 49, 86-87; Mauer, *U.S. Air Service in World War I*, 2: 11-17; Isaac Don Levine, *Mitchell Pioneer of Air Power* (New York: Duell, Sloan and Pearce, 1958), 84; Morrow, *Great War in Air*, 32.

9 Féquant, "Aviation de chasse et de bombardement de jour," 37; Gérard Hartmann, "Les Premiers Appareils Breguet," 2005, 19-20, www.hydroretro.net; Hartmann, "Les Moteurs d'Aviation Renault," 15; *Aérophile*, July 15, 1916, 213; Smith, *Aircraft Piston Engines*, 39; Chadeau, *De Blériot à Dassault*, 126; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 19, 98-99; Taylor, ed. *Combat Aircraft of the World*, 73-74.

Louis Breguet: *Aérophile*, Apr. 1, 1909, 145; Hartmann, "Les Premiers Appareils Breguet," 1-2; Chadeau, *De Blériot à Dassault*, 76; Christienne and Lissargue, *History of French Military Aviation*, 78.

10 Hartmann, "Les Moteurs d'Aviation Renault," 13, 16; J. E. Valluy, *La Première Guerre Mondiale Tome Second 1916-1918* (Paris: Librarie Larousse, 1968), 208; David Beecroft, "Conditions in the Automotive Industry Abroad," *SAE Transactions* 14, 1 (1919): 671, www.hathitrust.org.

11 William Mitchell, *Memoirs of World War I* (New York: Random House, 1960), 101-102.

12 Chadeau, *De Blériot à Dassault*, 49-54, 87, 132-133, 137, 144; Rémy Porte, "Mobilisation industrielle et guerre totale: 1916, année charnière," *Revue Historique des Armées* [*RHA*] 242 (2006), ¶ 23, www.rha.revues.org; Morrow, *Great War in Air*, 31, 55, 209, 368.

13 Chadeau, *De Blériot à Dassault*, 141-143 (quote, 143); NARA, RG 120, M990/6/351, A XXI, Dec. 11, 1917, No. 382, Bolling – CSO.

[14] Marie-Catherine Dubreil, "Le bombardement en 1916 une année charnière," *RHA* 203 (1996): 54-57; Féquant, "Aviation de chasse et de bombardement de jour," 40-43; Martinot-Lagarde, "Les moteurs d'aviation," 132; Christienne and Lissargue, *History of French Military Aviation*, 81-84; Thérèse Krempp, "Le commandant de Rose," *RHA* 245 (2006), 22, www.rha.revues.org; Gérard Hartmann,"La Societé des Moteurs Salmson," 2004, 8-9; www.hydroretro.net; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 20, 99-100; Dubreil-Villatoux, "L'Aéronautique militaire dans la Grande Guerre," 21-22; *Aérophile*, June 15, 1915, 135-137; ibid, Aug. 15, 1915, 174-175; Sept. 15, 1915, 199; Oct. 15, 1915, 220; ibid, Dec. 15, 1915, 272-273; Claude d'Abzac-Ebezy, "*'Une arme à finie la guerre' Pierre-Étienne Flandin ou la victoire par l'aviation*," *RHA* 212 (1998): 105, n. 5; Cuneo, *Air Weapon 1914-1918*, 371-372; *New York Evening World*, Aug. 26, 1915, 2, http://chroniclingamerica.loc.gov; Lee Kennet, *A History of Strategic Bombing* (New York: Charles Scribner's Sons, 1982), 27-28; Hoeppner, *Deutschlands Krieg in der Luft,* 40, 42-43; Mauer Mauer, ed. *The U.S. Air Service in World War I*. 4 vols. U.S. Air Force Historical Study 147 (Washington: Office of Air Force History, 1978), 4: 369-491; Dorand, "L'evolution des avions français pendant la guerre," in Brunoff, ed. *L'Aéronautique pendant la Guerre Mondiale*, 113; Jean Castex and Louis Laspalles and José Larès. *Général Barès: Créateur et inspirateur de l'Aviation* (Paris: Nouvelles Éditions Latines, 1994), 88-90, www.books.google.com.

[15] Chadeau, *De Blériot à Dassault*, 126-129; Dubreil, "Bombardement en 1916," 58-59; *Aérophile*, May 15, 1915, 102. Dorand, "L'evolution des avions français pendant la guerre," 116; Martinot-Lagarde, "Les Moteurs D'Aviation," 130; Morrow, *Great War in Air*, 67.

[16] *Aérophile*, Sept. 15, 1915, 216; ibid, Oct. 15, 1915, 228; Dec. 15, 1915, 292; Pernot, "Barès," 11; Dubreil-Villatoux, "L'Aéronautique militaire dans la Grande Guerre," 31; Christienne and Lissargue, *History of French Military Aviation*, 87-90, 138-139; Gérard Hartmann, "Les Errements de la III[e] République," (2007), 6, www.hydroretro.net; Chadeau, *De Blériot à Dassault*, 121; Morrow, *Great War in Air*, 207.

[17] Chadeau, *De Blériot à Dassault*, 129-130, 143-144 (quote, 129); Pernot, "Barès," 11.

[18] Chadeau, *De Blériot à Dassault*, 100-101, 109-110; Brunoff, ed. *L'Aéronautique pendant la Guerre Mondiale*, 586-589; *Aerial Age*, Dec. 12, 1918, 612-615; Patrick Facon, "1918, ou l'emploi en masse de l'aviation," *RHA* 212 (1998): 90; Gérard Hartmann, "Vers les Sommets Breguet 1919-1939," 1-5, hydoretro.net; *ZFM* 5, 4 (Feb. 28, 1914): 62-63; Christienne and Lissargue, *History of French Military Aviation*, 114-115; Benedict Crowell, *America's Munitions 1917-1918* (Washington: G.P.O., 1919), 242; Belmont: *Aerial Age*, May 7, 1917, 252; *Aviation*, March 28, 1921, 395; NARA, RG 120, M990/7/12, A XXII, June 29, 1917, No. 15, CSO – Bolling; ibid, M990/6/162, A XXI, July 17, 1917, No. 49, Bolling – CSO; ibid, M990/7/35, A XXII, July 15, 1917, AGWAR – Pershing; Elsbeth Freudenthal, *The Aviation Business* (New York: Vanguard Press, 1940), 27; James G. Harbord, *The American Army in France* (Boston: Little, Brown, and Co., 1936), 159; Bernard M. Baruch, *Baruch My Own Story* (New York: Henry Holt and Co., 1957), 166-175; Bascom Timmons, *Portrait of an American Charles G. Dawes* (New York: Henry Holt and Co., 1953), 173.

[19] Dubreil, "Bombardement en 1916," 58-60, 62; Morrow, *Great War in the Air*, 206; Neville Jones, *The Origins of Strategic Bombing* (London: William Kimber, 1973), 111, 113-115; G. K. Williams, *Biplanes and Bombsights*, 13, 56-57.

[20] Hartmann, "Les Moteurs d'Aviation Lorraine," 2, 5-9, 23; Angle, ed. *Aerosphere 1939*, 472; Martinot-Lagarde, "Les Moteurs D'Aviation," 132; Bradley, "The Lorraine-Dietrich Production of Airplane Engines," 449; *SAE Transactions*, 14, 1 (1919), 431, www.hathitrust.org; Gilles, *Flugmotoren*, 81, 130.

[21] Jesse G. Vincent, "The Liberty Aircraft Engine," *SAE Transactions* 14, 1 (1919): 390-393 (quote 390,) www.hathitrust.org; Neal, *Technical and Operational History Liberty Engine*, 36-37; Dickey, *Liberty Engine*, 15; NARA, RG 120, M990/7/6, A XXII, June 27, 1917, No. 6, CSO – Bolling; *Aérophile*, Aug. 1938, XVIII.

[22] Dorand, "L'evolution des avions français pendant la guerre," 115-117; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 193; Taylor, ed. *Combat Aircraft of the World*, 91; Christienne and Lissargue, *History of French Military Aviation*, 133; Vincent, "Liberty Aircraft Engine," 401.

3. United States

As per the Porsche design, the 1917 Liberty featured a separate, water-cooled cylinder with two, large diameter valves (for the Liberty 12A, 2.5 inch or 63 mm) inclined at the sides of the domed cylinder head enclosing a spherical combustion chamber, the head integral with the cylinder barrel. Like the Renault 12Fe, the Rolls-Royce Eagle and the Daimler-Mercedes D IVa, the overhead valves were inclined approximately 14° outward from the cylinder vertical center line. Like the Daimler-Mercedes D III, the head of the Liberty cylinder was slightly bumped to facilitate the use of large diameter valves. Like some of the Porsche and Austro-Daimler cylinders of practically the same dimensions, the 5 x 7 inch (127 x 178 mm) Liberty cylinder used a long stroke and a moderate compression ratio. The Liberty cylinder was of forged steel with welded, forged steel valve ports and welded, sheet metal water jackets, the valve gear driven by an overhead camshaft. Unlike the Daimler-Mercedes, the Liberty used aluminum pistons. And in significant contrast to the Daimler-Mercedes D III, the two spark plugs of the Liberty cylinder were located near the top of the head in a nearly vertical orientation and were enclosed by the camshaft casing,[1] this arrangement indicating the designers may not have fully understood the relation between the spherical combustion chamber and the combustion of the fuel-air mixture.

Ever since its wartime development, the design of the Liberty aero-engine cylinder has been widely identified as having been derived from that of the Lorraine-Dietrich and the Daimler-Mercedes,[2] both of which were derived from the Porsche design. Before the war, a principal export market for Daimler-Mercedes engines was the United States which imported disassembled Daimler-Mercedes automotive and aircraft engines. In 1915, it was a Daimler-Mercedes race car that took first place at the Indianapolis 500.[3] In the autumn of 1917, U.S. Secretary of War Newton Baker publicly stated that the Liberty "amounts practically to an international model" and that the designers of the Liberty had access to "the blueprints and models of the most successful engines the war has produced," blueprints and models which may have included not only those for the Lorraine-Dietrich and Daimler-Mercedes but also those for the Rolls-Royce engines.[4]

According to Jesse Vincent, one of the principal advantages of this cylinder design, and one of the reasons why it was selected for the Liberty, was that it provided "the best possible valve cooling," noting in regards four-valve cylinders such as those used in the Austro-Daimler 380 hp V-12 and the Daimler-Mercedes DIIIa and DIVa, that "four valves are much harder to cool than two and should not be used until the limit is reached with two valves."[5]

Besides the similar-sized cylinders of the Porsche and Lorraine-Dietrich engines, the Liberty's 5 x 7 inch cylinder dimensions had also been previously used in the United States in some Curtiss and Hall-Scott engines. The designers of the Liberty, Jesse G. Vincent, vice president of the Packard Motor Car Company of Detroit, Michigan and Elbert J. Hall, president of the Hall-Scott Motor Company of San Francisco, California, considered this to be the maximum size for reliable performance and thus it was the cylinder size itself that defined the Liberty V-12 as a high-power engine, its 400 hp at 1,650 rpm output greater than any other production aero-engine in combat service at the front in 1918; this with a moderate compression ratio, without over-speeding the engine and without supercharging. As described shortly after the war by U. S. Army Signal Corps Chief Signal Officer Maj. Gen. George O. Squier, the 5 x 7 inch cylinder was "the largest that could be relied upon to give satisfactory service" and that "the fundamental unit of engine design or construction is the cylinder and the evolution of engine power rested mainly with the unit-power capacity of that cylinder which could be taken as reproducing the largest practical size governed by the state of the art at that time."[6]

Aircraft Production Board (APB) chairman Howard E. Coffin, vice-president and chief engineer of the Hudson Motor Car Company of Detroit, agreed with Jesse Vincent that the U.S. should produce a standard aero-engine, a policy that Vincent acknowledged was influenced by the German standardization on the Daimler-Mercedes type.[7] Coffin was a leading advocate of standardization to facilitate mass production in the U.S. automotive and aviation industries and he was also, like Walter Rathenau and André Michelin, a proponent of bombardment aviation.[8]

It was Packard in Detroit that took the lead in the development and testing of the Liberty.[9] Packard's chief of production engineering, O.E. Hunt, initially fabricated the early cylinders by boring out solid steel billets, a practice also initially used at Ford and Lincoln. This procedure, similar to that employed to a greater or lesser extent at Gnôme-Rhône, Renault, Rolls-Royce and Daimler-Mercedes was, at least in retrospect, incredibly costly in terms of time and material.[10] To provide sufficiently large numbers of bomber aircraft to conduct an effective strategic bombing campaign against the industrial centers of western Germany in 1918, the Liberty aero-engine would have to be mass produced which in turn required the mass production of the Liberty's twelve cylinders.

In the summer and fall of 1917 at Detroit, it would be the Ford Motor Company and the Lincoln Motor Company that developed respectively the cylinder forging and machining processes required to achieve this mass production in the United States. At Ford, under the direction of C. Harold Wills, John Findlater and Carl Emde, the process began with a section of 0.25 inch thick, silicon-nickel-molybdenum steel tube beveled at one end. This steel was made in Ford's new, 1,500 pound electric furnace, cast into ingots, formed into bars and then drawn out and rolled into tubing. In a swaging procedure, the tube section was heated and pressed into a die that folded the long side of the bevel over the diameter of the cylinder, leaving a partial opening in the closed end that would become one of the valve portholes. In a second, similar procedure, the tube was re-heated and pressed into a second die which closed the cylinder and formed its spherical head as well as both portholes. These procedures also formed the bumped head with a diameter 10 mm greater than the outside diameter of the barrel. In another procedure, the cylinder was again heated and placed in a bulldozer press to extrude from the cylinder's lower portion what would become the hold-down flange. These procedures thus produced a cylinder with integral head and barrel, one advantage of which was the elimination of the need to precisely locate a separate head when screwed onto the barrel,[11] a requirement presented by the design of the Daimler-Mercedes D IVa.

One member of the Aircraft Production Board, Edward A. Deeds, whose Dayton Engineering Laboratories Co., Inc. (Delco) produced the ignition system for the Liberty, was a business owner and engineering manager who had pre-war experience with German industry. He personally took wooden models of the Liberty cylinder to Detroit to help Ford develop this forging process. Deeds was also familiar with the need for the precision tooling and close dimension tolerances required for the mass production of aero-engines, noting that "In aviation engines, however, the engines have to be made with extreme care and measured with the very best gauges…the maximum and minimum of tolerance…it is a well-known American practice…They get it fairly well in Germany. France has not been successful. England is making progress."[12] In England during the war, Henry Royce designed his aero-engines working not in metric or decimal units but to the nearest 1/32nd of an inch, leaving it to others to prescribe dimension tolerances.[13]

In July, 1917, Deeds notified Ford that the APB planned to place an order for the production of 20,000 Liberty cylinder forgings per month with production to begin in September. One week later, Ford replied that, with the required materials made available, it would be able to produce by the end of the year 1,000 forgings a day. On August 25, at Packard in Detroit, the Liberty 12 successfully completed its 50 hour type test with an average output of 315 hp. In September, Ford contacted its representative in Britain in an unsuccessful effort to procure a captured Daimler-Mercedes aero-engine from the British government.

Howard Coffin's initial idea concerning the manufacture of the Liberty cylinder forging was that it "could be made by any companies accustomed to making 6" shells of which there are many not now busy." But Ford's rapid development of its forging procedure and its famous potential for mass production precluded any *système globale* for the production forgings, all of which would be manufactured by Ford and, at its peak in 1918, this production reached approximately 2,000 forgings a day. To this production, centered on the second and third floors of Building W of its Highland Park plant located near Detroit, Ford devoted approximately 13,000 of its employees and over half a million square feet of factory floor space. With an enormous savings of time, material and cost, Ford had by February, 1919, produced a total of 433,826 cylinder forgings.[14] This was aviation industrial production on a scale comparable with that achieved in this country during the Second World War.[15] As evidenced by the Ford production, the United States during the First World War fully intended to achieve a maximum production of airplanes and aero-engines, that production "pushed to the limit without reference to possible deliveries of material in France," thereby enabling "this country to swamp any assembling facilities England and France could provide."[16]

The German immigrant Carl Emde was in 1918 a Ford employee of twelve years standing and was in charge of Ford tool design, including that for the Liberty cylinder production. An investigative report on the U.S. aviation industry issued shortly before the Armistice by Charles Evans Hughes, former and future U.S. Supreme Court justice and 1916 Republican presidential nominee, referred to Emde by name and suggested that he should have been dismissed from his position at Ford simply on the basis of his national origin. Henry Ford, refusing to bend to the blatant and occasionally violent anti-German hostility that flared up in this country during the First World War, rejected Hughes' argument and pointed out the significant savings in cost to the government directly resulting from Emde's work.[17]

The machining process required to finish Ford's massive cylinder forging output and make the cylinders ready for engine assembly was one of the principal achievements of Henry M. Leland's Lincoln Motor Company, a firm specifically founded in 1917 in Detroit to build the Liberty. As had Henry Crane, Charles Lawrance and other American engineers, Leland had previously visited wartime Europe to gain knowledge and experience in the development and production of aero-engines. As chief engineer at Cadillac, his proposal to build the Liberty in 1917 had been rejected by General Motors' William Durant, possibly in part due to Cadillac's interest in possible production of the British Bhp aero-engine. The multi-million dollar investment required to start Lincoln, most of which was advanced by the U.S. government, and the tremendous effort involved in rapidly entering into mass production of the Liberty[18] would have an important impact upon U.S. industry.

The sheer size of the Liberty and its components as well as their more precise dimensions, greater than those used in most Detroit automobile engines then being produced, demanded a massive output of production tooling of jigs, fixtures, gauges, etc. specific to the Liberty. The decision taken in the fall of 1917 to mass produce the Liberty 12 as a 400 hp engine, perhaps influenced to some extent by the Bolling misson's repeated recommendations at that time of U.S. production of the reportedly 500 hp Bugatti H-16 engine, in turn subsequently required that some of the initial procurement of Liberty production tooling had be replaced.[19] The inevitable delay in procuring all of this equipment meant that "the first several hundred engines were made more or less by hand,"[20] a necessity that may have been related to initial reliability problems when the first Liberty engines produced at Packard went into service in Europe in 1918. This historic procurement in turn was a principal cause of a major expansion of the U.S. machine tool industry, with an increased capacity characterized by the employment of heavier, more complex machine tools and which, except for the boom year of 1929, would not again be fully utilized until the advent of the Second World War.[21] Detroit's wartime production of the Liberty contributed to its post-war production of automobile engines of increased size, power and precision,[22] that increase partially a result of the determination to build the Liberty as a high-power aero-engine, that determination itself largely the result of desires to bomb Berlin and wage a strategic bombing campaign against the industrial centers of western Germany in the last year of the First World War.

Thus it made sense in 1917 to found a new, additional company to build the Liberty, particularly one owned and managed by Henry Leland, a man famed for his achievements in a type of precision manufacturing that employed a pervasive use of machine tools that produced the reliable interchangeability of multiple parts required for mass production. Leland, with his personal history as a young machinist working in the small arms factories of New England during and after the U.S. Civil War, was himself a living link between two of this country's major wars and a personification of the inter-relationship between modern war and mass production.[23]

At the Lincoln Motor Company, the principal difficulties in machining and welding the Ford Liberty cylinder forging were those presented by the cylinder's spherical head. It was initially found that the center of the head was not true with that of the barrel. "The centering was formerly done by scribing the point central with the outside of the dome. A large loss resulted because of the dome not being central with the body, and the bore would not clean up. So this was changed to locate the center by the body of the cylinder." During the boring and finishing operations, the face of the open end of the barrel was used to locate the interior depth of the spherical head as well as its radius. The finished head was of 0.1875 inch thickness, less than half the maximum thickness of the Daimler-Mercedes D IVa forged steel cylinder head. The 5 inch bore of the Liberty was finished by grinding to ± 0.001 inch using Heald rotary cylinder grinders, each grinder capable of finishing 45 cylinders in a nine-hour day. The 0.25 inch thick barrel was finally turned down, save for six, circumferential strengthening ribs, to 0.156 inch, 0.030 inch less than the minimum dimension of the barrel of the Daimler-Mercedes DIVa. The entire machining process at Lincoln reduced the Ford forging from 47 to 11 pounds.[24]

In welding the forged steel valve ports, or "elbows," to the domed head of the Liberty cylinder, the intense heat would distort the dome, a problem that in the production of the Daimler-Mercedes DIVa may have been avoided by the use of a separate head with a greater thickness. Solutions to this problem in the production of the Liberty included the use of butt welding at Ford and Lincoln as well the development at Lincoln of a fixture of three cap screws and a plug. "The top of the plug has the same radius as the top of the dome and was inserted in the center of the head…The ¾-inch capscrew was placed on the underside of the head so when it was tightened it would exert a pressure against the top of the dome." At Nordyke-Marmon in Indianapolis, something of a solution was reached using a combination of arc and acetylene welding. "The dome sunk in arc welding in reciprocal ratio in relation to the amount of expansion that took place when gas welding the balance, thus bringing the dome back to its original size."[25] At Ford, which did not begin series production delivery of the Liberty engine until June, 1918, several months after Packard and Lincoln, this problem was eliminated by welding the valve ports onto the head before the final boring of the cylinder. "By so doing, all cylinder distortion due to the welding was cut out in the finish boring." This Ford procedure may have been one reason why after the war Ford-built Liberty engines acquired a reputation for superior reliability.[26] A Ford-built Liberty, captured by Bolshevik forces during the Russian civil war, was copied as the metric dimension Soviet M-5, the most produced aero-engine in the Soviet Union during the 1920s.[27]

At Lincoln, the two-piece, 16 gauge sheet-metal water jacket was welded onto the cylinder using an arc welding machine developed at Lincoln specifically for this purpose. To keep pace with its machining operations, the Lincoln welding department built a house for twelve generators described as the "the largest equipment of [welding gas] generators in the world."[28]

By the time of the Armistice, Lincoln was producing 850 to 1,000 machined Liberty cylinders a day[29] and the principal contractors, Packard, Lincoln, Ford, General Motors and Nordyke-Marmon, had shipped a total of 13,574 Liberty aero-engines.[30] For its own production of the Liberty, Ford at its Oakland Avenue plant ran 55 hour tests day and night on fifty engine test stands and thereby ran some of its employees to a state of exhausted collapse.[31] In November 1918, Ford alone produced a daily average of 75 Liberty engines, greater than Rolls-Royce's maximum weekly delivery of its Eagle and Falcon aero-engines. By the summer of 1918, the chief of the U.S. War Industries Board's automotive products section estimated that productivity for the Liberty cylinder in the United States had reached 10 man-hours per cylinder while that for the Rolls-Royce aero-engine cylinder was at 150 man-hours,[32] the Rolls-Royce Eagle being the only British-built engine successfully employed by the British for the purpose of strategic bombing in the last year of the First World War.

Notes

[1] Angle, ed. *Aerosphere 1939*, 113-115, 467-468; Angle, ed. *Airplane Engine Encyclopedia*, 312; Marks, *Airplane Engine*, 68; *Aerial Age*, March 3, 1919, 1242; Dickey, *Liberty Engine*, 23-25; J. G. Vincent, "Reasons Behind the Liberty Aviation Engine," *SAE Transactions* 13, 1 (1918): 100, www.hathitrust.org.

[2] NARA, RG 120, M990/1/571, A I 21, E S. Gorrell, "Report on Early Activities," June 13, 1917, Coffin – Kuhn, 14; Mixter and Emmons, *Aircraft Production Facts*, 18; *Technische Berichte*, 2, 3 (1918): 94; Theodore MacFarlane Knappen, *Wings of War* (New York: G.P. Putnam's Sons, 1920), 77-78; Robert Schlaifer and S. D. Heron. *Development of Aircraft Engines and Development of Aviation Fuels*, (Boston: Harvard Univ. Press, 1950), 157; Dickey, *Liberty Engine*, 24; Gunston, *Development of Piston Aero Engines*, 119; Smith, *Aircraft Piston Engines*, 49; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 17.

[3] Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 124, 212.

[4] *Aeroplane*, 13, 16 (Oct. 17, 1917): 1049-1050 (quotes;) *Washington Evening Star*, May 1, 1917, 3, http://chroniclingamerica.loc.gov; Ian Lloyd, *Rolls-Royce The Growth of a Firm* (London: The MacMillan Press Ltd., 1978), 103, 110.

[5] Vincent, "Liberty Aircraft Engine," 408-409 (first quote;) Vincent, "Reasons Behind the Liberty Aviation Engine," 99 (second quote.)

[6] Mixter and Emmons, *Aircraft Production Facts*, 18; Dickey, *Liberty Engine*, 28; George O. Squier, "Details of Liberty Motor Development," *American Machinist* 50, 3 (Jan. 16, 1919): 130 (quotes), www.hathitrust.org.

Vincent: *Aviation*, March 28, 1921, 395; Neal, *Technical and Operational History Liberty Engine*, 5-6.

Squier: *Aviation*, March 28, 1921, 395; Sweetser, *American Air Service*, 37-38.

[7] Vincent, "Reasons Behind the Liberty Aviation Engine," 96; Howard E. Coffin, "Aircraft Industry Needs Standardization," *Aviation,* May 1, 1917, 309; *House Hearings War Expenditures – Aviation, 1919,* 9-10; Robert J. Kothe, "Howard E. Coffin," in *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, ed. George S. May (New York: Bruccoli, Clark, Layman, Inc. 1990), 103-105; Grosvenor B. Clarkson, *Industrial America in the World War The Strategy Behind the Line 1917-1918* (Boston: Hohgton Mifflin Co., 1923), 12-14, www.hathitrust.org; Daimler-Motoren-Gesellschaft, *Zum 25 Jährigen Bestehen*, 110-111.

[8] Holley, *Ideas and Weapons*, 57; Sweetser, *American Air Service*, 76-77.

[9] Neal, *Technical and Operational History Liberty Engine*, 18-21, 43, 48-52, 63, 66, 92-93; Charles K. Hyde, "Packard Motor Car Company," in George S. May, ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, 378; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515.

[10] *JSAE*, Jan. 1918, 8; Vincent, "Liberty Aircraft Engine," 394, 409; Timothy J. O'Callaghan, *The Aviation Legacy of Henry & Edsel Ford* (Ann Arbor: Proctor Publications, LLC, 2000), 163-164; Robinson, "Reminiscences of Mr. H. J. Robinson," 44; *Aerial Age*, 5, 13 (June 11, 1917): 425.

[11] Neal, *Technical and Operational History Liberty Engine*, 64, 107-108; Fred H. Colvin, "Operations on the Liberty Motor Cylinders," *American Machinst* 50, 16 (Apr. 17, 1919): 757-758, www.hathitrust.org; J. G. Vincent, "Reasons Behind the Liberty Aviation Engine," 97-98; Charles E. Lucke, "Steel in Aeroplane Engine Construction," *Aerial Age*, 5, 14 (June 18, 1917): 461; Mixter and Emmons, *Aircraft Production Facts*, 21; Allan Nevins and Frank Ernest Hill. *Ford Expansion and Challenge 1915-1933* (New York: Charles Scribner's Sons, 1957), 66; P. E. Haglund, "The Reminiscences of Mr. P.E. Haglund," 11-12, April 1955, Accession 65, FMCA-OHS, BFRC; Flink, "Mass Production," 324; Squier, "Details of Liberty Motor Development," 131.

[12] Isaac F. Marcosson, *Colonel Deeds Industrial Builder* (New York: Dodd. Mead & Co., 1948), 246-248; Knappen, *Wings of War*, 117; "Hughes and Gregory Reports on Aircraft Investigation," *Aerial Age*, 8, 9 (Nov. 11, 1918): 465-471; U.S. Senate. Hearings. Committee on Military Affairs. Investigation of the War Department. 65th Congress, 2nd Session, Part 6, Jan. 30 – Feb. 2, 1918. Washington: G.P.O., 1918 [*Senate War Department Hearings, 1918*], 2221-2222 (quote.)

[13] Taulbet, *Eagle*, 16.

[14] *Aerial Age*, 5, 23 (Aug. 27, 1917): 864; Neal, *Technical and Operational History Liberty Engine*, 107; Dickey, *Liberty Engine*, 35-36; NARA, RG 120, M990/1/571, A I 21, Gorrell, "Early Activities," June 13, 1917, Coffin – Kuhn, 14 (quote;) Nevins and Hill, *Ford Expansion and Challenge*, 66-68, 80; O'Callaghan, *Aviation Legacy of Henry & Edsel Ford*, 162-163; Timothy J. O'Callaghan, *Ford in the Service of America Mass Production for the Military During the World Wars* (Jefferson, NC: McFarland and Co., Publishers, 2009), 6-7, 11-12, 32.

[15] Irving Brinton Holley, Jr., *Buying Aircraft – Material Procurement for the Army Air Forces* (Washington: Office of the Chief of Military History, 1964), 548-549; "Pratt & Whitney Piston Engine Production," 10-28-2011, AEHS, www.enginehistory.org.

[16] NARA, RG 120, M990/7/27, A XXII, July 22, 1917, No. 45, AGWAR – Pershing (first quote); ibid, M990/7/26, A XXII, July 29, 1917, No. 40, CSO – Bolling (second quote.)

17 Nevins and Hill, *Ford Expansion and Challenge*, 12, 66, 79; *New York Times*, Nov. 1, 1918, 10; Waggoner, "Reminiscences of Mr. J. M. Waggoner," 18; Richard Kroll, "The Reminiscences of Mr. Richard Kroll," 25-27, October 1953, Acc. 65, FMCA-OHS, BFRC, www.oclc.org; U.S. House. Reports. Select Committee on Expenditures in the War Department, Subcommittee No. 1 – Aviation, 66th Congress, 2nd Session, No. 637, Parts 1 and 2 [*House Report 637, 1920*] (Washington: G.P.O. 1921), 1: 119-120; Louis P. Lochner, *Always the Unexpected* (New York: The MacMillan Company, 1956), 73-76; Arthur S. Link, ed. *The Papers of Woodrow Wilson* (Princeton: Princeton Univ. Press, 1984), 48: 171-173; Willa Cather, *One of Ours* (New York: Vintage Classics, 1991), 200-202.

18 Neal, *Technical and Operational History of Liberty Engine*, 47, 62-63, 67, 117-119; Marcosson, *Colonel Deeds*, 248; John B. Rae, "Henry Martyn Leland," in *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, ed. George S. May (New York: Bruccoli, Clark, Layman, Inc. 1990), 302; NARA, RG 120, M990/6/19, A XXI, July 1, 1917, No. 37, Bolling – Coffin; *Aerial Age*, 5, 6 (July 2, 1917): 521; H. J. Robinson, "The Reminiscences of Mr. H. J. Robinson," 33-34, 38, January, 1956, Acc. 65, FMCA-OHS, BFRC; *Aerial Age*, 5, 25 (Sept. 10, 1917): 961.

19 *House Report 637*, *1920*, 2: 27; Nevins and Hill, *Ford Expansion and Challenge*, 67-68; Sweetser, *American Air Service*, 182-183; Neal, *Technical and Operational History of Liberty Engine*, 66, 70, 106; Mixter and Emmons, *Aircraft Production Facts*, 23; Dickey, *Liberty Engine*, 39-40, 92-93; Crowell, *America's Munitions*, 277.

Bugatti: *Aircraft Piston Engines*, 82; Crowell, *America's Munitions*, 289-290; NARA, RG 120, M990/6/179, A XXI, Aug. 7, 1917, No. 78, Bolling – AGWAR; ibid, M990/6/179, A XXI, Sept. 5, 1917, No. 139, Bolling – AGWAR; ibid, M990/6/232, A XXI, Sept. 12, 1917, No. 3, Bolling – CSO; ibid, M990/6/251, A XXI, Sept. 30, 1917, No. 192, Bolling – AGWAR; M990/6/255-256, A XXI, Oct. 5, 1917, No. 240, Bolling – AGWAR; ibid, M990/6/556, A XXI, March 11, 1918, No. 713, GHQ AEF – AGWAR ; ibid, M990/11/1209, B XIV 3, E. L. Gros, "History of Air Service Liaison Section," 1.

20 Vincent, "Liberty Aircraft Engine," 397 (quote.)

21 *American Machinist* 49, 24 (Dec. 12, 1918): 1094; Edwin G. Nourse, *America's Capacity to Produce* (Washington, D. C.: The Brookings Institution, 1934), 278-280, 303, 566; Harless Wagoner, *The Machine Tool Industry from 1900 to 1950* (Cambridge: The M.I.T. Press, 1966), 37-39, 111, 151; Cristiano Andrea Ristuccia and J. Adam Tooze, "The Cutting Edge of Modernity: Machine Tools in the United States and Germany 1930-1945," CWPE 0342, September 2003, 18-21, www.econ.cam.ac.uk/research/repec/cam/pdf/cwpe0342.pdf.

22 H. A. Carhart, "Operations on the Liberty Motor Cylinders, II," *American Machinist* 50, 21 (May 22, 1919): 985; Henry M. Crane, "Possible Effect of Aircraft Engine Development on Automobile Practice," *SAE Transactions* 14, 1 (1919): 144; O. E. Hunt, "Probable Effect on Automobile Design of Experience with War Airplanes," *SAE Transactions* 14, 1 (1919): 161; Howard Marmon, "A Comparison of Airplane and Automobile Engines," *SAE Transactions* 14, 1 (1919): 149; Robinson, "Reminiscences of Mr. H. J. Robinson," 43.

23 Alfred P. Sloan, Jr. *My Years with General Motors*, eds. John McDonald and Catharine Stevens (Garden City: Doubleday & Co., 1963), 20-21; Nevins and Hill, *Ford Expansion and Challenge*, 173-174; Rae, "Henry Martyn Leland," 296; *Fortune*, Apr. 1940, 74; Holley, *Buying Aircraft*, 234-235.

24 Carhart, "Operations on the Liberty Motor Cylinders, II," 985-987 (quote 985); H. A. Carhart, "Finishing Operations on Liberty Motor Cylinders," *American Machinist* 50, 25 (June 19, 1919): 1200; Marks, *Airplane Engine*, 124.

25 H. A. Carhart, "Welding Operations on Liberty Motor Cylinders," *American Machinist* 50, 22 (May 29, 1919): 1019-1025 (quote 1023); Harold Hicks, "The Reminiscences of Mr. Harold Hicks," July 1952, 2-3, Acc. 65, FMAC- OHS, BFRC.

26 Fred H. Colvin, "How Ford Built Liberty Motors," *American Machinist* 51, 23 (Dec. 18, 1919): 1037 (quote); Smith, *Aircraft Piston Engines*, 50; O'Callaghan, *Aviation Legacy of Henry & Edsel Ford*, 4; *House War Expenditures Hearings – Aviation, 1919*, 202.

27 Victor Kotelnikov, *Russian Piston Aero Engines* (Ramsbury: Crowood Press, 2005), 49-52, 219, 241; Neal, *Technical and Operational History of Liberty Engine*, 369-370, 394-406.

28 Carhart, "Welding Operations on Liberty Motor Cylinders," 1021 (quote.)

29 Carhart, "Operations on the Liberty Motor Cylinders, II," 985; Rae, "Henry Martyn Leland," 303.

30 U.S. House. Hearings. Select Committee on Expendiures in the War Department, Subcommittee No.1 (Aviation), 66th Congress, 1st Session, Serial 2, Voume I [*House War Expenditures Hearings – Aviation, 1919*] (Washington, D. C.: G. P. O., 1919), 504, www.books.google.com.

31 Mrs. Victor J. Perrini, "The Reminiscences of Mrs. Victor J. Perrini," October 1956, 2-4, Acc. 65, FMCA-OHS, BFRC.

32 Nevins and Hill, *Ford Expansion and Challenge*, 68; Lloyd, *Rolls-Royce Growth of a Firm*, 115, 119; *JSAE*, 2, 6 (June 1918): 395; Morrow, *Great War in Air*, 328.

4. Britain

The British failure to bring a serviceable, high-power aero-engine to a state of mass production in 1918 was one of the most significant national failures of the 20th Century, particularly in regards the fact that it would ultimately prove to be an edifying failure; for as such, it would subsequently guide the development and production of the Rolls-Royce aero-engines that a generation later would prove to be a vital part of the narrow margin of British victory.[1]

The successful British employment of the de Havilland DH-4 as a day bomber for both tactical and strategic bombing during the First World War was due in no small part to the success of its Rolls-Royce Eagle aero-engine. Rolls-Royce had done some aero-engine development work for the Royal Aircraft Factory before the war had begun but it was not until August 1914 that Henry Royce, separated from the main production plant at Derby, began his design work on a water-cooled V-12 aero-engine. Development and production of Royce's engine continued under the auspices of the British Admiralty which placed a first order for what became the Eagle in January, 1915. This original procurement was for the purpose of equipping the twin-engine Handley Page 0/100 bomber. By March, a prototype Eagle was testing at 225 hp. Royce's design featured sub-assemblies to facilitate wartime maintenance and repair but the Eagle and other Rolls-Royce aero-engines continued to be produced according the company's hand-work methods,[2] methods which not only precluded parts inter-changeability and mass production but also would have hindered the licensed production of Rolls-Royce aero-engines by other manufacturers.

This situation was not dissimilar to that of Daimler-Mercedes in relation to the wartime production of German aero-engines and its benefits and detriments were matters publicly acknowledged in Britain by the summer of 1917, by which time the Eagle-equipped de Havilland DH-4 was in service at the British front as a day bomber. In contrast to the *système globale* adopted in France, the British government would persist until 1917 in a general policy of issuing each major aero-engine production order to just one manufacturer.[3] In 1916, 43% of British aero-engine procurement would consist of French aero-engines built in France or Britain.[4] And the efforts in 1917 of the British Air Board to select serviceable, high-power engines designed for mass production to supplement the production of the Rolls-Royce engines would prove to be a catastrophic failure, the Siddeley-Deasy Puma, the A.B.C. Dragonfly and the Sunbeam Arab all proving in the course of the last two years of the war to be unsuitable as service aero-engines.

The Puma had been developed in 1916-1917 from the B.H.P. design, a water-cooled, in-line, six cylinder, 200 hp engine with closed-end, threaded steel cylinders screwed into an aluminum monoblock. Throughout the war and afterwards the Puma would continue to be commonly be referred to as "the B.H.P." Two of the three designers of the original B.H.P, William Beardmore and T. C. Pullinger, had been British licensees of Ferdinand Porsche's Austro-Daimler aero-engines prior to the war. Prototypes of the B.H.P. and the de Havilland DH-4 day bomber made their first flight test in April 1916. In March, 1917, a large production order for the B.H.P. was placed by the British Air Board with Siddeley-Deasy, a firm located in Coventry. In July, the Air Board recommended U.S. production of the B.H.P., asserting "that if United States considers B H P too difficult to build in the United States then every war engine in Europe is too difficult for United States to build as B H P is simplest of all."

The principal modifications to this engine at Siddeley were the use of open-ended cylinder barrels in a twin-block configuration. Though the DH-4 day bomber had been designed around the B.H.P., Siddeley's failure to adapt its development of the Puma to the DH-4 would result in that aircraft continuing to be principally equipped by the Rolls-Royce Eagle. The Puma weighed nearly 240 pounds less than the geared, 12 cylinder Eagle and, with its lighter weight, lower engine speed and longer piston stroke, it was subsequently intended that as a more fuel-efficient engine the Puma would provide the de Havilland DH-9 day bomber with an increased range. However, problems in the development of aluminum casting technique, possibly related to the underdeveloped state of Britain's pre-war aluminum industry, would cause months of delay in the engine's production in 1917. And basic to the engine's eventual failure to achieve improved fuel-efficiency was the engine's design which would ultimately prove to be fundamentally flawed.

The aluminum block into which the threaded, upper portion of the Puma's steel cylinder barrel was screwed provided a flat cylinder head. These were three-valve cylinders, two exhaust and one inlet, all in vertical position. The middle sections of the three steel barrels extending below each block were separately encased by a cast aluminum water jacket bolted to a flange on the lower side of the block, thus leaving exposed and un-cooled the lower section of the barrels above the crankcase. This hybrid design, combining features of separate-cylinder and cast-block aero-engines, failed to provide, in the course of high-power, combat operations, adequate cylinder cooling. The Puma would be de-rated from 300 to 230 hp at 1,400 rpm before it was put into large-scale production, the first test flight of a DH-9 with a production Puma taking place in November, 1917, two months after members of the Bolling mission had recommended large-scale production of the DH-9 equipped with the Liberty aero-engine in the United States. The British produced thousands of Puma aero-engines during the war and this engine was continued in production after the war within an increased output of 250 hp at 1,800 rpm. Continued cooling deficiencies were addressed by recourse to the British penchant for solving a problem by laying a piece of pipe, an aluminum tube being inserted within the water jackets to direct "comparatively cool water on to the hottest places."[5]

The air-cooled A.B.C. Dragonfly used a cylinder similar to that of the Gnôme and other rotary aero-engines. The Dragonfly cylinder was machined, like the Gnôme, out of a solid, forged steel billet, the head integral with the barrel, the barrel featuring integral, circumferential, horizontal cooling fins. This was a three-valve cylinder with its vertical, twin exhaust valves and its vertical, single inlet valve arranged respectively fore-and-aft, the valve ports bolted onto the top of the cylinder head. However, the Dragonfly was built as a fixed radial aero-engine, its nine cylinders thereby deprived of the rotary motion of the Gnôme and other such engines which was the principal means of cooling the cylinders. A coating of copper on the fins of the Dragonfly cylinder to improve cooling proved ineffective. Like the pre-war Renaults, the Dragonfly was a low compression engine dependent upon a high fuel consumption, rich fuel mixture and frequent replacement of burnt out exhaust valves to achieve an occasionally satisfactory performance. Designed in 1917 to deliver 300 hp, then the development standard for a high-power aero-engine in service at the front, serial production did not begin until after the Armistice by which time a considerable part of the British aero-engine production capacity, including Walton Motors and some of the Vickers plant, had been assigned to the planned manufacture of some 12,000 of these engines.[6] And unlike the failure to bring the Rolls-Royce engines to a state of mass production, this failure of the Dragonfly would not subsequently prove to be similarly instructive. Beginning in the 1920s, the British development of high-power, air-cooled, fixed radial aero-engines would be characterized by on-going difficulties in cooling the cylinder, difficulties directly resulting from the failure to use large diameter, single inlet and exhaust valves and a spherical combustion chamber in the development of such engines. The failure to recognize the advantages of this design, one that was significantly developed in Britain by Gibson, Heron and others during and after the war, would lead Bristol, Britain's leading manufacturer of air-cooled, radial aero-engines, to adopt in the inter-war years the sleeve-valve cylinder. As late as 1931, Roy Fedden, chief engineer at Bristol, would inquire, "How is it possible for the large, air-cooled engines of 1760 cubic inches and above, when geared and supercharged, to get away with a single inlet and exhaust valve?...For this type of engine, we have found that four valves are essential."[7]

The Sunbeam Arab was the work of Louis Coatalen, the racing car designer who had joined the Sunbeam Motor Car Co., Ltd. in 1909. An automaker located at Wolverhampton in the British Midlands northwest of Birmingham and Coventry, Sunbeam began aero-engine work in 1912 and a number of water-cooled, vertical in-line, V- and W-types using cast-iron cylinders were produced before and during the war, some of which equipped some of Igor Sikorsky's Ilya Muromets four-engine bombers in Russia. Coatalen's response in 1917 to the war's demand for aero-engines of increased output horsepower and reduced weight was the Arab, a water-cooled, 90° V-8, aluminum cast-block engine with cylinders of precisely the same dimensions as the 150 and 220 hp Hispano-Suizas. In distinction to the Hispano, however, the Arab used an open-ended cylinder barrel that was pressed, not screwed, into the aluminum block. The Arab's cylinders used twin, 33 mm diameter exhaust valves and a single inlet valve inclined slightly from the cylinder vertical center line. The combustion chamber was slightly convex. Coatalen applied the principles of race car engines to his development of the Arab, Sunbeam's first aluminum cast-block aero-engine, initially using a high, 6.0:1 compression ratio and high engine speed of 2,000 rpm to achieve an output of 220 hp on the geared version of the Arab. In contrast, the engine speed of the geared Hispano-Suiza, an engine that used single inlet and exhaust valves, was increased to 220 hp at 2,000 rpm only after two years of development and production at which time it used a 5.3:1 compression ratio.[8]

In March, 1917, Sunbeam received a large production order for the Arab from the British government and, by April 10, four days after the U. S. declaration of war, Sunbeam had responded to a U. S. government inquiry concerning the procurement of one thousand Arab engines with a demand for $7 million. By the beginning of May, however, Arab development was experiencing cylinder and crankshaft failures and on May 2 the president of the British Air Board recommended that the Arab be replaced by the Hispano-Suiza in the British procurement program. This recommendation was rejected by Percy Martin, a member of the Air Board who was also controller of petrol engine supply in the aeronautical department of the Munitions Ministry. In mid-May, an Arab engine completed a 100 hour type test. On May 18 the British Air Board met with U. S. military and naval air attachés in London and later in May the Air Board recommended U. S. procurement of Sunbeam, Rolls-Royce and Hispano-Suiza aero-engines. No Sunbeam engine, however, was included in the U.S. aviation program, an omission subsequently endorsed by Colonel Bolling. On June 27, the day after the Bolling mission arrived at Liverpool, the British Ministry of Munitions announced in the House of Commons that "The production of all internal combustion engines is now under the direction of Mr. Martin." Martin was an American electrical engineer who before joining the Ministry had been a director of the Birmingham Small Arms Company and managing director of the Daimler Co., Ltd., the prestigious British automaker which before the war had separated from the Daimler Motorenwerke in Stuttgart.[9]

March 1917 orders for British production of thousands of Sunbeam Arabs included production at Austin, Napier and Lanchester and thus employed, like the orders for the A.B.C. Dragonfly, a significant share of the British wartime aero-engine production capacity, but by the end of the year less than 100 Arab engines had been delivered. Continued problems in successfully casting the aluminum blocks, a problem in common with the development of the Siddeley-Deasy Puma, may have been exasperated by crankshaft torsional vibration problems. In addition, there may also have difficulties presented, given the different coefficients of heat expansion of aluminum and steel, by the use of a cylinder barrel pressed into the aluminum block, a problem attenuated in the Hispano-Suiza by the use of a steel barrel, finely threaded over nearly its entire length, screwed into the aluminum block. The skilled labor, tooling and materials needed to fulfill the requirements of metallurgy and machining involved in such a threading procedure may not have been commonly available in wartime Britain, the British aluminum industry then being less developed than that of France.[10] By the beginning of 1918, hundreds of Bristol and S. E. 5 aircraft scheduled to equip front-line British pursuit squadrons had had their production or delivery delayed due to a lack of British-built Sunbeam Arab and Hispano-Suiza engines.[11] By August 1918, with the British army beginning its final offensive in France, over 4,000 British aircraft were in storage due to a lack of aero-engines.[12] When in October 1918, thirty S. E. 5s flown from Britain by U. S. aircrew arrived at the AEF Air Service's Orly acceptance field located near Paris, they were equipped with U.S.-built, Wright-Martin 180 hp Hispano-Suiza aero-engines.[13]

In the United States, Willys, the owner of the Curtiss Aeroplane and Motor Corporation, was also engaged in Sunbeam Arab parts production for one thousand engines with assembly at the Willys subsidiary in Canada for delivery to the British Air

Board. Willys offered to build this engine for the U.S. aviation program at its plant in Toledo, Ohio.[14] At the Sterling Motor Company, a marine engine manufacturer located at Buffalo, New York, an order was also placed for a 320 hp Sunbeam V-12 aero-engine. This geared engine's cast-iron, four-valve cylinders were cast in blocks of three and used a 6.0:1 compression ratio. The engine weighed over half a ton. Production was not successful. An associate of the Sterling company, Arthur Homer, was also a wartime business associate of U. S. Assistant Secretary of the Navy Franklin Roosevelt who twice during the war sent Homer to England to collect information concerning aero-engines.[15]

Throughout this collapse of the British aero-engine development program, Rolls-Royce had continued to develop and produce its Eagle and Falcon engines. Henry Royce's cylinder design for these engines was copied directly from that of the Daimler-Mercedes pre-war DF 80. Daimler's registered patents in Britain included that for the DF 80's cylinder and from the beginning of his design work Royce sought to avoid infringement of that patent. In the summer of 1917, the Rolls-Royce board went so far as to petition a British court to have the Daimler cylinder patent revoked. This petition was submitted on June 12, the day before the first daylight Gotha bomber raid on London. By July 26, a few weeks after the second daylight raid on London, the patent had been revoked, with court costs being assigned to the Daimler Motorenwerke of Stuttgart, Germany.[16]

The Rolls-Royce Eagle Mark VIII, like the Liberty, featured a water-cooled, V-12 configuration with separate steel cylinders encased by welded sheet-metal water jackets, an aluminum crankcase and aluminum pistons, a 6-throw, 7-bearing crankshaft, two valve ports welded to the sides of the domed cylinder head, and valve gear operated by an overhead camshaft. The cylinders of both the Eagle and Liberty, as per Ferdinand Porsche's design of 1911, featured an integral head and barrel and a spherical combustion chamber with large diameter, similarly inclined, single exhaust and inlet valves. The Eagle's cylinder weighed 11.5 pounds, almost precisely the same as the Liberty's larger cylinder. The Eagle, unlike the Liberty, the Daimler-Mercedes and Henry Royce's automobile engine of 1914, did not feature a bumped cylinder head. Though the overall dimensions of the two engines were about the same, the Eagle's smaller cylinder provided a total displacement that was just three-quarters that of the Liberty. With its reduction gear, the Eagle Mark VIII was approximately 60 pounds heavier than the direct-drive Liberty. The Eagle delivered a normal 360 hp at 1,800 rpm with a fuel efficiency equivalent to that of the Liberty. One advantage that the Liberty had over the Eagle was its use of a mixture petroleum oil and castor oil, as opposed to the Eagle's reliance on castor oil, in the lubrication system.

Royce's initial use of aluminum pistons was the result of a recommendation made in the summer of 1915 by Walter Bentley who had noted their use in a French racing automobile engine. The alloy used in the French pistons included a 12% copper content. By the fall of 1917, however, the pistons used in the Eagle Mark VIII were described in Rolls-Royce specifications as being Mercedes Gotha pistons and were made of 7% copper duralumin. This Rolls-Royce development and that of Hispano-Suiza would in turn influence the subsequent development of aluminum pistons in wartime Germany.[17]

Royce's principal alteration of the DF 80 cylinder design was to place the two spark plugs midway up the domed head. He believed that by so doing the time between spark and maximum pressure, as well as any tendency to detonation, would be reduced.[18] As in the Liberty cylinder with its vertical spark plugs located near the crown of the head, this design feature of the Eagle may indicate some lack of understanding of the relation between the geometry of the spherical combustion chamber and a complete, efficient combustion of the fuel-air mixture.

It would be the use of different production methods that would be the most significant difference between the Eagle and the Liberty. The Eagle cylinders were made out of "Tyre Steel," a metal used in locomotive wheels. While Rolls-Royce did engage in some wartime artillery shell production at its Derby factory, this production used low carbon steel and the company lacked the capability of producing forged steel tube. While in 1918, Rolls-Royce "was given the highest priority for materials and plant" and a number of producers, including the National Shell Factory in Derby, were brought in to assist the Rolls-Royce production, including that of cylinders, the 1918 production of Rolls-Royce aero-engines never exceeded more than one-third of its planned weekly rate. Each cylinder of the approximately 3,000 12-cylinder Eagle aero-engines produced during the war would be machined out of a solid, six inch diameter billet of the Tyre Steel, four and a half inches of which had to be removed by drilling, boring and interior grinding procedures, the resultant barrel turned down to a 0.125-inch thickness. The British term for chips is "swarf."[19]

This critical limitation, combined with Henry Royce's practice of designing a multiplicity of finely engineered parts, would prevent the Eagle from being put into large scale production during the First World War, a factor that was recognized in wartime Germany. As described by Jesse Vincent, the Eagle was "composed of a great many intricate parts, which would be very hard to manufacture in quantity under American production conditions…Many of the important forgings would have to be made much better than had been our practice in this country." As described by Newton Baker shortly after the war, "The Rolls-Royce is a hand-made engine, and you have to have very skilled mechanics to do that handwork. But even the British were not able to make them and that is the reason they wanted our Liberty motors."[20]

The rapid development of the Liberty in Detroit in the summer of 1917 was simultaneous with negotiations in Washington between the APB and Rolls-Royce concerning Rolls-Royce aero-engine production in the United States. The terms demanded by Rolls-Royce in the course of these talks were extraordinary and as such were similar to demands made by the firm of the British government during the war. This latter fact was noted by Major Bolling when he arrived in Britain on June 26, reporting that the British government agreed that the sharing of manufacturing rights should be handled on a government-to-government basis. "I think they feel it will strengthen them in dealing with their own manufacturers who evidently give them some trouble especially Rolls Royce" and that "Matter payments for British rights has very important industrial political and diplomatic aspects. Question much larger than first appears." On July 1, Bolling cabled, "Big British air programme contemplates only ten percent of big engines Rolls Royce simply because they consider no more can be produced…Air Board and ourselves recommend that you do not include Rolls Royce in our programme quantity production but that Rolls Royce be encouraged conclude their negotiations with Pierce Arrow…All agree Rolls Royce people most difficult to deal with. Reported here Duke American Tobacco chief owner Rolls Royce. Advise enquiry." On August 8, Bolling cabled "Strike Rolls Royce off Joint Technical Board Report…difficulties of manufacturing and maintenance in field." The successful completion of the Liberty 12's 50-hour type test in Detroit on August 25 coincided with the APB's termination of its talks with Rolls-Royce. Subsequent wartime Rolls-Royce aero-engine parts production in the United States did not result in any Rolls-Royce aero-engine being delivered to the British government prior to the Armistice.

Thus, similar to the Hispano-Suiza company's earlier reliance on Wright-Martin in New Jersey to fulfill much of its initial French government order for several hundred aero-engines, by January 1918, with the decisive battles of the First World War quickly approaching, the British would find themselves with the Rolls-Royce Eagle as their sole, serviceable, high-power aero-engine in production and with procurement plans for the Eagle relying on the United States to provide over half the Eagles then on order. In October 1917, before it had had its first test flight equipping a U.S.-built DH-4, the British government inquired about procurement of a half dozen Liberty 12 engines. In December, when serial production at Packard was just getting underway, General Pershing cabled the U.S. Army Signal Corps, inquiring if it could supply to the British thousands of Liberty 12s. In early January 1918, British Munitions Minister Winston Churchill informed Rolls-Royce that if the Liberty production proved successful, there would then be less need for the Eagle. On January 23, 1918, the British notified the U.S. government of a definite intention to place an order for 3,000 Liberty aero-engines "on the supply of which Britain came to place great reliance for her programme of bombing squadrons for the offensive against German industrial centers."[21]

This need and willingness of the British authorities to circumvent the Rolls-Royce Co., Ltd., was similar to the situations of Renault in France and Daimler-Mercedes in Germany as described above. In all three instances, the leaders of military aviation went around the largest producer of aero-engines in their respective countries, none of the manufacturers having agreed to the licensed production of their engines, to seek out alternative sources of additional or superior supply.

In the summer of 1919, the U.S. House of Representatives held a series of hearings on wartime government expenditures. Newton Baker, giving testimony before a subcommittee looking into the expenditures for aviation, was interrogated by Representative James A. Frear (R.-Wisconsin.) Frear, relying almost entirely on the records of the previous year's U.S. Senate committee hearings on aircraft production chaired by Senator Thomas, repeatedly questioned the Secretary of War as to the use of the DH-4 as a bomber, concerning which Mr. Frear may have gained some understanding as he wandered in and out of the laser light of Newton Baker's intelligence:

> Mr. Frear. Maj. Muhlenberg was before the Thomas committee, and he was a man, like Arnold, of some understanding of aviation matters because he had charge of the testing department at Wright Field. He testified:
>
> The de Havilland is by no means the machine we want for a fighter, nor the machine we want for a bomber. It may be all right for reconnaissance or artillery observation, but certainly not as a fighter or bomber.
>
> Then he gives a number of observations, to the Thomas committee but that was his objection at the time.
>
> Secretary Baker. Yes, sir.
>
> Mr. Frear. He speaks of the matter brought up a little while ago, as to the defects in ceiling, 15,000 feet, and says it should be greater. Consequently it gives only a very brief time to be in service as a bombing plane.
>
> Secretary Baker. Not as a bombing plane.
>
> Mr. Fear. As a bombing plane?
>
> Secretary Baker. As a fighting plane I do not think it –
>
> Mr. Frear. (interposing) For bombing purposes they had to rise for a period of three-quarters of an hour, which took up too much time.
>
> Secretary Baker. Yes, that would be bad from that point of view.
>
> Mr. Frear. Then he speaks of the pilot and the observer being too far apart. Then he mentions this fact, which, of course, I suppose must have been brought to Gen. Squier's attention, that there were structural defects showing it was not strong enough for its load, as it was a heavier machine, and why it interfered with the use of the de Havilland over there.
>
> Secretary Baker. The Liberty motor was not heavier.
>
> Mr. Frear. I thought it was. All through the Thomas hearings it was shown that that was the case as I understood.
>
> Secretary Baker. It may be, but I do not think so. I think the Liberty motor is the lightest engine for its horsepower that there is.
>
> Mr. Frear. Will you have that put in the record?
>
> Secretary Baker. Ask Gen. Squier about it, but I have never understood the contrary. But we could not get the Rolls-Royce.
>
> Mr. Frear. Couldn't you have manufactured them?
>
> Secretary Baker. The Rolls-Royce is a hand-made engine, and you have to have very skilled mechanics to do that handwork. But even the British were not able to make them and that is the reason they wanted our Liberty motors.
>
> Mr. Frear. What could a de Havilland plane with a Liberty motor be used for?
>
> Secretary Baker. For bombing purposes.
>
> Mr. Frear. Of what practical use was it if it took 48 minutes to go to the ceiling?
>
> Secretary Baker. I agree with you that that is a limitation on its use. As to Maj. Muhlenberg suggesting the Rolls-Royce, as he did, I will say that England had her storage spaces stacked up to the ceiling with planes because she could not make engines for them.[22]

Notes

[1] Sebastian Ritchie, *Industry and Air Power* (Portland: Frank Cass, 1997), 113-140; Schlaifer and Heron, *Development of Aircraft Engines*, 200-237; Anthony Furse, *Wilfried Freeman* (Staplehurst: Spellmount, 2000), 64-66; H. Montgomery Hyde, *British Air Policy Between the Wars 1918-1939* (London: Heinemann, 1976), 367-370; Derek Wood and Derek Dempster, *The Narrow Margin The Battle of Britain and the Rise of Air Power 1930-1940* (New York: McGraw-Hill Publishing Co., 1961), 84-85, 96-97, 204; C. P. Snow, review of A.L. Rowse, *Appeasement*, in *New York Times Book Review*, Dec. 24, 1961, 3.

[2] Taulbet, *Eagle*, 14, 23, 26, 38-39, 124, 162, 169, 187; Lloyd, *Rolls-Royce Growth of a Firm*, 33, 51-52, 68, 118, 151-153; www.rolls-royce.com/about/our-story/the-rolls-royce-heritage-trust/articles/aero-engines.aspx; Smith, *Aircraft Piston Engines*, 31-33; Angle, ed. *Airplane Engine Encyclopedia*, 669; *Aerial Age*, 5, 16 (July 2, 1917): 524.

[3] *Aeroplane*, 13, 4 (July 25, 1917): 266, 268; ibid, 13, 9 (Aug. 29, 1917): 563.

[4] *History of the Ministry of Munitions*, 12: 42-43, 54; Kevin D. Stubbs, *Race to the Front The Materiel Foundations of Coalition Strategy in the Great War* (Westport: Praeger, 2002), 313; Morrow, *Great War in Air*, 44-45.

[5] Bruce, "D.H. 9," 386-389, 392, 422; Angle, ed. *Airplane Engine Encyclopedia*, 131, 448-452; Marks, *Airplane Engine*, 11-12, 105-106, 123, 128 (second quote, 106); *History of Ministry of Munitions*, 12: 23, 77; Jones, *War in the Air*, 6: 38; Smith, *Aircraft Piston Engines*, 71, 93; Gilles, *Flugmotoren*, 85; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 513, 515; *Aerial Age*, 5, 17 (July 8, 1917): 525; *Flight*, Apr. 3, 1919, 429, www.flightglobal.pdfarchive.com; Grey, ed. *All the World's Aircraft 1919*, 43b; NARA, RG 120, M990/6/154-155, A XXI, July 16, 1917, No. 44, Bolling – AGWAR (first quote, 154.)

[6] Smith, *Aircraft Piston Engines*, 100-101; Angle, ed. *Airplane Engine Encyclopedia*, 8-10; Gunston, *Development of Piston Aero Engines*, 123; "Report on Tests of A. B. C. 'Dragonfly' Cylinder," *Air Service Information Circular* 3, 265 (July 21, 1921): 1-6, Robert A. Neal, AEHS, www.enginehistory.org; Morrow, *Great War in the Air*, 254; Jones, *War in the Air*, 6: 43-44; Grey, ed. *All the World's Aircraft 1919*, 7b-8b; Gilles, *Flugmotoren*, 139-140.

[7] NARA, RG 342, RD 1715, Box 8255, R. Chilton – G.W. Vaughn, Oct. 15, 1931, "Report on Trip to European Engine Plants", 2-13; NASM, John Jay Ide Papers [NASM-Ide], Box 1, File 9, Ide - George Lewis, March 25, 1931, 2 (quote); *Aviation*, Oct. 1933, 321-323; Smith, *Aircraft Piston Engines*, 69.

[8] Angle, ed, *Aerosphere 1939*, 731-732; Dempsey, "Notes on Hispano-Suiza WWI Engine"; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 160-161; Grey, ed. *All the World's Aircraft 1919*, 142b-146b, 152b-153b; *Aerial Age*, 5, 16 (July 2, 1917): 525; ibid, 5, 17 (July 9, 1917): 570-571; ibid, 5, 21 (Aug. 6, 1917): 724-725; Gilles, *Flugmotoren*, 85.

Ilya Muromets: Kotelnikov, *Russian Piston Aero Engines*, 38-39; Alexander Boyd, *The Soviet Air Force Since 1918* (New York: Stein and Day, 1977), xiv [foreword, John Erikson;] Morrow, *Great War in Air*, 48, 258.

[9] Lloyd, *Rolls-Royce Growth of a Firm*, 142-143; Mixter and Emmons, *Aircraft Production Facts*, 8; Jones, *War in the Air*, 6: 31, 34; Cooper, *Birth of Independent Air Power*, 87; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515; *House War Expenditures Hearings – Aviation, 1919*, 360.

Martin: *Aeroplane*, 13, 1 (July 4, 1917): 50, 52 (quote 50;) *Aerial Age*, 5, 2 (March 20, 1917): 46; *History of Ministry of Munitions*, 12: 75.

[10] Lloyd, *Rolls-Royce Growth of a Firm*, 78-79; Neal, *Liberty Engine*, 8; Dempsey, "Notes on Hispano-Suiza WWI Engine"; *History of Ministry of Munitions*, 12: 77; Cooper, *Birth of Independent Air Power*, 88; Morrow, *Great War in Air*, 252-253; Jones, *War in the Air*, 6: 35; Gilles, *Flugmotoren*, 135; Gibson, "Theories and Practices in the Air Cooling of Engines, Part II," 1157; British aluminum: Stocking and Watkins, *Cartels in Action*, 227; Edwards and Frary and Jeffries, *Aluminum Industry - Aluminum and Its Production*, 44-46; Kossmann, *Über die wirtschaftliche Entwicklung der Aluminumindustrie*, 30-31, 43-44, 59, 110; Taulbet, *Eagle*, 141-143.

[11] Jones, *War in the Air*, 6: 37, 42, 53, 82-84; Morrow, *Great War in Air*, 254-256; *House War Expenditures Hearings – Aviation, 1919*, 33; Kenneth Munson, *Fighters Attack and Training Aircraft* (New York: The MacMillan Company, 1968), 119-120.

[12] *History of Ministry of Munitions*, 12: 79; Jones, *War in the Air*, 6: 84.

[13] *Aviation*, May 9, 1921, 604; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 513-514; Dempsey, "Notes on Hispano-Suiza WWI Engine"; Sweetser, *American Air Service*, 241; NARA, RG 120, M990/6/677-678, A XXI, Apr. 22, 1918, No. 973, GHQ AEF – AGWAR; ibid, M990/4/1496, A XVII 316, May 2, 1918, No. 1224-R; ibid, M990/6/17, A XXI, May 5, 1918. No. 1052, GHQ AEF – AGWAR; ibid, M990/6/717, A XXI, May 6, 1918, No. 1057, GHQ AEF – AGWAR; ibid, M990/6/748, A XXI, May 15, 1918, No. 1116, GHQ AEF – AGWAR; ibid, M990/9/382-387, B III 49-54, "Report Supply Section London Branch."

[14] NARA, RG 120, M990/6/17, A XXI, July 1, 1917, No. 32, Bolling – Coffin; ibid, M990/7/28, A XXII, July 23, 1917, No. 47, AGWAR – Pershing; ibid, M990/7/28, A XXII, July 28, 1917, No. 65, AGWAR – Pershing.

15 Angle, ed. *Aerosphere 1939*, 726; *Aerial Age*, 5, 21 (Aug. 6, 1917): 719-720; Kenneth S. Davis, *FDR The Beckoning of Destiny 1882-1928* (New York: G.P. Putnam's Sons, 1971), 468.

16 Taulbet, *Eagle*, 42-44, 55, 91, 173, 234, 279.

17 Taulbet, *Eagle*, 20, 78-89, 141-143, 192-193, 213, 305; Grey, ed. *All the World's Aircraft 1919*, 131b-133b; Angle, ed. *Airplane Engine Encyclopedia*, 429-434; Smith, *Aircraft Piston Engines*, 31-33; Dickey, *Liberty Engine*, 24-25; Marks, *Airplane Engine*, 70, 98-103; Neal, *Technical and Operational History Liberty Engine*, 12-13; Schlaifer and Heron. *Development of Aircraft Engines*, 200.

Lubrication: NARA, RG 120, M990/6/558, A XXI, March 12, 1918, No. 719, GHQ AEF – AGWAR; ibid, M990/6/1011, A XXI, Aug. 5, 1918, GHQ AEF – AGWAR; Dickey, *Liberty Engine*, 36.

18 Taulbet, *Eagle*, 98.

19 ibid, 91-93; *History of Ministry of Munitions*, 12: 77-78 (quote 78.)

20 Taulbet, *Eagle*, 91-98, 234-235, 295-296; Vincent, "Liberty Aircraft Engine," 400 (first quote); *House War Expenditures Hearings – Aviation, 1919*, 32-33 (second quote); Lloyd, *Rolls-Royce Growth of a Firm*, 90; Gilles, *Flugmotoren*, 75-76, 86.

21 Lloyd, *Rolls-Royce Growth of a Firm*, 62-69, 73-79, 92-116, 151-153; *History of Ministry of Munitions*, 12: 75-81; Jones, *War in the Air*, 6: 48-53 (fifth quote, 52); Taulbet, *Eagle*, 209-211, 216, 225, 315-316; Mixter and Emmons, *Aircraft Production Facts*, 16-22, 26-27; Neal, *Technical and Operational History of Liberty Engine*, 47-55, 71; Sweetser, *American Air Service*, 173, 180; Morrow, *Great War in Air*, 252; NARA, RG 120, M990/7/22, A XXII, July, 16, 1917, AGWAR – Pershing; ibid, M990/6/6, A XXI, June 26, 1917, Bolling – CSO (first quote); ibid, M990/6/14, A XXI, June 30, 1917, 23, Bolling – CSO (second quote); ibid, M990/6/19, A XXI, July 1, 1917, No. 38, Bolling – Coffin (third quote); ibid, M990/6/183, A XXI, Aug. 8, 1917, No. 86, Bolling – AGWAR (fourth quote); ibid, M990/7/76, A XXII, Sept. 2, 1917, No. 146, AGWAR – HQ AEF; ibid, M990/6/68, A XXI, Oct. 26, 1917, No. 248, Bolling – Sec. State; ibid, M990/6/100, A XXI, Nov. 13, 1917, No. 258, Bolling – Sec. State; ibid, M990/6/340, A XXI, Dec. 10, 1917, No. 375, Pershing – CSO; ibid, M990/6/444, A XXI, Jan. 23, 1918, No. 527, GHQ AEF – AGWAR; ibid, M990/6/447, A XXI, Jan. 25, 1918, No. 532, GHQ AEF – AGWAR; ibid, M990/4/1525, A XVII, Jan. 25, 1918, No. 532-S; ibid, Feb. 7, 1918, No. 567-S; ibid, M990/6/491, A XXI, Feb. 14, 1918, No. 599, GHQ AEF – AGWAR; Gilles, *Flugmotoren*, 136.

Hispano-Suiza and Wright-Martin: U. S. Senate. Hearings. Committee on Military Affairs, Aircraft Production Subcommittee. 65th Congress, 2nd Session, vol. 1, June, 6, 1918 [*Senate Aircraft Production Hearings, 1918*], 316-317; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515; Dempsey, "Notes on Hispano-Suiza WWI Engine;" Pernot, "Barès," 10.

22 *House War Expenditures Hearings – Aviation, 1919*, 32-33; Muhlenberg: *Aviation*, June 27, 1921, 809.

Part II: Strategic Bombing

5. The Channel

On May 29, 1917, the same day that Vincent and Hall began their design of the Liberty, the U.S. Joint Army Navy Technical Board, having worked closely with aviation officers of the British and French missions, submitted recommendations to the U.S. government for U.S. aviation procurement to supply the AEF in France in 1918. Prominent among the Technical Board's recommendations as subsequently submitted to Congress was that for the procurement of 5,000 Rolls-Royce engines, "or equivalent," and 2,500 de Havilland DH-4s. In a June 13 memorandum addressed to the Army War College for the purpose of obtaining War College approval for this U.S. procurement program, these airplanes were described by the Aircraft Production Board as "Reconnaissance Machines for Advanced Training," the APB noting at that time that "We will concentrate on the reconnaissance and artillery control types." These recommendations were the basis upon which the U.S. Congress passed the $639 million Aviation Act of July 24, 1917, "the largest appropriation ever made by Congress for one specific purpose." As initially submitted to the War College in June, these recommendations were accompanied by the Technical Board's recommendations concerning the organization of U.S. military aviation. The objections of the War College and the Army General Staff to this organization proposal forced Newton Baker at the end of June to intervene and substitute his own endorsement of the Technical Board's recommendations for that of the War College and so allow the Technical Board's gigantic expenditures request to be submitted to Congress. The matter of Allied supply of the AEF Air Service was deferred pending the investigations and recommendations of the Bolling mission.[1]

The Aviation Act of 1917 said nothing about bombardment aviation or any possible relation it may have had to a separate or independent organization, agency or department for aviation, military or otherwise, and none of the details of the Technical Board's recommendations were included in the Act. However, in the third of this historic piece of legislation's twelve sections, the Congress of the United States of America did see fit to provide for the creation of the ratings of United States Army Signal Corps Chauffeur, First and Second Class, the famous race car driver and U.S. Army Signal Corps Private Edward V. Rickenbacker having embarked, along with General Pershing and the general staff of the American Expeditionary Force, on the S.S. *Baltic* at New York City on May 28. Rickenbacker was then 27 years old, two years older than the maximum age for recruitment as a U.S. Army Signal Corps pilot. Nevertheless, Rickenbacker, the *Baltic* and the others had then proceeded eastward across the Atlantic Ocean to Great Britain where they disembarked at Liverpool on June 8, 1917.[2]

The skepticism expressed in Germany during and after the war, not a little of it derived from American sources, in regards America's ability to rapidly develop its airpower and bring it to bear upon the course of the war[3] was contemporaneous in 1917 with the advice of a number of French officials, as well as that of Major William Mitchell, that the United States ought to rely on the French aviation industry to equip the AEF Air Service.[4] This viewpoint was not shared by Newton Baker or Woodrow Wilson nor by some of the French and other Allied military and naval air attachés and industry representatives at work in this country during the war, some of the latter recommending that the initial American contribution would be most effective if concentrated upon U.S.-built bombardment aviation and high-power aero-engines.[5]

The Lorraine-Dietrich 8B aero-engine cited in the Vincent-Hall report was an engine then being developed in France for bombardment aviation.[6] The 150 hp Hispano-Suiza engine, the licensed production of which by Wright-Martin was one of our earlier wartime contributions to Allied aviation, had been initially designed in 1915 in response to the French army's demand for engines of increased output to power its long-range bombers.[7] In November 1916, the Italian government was proposing to buy French-built 220 hp Hispano-Suizas for the purpose of equipping Italian air force Caproni bombers.[8] The famous Ribot cable upon which the initial U.S. aviation program was based was itself the result of a recommendation made earlier in May 1917 by the French army to the French government that U.S. aviation production to supply the AEF in France should consist of a front-line force of 4,500 service aircraft, half of which were to be bombers.[9] The recommendation of the Joint Army Navy Technical Board to procure thousands of de Havilland DH-4s equipped with Rolls-Royce or equivalent engines came less than two months after the DH-4 equipped with the Rolls-Royce Eagle began its initial service at the British front as a day bomber, work for which the DH-4 had been specifically designed.[10] The French would concur in our decision to build the DH-4.[11]

In July 1917 Major Bolling cabled Washington, asserting that “All information obtained is that 12 cylinders right size for long distance bombing machines and British recommend that these be our largest production…twelve-cylinder seems suited D.H. Four and Breguet machines,” adding “Day bomber and long range reconnaissance capable of defending itself. Recommend de Havilland Four but think some changes in design necessary give larger bomb carrying capacity. Has been successful with Rolls Royce engine and we think new Renault 450 new Fiat or new Isotta Fraschini or U.S. 12 engines suitable this machine.” In October, he stated that “Our business is build largest possible quantity day and night bombers de Havilland Nine and Caproni…United States should produce great quantity bombers which will give results that count…Germans have already started extensive bombing and confidential information indicates large bombing programs next year. We must meet and beat them at this.”[12] An early recommendation of the Italian government was that the U.S. should produce the Caproni three-engine bomber.[13] These actions and recommendations were accompanied by statements in the American and British press and by members of Congress and the House of Commons urging U.S. Production of aircraft to bomb Germany.[14]

In 1917 the French government looked upon French aviation as an asset that could be exchanged for the American raw materials and finance upon which wartime France was becoming increasingly dependent. French government planning in regards U.S. aviation in the summer of 1917 included the placing of French engineers and technicians in U.S. plants and the construction of new American aviation factories not in the U.S. but in France.[15] Given the limited availability of transatlantic tonnage, this planning was endorsed by Major Bolling who in the summer of 1917, asserted that it was “absolutely useless [to] consider shipping complete airplanes from America for the next twelve months because of the ship situation.”[16] In August 1917, one of France’s leading advocates of strategic bombing, Pierre-Étienne Flandin, head of the Inter-Allied Aircraft Board, prominent member of the Chambre des Députés and future French under-secretary of state for aviation, foreign minister and premier, was in this country publicly advising the United States to forego domestic aero-engine production.[17]

These plans and recommendations were coincident with demands from European government officials, as well as from Rolls-Royce and other European manufacturers’ representatives, for Aircraft Production Board contract approval for the licensed production of European aircraft and aero-engines in the United States. The European terms for many of these proposed contracts were considered by the members of the APB and many other people in this country to be excessive, “equivalent to taxing the American public or to making them pay the entrance fee to participate in the war.”[18] This refusal of European commercial terms was accompanied by the American demand for the free exchange of aviation manufacturing rights between the U.S. government and the governments of the Allied nations. The APB and Colonel Bolling would make exceptions to this policy[19] but it was generally adhered to and it was a policy that was consistent with the Wilson Administration’s free trade policies as well as Woodrow Wilson’s post-war refusal to agree to the commercialization of the Allied and German governments’ war debts.[20]

The American determination, personified by General Pershing, to maintain the integrity and independence of the American Expeditionary Forces extended to the equipment and deployment of the AEF Air Service. The two principal means of managing this U.S. aviation policy would be the supply of American raw materials and Liberty aero-engines to the Allies, means which would become increasingly coherent and identical with one another in the course of our direct participation in the First World War. Two American lawyers managed this policy, U.S. Secretary of War Newton D. Baker and Colonel Raynal C. Bolling.

Raynal Bolling led of the famous U.S. aviation mission sent to Europe in June 1917 by Newton Baker and the Aircraft Production Board. Besides being an aviator, he was also former general counsel for the United States Steel Corporation and brother-in-law of U.S. Assistant Secretary of State William Phillips who was the State Department's principal representative to the British mission to this country.[21] One member of the Bolling mission later recalled that "Col. Bolling was a man of unusual characteristics. He made friends everywhere he went…He was a lawyer of great ability and was therefore considered able to handle international questions which might arise and did arise."[22]

Bolling consulted with General Pershing shortly before the latter signed an August 30, 1917, $60 million U.S.-French aviation agreement to supply the AEF Air Service with thousands of French first-line and trainer airplanes and aero-engines, a procurement that corresponded to the recommendations of Major Mitchell and which was to include 1,000 Breguet 14B2 bombers and 1,500 Renault 300 hp aero-engines. The Liberty aero-engine was an important feature of this agreement's planned first phase, the U.S. agreeing to sell the Liberty to France in exchange for the French airplanes and aero-engines. This additional French production was to be partially facilitated by the conversion of some French industrial capacity from artillery to aero-engine production. Another essential element of this deal was the American supply of raw materials and machine tools to the French aviation industry.[23]

Throughout the latter half of 1917, Colonel Bolling and the APB would be vigorous and occasionally vehement in their demands that the U.S. and Allied governments agree to the free exchange of aviation patent and manufacturing rights. With the shortage of transatlantic tonnage and his confidence in European aviation design and production, Bolling continued to advocate for the French production as per the August 1917 agreement and that the United States should produce no complete aircraft for shipment to Europe. He instead urged the U.S. production of complete sets of airplane parts to be shipped to and assembled in Europe. Bolling's recommendations did not exclude the U.S. production and shipment to Europe of complete aero-engines and did include a reference to the development of the Liberty as "probably the most important consideration of engine production in the U.S." and did include the sharing of the rights to U.S. engines with the Allied governments.[24]

The French government continued to urge French officials in the U.S. to recommend French supply of the AEF Air Service.[25] Major Mitchell, born in Nice, fluent in French and himself a member of one of Milwaukee, Wisconsin's most prominent families, in his efforts to procure that same supply was working directly with French political and military leaders as well as with some of the leading American businessmen then resident in France.[26] Thus considerable pressure may have been brought to bear upon Raynal Bolling in the summer and fall of 1917 to recommend the foregoing of domestic U.S. aviation production. While Bolling was in basic agreement with what the French and Mitchell were advocating, any such pressure would nevertheless have been misplaced. In the recent words of two French historians, "*L'officier américain n'est pas homme à se laisser impressioner par de tels arguments, et il détermine son choix en son âme et conscience, tenant compte des intérêts supérieurs de son arme et son pays*." When faced with a hopeless situation in a chance encounter with enemy soldiers at the front in March 1918, the American corporate lawyer would choose to fight it out and die in combat rather than surrender.[27]

The demands placed upon the U.S. machine tool industry consequent of the decision by the U.S. government in 1917 to enter into the mass production of the Liberty aero-engine[28] did not delay timely supply U.S. machine tools to France and did not cause the failure of the French to supply to the AEF Air Service 8,500 aero-engines as per the August 1917 agreement. As early as July 1917 in his negotiations with French officials, Major Bolling was referring to a possible conflict between the French and U.S. demands for machine tools. One member of the Bolling mission, Robert A. Vail of the Dodge Motor Car Company, designated to examine those French demands, found them to be reasonable and returned to the U.S. in September 1917 to help organize their supply. An initial embargo on the export of machine tools from the U.S. that included the commandeering of orders awaiting shipment was replaced before the end of the year by a policy that made exports subject to government approval. One beneficiary of these actions in this country was the Ford Motor Company and its efforts to procure the cylinder grinding machines which were required for the precise machining of the cylinders of the Liberty and other U.S.-built, mass production aero-engines. It was these machines, specifically the rotary cylinder grinding machines made by the Heald Machine Company of Worcester, Massachusetts, that were a necessity for that production. The Heald company's supply to the Signal Corps Aviation Section and the AEF was supplemented the U.S. government's commandeering of these machines in Europe owned by Americans. By the beginning of April 1918 an estimated 98% of the total French demand for U.S. machine tools had been delivered.[29] It would be failure to satisfy French demands for U.S. skilled labor and raw materials, along with the French decision to increase production for their own air service, that would preclude scheduled delivery of French aircraft and engines as per the August 1917 agreement to the AEF in 1918.[30]

These latter failures were coincidental with the collapse of the British aero-engine program, the Italian defeat at Caparetto and the withdrawal of Russia from the war subsequent to the Bolshevik revolution, events all occurring in the autumn of 1917. This was the same time that the British government decided to renew its strategic bombing campaign against the war economy of western Germany. Despite the inauspicious circumstances, the British would nevertheless persist and the proximate cause of both that decision and that persistence was the series of German long-range bombing raids on Britain begun in May 1917.

While there was an understanding in Germany that effective bombing required massed formations of bomber aircraft,[31] it would be engine performance, not an insufficient number of bombers, that thwarted initial German plans to bomb Britain in the autumn of 1914.[32] The German army's policy early in the war to forego the development of high-power aero-engines in favor of production standardized on the Daimler and other manufacturers' six cylinder types led to the design of German long-range bombers as multi-engine aircraft, a development reinforced by the example of Igor Sikorsy's pre-war and wartime production of multi-engine bombers in Russia.[33] By the spring 1916, Daimler-Mercedes had in production the six cylinder D IVa, its 260 hp output comparable to the most powerful Rolls-Royce engine at the front that year, the 275 hp Rolls-Royce Eagle Mark V. Initial problems with crankshaft failure in test flights aboard the Gotha G II were followed by successful performance aboard the Gotha G III, Friedrichshafen G III and AEG G IV bombers. In March 1917, a group of twin-engine Gotha G IVs equipped with the Daimler-Mercedes D IVa began to gather at German airfields located in Belgium.

Like these other bombers and many other German service aircraft during the war, the Gotha G IV was of plywood and steel tube construction. A pusher biplane with a three man crew and armed with three machine guns, it carried a maximum bombload of approximately 1,000 pounds suspended externally. It had an airspeed of approximately 85 mph and a range of 522 miles or 6 hours flight time.[34] This was a performance somewhat less than the principal British twin-engine bomber then in service, the Rolls-Royce Eagle-equipped Handley-Page 0/100, an aircraft that would be relegated, like the Gotha G IV, to night bombardment duty in the autumn of 1917.[35]

The eight daylight Gotha bomber group raids that so provoked the British nation were conducted from May to August of 1917. Launched from airfields located near Ghent, the approximately 170 mile flight to London followed a flight path northwestward across the North Sea and the English Channel to the southeast coast of England and the mouth of the Thames estuary. Secondary targets, at a time when the Germans were conducting a campaign of unrestricted submarine warfare against Britain, included naval and maritime installations along the coast and the railroad stations, docks and munitions factories of London. A principal objective of these raids was the City of London, Britain's financial center.

The largest bomb used during these daylight raids was a 50 kg (112 lb) bomb generally considered incapable of damaging an industrial target, an operation for which the 100 kg (220 lb) bomb was considered the minimal size. The raids were conducted by groups of from ten to 22 aircraft, the twin-engine Gothas each carrying an average bombload varying from approximately 350 to 660 lb. Lightened of bombs and fuel, they were able to climb to 20,000 feet where they were generally able to elude the gathering defense of single-engine British fighters. No German bomber raiding Britain in 1917-1918 is known to have been brought down by London ground anti-aircraft fire. The majority of the total 62 German bombers lost during this series of day and night raids was the result of crash landings, particularly at night, when returning to the Ghent airfields.[36]

The first leader of the Gotha raids on Britain was Captain Ernst Brandenburg who after the war would head the aviation office of the German transportation ministry where he supervised the development of German civil and military aviation in the 1920s and early 1930s.[37]

Subsequent to the switch to night operations in August, the Gothas were joined in September by the Zeppelin-Staaken R (*Riesen*, Giant) types, a very large bi-plane bomber aircraft most of which were powered by four 260 hp Daimler-Mercedes D IVa engines arranged in tandem pairs driving tractor and pusher propellers.[38] One to five Zeppelin-Staaken R types participated in ten of the total nineteen night raids on Britain conducted from August 1917 to May 1918. Similar to the German Luftwaffe's conclusion of the London Blitz on April 16, 1941,[39] the final night raid of May 19, 1918, striking at London, Dover and Faversham, was a maximum effort, 28 Gothas, three Zeppelin-Staaken R types and two other aircraft dropping an approximate total of 14 tons.[40]

On the night of February 16, 1918, a Zeppelin-Staaken R VI dropped a one ton bomb on London and safely returned to Belgium along with all four of the other Zeppelin-Staaken R types which had participated in the raid. That particular aircraft was powered, as were two other Zeppelin-Staakens participating in the night raids on Britain, by tandem pairs of the Maybach airship engine. These six separate cylinder, in-line, water-cooled engines, as employed in the Zeppelin-Staakens, followed the "over-compressed, over-dimensioned" principle with each engine achieving an output of 245 hp. Like the NAG airship engines, the Maybachs had cylinders made up of steel barrels screwed into separate iron heads. These heads were flat and held five (two inlet, three exhaust) vertical valves. The water jackets were integral with the cylinders. Designed in Friedrichshafen and built by Daimler in the Stuttgart suburb of Cannstatt located just north of Untertürkheim,[41] they were the only aero-engines to have been successfully employed in airplanes for the purpose of long-range, strategic bombing during the First World War which did not follow the cylinder design of Ferdinand Porsche as developed in his Austro-Daimler 120 hp aero-engine of 1911.

The Daimler-Mercedes 260 hp D IVa aero-engine that powered most of the German bomber raids on Britain in 1917-1918 did follow the Porsche design, its well-cooled, thermal efficient cylinder with its spherical combustion chamber and long piston stroke operating at a low engine speed providing the fuel efficiency and endurance required for long distance flight. The large dimensions of the D IVa, particularly those of the greater thickness of its forged steel cylinder barrel and head, reinforced that durability. The increase of the D IVa's output horsepower, principally achieved by the increase of its cylinder bore to a near maximum dimension, followed the sequence of successful aero-engine development whereby a design of efficiency and reliability precedes increases of power output based on that design. One possible exception to this success in regards the D IVa's development may have been the engine's combination of twin exhaust valves, one of the D IVa's principal divergences from the Porsche cylinder design, with the maximum cylinder bore. The problem of incomplete combustion inherent in the wide bore, a problem susceptible to rapid changes of throttle and engine speed, may have exacerbated the problem of cooling two, small diameter exhaust valves. These problems may have also been exacerbated by the placement of the D IVa's spark plugs on the same side of the cylinder head. Engine failure hindered the initial series of daytime Gotha bomber raids on Britain. Two of the twenty Gothas that were launched on June 13, 1917, failed to reach England as a result of trouble with the Daimler-Mercedes D IVa.[42]

The D IVa's increase of power to 260 hp, combined with the use of a shiftable overhead camshaft to provide a low compression setting at take-off, enabled the twin-engine Gotha IV bomber to lift and carry a maximum 660 lb bombload over the 170 mile distance from Ghent to London.[43] The D IVa was thus an aero-engine that balanced its performance specifications of efficiency, durability and power so as to meet the specific requirements of that bombing campaign. During the maximum distance raids on London, both engines and aircraft were being employed at something close to their maximum capability. The nighttime take-off and flight of one bomber was described by one member of its aircrew as "*Mit machtigen Getöse gehen die Motore auf volle Touren, schwerfällig und stohnend unter Last setzt sich der schwarze Riesenvogel in Bewegung…Die Motore brummen ihren wohlklingenden, tief Bass, lange Feuerschweise zeichen ihren Weg*."[44]

The *lange Feuerschweise* may have been an aid to navigation during the night flights over the English Channel. Unable to fly in close formation during the night raids, each of the Gothas and Zeppelin-Staakens were launched at five minute intervals[45] and thus each of the night raids on Britain consisted of a series of single aircraft attacks that on a given target or area might be prolonged over the course of an hour or more. It was the sacrifice of some of the Gotha IV's airspeed to the requirements of range and bombload that defined that aircraft as being essentially a night bomber. The D IVa thus partly determined the moral, social, political and military implications inherent in such operations when directed against a metropolitan area of Europe in the era of the First World War. The Goerze bombsight employed by the Germans was essentially a telescope equipped with a level and a set of prismatic lenses some of which were manually adjusted by the bombardier allowing him to calculate the aircraft's ground speed and thus the bombing angle over the target.[46]

The Germans built approximately 1,500 G- and R-type bombers during the war, many of them equipped with some of Daimler-Mercedes' wartime production of approximately 4,000 D IVa aero-engines. Beginning in early 1918, many of these aircraft were used in night bombing operations against munitions and utilities plants, supply depots, railroad stations and other targets located in and around Paris, "especially against the aircraft factories and establishments." Flying approximately 80 miles from airfields located behind the German lines in northeast France, conducted in groups of up to 70 Gotha bombers, the night raids on Paris would continue intermittently until mid-September, inflicting casualties comparable to those inflicted by the German raids on London. AEF Air Service facilities located at the Le Bourget airfield on the north side of Paris were forced by these raids to move south to Orly.[47] One witness to these raids was Brigadier General Charles G. Dawes, chief of the AEF General Purchasing Board. One evening in Paris in June 1918, Dawes was standing near the front window of a room on the fourth floor of the Ritz Hotel overlooking the Place Vendôme watching a German air raid when the blast of a bomb exploding on the Place shattered the window and knocked Dawes off his feet and into an armchair halfway across the room. It was the thirtieth German air raid he had witnessed since arriving in wartime France.[48] The Chicago banker and civic leader and former U.S. Comptroller of the Currency had played a critical role in the initiation of wartime American lending to the Allies prior to our formal entry into the war.[49] He would return to Paris in 1924 to help mediate the German reparations plan that was given his name, an effort for which he was awarded the 1925 Nobel Peace Prize, and he would later serve as Vice President of the United States and U.S. Ambassador to Britain.[50]

The German bombing operations of 1917-1918 were accompanied by continued German developments of aero-engines for bombardment aviation. These developments consisted primarily of the use of over-dimensioned cylinders or of geared, high-speed versions of the standard six cylinder types or V-8 or V-12 types using the same basic cylinder designs. The German army's output horsepower specifications for some of these engines, including some of the six cylinder types, ranged from 500 to 600 hp. These developments were to some extent delayed by the army's rejection up to the end of 1917 of the V-12 type. None of these aero-engines were put into serial production prior to the Armistice.[51]

Shortly after the end of the war, General Ernst Hoeppner, the commanding officer of the German air forces, would state that it was the improving British air defenses, particularly along the coast of England which included fighter aircraft, anti-aircraft guns, barrage balloons and systems of observation and early warning, that had determined the German decision to halt daytime bombing operations against Britain. General Hoeppner also stated that the purpose of the bombing of London was to divert British air forces away from the front in France, a strategy that was at least partially successful.[52] The "collateral damage" of thousands of civilians killed and injured and millions of dollars worth of damage to civilian property were also consequences of the German bomber raids on Britain in 1917-1918.[53] Dissimilar to events in Britain, these German raids did not lead to an independent German air force or air ministry. But if an essential element of the definition of strategic bombing is an intention to destroy enemy economic power, then the German airplane bombing of Britain of 1917-1918, despite its sporadic frequency and inevitable imprecision, may very well be considered to be history's first instance of strategic bombing operations. Its most important historical significance lies in its provocation of a British response,[54] the first phase of which began in the autumn of 1917 with the beginning of a strategic bombing campaign conducted by British and U.S. forces flying from fields in France to western Germany, to the Rhine and still further.

Notes

[1] Neal, *Technical and Operational History Liberty Engine*, 16-40; *House War Expenditures Hearings – Aviation, 1919*, 211, 356-360 (first quote, 360;) "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 512; Mauer, ed. *U.S. Air Service in World War I*, 2: 105, 123; *House Report No. 637, 1920*, 1: 96-97, 2: 5; Sweetser, *American Air Service*, 66-68; Crowell, *America's Munitions*, 236-240; Mixter and Emmons, *Aircraft Production Facts*, 7 (fourth quote;) Bruce, "D.H. 4," 510; Palmer, *Newton D. Baker*, 1: 287-288; Holley, *Ideas and Weapons*, 40-45; NARA, RG 120, M990/1/560-567, A I 10-17, E.S. Gorrell, "Report on the Early Activities of the Air Service, American Expeditionary Forces," 3-10 (second quote, 8, third quote, 10;) ibid, M990/1/636, A I 86, B. D. Foulois, "Air Service Lessons Learned During the Present War," Jan. 29, 1919, 5.

[2] Sweetser, *American Air Service*, 341-347; John J. Pershing, *My Experiences in the World War*, 2 vols. (New York: Frederick A. Stokes, 1931), 1: 36, 44; Edward V. Rickenbacker, *Rickenbacker* (Englewood Cliffs: Prentice-Hall, Inc., 1967), 81-88.

[3] *Technische Berichte* 3, 1 (1918): 22-23; ibid, 3, 2 (1918): 53-54; Hoeppner, *Deutschlands Krieg in der Luft*, 140-141; Neumann, ed. *Deutschen Luftstreitkräfte*, 67-68, 72-74; NARA, RG 120, M990/6/6, A XXI, June 26, 1917, Bolling – CSO; Morrow, *German Air Power in World War I*, 95-96.

[4] W. Mitchell, *Memoirs*, 16-17, 101-102, 123, 137; *Aerial Age*, 5, 21 (Aug. 13, 1917): 767; Marie-Catherine Villatoux and Patrick Facon, "La coopération franco-américaine en matière d'aèronautique 1917-1918," *RHA* 246 (2007), ¶ 14, www.rha.revues.org; Hudson, *Hostile Skies*, 48, 53.

[5] *JSAE*, 1, 1 (Jan. 1917): 11; *House War Expenditures Hearings – Aviation, 1919*, 218, 358-361; *Aerial Age*, 5,5 (June 15, 1917): 487; Link, ed. *Wilson Papers*, 42: 191-193, 201-202; Mark Clodfelter, *Beneficial Bombing The Progressive Foundations of American Air Power, 1917-1945* (Lincoln: Univ. of Nebraska Press, 2010), 12; Sweetser, *American Air Service*, 76-77; Holley, *Ideas and Weapons*, 55; Morrow, *Great War in Air*, 280.

[6] *Aérophile*, Aug. 1938, XVIII; Jesse G. Vincent, "The Liberty Aircraft Engine," 390-393, 401; Neal, *Technical and Operational History Liberty Engine*, 36-37; Dickey, *Liberty Engine*, 15; Dorand, "L'evolution des avions français pendant la guerre," 115-117; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 193; Taylor, ed. *Combat Aircraft of the World*, 91.

[7] Chadeau, *De Blériot à Dassault*, 131; Pernot, "Barès, 8-10.

[8] Facon, "Coopération aéronautique franco-italienne," ¶ 24.

[9] Holley, *Ideas and Weapons*, 41-43; Mauer, ed. *U.S. Air Service in World War I*, 2: 105; Villatoux and Facon, "Coopération franco-américaine," ¶ 14; d'Abzac-Ebezy, "*'Une arme à finie la guerre'*," 106.

[10] *House War Expenditures Hearings – Aviation, 1919*, 360-361; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 511; Sweetser, *American Air Service*, 192; W. Mitchell, *Memoirs*, 150-151; Bruce, "D. H. 4," 506; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 137; Taylor, ed. *Combat Aircraft of the World*, 336-338; Morrow, *Great War in Air*, 243; Taulbet, *Eagle*, 183.

Contra: Holley, *Ideas and Weapons*, 126-131; Jones, *War in the Air*, 6: 164-165; Knappen, *Wings of War*, 144; Clodfelter, *Beneficial Bombing*, 14, 30.

[11] *House War Expenditures Hearings – Aviation, 1919*, 211.

[12] NARA, RG 120, M990/6/146-148, A XXI, July 11, 1917, No. 37, Bolling – AGWAR (first quote, 148); ibid, M990/6/170-172, A XXI, July 20, 1917, No. 70, Bolling – AGWAR (second quote); ibid, M990/6/190, A XXI, Aug. 12, 1917, No. 96, Bolling – AGWAR; ibid, M990/6/50, A XXI, Oct. 9, 1917, Bolling – CSO (third quote); ibid, M990/6/57 A XXI, Oct. 17, 1917, No. 210, Bolling – CSO; ibid, M990/6/64, A XXI, Oct. 24, 1917, No. 224, Bolling – CSO.

[13] *Foreign Relations of the United States* [*FRUS*], *1917*, supp. 2, vol. 1 (Washington: G. P. O., 1932), 123, 763.75/5790, T. N. Page – Sec. State, July 10, 1917.

[14] *Aerial Age*, 5, 11 (May 28, 1917): 350; ibid, 5, 14 (June 18, 1917): 452; ibid, 5, 24 (Sept. 3, 1917): 914; *Senate War Department Investigation Hearings, 1918*, 2160; *Aeroplane*, 13, 3 (July 18, 1917): 148; Knappen, *Wings of War*, 162; Pershing, *Experiences*, 2: 18.

[15] Villatoux and Facon, "Coopération franco-américaine," ¶ 13-14; *Aerial Age*, 5, 11 (May 28, 1917): 350; ibid, 5, 21 (Aug. 13, 1917): 773; Valluy, *Première Guerre Mondiale 1916-1918*, 8-9, 49; NARA, RG 120, M990/1/585, A I 35, Gorrell, "Early Activities," 28.

[16] NARA, RG 120, M990/6/25-26, A XXI, July 8, 1917, No. 49, Bolling – Sec. State (quote); ibid, M990/6/160, A XXI, July 14, 1917, Bolling – CSO.

[17] *Aerial Age*, 5, 21 (Aug. 13, 1917): 767; Dubreil, "Le bombardement en 1916," 56; Morrow, *Great War in Air*, 207, 289.

[18] Mixter and Emmons, *Aircraft Production Facts*, 8; Arnold, *Global Mission*, 65-66; *House Report No. 637, 1920*, 2: 6-7, 25; Crowell, *America's Munitions*, 240; *Senate War Department Investigation Hearings, 1918*, 2213; Knappen, *Wings of War*, 20; Villatoux and Facon, "Coopération franco-américaine," ¶ 15-18; E. David Cronon, ed. *The Cabinet Diaries of Josephus Daniels 1913-1921* (Lincoln: Univ. of Nebraska, 1963), 194; Holley, *Ideas and Weapons*, 51; NARA, RG 120, M990/7/5, A XXII, June 27, 1917, CSO – Bolling; ibid, M990/1/575, A I 25, Gorrell, "Early Activities," 18 (quote.)

[19] NARA, RG 120, M990/7/44, A XXII, Aug. 5, 1917, No. 75-R, AGWAR - HQ AEF; ibid, M990/1/597-601, A I 47-51, Gorrell, "Early Activities," 40-44, Aug. 15, 1918, "Report of Aeronautical Commssion."

[20] Philip Mason Burnett, *Reparation at the Paris Peace Conference from the Standpoint of the American Delegation*, 2 vols. (New York: Octagon Books, 1965) 1: 135, 1015-1019, 1127-1129; Anne Orde, *British Policy and European Reconstruction after the First World War* (Cambridge: Cambridge Univ. Press, 1990), 54-56; Bernard M. Baruch,*The Making of the Reparation and Economic Sections of the Treaty* (New York: Harper & Bros. Publishers, 1920), 53, 73; David Lloyd George, *Memoirs of the Peace Conference* 2 vols. (New Haven: Yale Univ. Press, 1939), 1: 296-334; Hjalmar Schacht, *The End of Reparations*, trans. Lewis Gannett (New York: Jonathan Cape & Harrison Smith, 1931) , 208-209; Carl P. Parrini, *Heir to Empire United States Economic Diplomacy 1916-1923* (Univ. of Pittsburgh Press, 1969), 66-67.

[21] Mauer, ed. *U.S. Air Service in World War I*, 2: 131; NARA, RG 120, M990/1/576, A I 26, Gorrell, "Early Activities," 19-20; ibid, M990/1/585-586, A I 35-36, Gorrell, "Early Activities," 28-29; Dickey, *Liberty Engine*, 6; Roger G. Miller, *Billy Mitchell "Stormy Petrel of the Air."* (Washington, D.C.: Office of U.S. Air Force History, 2004), 8; Chase C.Mooney and Martha E. Layman. *Organization of Military Aeronautics, 1907-1935 (Congressional and War Department Action)*. U.S. Air Force History Study No. 25. Assistant Chief of Air Staff, Intelligence Historical Division, December 1944, 27, www.afhra.af.mil; Holley, *Ideas and Weapons*, 53, 85; *House War Expenditures Hearings – Aviation, 1919*, 214, 392; *New York Times*, Dec. 3, 1915, 14; *New York Tribune*, May 12, 1917, 2, http://chroniclingamerica.loc.gov.

[22] *House War Expenditures Hearings – Aviation, 1919*, 214 (quote); NARA, RG 120, M990/1/583, A I 33, Gorrell, "Early Activities," 26.

[23] Mixter and Emmons, *Aircraft Production Facts*, 49, 55-57; Sweetser, *American Air Service*, 208-209; *House War Expenditures Hearings – Aviation, 1919*, 165, 375, 395, 556; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 511-512; Villatoux and Facon, "La coopération franco-américaine," ¶ 18; d'Abzac-Ebezy, "*Une arme à finie la guerre*," 107, n. 27; NARA, RG 120, M990/6/191-193, A XXI, Aug. 14, 1917, No. 100-S, Bolling - AGWAR; ibid, M990/1/587, A I 37, Gorrell, "Early Activities," 30; ibid, M990/1/650-651, A I 100-101, Foulois, "Lessons Learned," 19-20; Valluy, *Première Guerre Mondiale 1916-1918*, 121; Crowell, *America's Munitions*, 241-242; Mason M. Patrick, "Final Report of Chief of Air Service, American Expeditionary Forces." In *United States Army in the World War 1917-1919*, vol. 15, *Reports of Commander-in-Chief, Staff Sections and Services,* 225-290. (Washington, D.C.: Center of Military History, United States Army, 1991), 238; Pershing, *Experiences*, 1: 142, 157, 193-194; Harbord, *American Army*, 140; *House Report No. 637, 1920*, 2: 7-8; Knappen, *Wings of War*, 54-56; Neal, *Technical and Operational History Liberty Engine*, 60.

[24] NARA, RG 120, M990/7/24, A XXII, July 20, 1917, No. 40, CSO- Bolling; ibid, M990/1/593, A I 43, Gorrell, "Early Activities," 36; ibid, M990/1/597-609, A I 47-59, Gorrell, "Early Activities," 40-52, Aug. 15, 1918, "Report of Aeronautical Commssion;" Morrow, *Great War in Air*, 268-269.

[25] Villatoux and Facon, "La coopération franco-américaine," ¶ 16-21.

[26] W. Mitchell, *Memoirs*, 21, 24-25, 32, 48-50, 67-71, 100-102, 118; Mauer, ed. *U.S. Air Service in World War I*, 2: 107; Burke Davis, *The Billy Mitchell Affair* (New York: Random House, 1967), 27-31; Hudson, *Hostile Skies*, 53; Knappen, *Wings of War*, 153; NARA, RG 120, M990/1/586, A I 36, Gorrell, "Early Activities," 29.

[27] Villatoux and Facon, "La coopération franco-américaine," ¶ 18 (quote); *Air Service Journal*, 4, 8 (Feb. 22, 1919): 9; Sweetser, *American Air Service*, 65, n. 1; NARA, RG 120, M990/6/666, A XXI, Apr. 18, 1918, No. 941, GHQ AEF – AGWAR.

[28] *American Machinist* 49, 24 (Dec. 12, 1918): 1094; Mixter and Emmons, *Aircraft Production Facts*, 23; Dickey, *Liberty Engine*, 92-93.

[29] Clarkson, *Industrial America in World War*, 454; *American Machinist*, 48, 12 (March 21, 1918): 490; ibid, 49, 24 (Dec. 12, 1918): 1093-1094; NARA, RG 120, M990/6/163, A XXI, July 18, 1917, No. 51, GHQ AEF – AGWAR; ibid, M990/6/177-180, A XXI, Aug. 1, 1917, No. 78, Bolling – AGWAR; ibid, M990/1/607, A I 57, Gorrell, "Early Activities," 50, Aug. 15, 1918, "Report of Aeronautical Commssion"; ibid, M990/6/66, A XXI, Oct. 24, 1917, Bolling – Sec. State; ibid, M990/6/279, A XXI, Nov. 1, 1917, No. 264, Bolling – AGWAR; ibid, M990/6/84, A XXI, Nov. 6, 1917, No. 242, Bolling – Sec State; ibid, M990/7/236, A XXII, Nov. 23, 1917, No. 432, AGWAR - GHQ AEF; ibid, M990/1/722, A I, Foulois, "Lessons Learned," 91, Apr. 3, 1918, CAS – C in C; ibid, M990/1/672, A I 122, Foulois, "Lessons Learned," 41, W.C. Allen, "Review of Activities. Production and Maintenance Division."

[30] NARA, RG 120, M990/1/653-655, 722, A I 103-105, Foulois, "Lessons Learned," 22-24, 91; ibid, M990/1/704-729, A I, Foulois, "Lessons Learned," 73-98.

[31] Hoeppner, *Deutschlands Krieg in der Luft*, 20; Neumann, ed. *Deutschen Luftstreitkräfte*, 434, 462.

[32] Hoeppner, *Deutschlands Krieg in der Luft*, 23; [Wilhelm] Siegert, "Bomben- und Nachtflüge," in Georg Paul Neumann, ed. *Deutschen Luftstreitkräfte im Weltkriege* (Berlin: Ernst Siegried Mittler und Sohn, 1920), 428, www.hathitrust.org; Fredette, *Sky on Fire*, 35-36.

[33] Gilles, *Flugmotoren*, 6, 72-73; Morrow, *Great War in Air*, 37.

[34] Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 24-25, 103-105, 149-150; Fredette, *Sky on Fire*, 38-44; Taylor, ed. *Combat Aircraft of the World*, 159-161; White, *Gotha Summer*, 35, 38-44, 52; Morrow, *Great War in Air*, 232; Hoeppner, *Deutschlands Krieg in der Luft,* 90; Valluy, *Première Guerre Mondiale 1916-1918*, 29.

[35] Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 151-152; Williams, *Biplanes and Bombsights*, 84-86; Peter Fearon, "The Vicissitudes of a British Aircraft Company: Handley-Page Ltd. between the Wars," *Business History* 20, 1 (Jan. 1978): 63-65.

[36] White, *Gotha Summer*, 38-39, 44-48, 79-91, 105-108, 112-124, 139-156, 185-194, 200-205; Fredette, *Sky on Fire*, 16-24, 53-61, 75-79, 85, 102-110, 147, 187 and "Summary of the Gotha and Giant Raids on England"; Hoeppner, *Deutschlands Krieg in der Luft*, 110-112; Morrow, *German Air Power in World War I*, 116-117; Neumann, ed. *Deutschen Luftstreitkräfte*, 115; *Aeroplane*, 13, 9 (Aug. 28, 1917): 568.

Bomb size: Neumann, ed. *Deutschen Luftstreitkräfte*, 80-81, 245, 585; G. K. Williams, *Biplanes and Bombsights*, 24; Robert S. Ehlers, Jr., *Targeting the Third Reich. Air Intelligence and the Allied Bombing Campaigns* (Lawrence: Univ. Press of Kansas, 2009), 24, 30.

[37] Fredette, *Sky on Fire*, 39-40; James S. Corum, *The Luftwaffe* (Lawrence: Univ. of Kansas Press, 1997), 77; Budrass, *Flugzeugindustrie*, 164-165; Heinkel, *Stürmisches Leben*, 144-145.

[38] Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 158-160; Fredette, *Sky on Fire*, 133-136; Neumann, ed. *Deutschen Luftstreitkräfte*, 103-110; Siegert, "Bomben- und Nachtflüge," 433, 435, 449.

[39] John W. Huston, ed. *American Airpower Comes of Age General Henry H. "Hap" Arnold's World War II Diaries* (Maxwell Air Force Base, Alabama: Air University Press, January, 2002), 148, www.afhra.af.mil.

[40] Fredette, *Sky on Fire*, 207-211; Hoeppner, *Deutschlands Krieg in der Luft*, 119, 160.

[41] Fredette, *Sky on Fire*, 188; Angle, ed., *Airplane Engine Encyclopedia*, 330-331; Morrow, *Great War in the Air*, 232; Neumann, ed. *Deutschen Luftstreitkräfte*, 117; Hoeppner, *Deutschlands Krieg in der Luft,* 59; Grey, ed. *All the World's Aircraft 1919*, 93b; *Aerial Age*, 8, 3 (Sept. 30, 1918): 123-125.

[42] White, *Gotha Summer*, 77, 209; Fredette, *Sky on Fire*, 44, 54.

[43] White, *Gotha Summer*, 39, 44, 47.

[44] Neumann, ed. *Deutschen Luftstreitkräfte*, 436 (quote.)

[45] ibid, 435.

[46] ibid, 248; *Aerial Age*, 5, 23 (Aug. 27, 1917): 868-869; White, *Gotha Summer*, 47.

[47] Gérard Hartmann, "Ca a Commencé le 23 Mars," 2006, 11-13, www.hydroretro.net; Neumann, ed. *Deutschen Luftstreitkräfte*, 445-449; Hoeppner, *Deutschlands Krieg in der Luft,* 152-153; Christienne and Lissargue, *History of French Military Aviation*, 171; Morrow, *Great War in Air*, 297-299; NARA, RG 120, M990/1/667-668, A I 117-118, Foulois, "Lessons Learned," 36-37 (quote.)

[48] Charles G. Dawes, *A Journal of the Great War* (Boston: Houghton, Mifflin Co., 1921), 132; Bascom Timmons, *Portrait of an American Charles G. Dawes* (New York: Henry Holt and Co., 1953), 183.

[49] Edward M Lamont, *The Ambassador from Wall Street. The Story of Thomas W. Lamont, J.P. Morgan's Chief Executive* (Lanham: Madison Books, 1994), 77-81; Timmons, *Dawes*, 65-83, 165.

[50] Timmons, *Dawes*, 203-209, 210-226; Charles G. Dawes, *Journal as Ambassador to Great Britain* (New York: The MacMillan Co., 1939), 18-19.

[51] Gilles, *Flugmotoren*, 72, 107-112, 152, 156, xvi-xviii.

[52] Hoeppner, *Deutschlands Krieg in der Luft*, 112-113; Fredette, *Sky on Fire*, 8, 64-65, 87-92 180, 261.

[53] Fredette, *Sky on Fire*, 262; Neumann, ed. *Deutschen Luftstreitkräfte*, 588; *New York Times*, Oct. 3, 2015, 1 (quote.)

[54] Fredette, *Sky on Fire*, 241-252; Horst Boog, "Das Problem der Selbstständigkeit der Luftstreitkräfte in Deutschland 1908-1945," *Militärgeschichtliche Mitteilungen* 1 (1988): 36; James S. Corum. "The Development of Strategic Air War Concepts in Interwar Germany, 1919-1939," *Air Power History* 44, 4 (Winter 1997) 18-20; Hoeppner, *Deutschlands Krieg in der Luft,* 56-57.

6. The Rhine

In Britain, on July 9, 1917, two days after the second of the two daylight Gotha bomber raids on London, the British war cabinet was informed by members of the Munitions Ministry and the Air Board that increasing rates of aircraft and aero-engine production would soon provide a supply in excess of the immediate needs of the British army and navy. That evening, in a closed session of the House of Commons, Prime Minister David Lloyd George repeated these assertions, stating that there would soon be sufficient supplies to equip Britain's aviation needs for tactical operations at the front, for home defense, and for independent bombing operations. In mid-August, an advisory report to the British War Cabinet by General Jan Christian Smuts recommended, on the basis of that surplus, the institution of an independent air force for the purpose of strategic bombing. It was on a similar basis that the Bolling mission at that same time recommended to the U.S. government the equipment of air forces for that same purpose, a recommendation that emphasized the potential of night bombardment. By early September, the British Air Board had received a plan detailing a strategic bombing campaign against Germany that specified a number of industrial production targets including munitions plants.[1]

In early October 1917, subsequent to a week-long intensification of the German night-time raids on London, the British war cabinet decided to order 20 DH-4 day bombers of the British army's Royal Flying Corps (RFC) to move to the French airfield at Ochey, located 12 miles southwest of Nancy behind the southern sector of the French front in eastern France. It was the expressed intention of the British government that the British DH-4s and other bombers sent to Ochey in the autumn of 1917 should conduct long-range bombing raids on German munitions plants as well as retaliatory raids on German cities. This decision was part of a larger aviation policy directed at building an expanded British airpower and it was a direct result of the German raids on London.[2] The British Ministry of Munitions had assumed the administration of aviation production in early 1917 and Winston Churchill, appointed to head the Ministry in July 1917, would be a proponent of this policy of strategic bombing.[3]

The Royal Naval Air Service had previously used the Ochey field as well as other French fields located further south at Luxeuil-les-Bains during the latter part of 1916 and early 1917 to conduct long-range bombing raids. These raids were directed under French supervision at German airship hangars and industrial and railway targets in Germany and German-occupied Lorraine. On October 12, 1916, French and British aircraft had flown approximately 100 miles northeast from Luxeuil, crossed the Rhine and attacked the Mauser small arms factory at Oberndorf located south of Stuttgart. This was the raid during which the French bomber force suffered such heavy casualties that as a consequence the French army general staff decided to call a halt to daylight bomber raids on Germany. Escorting these bombers to and from the Rhine were pursuit aircraft of the Lafayette Escadrille and it was in this service and during this raid that Escadrille leader Norman Prince lost his life in an airplane crash.[4]

The RFC's 41st Wing organized in the autumn of 1917 at the Ochey airfield consisted of the DH-4-equipped No. 55 day bombardment squadron as well as two night bombardment squadrons equipped with Handley-Page 0/100s and FE 2bs. These were the same types of bombers employed by the RFC's sixteen other bombing squadrons engaged in short-range, tactical bombing operations in support of the British army at the front in northern France in the latter part of 1917. The RFC DH-4s used exterior bomb racks attached underneath the fuselage and/or lower planes and when on long range bombing missions carried one 230 lb or two 112 lb demolition bombs, bombing from an average altitude of approximately 13,000 feet. This bombload was half that carried by the RFC DH-4s for short-range, tactical bombing.

The first raid of the renewed bomber offensive was launched from Ochey during daylight on October 17, 1917, eight (of eleven launched) DH-4s of the No. 55 Squadron, equipped with 270 hp Rolls-Royce Eagle Mark III aero-engines, flying approximately 60 miles northeastward to Saarbrücken. On this particular raid, each bomber carried two 112 lb bombs. Of the sixteen bombs dropped, three struck the targeted steel foundry in the Saarbrücken suburb of Burbach.[5] Eleven days later, a U.S.-built DH-4 equipped with a 315 hp Liberty 12 aero-engine made a first test flight at Dayton, Ohio.[6]

The FE 2b, like the Voisin bomber, was a single-engine pusher biplane with a metal lattice framework tail section. The FE 2b was powered by one 160 hp Beardmore aero-engine the design of which was based on Beardmore's pre-war licensed production of Ferdinand Porsche's Austro-Daimler engines and the FE 2b, operating over a tactical radius of up to 80 miles, could carry a 230 lb bomb. It was most often used in the night operations conducted from the Nancy airfields against railway facilities serving the foundries and mills of the Saar. The first commander the 41st Wing's FE 2b night bomber squadron was Major Malcolm Graham Christie. Christie before the war had studied engineering and worked in manufacturing in Germany and he would be severely injured leading one of these night attacks on German industry in the autumn of 1917. He would return to Germany in the 1920s as the British military air attaché and in the following decade, as a private individual, would play a key role in alerting the British government to the build-up of German airpower.[7]

The DH-4s of No. 55 Squadron continued daytime raids on industrial, munitions and railway targets located in the Saar region throughout the fall of 1917. On Christmas Eve, ten of the squadron's DH-4s, each carrying an average bombload of approximately 230 lb, flew 120 miles northeast from a French airfield at Tantonville, located south of Nancy, and bombed Mannheim-Ludwigshafen on the Rhine River. Targets included the Badische Anilin- und Sodafabrik (BASF) plant in Ludwigshafen on the west bank of the river. BASF, then and today Germany's largest chemical engineering firm, was then engaged in the production of dyes, fertilizers, explosives and poison gas. This plant was throughout the war one of the targets most frequently attacked by French and British long range bombers. Also attacked was the Heinrich Lanz, AG factory located across the Rhine in Mannheim. Lanz was, and continues to be, one of Germany's leading manufacturers of tractors and farm machinery and before the war the firm had been engaged in the development, production and promotion airship and airplane engines. It also developed and produced the wooden framework Schütte-Lanz dirigible airships used by the German navy during the war and, by the time of this Christmas Eve 1917 raid, Lanz was engaged in the production of Zeppelin-Staaken long range bombers. Other possible targets in Mannheim would have been Benz & Cie., Germany's second-largest manufacturer of aero-engines and the Rhenania-Motorenfabrik AG, then developing its production of the Le Rhône air-cooled rotary aero-engine.[8]

This emphasis on industrial and munitions targets characterized the daytime operations of No. 55 Squadron in its first six months of operations through March 1918, over half the tonnage dropped by 41st Wing being directed at such targets, No. 55 Squadron accounting for over half the Wing's total flying time. Included in these objectives were the railroad yards and iron and steel foundries of the Thionville-Briey iron ore region of northeastern France, among which were the railroad yards at Conflans. These raids were part of French efforts to impose an aerial blockade on the region by attacking its rail transportation. At this same time, plans to expand this long-range bombing force to one of up to 66 squadrons began to be implemented, the French supplying men, equipment and material to build additional airfields in the Nancy area.[9]

On March 10, 1918, eleven of No. 55 Squadron's DH-4s, each carrying an approximate bombload of 250 lb, flew 150 miles almost due eastward from the Tantonville airfield, crossed the Rhine and bombed Stuttgart, home of the Daimler Motorenwerke as well Bosch, Germany's and the world's leading manufacturer of aero-engine magnetos. British bombers would strike Stuttgart three times in 1918, weather conditions and the failure of the Puma aero-engine forcing diversion to secondary targets on several other occasions. On May 18, 1918, the day before the final German bomber group night raid on Britain, six DH-4s of No. 55 Squadron, fitted with auxiliary fuel tanks, flew approximately160 miles north-northeast from Tantonville and dropped nearly 1400 lb on railway and other targets at Cologne.[10]

Thus, on this latter flight to Cologne over a maximum distance equivalent to that of the German raids on London, the single engine DH-4s equipped with the 270 hp Rolls-Royce Eagle aero-engine each carried an average bombload of approximately 230 lb, while the twin-engine Gotha G IVs equipped with the 260 hp Daimler-Mercedes D IVa each carried an average bombload of approximately 500 lb, the respective engines both featuring a cylinder of the same basic design. As one American pilot who flew with Independent Force Squadron No. 55 in the summer of 1918 shortly thereafter recalled, it was the DH-4s that "did the extremely long work on towns along and behind the Rhine, while the D.H.9 squadrons did work along the Rhine and this side of it, principally along the Saar valley and the Metz-Thionville-Treves area. The D.H.4 squadron was able to get to a higher altitude and more speed, due to the more refined and higher powered motor, so it was natural that the longer work should fall on them."[11]

As with the Gotha raids on London, these long range raids on Germany by the Eagle-equipped DH-4s required a maximum performance by men and machines and it would be initial failures of the Rolls-Royce Eagle aero-engine that would most commonly require a DH-4 to abort its mission, typically one or two of a dozen DH-4s launched returning to Tantonville before reaching the target.[12] By the time of the British raid on Cologne in May 1918, the first U.S.-built DH-4s equipped with 400 hp Liberty 12 aero-engines were undergoing flight tests in France.[13]

Also in May 1918, two additional day bombardment squadrons joined the British bomber units at Nancy to form in the following month the British Independent Force under the command of Brigadier General Hugh Trenchard and Colonel Cyril Newall. Both squadrons were equipped with the de Havilland DH-9 and all of these aircraft were powered by the 220 hp Siddeley-Deasy Puma aero-engine.

In March 1918, just before the beginning of the German offensive in northern France, the climatic battle of the First World War, Trenchard had resigned as Chief of the Air Staff in a dispute with the Air Minister. In May he accepted an offer to take command of the new Independent Force,[14] an offer made by the new Air Minister, William Weir, who during 1917 had overseen British aviation production as the Munitions Ministry's Controller of Aeronautical Supplies as well as a member of the Air Board.

The Glasgow manufacturer William Weir was, like Walter Rathenau, André Michelin and Howard E. Coffin, a leading industrialist of the era of First World War who advocated aerial bombardment of the enemy hinterland. During the war, his firm of G. and J. Weir produced the FE 2 and throughout 1917 and 1918 he would demand a sustained campaign of repeated bombardment against the industrial centers of Germany. Yet he was also a leading proponent within the British government of the fundamentally flawed Dragonfly aero-engine. It was Weir who in July 1917 had informed Lloyd George that British aviation production would soon provide a surplus in excess of the immediate needs of the army and navy. And in August, with the Puma aero-engine's problems continuing, it was Weir who initiated an effort to procure British and U.S. licensed production of the 250 hp FIAT A-12 aero-engine to equip the DH-9 day bomber.[15] This was an engine without a future as a powerplant for long range bomber aircraft.

The water-cooled, in-line six cylinder FIAT A-12's cylinder design was a copy of the cylinder in the Daimler-Mercedes D IVa, save for the differences of the A-12's use of a lower compression ratio and an integral cylinder head and barrel. This latter feature, combined with a maximum diameter bore and two, small diameter exhaust valves, failed to provide adequate cylinder cooling and complete fuel-air mixture combustion when FIAT, the gigantic Italian industrial concern located at Turin in northern Italy, attempted to increase the output of this engine to 300 hp with an increase of compression ratio approaching that used in the D IVa, an increase that actually degraded the FIAT engine's fuel efficiency. Throttling down of 300 hp FIAT A-12 *bis* aero-engines during landing would result in engine fires breaking out aboard Caproni and Voisin bomber aircraft. Nearly half of the entire Italian wartime aero-engine production would consist of these two FIAT engines and it was the FIAT A-12 *bis* that was chosen to equip the tri-engine Caproni 600 biplane bomber upon which the French and Italians attempted and failed to standardize their long-range bomber production in the last two years of the war. The French planned in 1917-1918 to import over 2,000 FIAT A-12s to equip their production of the Caproni bomber as well as the reconnaissance Breguet 14A and other aircraft. Colonel Bolling also placed a tentative order with the Italian government in September 1917 for 1,500 of the A-12 *bis* engines to equip AEF SPAD VIIb and Breguet aircraft. By the spring of 1918, the AEF Air Service in France had taken delivery of hundreds of these FIAT engines with a total payment of $2.9 million for these engines being eventually made to the French government.[16]

In September 1917, following the termination of U.S. Aircraft Board – Rolls-Royce talks in the United States, William Weir reported to the British war cabinet that “America could not be expected to provide any early help with regard to long distance bombing.” In that same month, Colonel Bolling in France cabled the U.S. War Department that “British have great need large engines for D.H. 9 and would now take Renaults and Fiats which I have bought here because both give good results D.H. 9.” When in November, British army commander General Douglas Haig joined General Trenchard in expressing concerns about the Puma aero-engine, Haig suggesting that the DH-9 could be re-equipped with the Liberty or a Rolls-Royce engine, Weir’s reply was that it would be the Puma in the DH-9 or nothing.[17] By the beginning of December, however, Weir was urgently demanding the shipment of two dozen Liberty 12 engines to Europe for flight testing in de Havilland, Breguet and other aircraft.[18] At the end of December, the AEF demanded that the U.S. War Department “cable immediately fuel capacity of D H 4. Important. Question whether D H 9 entirely satisfactory as day bomber.” In February 1918, Winston Churchill would make William Weir the official at the Munitions Ministry directly responsible for the production of British aero-engines.[19]

In December 1917, coincident with the collapse of the British aero-engine program and the beginning of the British strategic bombing campaign against Germany, General Trenchard recommended to the British government the eventual replacement of British airpower with American airpower in the equipment, manning and command of that campaign. In this regard, Trenchard also in December initiated talks with the AEF Air Service. On Christmas Day, 1917, Pierre-Étienne Flandin, the French politician and strategic bombing advocate, addressed to French premier Georges Clemenceau a twelve page memorandum that concurred in Trenchard’s recommendations. On one annotated copy of Flandin’s memorandum, beside a paragraph urging American command of the bombing campaign against Germany, appears a marginal, hand-written, single word comment: “*Boum!*”[20]

Within one month of the Puma-equipped DH-9 squadrons’ arrival at Nancy in May 1918, Trenchard was calling for their re-equipment. The use of the Puma in long range bombing operations in the last six months of the war would prove fatal to the squadrons’ men and machines and the Independent Force’s daytime strategic bombing campaign. Beginning in the latter part of May, DH-9 daytime bombing missions were directed at rail and industrial targets in Lorraine, the Saar and along the Rhine. In the spring of 1918, with the shift of French bomber forces to tactical operations, the Independent force's DH-9 daytime bombing missions were often directed at rail targets in the iron ore region that had been the object of earlier French operations, particularly at the rail yards at Metz and Thionville. In the summer of 1918, as the Allies went on the offensive in France, these Independent Force DH-9 strategic bombing missions were largely re-directed to tactical operations against airfields and troop and material concentrations located behind the German lines as well as on German airfields located east of Nancy on the east bank of the Rhine. A standard bombload of approximately 230 lb was carried during these missions and none these missions exceeded the longest distances flown by the Eagle-equipped DH-4s of No. 55 Squadron. Continual problems with cracked cylinder heads, burned-out exhaust valves and broken valve springs, all characteristics of poor cylinder cooling, added to failures in fuel lines as well as damage done by enemy fire to the Puma’s ventral radiator, combined to make the Puma a decisive liability in combat.

The arrival of the Puma-equipped DH-9 squadrons at the front in May coincided with that of the first of hundreds of Fokker D VIIs, a significant improvement in the quality if not the quantity of the German air defenses. With aircraft unable to take-off or forced to abort the mission due to engine problems, a depleted DH-9 squadron of ten or fewer aircraft would then be attacked on its way to and from the target by Fokker and Albatros pursuit formations of up to forty aircraft, aircraft which had a twenty mile per hour air speed advantage over the Puma-powered DH-9. In the summer and fall of 1918, Ernst Udet, flying Fokker D VIIF fighters powered by the 185 hp BMW IIIa aero-engine, would lead the defense of Mannheim and other Rhineland cities against this fatally flawed British air offensive and in so doing chalk up nearly half of his 62 victories. The consequent British losses of men and machines negated the British success of bringing the Puma to a state of wartime serial production, the engine's poor quality trumping its production quantity, the engine thereby becoming a critical factor in preventing the British Independent Force from building up strength sufficient to wage a significant strategic bombing campaign against the war economy of western German in 1918.[21]

In August 1918, four additional bomber squadrons joined the Independent Force at the Nancy airfields bringing the IF's total bomber strength to its wartime maximum of nine squadrons. Three of these new units consisted of twin-engine Handley-Page 0/400 night bombers equipped with the 360 hp Rolls-Royce Eagle Mark VIII aero-engine. The DH-4s of No. 55 Squadron were also at this time re-equipped with the Eagle Mark VIII. It would be the Independent Force's night bombardment squadrons which would account for two-thirds of the 543 total tons dropped by the Force in the last five months of the war and the post-war British and U.S. bombing surveys would both consistently indicate that it was these night raids that caused the most damage to targets in Germany, the Handley-Pages dropping bombs weighing up to 1,650 lb.[22]

The fourth new squadron to arrive at Nancy in August 1918, No. 110, was a day bombardment unit consisting of DH-9As powered not by the Rolls-Royce Eagle or any other British engine but by the U.S.-built Liberty 12A. Beginning in mid-August, this aircraft would be the principal reinforcement of the Independent Force, 55 of 69 replacement bombers supplied to the IF in the final months of the war being DH-9As used to replace No. 110 Squadron's heavy losses and to re-equip another of the day bomber squadrons at the time of the Armistice. Reportedly all of the DH-9As put into service during the war were equipped with the Liberty. Some of these engines may have been provided to the British in the summer of 1918 by the U.S. Navy. The DH-9A's installation of the Liberty in place of the Puma required elimination of the DH-9's bomb bay located between the engine and the pilot's cockpit. Also, by mid-August, some U.S.-built DH-4s had also been supplied to the IF and thus the Liberty 12A may have gone into front-line, daytime service with the British Independent Force before the Rolls-Royce Eagle Mark VIII.

The Liberty aero-engine proved more reliable in service than the Puma and the Liberty's 400 hp output provided the DH-9As with an increased air speed of 123 mph. Fitted with two 50 gallon fuel tanks, the DH9A had a flight time of over 5 hours.[23] Beginning in September, 1918, Independent Force Squadron No. 110 flew the first of nine combat missions conducted before the Armistice, five of which were directed at industrial and rail targets in Germany. On the raids into Germany, it carried an increased, average bombload of approximately 300 lb. However, with poor weather and an increase in German home air defense fighter squadrons in the last two months of the war, No. 110 Squadron lost a total of 17 aircraft to enemy action during the five raids directed at Mannheim-Ludwigshafen, Frankfurt-am-Main, Trier and Kaiserlautern.

These losses included some of the seven DH-9As that failed to return on October 21, 1918, when the aircraft of No. 110 Squadron, each carrying average bombload of more than 300 lb and manned by British and American aircrew, flew 155 miles northeast from its field at Bettoncourt, located 20 miles south of Nancy, to attack rail and chemical engineering targets at Frankfurt. This was the last of the five Independent Force raids on Frankfurt, three of which were conducted during daytime. One other possible target in Frankfurt would have been the Oberursel firm, since 1917 part of the holdings of Antony Fokker and which was one of Germany's principal manufacturers of air-cooled rotary aero-engines, some of which equipped the Fokker tri-plane fighters that had been flown by Richtofen and his famous *Jagdgeschwader 1*.[24] One of Germany's leading chemical engineering firms located near Frankfurt was the Chemische Fabrik Griesheim (CFG,) then engaged in production of explosives as well as the synthesis of elektron, the kaolin clay-based magnesium substitute for duralumin. CFG, AEG and the German government had been the three principal participants in 1917 in the formation of the Vereinigte Aluminumwerke, a company which remained the basis of the German aluminum industry in the inter-war years. In 1938, when

German aviation played a decisive role in the dramatic events of that year, the German aluminum industry would be the world's largest producer. Before the First World War, the Chemische Fabrik Griesheim had also manufactured and exported thousands of magnetite anodes used in the electrolytic refinery of ore at the Chuquicamata copper mine in northern Chile. CFG held the rights to a U.S. patent on these anodes and when the outbreak of the war prevented their continued delivery, the owner of Chuquicamata, M. Guggenheim's Sons' Chile Exploration Company, was forced to seek a substitute which it found in the cast-iron anodes produced by the Duriron Casting Company of Dayton, Ohio.[25]

The Independent Force's increasing use of the Liberty aero-engine to conduct its daytime strategic bombing operations coincided with its employment beginning in June of 1918 of three dozen bomber pilots of the AEF Air Service. Reflecting similar losses suffered by the Independent Force's British aircrew, half of this American contingent would be killed, wounded or captured while serving in the Independent Force. One AEF Air Service pilot would command Independent Force Squadron No. 104 in the last weeks of the war and one American veteran of 13 missions with the Independent Force would take command of one the AEF Air Service bomber squadrons in September 1918.[26]

In 1918, over five hundred Americans serving in three AEF Air Service ground crew squadrons worked at the British Independent Force air depot at Courban, located to the west of AEF General headquarters at Chaumont. These men had been trained at British aviation factories, airfields and air depots in Britain and began to report for duty at Courban in May 1918. There they helped to assemble, test, salvage and repair the aircraft and aero-engines of the Independent Force, including the IF's Handley Page and de Havilland bomber aircraft and Rolls-Royce and Liberty aero-engines.[27]

Several dozen AEF Air Service day and night bomber pilots and observers also received training and combat experience flying with front-line French bomber units in 1918, on one occasion some members of the U.S. aircrew reportedly participating in "a low bombing expedition into Germany." Many of these men, like the American aviators and ground crew with the Independent Force, would return to AEF service in the last months of the war.[28]

Notes

1 White, *Gotha Summer*, 32, 160-163; *History of the Ministry of Munitions*, 12: 9, 11, 54; Jones, *War in the Air*, 6: 8-13; G. K. Williams, *Biplanes and Bombsights*, 38; Matthew Cooper, *The Birth of Independent Air Power British Air Policy in the First World War* (London: Allen & Union, 1986), 89-90, 101-105; George K. Williams, "'The Shank of the Drill': Americans and Strategical Aviation in the Great War," *Journal of Strategic Studies* 19, 3 (Sept. 1996): 371-372, 393-394, www.oclc.org; Morrow, *Great War in Air*, 247; Mauer, ed. *U.S. Air Service in World War I*, 2: 131; NARA, RG 120, M990/6/6, A XXI, June 26, 1917, Bolling – CSO; ibid, M990/1/602-604, A I 52-54, Gorrell, "Early Activities," 45-47, Aug. 15, 1918, "Report of Aeronautical Commssion."

2 Jones, *War in the Air*, 6: 122-123; Cooper, *Birth of Independent Air Power*, 115-116; G. K. Williams, *Biplanes and Bombsights*, 34-44, 133-142; Morris, *First of the Many*, 23-24; *Aeroplane*, 13, 1 (July 3, 1917): 9-10, 12.

3 Cooper, *Birth of Independent Air Power*, 84-86; Martin Gilbert, *Winston S. Churchill Volume 4 1916-1922 The Stricken World* (Boston: Houghton Mifflin Co., 1975), 43-44, 46, 54, 67, 72; Churchill, *World Crisis 1916-1918*, 2: 24-25, 30-32, 312-313; Hoeppner, *Deutschlands Krieg in der Luft,* 139.

4 Christienne and Lissargue, *History of French Military Aviation*, 104-105; Morris, *First of the Many*, 19-20; N. Jones, *Origins of Strategic Bombing*, 111-122; G. K. Williams, *Biplanes and Bombsights*, 6-8; *History of Ministry of Munitions*, 12: 12-13.

5 Jones, *War in the Air*, 6: 123-126; G. K. Williams, *Biplanes and Bombsights*, 44, 95, 112; Morris, *First of the Many*, 25-27, 48; NARA, RG 120, M/990/10/1067-1068, 1078, 1102, B VII 80-81, 91, 115, "Statistical Analysis of Aerial Bombardments," 9-10, 20.

6 Dickey, *Liberty Engine*, 42.

7 Morris, *First of the Many*, 25, 36-37, 178, App. D; G. K. Williams, *Biplanes and Bombsights*, 84-87, 110; Wesley K. Wark, "British Intelligence on the German Air Force and Aircraft Industry, 1933-1939," *Historical Journal* 25, 3 (Sept. 1982): 636-640; Wesley K. Wark, *The Ultimate Enemy* (Ithaca: Cornell Univ. Press, 1985), 49-60; T. P. Conwell-Evans, *None So Blind* (London: Harrison & Sons, Ltd., 1947.)

Beardmore: Angle, ed. *Airplane Engine Encyclopedia*, 131; Ludvigsen, *Ferdinand Porshe*, 247; Munson, *Fighters Attack and Training Aircraft*, 99-100; *History of the Ministry of Munitions*, 12: 23; Neal, *Technical and Operational History Liberty Engine*, 11.

8 Jones, *War in the Air*, 6: 126-127; G. K. Williams, *Biplanes and Bombsights*, 63, 87, 97-98; Morris, *First of the Many*, 31; *Aerial Age*, 8, 5 (Oct. 14, 1918): 230; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 158-159; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 15; Morrow, *Great War in Air*, 296; Gilles, *Flugmotoren*, 98; Maurer, ed. *U.S. Air Service in World War I*, 4: 461-463.

[9] Jones, *War in the Air*, 6: 77; G. K. Williams, *Biplanes and Bombsights*, 75-77, 87, 116, 135-136, 171; Morris, *First of the Many*, 23; Bruce, "D.H. 4," 507; NARA, RG 120, M990/9/845, B III, Oct. 20, 1918, HQ IF RAF, "Total flying time for squadrons of the 41st Wing;" ibid, M990/10/843-845, 851 B VI 270-272, "History of the Night Bombardment Section in France."

[10] Jones, *War in the Air*, 6: 129, 132, 140-141; N. Jones, *Origins of Strategic Bombing*, 192; G. K. Williams, *Biplanes and Bombsights*, 83,166, 178, 188, 217, 272-273; Bruce, "D.H. 4," 507; Morris, *First of the Many*, 58, 48-49, 64, 91-92, 122; *Aerial Age*, 8, 4 (Oct. 7, 1918): 180; Cleona Lewis, *America's Stake in International Investments* (Washington, D.C.: Brookings Institution, 1938), 102.

[11] NARA, RG 120, M990/11/855, B XII 125, "American Fliers with the I.A.F.," 17 (quote.)

[12] G. K. Williams, *Biplanes and Bombsights*, 94, 103-104, 271-287.

[13] Sweetser, *American Air Service*, 198.

[14] Cooper, *Birth of Independent Air Power*, 120-121, 129; G. K. Williams, *Biplanes and Bombsights*, 145-146.

[15] Jones, *War in the Air*, 6: 16, 22-26, 42, 103-104, G. K. Williams, *Biplanes and Bombsights*, 49-51, 145-146, 153-155; Morrow, *Great War in Air*, 320, 322; White, *Gotha Summer*, 160-163; *Aeroplane*, 13, 17 (Oct. 24, 1917): 1164; *History of Ministry of Munitions*, 12: 5, 12-14, 50, 63; Gunston, *Development of Piston Aero Engines*, 123.

[16] Angle, ed. *Aircraft Engine Encyclopopedia*, 192-196, 266-268; Gilles, *Flugmotoren*, 93, 140-141; *Smith*, *Aircraft Piston Engines*, 41, 43; Morrow, *Great War in Air*, 49, 263-264, 285, 294, 333-334; Facon, "Coopération aéronautique franco-italienne," 23; Hudson, *Hostile Skies*, 245; *House Hearings War Expenditures – Aviation, 1919,* 584; NARA, RG 120, M990/6/217, A XXI, Sept. 5, 1917, No. 139, Bolling – AGWAR; ibid, M990/6/722, A XXI, May 8, 1918, No. 1067, GHQ AEF – AGWAR; ibid, M990/6/808, A XXI, May 31, 1918, No. 1222, GHQ AEF – AGWAR; ibid, M990/9/118-119, B I 116-117, Feb. 8, 1918, F. H. La Guardia, "Report Aviation Conditions in Italy," 1-2; ibid, M990/9/28, B I 25, J. H. Lowman, "History of Combat Division," 3; Hartmann, "Les Moteurs d'Aviation Lorraine," 7.

[17] Jones, *War in the Air*, 6: 81, 142, 168-170 (first quote, 81); Morris, *First of the Many*, 30-31; Bruce, "D. H. 9," 387; N. Jones, *Origins of Strategic Bombing*, 177; Morrow, *Great War in the Air*, 255; NARA, RG 120, M990/6/230-232, A XXI, Sept. 12, 1917, No. 3, Bolling – CSO (second quote, 231); Munson, *Fighters Attack and Training Aircraft*, 99-100; Robert Blake, ed. *The Private Papers of Douglas Haig 1914-1919* (London: Eyre & Spottswoode, 1952), 273, 280

[18] NARA, RG 120, M990/6/135-136, A XXI, Dec. 4, 1917, No. 294, Bolling – Sec. State.

[19] Churchill, *World Crisis 1916-1918*, 2: 284.

[20] NARA, RG 120, M990/10/971-972, B VI 390-391, "Early History of the Strategical Section, Air Service – Early History of Strategic Bombing;" Morrow, *Great War in Air*, 288-289; G. K. Williams, *Biplanes and Bombsights*, 49-51; Mauer, ed. *U.S. Air Service in World War I*, 2: 152; d'Abzac-Ebezy, "*Une arme à finie la guerre*," 99-110 (quote 105, n. 20.)

[21] Jones, *War in the Air*, 6: 128, 134, 140-142, 149; G. K. Williams, *Biplanes and Bombsights*, 189-203, 227-229, 283; J.M. Bruce, "D.H. 9," 386-388, 392; Morris, *First of the Many*, 63, 66, 70-71, 79-81, 83, 87, 92-93, 118, 160; Cooper, *Birth of Independent Air Power*, 134-135, 150; *Aerial Age*, 8, 3 (Sept. 30, 1918): 114; *Aeroplane*, Jan. 8, 1919, 129-130; Morrow, *Great War in Air*, 300-301, 315; Christienne and Lissargue, *History of French Military Aviation*, 122, 128; Angle, ed., *Airplane Engine Encyclopedia*, 448.

Udet: Morris, *First of the Many*, 122; Mönnich, *BMW*, 65-68; NARA, RG 242, T-971/6/773, 4376-426, Personalnachweis, Udet, Ernst.

[22] *Aeroplane*, Jan. 8, 1919, 130; Jones, *War in the Air*, 6: 157; G. K. Williams, *Biplanes and Bombsights*, 208-209, 217; Morris, *First of the Many*, 122, 135; Morrow, *Great War in Air*, 322; Gersdorff and Grasmann, *Flugmotoren und Strahltriebwerke*, 22.

[23] Grey, ed. *All the World's Aircraft, 1919*, 266a; *Aeroplane*, Jan. 8, 1919, 129-130; www.raf.mod.uk/history/dehavilland.cfm; Ministry of Munitions. Technical Department – Aviation Production. *The 12 Cylinder Liberty Aero Engine*. September 1918, 138, www.hathitrust.org; Angle, ed., *Airplane Engine Encyclopedia*, 22; NARA, RG 120, M990/6/544, A XXI, March 8, 1918, No. 693, GHQ AEF – AGWAR; ibid, M990/4/1233, A XVII 56, July 26, 1918, No. 1799-R; ibid, M990/9/390-391, B III 57-58; ibid, M990/9/629, B III 262, Dec. 20, 1918, "Report of Technical Department, Office of the Aviation officer, Base Section No. 3, SOS AEF, London."

[24] G. K. Williams, *Biplanes and Bombsights*, 199-203, 206-209, 253, 282-287; *Aeroplane*, Jan. 8, 1919, 129-130; Morris, *First of the Many*, 88, 124-125; Jones, *War in the Air*, 6: 142, 545-547; Cooper, *Birth of Independent Air Power*, 134; Morrow, *Great War in the Air*, 217; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515.

[25] Dieter Wagner, "Chemische Fabrik Griesheim – Pioneer of Electrochemistry," *Journal of Business Chemistry* 3, 2 (May 2006): 33-35, www.hathitrust.org; *Engineering and Mining Journal*, 97, 17 (Apr. 25, 1914): 870; ibid, 101, 2 (Jan. 6, 1916): 53; 101, 7 (Feb. 12, 1916): 307-314, 321-326; *Aerial Age*, 5, 21 (Aug. 6, 1917): 716. 1938 aluminum: NARA, RG 242, T177/16/3700402, GL 2 II, 23.Okt.1939, Hüttenproduktion von Aluminium.

[26] Hudson, *Hostile Skies*, 189, 250-251; Morris, *First of the Many*, 88, 97, 115; Mauer, ed. *U.S. Air Service in World War I*, 4: 94-95; G. K. Williams, *Biplanes and Bombsights*, 196; NARA, RG 120, M990/11/839-861, B XII 109-131, "American Fliers with the I.A.F."

[27] NARA, RG 120, M990/11/866-880, B XII 135-150A, "Written by Lt. M.C. Randall."

[28] Hudson, *Hostile Skies*, 239-240; NARA, RG 120, M990/11/755-797, B XII 28-68 (quote 32-33,) "History of American Aviation, G.D.E."

7. Amanty

Throughout the fall of 1917 and the winter of 1918, the United States continued to send to France the raw materials and machine tools agreed to in the August 1917 U.S.-French aviation agreement. The French supply of aircraft and engines would constitute most of the AEF Air Service equipment deployed during the war, the service aircraft procurement of SPAD pursuit, Salmson observation and Breguet bombers equipped with respectively Hispano-Suiza, Salmson and Renault aero-engines basically adhering to the recommendations made by Major William Mitchell in the spring of 1917.

The AEF spent over one billion dollars for its purchases in Europe, a mountain of money for that era and one that may be best regarded as prelude to the massive flow of American finance and investment that was directed to Europe after the war. Included in the AEF's expenditures was $139 million for its Air Service equipment, supplies and construction. This latter figure included approximately $30 million for aero-engines and engine spares, almost all of which were French. By the beginning of April 1918, approximately 1,000 French airplanes and 1,500 French aero-engines had been delivered to the AEF, most of which were for training, although these deliveries did include 20 Breguet 14B2 bombers and 26 Renault 12Fe 300 hp aero-engines. "It was not until May, 1918," AEF Air Service Chief Brigadier General Benjamin Foulois would later recall in Congressional testimony "that we got sufficient raw materials over there, about 85 percent, to give me enough of a club to go to them and say, 'You have got to deliver the goods to us.'"[1]

The 300 hp Renault 12Fe also equipped later versions of the Voisin bomber and this industrial effort would be directly translated into military power in 1918 when massed formations of French army air service single- and twin-engine Breguet, Voisin and Caudron bombers, equipped with Renault and other engines and carrying loads of fragmentation and other type bombs, engaged in large-scale, daytime, tactical bombing operations in direct and devastating support of the advancing Allied armies in France. One of the leaders of these French operations in 1918 was Captain Joseph Vuillemin who two decades later, as French Chief of Air Staff, would play a key role in the French government's policy of appeasement at the time of the Munich crisis.

These massed units of French bombers, organized as elements of Colonel Duval's *division aérienne*,[2] represented a concentrated, maximum effort. By the end of 1917, delays in the delivery of the Renault engine were hindering deliveries of the Breguet 14B2 bomber to the French air service.[3] One reason for this delay may have been the continuing need for Renault to devote its forging capacity to the increasing demands for other munitions production and the consequent need for the cylinders of the Renault 12Fe, like those of the Rolls-Royce Eagle, to be machined out of solid billets of forged steel.[4] And, similar to the situations of Rolls-Royce in Britain and Daimler-Mercedes in Germany, there would be no wartime licensed production of Renault aero-engines in France.[5]

In the summer of 1918, the French army air service front line strength of 2,820 aircraft included 435 day and night bombers. While General Pétain continued to include strategic bombing in his planning, it may have been a scarcity of adequate French bomber aircraft, as well as his determination to use aviation primarily to support French army ground operations, that influenced recommendations made by Pétain's staff to the French government on May 6, 1917, that the U.S. government be advised to place an emphasis on the U.S. production of bomber aircraft.[6]

In 1918, a secondary mission assigned to the French bomber formations would be the continued effort to impose an aerial blockade, described on at least one occasion as an encirclement, of the Thionville-Briey iron ore mining region of northeast France, then occupied by the German army, an area which served as a principal source of raw materials production consumed by the German war economy. This strategic bombing campaign was directed principally at the region's railroads. In March 1918, the German bombardment of the French bomber units' airfield at Nancy-Malzéville forced those units to move southwestward to another field at Epiez, described by one French air unit leader as "a point particularly chosen and well placed for all offensive operations against the Briey basin." During March, these French bomber units conducted raids on Conflans and other railroad stations and factories in the iron ore region as well as at least one raid on the BASF plant at Ludwigshafen. At the end of March, these units moved from Epiez to Champagne where they supported the French army throughout the spring and summer of 1918.[7] Less than one mile south of Epiez was another French airfield located at Amanty.

Shortly after the Armistice, an AEF Air Service bombardment unit commander, dissatisfied with the de Havilland DH-4 as a bomber, would advise that the Breguet 14 equipped with a Liberty aero-engine could prove to be "close to the ideal bombing plane." Carrying a 500 lb bombload, the single-engine Breguet 14B2, featuring a duralumin fuselage framework, had a 2.5 hour flight time with an airspeed of 108 mph at 10,000 feet.[8] A Breguet aircraft "complete with bomb carrier and bomb dropping device" and a Renault 300 hp engine were among the items included in the initial French aviation sample material sent to the United States in August 1917. Louis Renault had insisted that his engine be included with the Clerget, Lorraine-Dietrich and Gnôme engines for which the U.S. government initially agreed to pay $100,000 each whether put into production or not. In July, this arrangement had been endorsed by Major Bolling who explained in a cable to Washington that "Renault desires greatly to be included in manufacturers who are to receive one hundred thousand dollars each and offers send his present three hundred engine and plans, new engine above four hundred with engineers and technical men to give us all his experience period While his present three hundred engine will be superseded if other arrangements are successful it is highly regarded by both British and French for the use of Breguet bombing machines period Renault has a manufacturing establishment that now employs some twenty-four thousand workmen under conditions manufacture more like those United States than any other French plant period He is probably most effective and reliable among French engine makers and offers unusual opportunity interchange French experience and advice regarding manufacture aeroplane engines in the United States comma all of which he is not only willing but eager to give period French advise and I strongly recommend that he be included in French manufacturers receiving recognition from United States through payment mentioned." The deliveries of the Renault 300 hp engines to equip the AEF Air Service, a procurement that had been specifically endorsed as early as July 1917 by General Pershing, would however be delayed due to Renault's reliance on the supply of U.S.-built crankshafts and connecting rods to fulfill this order.[9] By the time of the Armistice, the AEF Air Service had received at the front just 36 Breguet 14B2 bombers and 117 Breguet 14A2 reconnaissance aircraft.[10]

Renault's failure to meet the French and American demand for its 300 hp engine did not result in a large supply of Liberty aero-engines to France during the war. On May 31, 1918, Secretary of War Baker responded to a request made in Washington by French High Commissioner André Tardieu for 1,000 Liberty engines with an agreement to deliver 250 by August 1.[11] After the war, General Pershing would recall a certain reluctance in wartime France to accept the Liberty, France taking delivery of just 122 Liberty engines before the Armistice and only after the Armistice formally agreeing to take delivery of several thousand Liberty engines and sets of spares, thousands of which were then sold by the French to the Soviet Union.[12] In this particular instance, the Liberty, intended for use during the war as weapon of strategic bombing, may be best regarded as having been converted into a trade commodity to help square up the post-war accounts of the United States and the Allies.

The principal exception to William Mitchell's recommendations of French supply to the AEF Air Service would be the Liberty-powered, U.S.-built DH-4, this aircraft by the time of the Armistice equipping three of the AEF Air Service's four front-line bomber squadrons and nine of its twenty-one front-line observation squadrons.[13] Of the 628 AEF Air Service DH-4s dispatched to the front in 1918, 329 were equipped for and sent to observation squadrons and 293 were equipped for and sent to bombardment squadrons.[14] One possible reason why more of these aircraft were not assigned to day bombardment duty may have been the failure to deliver all of these aircraft with bomb suspensions and releases as per AEF directive: "All DH 4 planes should arrive completely equipped for carrying American 75 millimeter fragmentation bombs and American 100 pound demolition bombs horizontally under the wings." As late as August 1918, the AEF was cabling the War Department that "Majority of DH 4 planes designed for day bombing have arrived without complete bomb equipment and must be used for reconnaissance."[15]

Following the initial recommendations of the Joint Army Navy Technical Board for U.S. production of the DH-4, U.S. aviation procurement planning had followed that of the British, changing in the summer of 1917 from the DH-4 to the DH-9. In October, the British government inquired about possible procurement of thousands of U.S.-built DH-9s "complete with engines." It was only at the beginning of 1918, after the failure of the Puma-equipped DH-9 in Britain had become evident, that U.S. procurement planning was switched back to the DH-4. As per the agreement reached in the summer of 1917 between the British authorities and Colonel Bolling, there would be no wartime licensing or royalty payments for the American production of these aircraft or of Handley Page 0/400 parts sets. The three manufacturers of the DH-4 in the United States were the Dayton-Wright Airplane Company of Dayton, Ohio, the Standard Aircraft Corporation of Elizabeth, New Jersey, a firm controlled by the Mitsui interests of Japan, and the Fisher Body Corporation of Detroit, Michigan, Fisher then being the world's largest producer of auto bodies. By January 1918, U.S. procurement plans called for the U.S. production of 8,000 DH-4 airplanes and over 20,000 Liberty 12A aero-engines. In France in 1918, the DH-4s, all equipped with the Liberty, were the only U.S.-built aircraft used by the AEF Army Air Service in front-line combat duty. In the summer of 1918, the DH-9 would be returned to the U.S. procurement planning with U.S. production of 9,000 DH-9s called for at the time of the Armistice.[16]

The other major bomber production effort in the United States during the First World War was U.S. production of another aircraft designed in Britain, the Standard Aircraft Corporation's and other manufacturers' production of the Handley-Page 0/400 night bomber. In August 1917, Frederick Handley Page had proposed to Major Bolling a plan for the assembly in France of U.S.-built parts for this aircraft. In September, planning for U.S. production called for 1,500 Handley-Pages. However, by January 1918 Britain and the U.S. had agreed on a plan calling for U.S. production of Handley-Page 0/400 parts to be followed by shipment to and assembly in Britain. Sets of parts for approximately one hundred Handley-Page 0/400s were shipped to Britain from the United States in 1918 but none of these aircraft entered front-line service with the AEF prior to the Armistice. Assembly took place at converted factory space formerly engaged in textile production in the Manchester suburb of Oldham, Winston Churchill's first House of Commons constituency.[17]

This plan had been opposed in the autumn of 1917 by Colonel Bolling who recommended an alternative but similar program for the Caproni bomber, with assembly in France of U.S.-built parts, these tri-engine biplanes to be powered by the Liberty 12. Bolling also recommended, and the APB initially agreed to, the purchase of Italian-built Caproni bombers to be equipped with FIAT and Isotta-Fraschini engines.[18]

The AEF Air Service's Handley Page bombers were to be equipped with low-compression Liberty 12 engines, the same type supplied to the U.S. Navy to equip its seaplanes and flying boats. One possible reason for this may have been an intention to increase the bombload lift capacity of these Handley Page landplanes. Also, in February 1918, the AEF notified the War Department that a tactical radius of 190 miles would be necessary for the aircraft of its night bombardment program, a capability that was reiterated for both day and night bombers in October and which would have placed Germany's mining and heavy industry concentration of the Ruhr within striking distance of AEF Air Service airfields located in the Toul sector of the western front: "Objectives day and night are factories, bridges, railroad tracks, trains, shops, stations, airdromes, rest camps, dumps of all kinds, troops in all possible formations and all kinds of transport especially in column on roads…Night bombing is essentially precision bombing and maximum accuracy desired." Planning included an initial deployment of twelve of a total thirty night bomber squadrons, each bomber carrying a bombload of up to one ton consisting of 112, 250 and/or 550 lb high explosive demolition bombs. In September 1918, the AEF Air Service ordered 550 radio-direction finding navigation sets specifically for its Handley Page night bombers.[19]

The AEF Air Service DH-4 day bomber was a biplane with spruce wood airframe covered with treated cotton fabric. It was armed with two fixed Marlin machine-guns for the pilot and one or two flexible Lewis guns for the observer and carried a standard bombload of 230 pounds on long range missions. Powered by a single, 400 hp Liberty 12A aero-engine, it had an air-speed of 117 mph at 10,000 feet altitude. Loaded, it required 14 minutes to climb to 10,000 feet.[20]. By the beginning of August 1918, the AEF DH-4 was being built with an increased fuel capacity of 98 gallons and, following consultations with French engineers at Lorraine-Dietrich, with an improved version of the French-designed Zenith carburetor featuring a fuel jet with an enlarged inner diameter. The Liberty 12 was able to maintain its specific fuel consumption of 0.51 lb/bhp/hr, then considered the standard for a well-cooled aero-engine, at three-quarters throttle and was thus able to provide the AEF DH-4 by the summer of 1918 with a flight time of up to three and three-quarters hours and a tactical radius of approximately 150 miles.[21]

One of the principal problems arising from putting the large, powerful Liberty into the DH-4 biplane was the resulting vibration of the DH-4's spruce wood framework. At the end of 1918, the U.S. Post Office would reject the Liberty-equipped DH-4 for long distance air mail service, its structure reportedly proving inadequate to carry an 800 lb load from New York to Chicago.[22]

The U.S. Marine Corps also employed the DH-4 as a day bomber during the First World War, operating out of bases at Eastleigh on the southern coast of England and near Dunkirk on the northern coast of France. These operations, conducted in conjunction with units of the British Navy and the RAF, some of which were also equipped with the DH-4, were directed principally at German submarine and naval air bases and activities located along the Belgian and Dutch coastlines. When, in August 1918, U.S. Assistant Secretary of the Navy Franklin Roosevelt visited a U.S. naval air facility at a British airfield near Dunkirk, he met with the facility's commanding officer, Thomas A. Lovett, son of the president of the Union Pacific Railroad and future U.S. Assistant Secretary of War for Air during the Second World War. Roosevelt and Lovett were then anticipating the arrival of Italian-built Caproni bombers to equip planned U.S. night bombing operations. Eighteen of the Capronis did arrive before the Armistice but they were equipped with FIAT aero-engines.[23]

The AEF Army DH-4 bombers were used during the St. Mihiel and Meuse-Argonne offensives to attack German troop and material concentrations as well as to bomb railroad centers. Prominent among this latter category of targets were four of the railroad yards of the Thionville-Briey iron ore basins. This vital area had been, up to the end of August 1918, a major objective of General Pershing's plans for the St. Mihiel offensive.[24] One of the railroad yards serving that area, located at Dommary-Baroncourt, was the target of the first combat bombing mission undertaken by an AEF Army Air Service bombardment unit when it was attacked on June 12, 1918, by six Breguet 14B2 bombers powered by 300 hp Renault 12Fe aero-engines. These aircraft were flown by the American aircrew of the AEF's 96th Aero Squadron. The rail yards at Dommary-Baroncourt were a target designated not by the AEF Strategical Aviation Section nor by the AEF General Staff but by the staff of Allied commander-in-chief General Ferdinand Foch.[25]

Before going into combat, the 96th Squadron's aircrew and ground crew had had nearly six months instruction and training in day bombardment and the Breguet-Renault bomber at the AEF's 7th Aviation Instruction Center located at Clermont-Ferrand in central France, Clermont-Ferrand being also the location of Michelin's main production plant. While some AEF aircrew received night bombing training in the U.S., in Britain, in Italy and with the Independent Force, all of the instruction at Clermont-Ferrand, instruction that was begun in December 1917, would be in day bombardment.[26] On May 18, 1918, the 96th had moved to its operational airfield at Amanty to continue its training prior to its first mission. "At this same time, through the courtesy of General Trenchard, Major A. Gray, Commanding Officer of the British 55th Squadron, I.A.F., came to spend ten days as an informal adviser to the squadron. He was able to give many practical hints which were of great value in our work."[27]

All of the thirty-six Breguet 14B2 bombers supplied to the 96th Squadron during the war were built by Michelin[28] and to the end of the war, the squadron's bombers would continue to be equipped with the Renault engine.[29] This supply would be supplemented in the summer and fall of 1918 by approximately two dozen Breguet 14A2 reconnaissance aircraft which the squadron's mechanics modified for bombardment operations. The 96th Squadron would continue to operate at the front with the Bregeut until the end of the war, using a version of the French *Vol du Canard* formation during its bombing missions, the aircrew and ground crew praising the Breguet's durability and one mechanic describing the Renault engine as "splendid." By the time of the Armistice, the 96th would account for half the total tonnage dropped by AEF bomber units.[30]

In September, three other AEF day bombardment squadrons, all equipped with the DH-4 powered by the 400 hp Liberty 12A, would be assigned to frontline service to form, along with the 96th Squadron, the First Day Bombardment Group, initially located at Amanty. The first two of these new squadrons had not been formed specifically as bomber units. Hastily outfitted with bombing equipment on the eve of the St. Mihiel offensive, the new squadrons were soon committed to daylight bombing operations during which they suffered heavy losses.

Throughout the St. Mihiel and Meuse-Argonne offensives U.S. First Army Air Service Chief Colonel William Mitchell would order his forces, including his AEF bomber squadrons, to concentrate on ground support operations,[31] particularly after an October 16, 1918, conference on that subject with General Pershing and Pershing's own conference with Marshal Foch three days earlier.[32] However, one-third of the approximately 125 total tons of ordnance dropped exclusively during daylight by AEF Air Service bombardment squadrons in combat in France in 1918 would be directed at the Dommary-Baroncourt, Conflans, Audun-le-Roman and Longuyon rail yards located on the western side of the Thionville-Briey iron ore region that also served the movement of German troops and material.[33] Most of these strategic bombing missions, supplementary to the French and British efforts to impose an aerial blockade or encirclement of the region, were conducted by the 96th Squadron prior to the beginning of the St Mihiel offensive on September 12. The AEF DH-4s also used on some of these raids generally carried a bombload of approximately 230 lb, the maximum size commonly used being a 112 lb demolition bomb, the Michelin 155 mm long, and for these DH-4 bombers the maximum tactical radius flown, that from the Amanty airfield to the Longuyon railroad yard, was a distance of approximately 60 miles. Shortly before the Armistice, the commander of the 1st Day bombardment Group identified the primary mission of day bombardment as "to destroy and harrass rear areas of the battle fields, and to attack military and industrial objectives beyond the range of artillery."[34]

As with the Daimler-Mercedes D IVa and the Rolls-Royce Eagle, the Liberty 12A would be a source of difficulty when first employed for bombing duty. The AEF DH-4 bomber squadrons would be hampered by sortie abortions due to engine failure, typically two or three, and sometimes more, of a squadron's DH-4s in their initial weeks of operations returning to their airfield before bombing the target.[35] One of the causes of these failures was the Liberty's tendency to overheat when climbing to altitude, a problem that may have been related to the relatively thin dimensions of the Liberty cylinder's head and barrel. This overheating problem was partially addressed by radiator and carburetor alterations in the summer and autumn of 1918.[36]

Both Britain and France would eventually pay millions of dollars for thousands of Liberty engines and both countries would also agree to share in financing the Liberty's development costs. Yet, in September 1918, with the British army on the offensive in northern France, the British Independent Force continuing its strategic bombing campaign including its raids into Germany, that campaign continuing to receive French logistical support, and thousands of British aircraft in storage due to lack of engines, Winston Churchill would complain in regards the Liberty that "A great part of these precious engines on which the whole of our air offensive bombing programme depends has, up to date, been swallowed up by American aviation." Shortly after the war, Newton Baker would recall that he "went to France and England and I talked to many ministers, and I want to say that those officials would have traded their guns or the Houses of Parliament for the Liberty motor.

Our conversations, no matter on what subject, always ended when they asked me how many Liberty motors we could give them and how soon we could send them over."[37] The British need for the Liberty may also have played a not insignificant part in the Wilson Administration's ability to support General Pershing's successful resistance to British efforts to amalgamate battalions of U.S. troops into British divisions in late 1917 and early 1918, efforts that were at least initially supported by presidential adviser Edward M. House. House was the son of a Galveston, Texas, cotton merchant and the Port of Galveston was a principal point of shipment of U.S. cotton exports, this country's leading trade commodity, most of which in the pre-war years was shipped to Liverpool and the textile mills of Lancashire and to Bremen, Germany, whence it was distributed to the textile mills of central Europe.[38]

Besides the Liberty aero-engine, Newton Baker possessed another powerful instrument of American policy in the year 1918 — our control of much of the world's supply of industrial raw materials. By the beginning of 1918, Allied plans to use an international control of this trade to control the post-war economic life of Germany had been explicitly rejected by American business interests and the Wilson Administration.[39] This American rejection of Allied policy did not preclude our own use of a control of raw materials supply that included our virtual monopoly of the world supply of the silver spruce wood used in Allied airframe construction and that also extended to other parts of the aviation industries, particularly the aero-engine industries, of Britain, France and Italy during the war. As one former member of both the Joint Army Navy Technical Board and the Bolling mission would note shortly after the war, "It was evident that the services which controlled the allocation of raw materials, could thereby to a large extent, control the types of machines to be manufactured."[40] One key factor of this American control was Britain's total reliance during the war on the United States for its supply of copper,[41] a vital element in the war's gigantic production of artillery shells. But an even more important aspect of this particular form of American power involved our economic relations with Germany.

The United States before, during and after the war controlled the supply of copper on the world market, copper, along with cotton and grain, then being one of our principal export commodities. As with cotton, over half of our pre-war copper production was exported and fully half of these copper exports went to Germany where American copper supplied over three-quarters of the total yearly German consumption. The principal consumer of this copper was the German electrical engineering industry, an industry lead by Siemens and AEG, and which itself supplied the principal share of the pre-war world electrical engineering market. This major consumption enabled the organized, pre-war German buying of American copper at prices less than those then available in the United States. One of the First World War's most important effects upon the economic history of the 20th Century would be the displacement of Germany by the United States as the principal supplier in the world electrical engineering market, a transition facilitated by the resumption of U.S. copper exports to Germany shortly after the war, exports financed not as before the war by European capital but by Wall Street.[42] The German electrical engineering and utilities industries would subsequently be recipients of much of the American finance and investment that flooded into Germany through the Dawes and Young reparations agreements of the 1920s, agreements principally mediated by the chairman of the General Electric Company, Owen D. Young, a lawyer. This important chapter in 20th Century financial history featured substantial sales of German government and corporate bonds in this country.[43]

Bernard M. Baruch, the Wall Street speculator and South Carolinian son of a German immigrant, had been in charge of the War Industries Board (WIB) raw materials division since the board's formation in the summer of 1917 and he would become chairman of the board in March 1918. Baruch had made his first Wall Street fortune in 1901 by successfully short-selling an attempt by the Rockefeller and other interests then in control of the Anaconda Copper Company to corner the world copper market. He would continue to be associated for a number of years with the Guggenheim interests which included such copper holdings as the Kennecott Copper Company.[44] After the war, he would head the U.S. delegation to the Economic Commission of the Paris Peace

Conference. One of his most notable achievements in this work was the inclusion in the Treaty of Versailles of Article 310 which specifically exempted pre-war U.S.-German manufacturing license agreements from the Treaty's general cancellation of such agreements between Germany and other countries. Article 310 was one of the hundreds of military, naval, aviation, economic and reparations articles of the Treaty of Versailles that were agreed to by the U.S. Senate on October 18, 1921, when the Senate ratified by a vote of 60 to 18 the U.S. Treaty of Peace with Germany. This treaty was a major step towards the institution of our unconditional most favored nation trade policy, the cornerstone of our modern foreign policy. The principal architect of the post-war implementation of this policy was U.S. Secretary of State Charles Evans Hughes.[45]

In 1912, during Woodrow Wilson's first presidential campaign, Bernard Baruch became a political ally of Wilson campaign co-chairman William G. McAdoo who subsequently became Wilson's Treasury Secretary and son-in-law. Also supporting the Wilson campaign in 1912 were two of the leaders of the U.S. copper industry, Cleveland H. Dodge, vice-president of Phelps Dodge and Company, and John D. Ryan, president of the holding company then in control of the Anaconda Copper Mining Company. These two companies were based respectively in Arizona and Montana, states carried by Wilson in the presidential election in 1912 and, most crucially, in 1916 when Wilson defeated Charles Evans Hughes in the general election and when these two states were part of that victory's narrow margin added to Wilson's political base in the cotton producing and cotton exporting South. In January 1918, upon the resignation the chairman of the War Industries Board (WIB,) Secretary of the Treasury McAdoo recommended Bernard Baruch to President Wilson as a replacement. Secretary of War Baker's recommendation was John Ryan.

In the early 1890s at Johns Hopkins University in Baltimore, Newton Baker had studied politics in classes taught by Woodrow Wilson. Baker a decade later would become the protégé of and successor to the Democratic reformist mayor of Cleveland, Ohio, Tom Johnson, during which time Baker, in his advocacy of government ownership of public utilities, oversaw the construction of Cleveland's municipal electrical power plant. In 1912, at the Democratic national convention held that year in Baltimore, Baker played a key role in securing part of the Ohio delegation's votes for Wilson. In March 1916, at the behest of Wilson, Baker resigned his office as the mayor of Cleveland and went to Washington to become Secretary of War and supervise the Administration's military preparedness program. Throughout his five years as Secretary of War, Newton Baker's principal purpose would be to serve Woodrow Wilson.

By the time of Baker's January 1918 recommendation of John Ryan as chairman of the WIB, Ryan was president of a re-organized Anaconda Copper Company in which his interests and those of other owners associated with him had replaced some of the control previously exercised in the company by the Rothschild and Rockefeller interests.[46] Bernard Baruch's appointment to lead the WIB was delayed until March by public and Congressional criticisms of the Wilson Administration's conduct of the war, criticisms which focused on the U.S. aviation program. Much of this criticism was inadvertently prompted by Newton Baker and advertently conducted by Colonel H. H. Arnold, head of the U.S. Army Signal Corps Aviation Section Aeroplane Division Information Office and a soldier possessed of fearsome political skills.[47]

Also in January, Baruch and Ryan publicly confirmed the current price being paid by the U.S. government for refined copper, 23.5 ¢/lb. This price, subsequently increased, guaranteed even to the high cost producers a substantial profit in return for a maximum production and the payment of relatively high wages in the wartime copper industry. This maximum production was continued, as with the Liberty aero-engine production, up to and after the time of the Armistice when the U.S. government and the U.S. copper industry would find themselves in possession of an enormous surplus of the metal.[48]

In January, the Allied Supreme War Council, meeting in Paris without the participation of its American representative, agreed to form an inter-allied aviation committee. The three purposes of this committee were the definition of common Allied aviation requirements, the rapid formation of the Allied strategic bombing units required for the scientific and systematic destruction of centers of enemy munitions production and the preparation of air forces to be deployed to the eastern Mediterranean. The first meeting of this committee did not take place until May.[49] In London, in January, as it had been throughout the latter half of 1917, supplies of copper were reported to be "very satisfactory" with the listed ingot ton price at half that for aluminum.[50]

In February 1918, in Washington, William C. Potter was appointed to lead the U.S. Army Signal Corps Aviation Section Equipment Division. Potter was the only non-family member of the Guggenheim Bros. firm that had been re-organized in March 1916 and he had worked as an executive in both the Guggenheims' American Smelting and Refining Company (ASARCO) and the Guggenheim Exploration Company. By 1918, he was chairman of the Continental Rubber Company of New York and the Intercontinental Rubber Company and also a director of the Guaranty Trust Company and the Guggenheims' Kennecott Copper Company.[51]

Also in February, U.S. Army Signal Corps Colonel Ambrose Monnell, president of the International Nickel Company, vice president of the Remington Arms Company and a director at Midvale Steel, was made head of the AEF Strategical Section in France and subsequently placed in charge of our night bombardment program of twin-engine Handley-Page bombers that were to be equipped with Liberty aero-engines, a program that Monnell would pattern upon the British strategic bombing program. Colonel Bolling in September 1917 had replied to an APB recommendation that Monnell be sent to France, cabling "Urgent need business man immediately approve suggestion Ambrose Monnell slight acquaintance with him but highest reports his qualifications." General Foulois later recalled that Monnell's "knowledge of big industrial organization and development along business lines was invaluable in the initial development and operation of the main air service depots, repair, and assembly plants."[52]

Formed in 1902 under the auspices of the United States Steel Corporation and with Monnell as president, the International Nickel Company was a consolidation of U.S., Canadian and British nickel and copper mines and refineries that was designed to "control with the Rothschilds…the entire output of nickel of the world." By 1918, the International Nickel Company was also the world's sole producer of Monel metal, the copper alloy containing 29% nickel. Monel was used for the water jackets encasing the cylinders of the many of the more than 15,000 Curtiss Aeroplane and Motor Corporation OX, OXX and V aero-engines produced during the war. Trainer airplanes equipped with these engines were a vital part of both the British and American wartime aviation programs. One of the principal raw material shortages hindering German wartime aero-engine production was that of nickel, forcing the Germans to use nickel-free aero-engine crankshafts in the last two years of the war.[53]

In April 1918, Howard E. Coffin resigned as chairman of the Aircraft Board. In May, Newton Baker drafted the executive order that named John D. Ryan to head the newly created Bureau of Aircraft Production, an organization that replaced the Aircraft Board. Besides being president of Anaconda, Ryan was also a director of the American International Corporation (AIC,) a firm then involved in the supply of American spruce wood to the American and Allied aviation industries as well as in the construction of the Hog Island naval shipyard. AIC would also later play a key role in the renewal of U.S. copper exports to Germany and after the war Ryan would become chairman of the Westinghouse Electric and Manufacturing Company. Appointed in August 1918 as an Assistant Secretary of War and Director of the Air Service, Ryan for the remainder of the war would oversee, as per Newton Baker's re-organization plan, not only the activities of the Bureau of Aircraft Production, managed by William C. Potter, but also those of the Directorate of Military Aeronautics, an organization separated from the U.S. Army Signal Corps and led by Major General William Kenly and his assistant, Colonel H. H. Arnold.[54]

In May, the Inter-Allied Aviation Committee held it its first meeting in Paris. Representatives included British Royal Air Force commander General Frederick Sykes and French air service commander Colonel Maurice Duval. Duval was accompanied by Lt. Colonel Dhé, an artillery officer designated by Premier Clemenceau the previous autumn as the head of the re-instituted Direction de l'Aèronautique in the

French war ministry. The U.S. representative was AEF Air Service Chief Brigadier General Benjamin Foulois, the principal author of the Joint Army Navy Technical Board report of May 1917 concerning AEF Air Service equipment procurement. Foulois, in December 1917, had made a favorable initial response to General Trenchard's inquiries as to American participation in the strategic bombing campaign against Germany. Accompanying Foulois in May 1918 to the Inter-Allied Aviation Committee meeting was Colonel Stanley D. Embick, an artillery officer and member of the Army General Staff who since September 1917 had also been the Staff's liaison officer to the Aircraft Board in the United States. Two decades later, as chief of the U.S. Army's War Plans Division, Embick would be the principal opponent within the Army General Staff to this country's military involvement and intervention in the events in Europe leading up to the outbreak of the Second World War.

At this first meeting of May 9, General Sykes confirmed to the Inter-Allied Aviation Committee the British intentions to proceed with their plans for the strategic bombing of Germany with the institution of the Independent Force. Colonel Duval, at a time when France had offered to the United States a monthly supply 150 Breguet bombers, repeated an earlier rejection of French participation, citing as one reason an insufficient quantity of French bombers. At a second meeting, held at Versailles on May 31, General Foulois would question the British decision to place Trenchard and the Independent Force under the direction of officials located in London and Foulois would concur with the French and Italian representatives that any inter-allied independent air force ought to be placed under Allied commander-in-chief General Ferdinand Foch. Foulois two days earlier had been relieved as AEF Air Service Chief by Brigadier General Mason Patrick, a West Point classmate of General Pershing and an engineering officer with no previous immediate experience in aviation.[55]

On May 29, the day he took command of the AEF Air Service, General Patrick sent a memorandum to the AEF Chief of Staff proposing the establishment of a night bombardment section and cooperation with the British Independent Force in regards joint use of the IF air depot at Courban as well as mutual U.S.-British studies of bombardment ordnance, training and target selection. In reply, on June 18, the AEF Chief of Staff demanded that AEF Air Service bombardment operations maintain their independence from the Independent Force, specifically in regards training and target selection.[56] This demand coincided with General's Trenchard's own demands for his own independent authority when he formally took command of the IF in early June. It was at this point that General Patrick turned to Ambrose Monnell.

On June 28, Patrick named Monnell as chief of the newly established AEF Air Service Night Bombardment Section. On July 9 it was Monnell who signed with General Trenchard an agreement under which three Air Service squadrons comprising hundreds of AEF Air Service ground crew did assembly and repair work at the British Independent Force depot at Courban as described above, this work in preparation for similar duty in the AEF Air Service Handley Page night bombardment program. This agreement was confirmed during Patrick's conference with Trenchard on July 26 when the two generals agreed to designate in the Zone of Advance the "Location of airdromes used by American squadrons operating with the Independent Force." And it would be Ambrose Monnell who would select the site of the AEF Air Service Handley Page night bombardment airfields at Saint-Blin, located approximately 45 miles southwest of Nancy and 15 miles northeast of the AEF headquarters at Chaumont.[57]

By the end of July, of the approximate total of 4,000 Liberty aero-engines produced in the United States, 620 had been delivered to the British, General Pershing intervening in the April of 1918 to demand that, if necessary, delivery to the British be given priority over that to the AEF, a priority necessitated by the fact that throughout the four years of the war Rolls-Royce, Britain's leading wartime producer, managed to produce little more than 5,000 aero-engines, including little more than 3,000 Eagles.[58]

Foreseeable delays in the delivery of Renault engines and U.S.-built DH-4s had by early 1918 led the AEF to inquire if the United States could supply Liberty engines to equip AEF Breguet aircraft. In early 1918, the French government and the French mission in the U.S. stated that Breguet airplanes would be available if the AEF had the engines to equip them. In the spring of 1918, both the War and Navy Departments agreed to supply the AEF Air Service with Liberty engines for the specific purpose of equipping the Breguet aircraft.[59] On June 14, by which time the first AEF bomber squadron equipped with Renault-powered Breguet 14B2s had begun combat operations at the front, General Pershing stated in a cable addressed to the U.S. Army Chief of Staff in Washington that "I urged strongly the shipment of 225 Liberty engines as they were intended for use in 150 Breguet type B2 planes, which the French will place at out disposal as soon as these engines arrive." The next day, the AEF, with orders placed to take delivery of 1,300 Liberty-powered Breguet 14B2 bombers by the end of the year, cabled the War Department to inquire about the supply of 100, 250 and 500 lb demolition bombs "in view of possible use of Breguet planes."[60]

On July 5, Newton Baker ordered the following allocation of Liberty engines for the AEF:[61]

	July	**August**	**September**
Breguet Planes for Army	180	300	375
U.S.-built Planes for Army	488	825	1,530
U.S. Navy	543	677	626
during which:			
Actual U.S. production[62]			
Liberty engine	1,589	2,297	2,362
DH-4	484	224	757

When Major General W.S. Brancker, the former British deputy director of military aeronautics, had visited Washington in early July in regards American participation in a British program to bomb Berlin with aircraft launched from airfields in England, Baker stated that his priority purpose for the U.S. aviation program was the support of the AEF in France.[63] By the end of July, with the Allied armies back on the offensive in France, War Department deliveries of Liberty engines to the British were stopped and they would not be resumed until the time of the Armistice, despite the recommendations of the AEF. Throughout the last few months of the war, with the British Independent Force continuing its strategic bombing campaign against Germany, with that campaign continuing to receive French construction and logistics support, and with thousands of British airplanes in storage due to a lack of aero-engines, the AEF would repeat its recommendations that the War Department supply the Liberty to the Allies, the AEF estimating monthly surpluses of several hundred engines beyond the immediate requirements of the AEF Air Service. In August, with a total production by the end of that month of 6,000 Liberty engines, five times the total U.S. DH-4 production, the AEF cabled the War Department urging that approximately half of the allocation of Liberty production for the balance of the year be delivered to the Allies and that the same be done in 1919: "There must be supplied at least 5000 engines which can thus be allocated to our Allies by 31 December 1918…after 1 January 1919 there should be available for allocation to our Allies not less than 2000 Liberty engines per month." In response, the War Department referred to War Secretary Baker's July 5th Liberty allocation directive, adding "We expect to deliver very few engines to Allies prior to October 1st."[64]

It was U.S. Assistant Secretary of War and Director of Air Service John D. Ryan who would handle the negotiations with the Allies, negotiations that included Ryan's meeting with Winston Churchill, for the Allies' procurement of the Liberty aero-engine when Ryan accompanied Newton Baker to Europe in August and September 1918. On September 27, with the stop on War Department Liberty deliveries to the British still in effect, Ryan made a verbal agreement with French authorities for the delivery of 1,500 Liberty engines. On September 28, Ryan cabled Washington, stating "I have decided that after deducting allotment for the Navy in accordance with present arrangements all the remaining Liberty 12 engines must be shipped upon completion to the Air Service production center…where they will distributed to the AEF and the French…I will modify this later by British allotment." On October 24, by which time Liberty production designated for delivery to the British had been resumed in the United States, Ryan, anticipating the delay until December of assembly in England of the first AEF Liberty-powered Handley Page bombers, cabled the AEF Service of Supply: "Suggest we hold shipment of engines from United States until 30 days before components are ready for erection. Important that no engines remain idle. If engines already shipped for Handley Page will not be used for some time, suggest you give them to British if they can use them now."[65]

Newton Baker would later recall that Ryan during their visit to Europe "was especially interested in aircraft, and went up to the front where the squadrons were." At that time, Ryan had the opportunity to meet with Brigadier General William Mitchell who later recalled that Ryan possessed what appeared to Mitchell to be a superior understanding of the situation in which both men found themselves. In early November, one week before the Armistice, United States Secretary of War Newton Diehl Baker would write to the U.S. Army Chief of Staff to denounce the unnecessary bombing of civilian and industrial targets in enemy countries.[66]

The AEF Air Service's strategic and ground support bombing missions were initially conducted from the Amanty airfield, a site which thus may properly be considered to be the birthplace of U.S. strategic bombing operations. Amanty is a small rural town in the Meuse department of eastern France located approximately 35 miles southwest of Nancy and five miles north of Domrémy-la-Pucelle, the birthplace of Saint Joan of Arc. On June 12, 1918, British Independent Force commander Brigadier General Hugh "Boom" Trenchard was present at the Amanty airfield when the AEF Air Service began those operations.[67] Six months earlier, when upon the collapse of the British aero-engine development program General Trenchard had made proposals to the AEF Air Service in regards the conduct of strategic bombing operations against Germany, he had had the opportunity to meet with one of the principal architects of American airpower in the 20th Century, the then twenty-six year old U.S. Army Signal Corps Major Edgar Staley Gorrell, head of the AEF Air Service Strategical Section and a native of Baltimore, Maryland, who earlier in the year had been a member of both the Joint Army Navy Technical Board and the Bolling mission and whose post-war statements have been frequently quoted in the above.[68]

American planning for long-range strategic bombing during the First World War had culminated in Gorrell's November 28, 1917, "Proposal for Bombing Campaign," a plan derived, and for the most part copied, directly from British and French plans. Predicting a continuation of the German Gotha bomber raids on England, Gorrell called for a bombing campaign directed against German industry "in order that we may not only wreck Germany's manufacturing centers but wreck them more completely than she will wreck ours next year."[69] Gorrell's proposed targets included "the large Mercedes engine plants and the Bosch magneto factories" located in Stuttgart as well as other industrial sites in the Ruhr, the Saar, Mannheim-Ludwigshafen and Frankfurt-am-Main. As bases for this campaign, Gorrell proposed airfields near Toul and Souilly. Souilly, the headquarters of General Pétain located on the famed *Voie Sacrée* southwest of Verdun, would also serve as headquarters in the last weeks of the war for Lieutenant General Pershing and Brigadier General Mitchell. The distance from Souilly to Mannheim is 150 miles. And to conduct this strategic bombing campaign Gorrell referred, a month before the first of the modified airplane production contracts was signed and more than two months before the first deliveries were made in the United States, to a possible force of "two thousand daylight bombarding airplanes of the DH-4 type."[70]

Edgar Gorrell's "Proposal for Bombing Campaign" also contains the "shank-of-the-drill" metaphor, often referred to and cited by historians of U.S. strategic bombing,[71] as well as an identification of the American proponents of the bombing of Germany, a group notable for its failure to include the Administration of President Woodrow Wilson:

> By strategical bomb-dropping is meant, in the larger sense of the word, bomb-dropping against the commercial centers of Germany. An army may be compared to a drill. The point of the drill must be strong and must stand up and bear the brunt of much of the hard work with which it comes into contact; but unless the shank of the drill is strong and continually reinforcing the point, the drill will break. So with the nation in a war of these days, the army is like the point of the drill and must bear the brunt of constant conflict with foreign obstacles; but unless the nation – which represents the shank of the drill – constantly stands behind and supplies the necessary aid to the point, the drill will break and the nation will fail…
>
> The money appropriated by the American Congress was appropriated with the idea in view of dropping the maximum tonnage of bombs on German manufacturing centers and means of transportation, and the American public as well as American industries and financial purse-strings lend themselves to this idea and have so lent themselves since

the beginning of the War. We find America today building an aerial program with the sole idea of such a campaign against Germany.[72]

Notes

[1] Mauer, ed. *U.S. Air Service in World War I*, 1: 25, 117; *House War Expenditures Hearings – Aviation, 1919*, 375 (quote), 487, 552-554; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 512; Dawes, *Journal of Great War*, 227; Mingos, ed. *Aircraft Yearbook 1922*, 195-196; *Aviation*, Apr. 25, 1921, 525; NARA, RG 120, M990/6/24, A XXI, July 6, 1917, Bolling – Sec. State; ibid, M990/6/808, A XXI, May 31, 1918, No. 1222-S, GHQ AEF – AGWAR.

[2] Christienne and Lissargue, *History of French Military Aviation*, 115-116, 122-128; W. Mitchell, *Memoirs of World War I*, 265-266; Facon, "Aperçus sur la doctrine d'emploi de l'aéronautique," 88-89; Facon, "1918, ou l'emploi en masse de l'aviation," 95-97; Patrick Facon, "Coopération aéronautique franco-italienne pendant la Grande Guerre," *RHA* 252 (2008), ¶ 26; Valluy, *Première Guerre Mondiale 1916-1918*, 168-169, 195; Morrow, *Great War in Air*, 282-287; Taylor, ed. *Combat Aircraft of the World*, 133; NARA, RG 120, M990/10/846, B VI, Feb. 15, 1918, "French Day and Night Bombardment Squadrons."

[3] Morrow, *Great War in Air*, 213.

[4] Chadeau, *De Blériot à Dassault*, 101; Sherbondy, "Details of German Aviation Engines," 524; NARA, RG 120, M990/25/505, H III 408, Lr. Gray, "Renault Water-Cooled Engine 300 H.P.," Technical Memorandum No. 64, HQ, 2nd Motor Mechanics Regiment, 26.

[5] Gérard Hartmann, "Les Moteurs d'Aviation Renault," 15; Morrow, *Great War in Air*, 293.

[6] Facon, "1918, ou l'emploi en masse de l'aviation," 93; *House Hearings War Expenditures – Aviation, 1919,* 167-169; Patrick Facon, "Le comité interalliée de l'aviation ou le problème du bombardement stratégique de l'Allemagne en 1918," *RHA* 180 (1990): 94, www.rha.revues.org; Facon, "Aperçus sur la doctrine," 88; Morrow, *Great War in Air*, 199-200, 288.

[7] Chambre des Députés. *Procès-Verbaux de la commission d'enquète sur le rôle et al situation de la métallurgie en France (Bombardement de bassin de Briey)*, No. 6026. Paris: Martinet, 1919, 3: 16, 34-35, 47-48 (quote 16), www.hathitrust.org; Dubreil, "Le bombardement en 1916," 61; Mauer, ed. *U.S. Air Service in World War I*, 4: 367-411; Morrow, *Great War in Air*, 287; G. K. Williams, *Biplanes and Bombsights*, 55-57, 61.

[8] Mauer, ed. *U.S. Air Service in World War I*, 4: 84-93 (with quote, 89;) NARA, RG 120, M990/10/280, B VI, "Comparative Data on Night Bombardment Planes."

[9] NARA, RG 120, M990/6/24, A XXI, July 6, 1917, Bolling – Sec. State (first quote); ibid, M990/6/160, A XXI, July 14, 1917, Bolling – CSO; ibid, M990/6/159, A XXI, July 17, 1917, No. 47, Bolling – AGWAR (second quote); ibid, M990/6/161, A XXI, July 17, 1917, GHQ AEF – AGWAR; ibid, M990/7/31, A XXII, July 23, 1917, No. 48, AGWAR – Pershing; ibid, M990/7/28, A XXII, July 23, 1917, No. 47, AGWAR – Pershing; ibid, M990/7/44, A XXII, Aug. 5, 1917, No. 75, AGWAR - HQ AEF; ibid, M990/6/179, A XXI, Aug. 7, 1917, No. 78, Bolling – AGWAR; ibid, M990/6/182, A XXI, Aug. 8, 1917, No. 86, Bolling – AGWAR; ibid, M990/6/238-239, A XXI, Sept. 19, 1917, No. 168, Bolling – AGWAR; ibid, M990/6/35, A XXI, Sept. 20, 1917, No. 171, Bolling – Sec. State; ibid, M990/7/179, A XXII, Oct. 30, 1917, No. 350, AGWAR - HQ AEF; ibid, M990/7/201, A XXII, Nov. 11, 1917, No. 380, AGWAR - HQ AEF; ibid, M990/7/221, A XXII, Nov. 18, 1917, No. 408, AGWAR - HQ AEF; ibid, M990/6/123, A XXI, Nov. 26, 1917, No. 282, Bolling – Sec. State; ibid, M990/6/394, A XXI, Jan. 5, 1918, No. 450, GHQ AEF – AGWAR; M990/7/359-360, A XXII, Jan. 11, 1918, No. 618, AGWAR - GHQ AEF; ibid, M990/7/365, A XXII, Jan. 12, 1918, No. 624, AGWAR - HQ AEF; ibid, M990/4/1287, A XVII 110, Feb. 27, 1918, No. 833-R; Gérard Hartmann, "Les Moteurs d'Aviation Renault," 15.

[10] Mauer, ed. *U.S. Air Service in World War I*, 1: 25; Taylor, ed. *Combat Aircraft*, 74.

[11] *House Hearings War Expenditures – Aviation, 1919,* 555.

[12] Neal, *Technical and Operational History Liberty Engine*, 207-211; NARA, RG 120, M990/4/1541, A XVII 361, Sept. 28, 1918, No. SOS 193-S; ibid, M990/6/1131, A XXI, Dec. 27, 1918, No. 2011, GHQ AEF – AGWAR; Pershing, *Experiences*, 2: 130.

[13] Mauer, ed. *U.S. Air Service in World War I*, 3: 132, 162; 4: 95, 119-120, 131-132, 248; *House War Expenditures Hearings – Aviation, 1919*, 32-33, 36, 166-181, 354, 487; *House Report No. 637, 1920*, 1: 2, 7-14, 2: 20-24; *Senate Aircraft Production Hearings, 1918*, July 16, 1918, 750-759; Sweetser, *American Air Service*, 307.

[14] NARA, RG 120, M990/1/670, A I 120, Foulois, "Lessons Learned," 39, W.C. Allen, "Review of Activities. Production and Maintenance Division."

[15]NARA, RG 120, M990/6/867, A XXI, June 14, 1918, No. 1303, GHQ AEF – AGWAR (first quote); ibid, M990/6/946, A XXI, July 12,1918, No. 1154, GHQ AEF – AGWAR; ibid, M990/6/966, A XXI, July 18, 1918, No. 1481, GHQ AEF – AGWAR; NARA, RG 120, M990/4/1231, A XVII 54, July 20, 1918, No. 1750-R; ibid, M990/4/1232, A XVII 55, July 26, 1918, No. 1765-R; ibid, M990/6/1017, A XXI, Aug. 6, 1918, No. 1564, GHQ AEF – AGWAR (second quote.)

16 *House War Expenditures Hearings – Aviation, 1919*, 194-210; *House Report No. 637, 1920*, 1: 2, 98-99, 102, 107-108; 2: 16-19; *Senate Aircraft Production Hearings, 1918*, 283-285; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 515; NARA, RG 120, M990/6/19, A XXI, July 1, 1917, No. 39, Bolling - CSO; ibid, M990/6/20, A XXI, July 1, 1917, No. 42, Bolling – Coffin; ibid, M990/6/190, A XXI, Aug. 12, 1917, No. 96, Bolling – AGWAR; ibid, M990/6/201, A XXI, Aug. 20, 1917, No. 115, Bolling – AGWAR; ibid, M990/7/124, A XXII, Oct. 10, 1917, No. 260, AGWAR – GHQ AEF (quote); ibid, M990/9/419-420, B III 84-85, Dec. 23, 1918, "Report of Activities of Finance and Accounts Office, United States Air Service, Headquarters, London," 18-19; ibid, M990/4/1219, A XVII 42, Dec. 26, 1917, No. 565, AGWAR – GHQ AEF; Mauer, ed. *The U.S. Air Service in World War I*, 1: 25, 88; *Aerial Age*, Sept. 30, 1918, 113; Mingos, ed. *Aircraft Yearbook 1922*, 191-192; Sweetser, *American Air Service*, 192; Mixter and Emmons, *Aircraft Production Facts*, 47-48; Bruce, "D.H. 4," 506-507; J.M. Bruce, "The De Haviland D.H. 9," *Flight,* April 6, 1956, 386-389, 392; ibid, *Flight*, 69, 2463, (April 13, 1956): 422, 425, www.flightglobal.com/pdfarchive.

17 Patrick, "Final Report," 252-253; "Hughes Aircraft Report," *Aerial Age*, 8, 10 (Nov. 18, 1918): 514; Sweetser, *American Air Service*, 203-205, 310; Mixter and Emmons, *Aircraft Production Facts*, 51-52; NARA, RG 120, M990/6/203, A XXI, Aug. 23, 1917, No. 121, Bolling – AGWAR; ibid, M990/6/361, A XXI, Dec. 12, 1917, Bolling – AGWAR; ibid, M990/7/240, A XXII, Nov. 24, 1917, No. 438, AGWAR - GHQ AEF; M990/9/408-409, B III 73-74, Dec. 23, 1918, "Report of Activities of Finance and Accounts Office, United States Air Service, Headquarters, London," 6-7; ibid, M990/10/557-575, B VI 1-17, "History of the Night Bombardment Section in France;" Hudson, *Hostile Skies*, 19-20, 40; *History of Ministry of Munitions*, 12: 81, 98-99; Williams, "Shank of the Drill," 408; Mauer, ed. *U.S. Air Service in World War I*, 2: 191; Clodfelter, *Beneficial Bombing*, 29.

18 NARA, RG 120, M990/6/238-239, A XXI, Sept. 19, 1917, No. 168, Bolling – AGWAR; ibid, M990/7/113, A XXII, Oct. 2, 1917, No. 229, AGWAR – GHQ AEF; ibid, M/990/6/45-46, 49, A XXI, Oct. 9, 1917, No. 193, Bolling – Sec. State; ibid, M990/6/81, A XXI, Nov. 3, 1917, No. 239, Bolling – Sec State; ibid, M990/6/109, A XXI, Nov. 19, 1917, No. 269, Bolling – Sec. State; ibid, M990/6/110-112, A XXI, Nov. 20, 1917, No. 273, Bolling – Sec. State; ibid, M990/6/130, A XXI, Nov. 30, 1917, No. 288, Bolling – Sec. State; ibid, M990/6/378, A XXI, Dec. 21, 1917, No. 422, Bolling – CSO.

19 NARA, RG 120, M990/4/1509, A XVII 329, Oct. 2, 1918, No. London 217-R; ibid, M990/4/1512, A XVII 332, Oct. 24, 1918, No. SOS 211-R; ibid, M990/6/517, A XXI, Feb. 22, 1918, No. 635, GHQ AEF – AGWAR; ibid, M990/4/1494, A XXI 314, Apr. 2, 1918, No. 1023-R; ibid, M990/6/1075-1076, A XXI, Oct. 3, 1918, No. 1738, GHQ AEF – AGWAR (quotes;) ibid, M990/10/831, 841-842, B VI 258, 268-269.

20 Mixter and Emmons, *Aircraft Production Facts*, 47-48, 63-64; *House War Expenditures Hearings – Aviation, 1919*, 166, 175-176; *House Report No. 637, 1920*, 2: 20-21; Munson, *Bombers Patrol and Reconnaissance Aircraft 1914-1919*, 60, 137-138; Arnold, *Global Mission*, 66; Crowell, *America's Munitions*, 254-256; *Aerial Age*, 3, 1 (March 19, 1917): 13.

21 Vincent, "The Liberty Aircraft Engine," 420-421, 426; Marks, *Airplane Engine*, 28, 36-37; Dickey, *Liberty Engine*, 52; *Senate Aircraft Production Hearings, 1918*, 752-754; Arnold, *Global Mission*, 66; Bruce, "D.H. 4," 510; Mixter and Emmons, *Aircraft Production Facts*, 47-48; NARA, RG 120, M990/4/1232, A XVII 55, July 20, 1918, No. 1704-R; Crowell, *America's Munitions*, 256; *House Report No. 637, 1920*, 2: 16, 20-21; Sweetser, *American Air Service*, 247; Bradley, "Lorraine-Dietrich Production of Airplane Engines," 449.

Fuel efficiency: H. Marmon, "Comparison of Airplane and Automobile Engines," 152; A. H. Gibson, "Aero-engine Efficiencies," 239.

22 *Air Service Journal*, 4, 2 (Jan. 11, 1919): 15; Mauer, ed. *U.S. Air Service in World War I*, 4: 87-88; Robert J. Raymond, "The Liberty Engine and Torsional Vibration," July 17, 2008, AEHS, www.enginehistory.org.

23 *Aviation*, Aug. 2, 1926, 178-179; *Aerial Age*, 8, 8 (Nov. 4, 1918): 416; Morrow, *Great War in the Air*, 340; Elliott Roosevelt, ed. *The Roosevelt Letters. Volume Two. 1905-1928* (London: George G. Harrop & Co., Ltd., 1950), 319-320; NARA, RG 120, M990/10/563, B VI 5, "History of the Night Bombardment Section in France," 5; G. K. Williams, *Biplanes and Bomsights*. 34; Heinkel, *Stürmisches Leben*, 89-93.

24 Mauer, ed. *U.S. Air Service in World War I*, 1: 357-375 ; 2: 238-239; 4: 367-369; Pershing, *Experiences*, 2: 171-172, 245, 250-253, 263, 270, 377-378, 383; Philip Noel-Baker, *The Private Manufacture of Armaments* (New York: Oxford Univ. Press, 1937), 42-46; Valluy, *Première Guerre Mondiale 1916-1918*, 134; G. K. Williams, *Biplanes and Bombsights*, 61; Kennet, *History of Strategic Bombing*, 29, 49-50; *United States Army in the World War 1917-1919*, 8: 240-241.

25 Patrick, "Final Report," 227; Mauer, ed. *U.S. Air Service in World War I*, 1: 357-361; 4: 371-372; Sweetser, *American Air Service*, 319-320; Hudson, *Hostile Skies*, 85-86; NARA, RG 120, M990/1/617, A I 67, Gorrell, *Early Activities*, 60, Aug. 15, 1918, "Report of Aeronautical Commssion"; Clodfelter, *Beneficial Bombing*, 26.

26 Hudson, *Hostile Skies*, 34-35, 39-40; Sweetser, *American Air Service*, 311-312; NARA, RG 120, M990/1/630, A I 80, E. S. Gorrell, "Early Activities," 73; ibid, M990/14/62, C VIII 59, "1st Day Bombardment Group." 1; ibid, M990/19/624, E XIV 2, "96th Aero Squadron (Bombardment)," 2.

27 NARA, RG 120, M990/19/626-626, E XIV 3-4, "96th Aero Squadron," 3-4 (quote.)

Gray: Morris, *First of the Many*, 36, 177.

28 Neal, *Technical and Operational History Liberty Engine*, 207-209; Mauer, ed. *U.S. Air Service in World War I*, 1: 25.

29 NARA, RG 120, M990/2/108, A IV 82; ibid, M990/2/966-969, A VII 134-137, July 29, 1918, "Airplane Program Proposed by General Patrick – Day Bombing," 28-31; ibid, M990/2/222, A IV 186, Oct. 1918, "Motors – Status and Progress (Installed and Spare.)

30 NARA, RG 120, M990/14/69-70, C VIII 66–67, "1st Day Bombardment Group," 4-5; ibid, M990/19/691, 696-697, E XIV 69, 74-75 (quote 75), "Engineering Department 96th Squadron;" ibid, M990/19/625, 633 E XIV 3, 11 "96th Aero Squadron," 3, 11.

31 Mauer, ed. *U.S. Air Service in World War I*, 1: 19; 2: 247-249, 365, 368, 371; 3: 137-137; 4: 95, 119-120 , 367; Hudson, *Hostile Skies*, 170-191, 261, 271-278; NARA, RG 120, M990/14/7, C VIII 4, Jan. 6, 1919, "Air Service in 1st Army – Date of Organization;" ibid, M990/16/750, E III 1, "Report upon the Organization and Training of 11th Aero Squadron," 1; ibid, M990/19/625, E XIV 3, "96th Aero Squadron," 3.

32 Mauer, ed. *U.S. Air Service in World War I*, 1: 317-318, 344; Pershing, *Experiences*, 2: 335, 337; *United States Army in the World War 1917-1919*, 8: 92; Foch, *Memoirs*, 434-435; Christienne and Lissargue, *History of French Military Aviation*, 174.

33 Mauer, ed. *U.S. Air Service in World War I*, 1: 20; Morrow, *Great War in Air*, 287; NARA, RG 120, M990/14/84, C VIII 81, "1st Day Bombardment Group Summary August 1918."

34 Hudson, *Hostile Skies*, 272-273; Mauer, ed. *U.S. Air Service in World War I*, 4: 366-376; Holley, *Ideas and Weapons*, 157; *Aerial Age*, 8, 2 (Sept. 23, 1918): 61-62; Christienne and Lissargue, *History of French Military Aviation*, 174; NARA, RG 120, M990/6/855-858, A XXI, June 14, 1918, No. 1303, GHQ AEF – AGWAR; ibid, M990/14/12, C VIII 9, Oct. 29, 1918, HQ 1st Day Bomb Grp – CAS (quote;) ibid, M990/19/627, E XIV 5, "96th Aero Squadron," 5.

35 Mauer, ed. *U.S. Air Service in World War I*, 1: 19, 357-375; 3: 213-218, 437-450, 474-479, 548, 616-619, 628, 648-650; Hudson, *Hostile Skies*, 86, 128-131, 272.

36 Dickey, *Liberty Engine*, 46; Sweetser, *American Air Service*, 196; Neal, *Technical and Operational History Liberty Engine*, 132; Marks, *Airplane Engine*, 124-125.

37 *Air Service Journal*, 4, 6 (Feb. 8, 1919): 7 (second quote;) Neal, *Technical and Operational History Liberty Engine*, 71, 121, 197-198; Jones, *War in the Air*, 6: 49-54 (first quote, 54); *House War Expenditures Hearings – Aviation, 1919*, 13, 36, 128-129, 153, 174, 217, 225, 504, 555, 555A; *House Report No. 637, 1920*, 2: 27-28; *History of Ministry of Munitions*, 2: 87; ibid,12: 81; Mixter and Emmons, *Aircraft Production Facts*, 25-26; Sweetser, *American Air Service*, 181, 239-240; Crowell, *America's Munitions*, 278-280; Dickey, *Liberty Engine*, 66-67; Palmer, *Newton D. Baker*, 2: 338; Pershing, *Experiences*, 2: 125, 130, 177; Morris, *First of the Many*, 89; G. K. Williams, *Biplanes and Bombsights*, 171.

38 Link, ed. *Papers of Woodrow Wilson*, 45: 323-324, 328, 438; 46: 8-11, 42-44, 162, 196-198, 211-212; 47: 229, 369-379, 436, 455; 48: 71.

Cotton: Donald L. Breed, "Cotton Textile Industry of Germany," *Trade Information Bulletin No. 9*, March 31, 1922, 1; H.M. Strong, "Distribution of Agricultural Exports from the United States," *Trade Information Bulletin No. 177*, Jan. 24, 1924, 5-6, 11-12, 18-20; Ernest L. Tutt and William R. Meadows, "Marketing Cotton for Export," *Trade Information Bulletin No. 288*, Nov. 1924, 1-4, 11-12.

39 Parrini, *Heir to Empire*, 15-16, 37, 214-215; Orde, *British Policy and European Reconstruction*, 6-20; Link, ed. *Papers of Woodrow Wilson,* 45: 440-441, 459, 551; 46: 5-8, 14-15.

40 *House War Expenditures Hearings – Aviation, 1919*, 386, 395; *History of Ministry of Munitions*, 2: 101; ibid, 12: 62, 121, 125; *FRUS 1917*, supp. 2, vol. 1, 431-445; NARA, RG 120, M990/6/11, A XXI, June 28, 1917, Bolling – Coffin; ibid, M990/6/20, A XXI, July 1, 1917, No. 42, Bolling – Coffin; ibid, M990/6/154-155, A XXI, July 16, 1917, No. 44, Bolling – AGWAR; ibid, M990/6/156-157, A XXI, July 16, 1917, No. 46, Bolling - AGWAR; ibid, M990/6/34, A XXI, Sept. 19, 1917, Bolling – Sec. State; ibid, M990/6/89, A XXI, Nov. 7, 1917, No. 248, Bolling – Sec State; ibid, M990/6/13, A XXI, Dec. 3, 1917, No. 293, Bolling – Sec. State; ibid, M990/6/403, A XXI, Jan. 8, 1918, No. 466, HQ AEF – AGWAR; ibid, M990/1/624, A I 74, Gorrell, "Early Activities," 67 (quote;) d'Abzac-Ebezy, "*Une arme à finie la guerre*," 107; *Aviation*, May 9, 1921, 604; *Aerial Age*, 8, 6 (Oct. 21, 1918): 304.

41 *History of Ministry of Munitions*, 2: 60-61; ibid, 7: 42-43.

42 *New York Times*, Feb. 10, 1918, II: 4; ibid, March 24, 1918, VIII: 6; Rudolf Lenz, *Der Kupfermarkt unter dem Einflusse der Syndikate und Trusts* (Berlin: Verlag für Fachliterateur G.m.b.H., 1910), 30-31, 138, 141-142, www.hathitrust.org; *Engineering and Mining Journal*, 97, 23 (June 6, 1914): 1160; Parrini, *Heir to Empire*, 28-29, 75-76, 95-97; *House Hearings War Expenditures – Aviation, 1919,* 76-79; Link, ed. *Papers of Woodrow Wilson,* 46: 58-59; Lewis, *America's Stake in International Investments*, 233-234, 299; Isaac F. Marcosson, *Anaconda* (New York: Dodd, Mead & Co., 1957), 160; Ron Chernow, *The Warburgs*. New York: Random House, 1993, 224; Wilfried Feldenkirchen, *Siemens 1918-1945* (München: R. Piper GmbH & Co. KG, 1995), 118; Werner Link, *Die amerikanische Stabilierungspolitik in Deutschland 1921-32* (Düsseldorf: Droste Verlag, 1970), 69-71; Newton D. Baker, *Why We Went to War* (New York: Harper & Bros., 1936), 110; Thomas Butts, "Exports of Electrical Equipment from Germany 1913-1927," *Trade Information Bulletin 548*, 1928, ii, www.hathitrust.org.

43 "American Underwrititng of German Securities," *Trade Information Bulletin 648*, 1929, 3, 14; "American Underwriting of Foreign Securities in 1930," *Trade Information Bulletin 746*, 1931, 13; U.S. Senate. Hearings. Committee on Finance. Sale of Foreign Securities. 72nd Congress, 1st Sess. Part I, Dec. 18, 19, 21, 1931, Part II, Jan. 4-7, 1932, 496, 506; James W. Angell, *The Recovery of Germany* (Westport: Greenwood Press, 1972), 155; Sigfrid v. Weiher, and Herbert Goetzeler, *Weg und Wirken der Siemens-Werke in Fortschrtitt der Elektro Technik, 1847-1972* (Göttingen: Zeitschrift für Firmengeschichte und Unternehmerbiographie, 1972), 95, 99; Link, *Amerikanische Stabilierungspolitik*, 371-374; Feldenkirchen, *Siemens*, 109, 117-119, 482-483, 488, 702; Gerald D. Feldman,"The Deutsche Bank from World War to World Economic Crisis," in *The Deutsche Bank* (London: Weidenfeld & Newton, 1995), 238; Mira Wilkins, *The Maturing of Multinational Enterprise. American Business Abroad from 1914 to 1970* (Cambridge: Harvard Univ. Press, 1974), 67-69; Robert C. Perez and Edward F. Willett, *The Will to Win. A Biography of Ferdinand Eberstadt* (New York: Wood Press, 1989), 31; Robert Sobel, *The Life and Times of Dillon, Read* (New York: Truman Talley Books/Dutton, 1991), 102-105, 167.

44 Marcosson, *Anaconda*, 93-95; Bernard M. Baruch, *Baruch My Own Story* (New York: Henry Holt and Co., 1957), 126-131; Clarkson, *Industrial America in World War*, 22-27; Thomas W. Lawson, *Frenzied Finance Volume I The Crime of Amalgamated* (New York: The Ridgway-Thayne Co., 1905), 3-4, 23-48, www.hathitrust.org.

45 Bernard M. Baruch, *The Making of the Reparation and Economic Sections of the Treaty* (New York: Harper & Bros. Publishers, 1920), 116-122, 279; *Senate Peace Treaty with Germany, 1921*, 95-96, in U.S. Senate. Reports. Committee on Foreign Relations. 67th Congress, 1st Sess. Report No. 2, Parts 1-2. Peace with Germany, April 25, 1921, www.hathitrust.org; Link, *Stabilierungspolitik*, 89-100; Merlo J. Pusey, *Charles Evans Hughes* (New York: Macmillan Co., 1951), 440-442; Charles Cheney Hyde, "Charles Evans Hughes," in *The American Secretaries of State and Their Diplomacy*, vol. 10, ed. Samuel Flagg Bemis (New York: Cooper Square Publishers, 1963), 227-228.

46 William G. McAdoo*, Crowded Years* (Boston: Houghton Mifflin Co., 1931), 109-122; Marcosson, *Anaconda*, 99; Lenz, *Kupfermarkt*, 109, 112, 122, 124; Clarkson, *Industrial America in World War*, 54-58; *Report of the Amalgamated Copper Company for the Sixteen Months Ending April 30, 1915*, www.hathitrust.org; Link, ed. *Papers of Woodrow Wilson,* 46: 17; Arthur S. Link, *Wilson The Road to the White House* (Princeton: Princeton Univ. Press, 1947), 403; Daniel R. Beaver, *Newton D. Baker and the American War Effort 1917-1919* (Lincoln: Univ. of Nebraska, 1966), 75.

Baker: C. H. Cramer, *Newton D. Baker A Biography* (Cleveland: The World Publishing Co., 1961), 23, 40-70; Link, *Wilson Road to White House*, 439.

47 Clarkson, *Industrial America in World War*, 48-49; NARA, RG120, M990/1/621, A I 71, Gorrell, "Early Activities," 64; Link, ed. *Papers of Woodrow Wilson,* 45: 69-70, 102, 155-156, 266, 280-281, 356-358, 426-427, 600-601; 46: 15, 17, 40-41, 49, 57-58, 82, 91-92, 94-96, 105-106, 111-112, 150, 208-209, 215-217, 229-230, 445; 47: 321-323, 328-332.

Arnold: Arnold, *Global Mission*, 78; *Aerial Age* 5, 20 (July 30, 1917): 676-677; *Senate Aircraft Production Hearings, 1918*, 743-747, 752-756, 762-763; Thomas Coffey, *Hap: The Story of the U.S. Air Force and the Man Who Built It, General Henry "Hap" Arnold* (New York: Viking Press, 1982), 91-94.

48 Clarkson, *Industrial America in World War*, 345-352; *Engineering and Mining Journal*, 106, 3 (July 20, 1918): 190-191; ibid, 106, 7 (Aug. 17, 1918): 312; ibid, 106, 21 (Nov. 23, 1918): 921, 933; ibid, 106, 25 (Dec. 21, 1918): 1092; ibid, 106, 26 (Dec. 28, 1918): 1134-1135; Marcosson, *Anaconda*, 157-163.

49 Facon, "Comité interalliée de l'aviation," 91-92.

50 *Aeroplane*, Oct. 10, 1917, 1052; ibid, Oct. 17, 1917, 1112; ibid, Oct. 24, 1917, 1206; ibid, Jan. 2, 1918, 89 (quote); *New York Times*, Jan. 6, 1918, V: 6; Link, ed. *Papers of Woodrow Wilson,* 46: 58-59; 47: 350.

51 *House Hearings War Expenditures – Aviation, 1919,* 61-66; *House Report No. 637, 1920*, 1: 80; *Engineering and Mining Journal*, 101, 11 (March 11, 1916): 493.

52 Mauer, ed. *U.S. Air Service in World War I*, 2: 155-156; Clodfelter, *Beneficial Bombing*, 24; NARA, RG 120, M990/7/88, A XXII, Sept. 18, 1917, No. 182, AGWAR – HQ AEF; ibid, M990/6/35, A XXI, Sept. 21, 1917, No. 173, Bolling – Sec. State (first quote); ibid, M990/7/109, A XXII, Sept. 30, 1917, No. 225, AGWAR – GHQ AEF; ibid, M990/1/740, A I 190, Foulois, "Lessons Learned," 109 (second quote;) ibid, M990/10/560-567, 574-583 B VI 2-9, 21-25. "History of the Night Bombardment Section in France," 2-9, 21-25; ibid, M990/10/971-972, B VI 399, "Early History of the Strategical Section, Air Service – Early History of Strategic Bombing," 29."

53 Gilles, *Flugmotoren*, 55, 116, xviii; Norman Mosley Penzer, "Nickel – Production," in *Encyclopedia Britannica*, Chicago: Encyclopedia Britannica, Inc., 1946, 16: 425; *New York Times*, Apr. 2, 1902, 10 (quote.)

Curtiss: Angle, ed. *Aircraft Engine Encyclopedia*, 143-153; Kimble D. McCutcheon, "Curtiss OX-5," 2, AEHS, www.enginehistory.org; Neal, *Technical and Operational History Liberty Engine*, 2-3; Crowell, *America's Munitions*, 251-252, 282-283; NARA, RG 120, M990/7/173, A XXII, Oct. 31, 1917, No. 340, AGWAR – HQ AEF; *House Hearings War Expenditures – Aviation, 1919,* 492, 498-499, 503, 550.

54 Palmer, *Newton D. Baker*, 2: 193-194; Mixter and Emmons, *Aircraft Production Facts*, 9-10; *Aviation*, May 5, 1918, 537; *House Hearings War Expenditures – Aviation, 1919,* 61; Link, ed. *Papers of Woodrow Wilson,* 46: 91-92; ibid, 48: 73-74; ibid, 49: 349-351; Parrini, *Heir to Empire*, 95-97; Chernow, *Warburgs*, 224.

55 Facon, "Comité interalliée de l'aviation," 92-100; Facon, "1918, ou l'emploi en masse de l'aviation," 94; Cooper, *Birth of Independent Air Power*, 136-138; *House Hearings War Expenditures – Aviation, 1919,* 163-164, 356-363; Mauer, ed. *U.S. Air Service in World War I*, 2: 105, 152, 161-163; NARA, RG 120, M990/1/681-686, 770, A I 131-136, 220, Foulois, "Lessons Learned," 50-55, 139; Morrow, *Great War in Air*, 212, 286; G. K. Williams, "Shank of the Drill," 399, 409; Jones, *War in the Air*, 6: 105-106.

Embick: *Aerial Age*, 5, 20 (July 30, 1917): 676; ibid, 6, 2 (Sept. 24, 1917): 58; Forrest C. Pogue, *George C. Marshall Ordeal and Hope 1939-1942* (London: MacGibbon & Kee, 1968), 132-133.

56 Mauer, ed. *U.S. Air Service in World War I*, 2: 153, 191; Clodfelter, *Beneficial Bombing*, 28-29; NARA, RG 120, M990/10/598-601, B VI 39-41, May 29, 1918, CAS – AEF COS; ibid, M990/10/601, B VI 42, June 18, 1918, GHQ AEF – CAS HQ SOS.

57 NARA, RG 120, M990/10/604-605, B VI 45-46, June 24, 1918, Patrick – Monnell; ibid, M990/10/606-607, B VI 47-48, June 28, 1918, CAS memorandum; ibid, M990/11/867-869, B XII 137-139, "Written by Lt. M. C. Randall;" ibid, M990/10/608-609, B VI 49-50 (quote 50) July 26, 1918 memorandum.

58 NARA, RG 120, M990/6/649, A XXI, Apr. 12, 1918, No. 904, Pershing – AGWAR; ibid, M990/4/1494-1495, A XVII 314-315, Apr. 12, 1918, No. 1088-R; ibid, M990/4/1503, A XVII 323, Aug. 8, 1918, No. 1816-R; Morris, *First of the Many*, 89; Taulbet, *Eagle,* 315-316; *History of Ministry of Munitions*, 81.

59 NARA, RG 120, M990/4/1526, A XVII 346, Feb. 18, 1918, No. 614-S; ibid, M990/6/366, A XXI, Dec. 21, 1917, No. 403, HQ AEF – AGWAR; ibid, M990/4/1290, A XVII 113, Jan. 22, 1918, No. 524-S; ibid, M990/4/1526, A XVII 346, Feb. 18, 1918, No. 614-S; ibid, M990/4/1287, A XVII 110, May 18,1918, No. 1347-R; ibid, M990/4/1501, A XVII 321, June 24, 1918, No. 1591-R.

60 NARA, RG 120, M990/6/869, A XXI, Apr. 8, 1918, No. 869, GHQ AEF – AGWAR; ibid, M990/6/776, A XXI, May 24, 1918, No. 1175, GHQ AEF – AGWAR; ibid, M990/6/860, A XXI, June 14, 1918, No. 1308, Pershing – COS (first quote); ibid, M990/6/863, A XXI, June 15, 1918, No. 1312, GHQ AEF – AGWAR (second quote); ibid, M990/6/875, A XXI, June 19, 1918, No. 1340, GHQ AEF – AGWAR; ibid, M990/4/1293, A XVII 116, Oct. 19, 1918, No. SOS 253-R.

61 NARA, RG 120, M990/4/1503, A XVII 323, Aug. 8, 1918, No. 1816-R.

62 *House Hearings War Expenditures – Aviation, 1919,* 504, 518.

63 Palmer, *Newton D. Baker*, 2: 267; Jones, *War in the Air*, 6: 173-174; Morris, *First of the Many*, 137-139; Morrow, *Great War in Air*, 342.

Brancker: *Aeroplane*, Oct. 17, 1917, 1084; Lloyd, *Rolls-Royce Growth of a Firm*, 79.

64 NARA, RG 120, M990/6/1043, A XXI, Aug. 1918, No. 1623-S, GHQ AEF – AGWAR (first quote); ibid, M990/4/1503, A XVII 323, Aug. 8, 1918, No. 1816-R (second quote;) ibid, M990/4/1505, A XVII 325, Sept. 7, 1918, No. SOS 57-R; ibid, M990/4/1507, A XVII 327, Sept. 26, 1918, No. London 210-R.

65 *Aerial Age*, 8, 2 (Sept. 23, 1918): 61; ibid, 8, 3 (Sept. 30, 1918): 115; ibid, 8, 5 (Oct. 14, 1918): 214; ibid, 8, 6 (Oct. 21, 1918): 239, 323; ibid, 8, 7 (Oct. 28, 1918): 365-366; *House Hearings War Expenditures – Aviation, 1919,* 504; Neal, *Technical and Operational History Liberty Engine*, 207-209; NARA, RG 120, M990/4/1541, A XVII 361, Sept. 28, 1918, No. SOS 193-S (first quote); ibid, M990/6/1131, A XXI, Dec. 27, 1918, No. 2011, GHQ AEF – AGWAR; ibid, M990/4/1515, A XVII 335, Dec. 2, 1918, No. London 210-R; ibid, M990/4/1508, A XVII 328, Sept. 28, 1918, No. 1988-R; ibid, M990/4/1512, A XVII 332, Oct. 24, 1918, SOS 211-R (second quote.)

66 *House Hearings War Expenditures – Aviation, 1919,* 17, 69-70, 278 (quote, 17); W. Mitchell, *Memoirs of World War I*, 264; Beaver, *Newton D. Baker*, 169; Clodfelter, *Beneficial Bombing*, 32-33.

67 Hudson, *Hostile Skies*, 85; NARA, RG 120, M990/19/625, 633 E XIV 4-5, "96th Aero Squadron."

68 Mauer, ed. *U.S. Air Service in World War I*, 1: 4, 13; *Aviation*, May 2, 1921, 570; http://apps.westpointaog.org/Memorials/Article/5049; Clodfelter, *Beneficial Bombing*, 8, 34.

69 G. K. Williams, "Shank of the Drill," 397, 400; NARA, RG 120, M990/10/954-971, B VI 373-390, "Early History of the Strategical Section, Air Service – Proposal for Bombing Campaign," 5 (first and second quotes;) Mauer, ed. *U.S. Air Service in World War I*, 2: 141-142 (first quote); Kennet, *History of Strategic Bombing*, 24-26.

70 Mauer, ed. *U.S. Air Service in World War I*, 2: 143-148 (second quote 148); 4: 438-466; NARA, RG 120, M990/10/956, B VI 375, E.S. Gorrell, "Early History of the Strategical Section, Air Service – Proposal for Bombing Campaign," 5 (first quote;) ibid, M990/1/621, A I 71, Gorrell, "Early Activities," 64.

71 G. K. Williams, "Shank of the Drill," 400-405; Clodfelter, *Beneficial Bombing*, 19-22; Thomas H. Greer, *The Development of Air Doctrine in the Army Air Arm 1917-1941* U.S. Air Force Historical Study 89 (Washington, D.C.: Office of Air Force History, 1985), 10-12, www.afhra.af.mil; Donald Wilson, "Origin of a Theory for Air Strategy," *Aerospace Historian* 18, 1 (March 1971): 22; Ehlers, *Targeting the Third Reich*, 35-36.

72 NARA, RG 120, M990/10/957,970, B VI 376, 389, E.S. Gorrell, "Early History of the Strategical Section, Air Service – Proposal for Bombing Campaign," 6 (first quote,) 19 (second quote;) Mauer, ed. *U.S. Air Service in World War I*, 2: 143 (first quote,) 151 (second quote.)

Conclusion

The Porsche aircraft engine cylinder largely determined the nature and extent of the strategic bombing operations of the First World War. Its most important development during that war was the historic success of the production of the Liberty aircraft engine in the United States, a success that converted technological progress and military purpose into an instrument of the expansion of American economic power. Thus, the Liberty engine may be properly considered as a prototype of the double-edged sword of expanded trade and strategic bombing with which our country continues to conduct much of its foreign policy.

Bibliography

Primary Source

Smithsonian National Air and Space Museum Archives, Steven F. Udvar-Hazy Center, Chantilly, VA [NASM]
- Arthur Nutt Collection
  - Box 2, File 2, "Comparison of European and American Aircraft Engines" [1935]
- John Jay Ide Papers
  - Box 1, File 9, Ide - George Lewis, March 25, 1931

National Archives and Records Administration, College Park, Maryland [NARA]
- RG 120, Records of the American Expeditionary Forces, Gorrell History, www.fold3.com
  - Microfilm M990, Rolls 1, 2, 4, 6, 7, 9, 10, 11, 14, 16, 19, 25, 37, 40, 44, 48
  - Series A. Early History and General Organization of the AEF Air Service
    - Vol I. Report of the Organization of the AEF Air Service
    - Vol IV. Weekly Progress Reports on Air Service Activities June 30 –Oct. 30, 1918
    - Vol VII. History of the Various Air Service Programs
    - Vol XVII. Cablegrams Exchanged between GHQ and SOS, AEF, and the War Department
    - Vol. XXI. Cables Sent to the United States through GHQ
    - Vol XXII. Cables Received by GHQ AEF from War Department
  - Series B. Air Service Activities with the French, British and Italians
    - Vol I. History of the Air Service in Italy
    - Vol III. History of American Aviation Office in London
    - Vol VI. History of the Night Bombardment Section in France
    - Vol VII. Statistical Analysis of Aerial Bombardments
    - Vol XII. History of American Personnel with Allied Aviation Units
    - Vol XIV. Histories of the American Liaison Section and the French and British Missions
  - Series C. Tactical Units
    - Vol VIII. 1st Day Bombardment Group
  - Series E. Squadron Histories
    - Vol III. 11th – 13th Aero Squadrons
    - Vol XIV. 96th Aero Squadron
  - Series H. Mechanics Regiments
    - Vol II. History of the Second Regiment, Air Service Motor Mechanics
- RG 242, Captured Foreign Documents, microfilm
  - T971/6/773, 4376-426, Personalnachweis, Udet, Ernst
  - T177/16/3700402, GL 2 II, 23.Okt.1939, Hüttenproduktion von Aluminium.
- RG 342, Records of United States Air Force Commands, Activities, and Organizations
  - RD 1715, Box 8255, R. Chilton - G.W. Vaughn, Oct. 15, 1931, "Report on Trip to European Engine Plants"

U.S. Air Force Historical Research Agency, Maxwell Air Force Base, Montgomery, Alabama [AFHRA]
- K113.8231, vol. 1, Technik: Production Triebwerke
- Microfilm A1127, 137.3041-5 to 137.3055B, U.S. Strategic Bombing Survey, European War, Summary Report, 1947.
  - Equipment Division, Machine Tool Section, "Machine Tool Industry"

Secondary Source (with selected periodical literature)

d'Abzac-Ebezy, Claude. "'Une arme à finie la guerre' Pierre-Étienne Flandin ou la victoire par l'aviation," *Revue d'Histoire des Armées* 212 (1998): 99-110.

Aircraft Yearbook: see Mingos, Howard.

Angle, Glenn D., ed. *Aerosphere 1939*. New York: Aircraft Publications, 1940.

Angle, Glenn D., ed. *Airplane Engine Encyclopedia*. Dayton: The Otterbein Press, 1921.

Arnold, H.H. *Global Mission*. New York: Harper & Brothers, Publishers, 1949.

Baker, Newton D. *Why We Went to War*. New York: Harper & Bros., 1936.

Baruch, Bernard M. *Baruch My Own Story*. New York: Henry Holt and Co., 1957.

Baruch, Bernard M. *The Making of the Reparation and Economic Sections of the Treaty*. New York: Harper & Bros. Publishers, 1920.

Beaver, Daniel R. *Newton D. Baker and the American War Effort 1917-1919*. Lincoln: Univ. of Nebraska, 1966.

Beecroft, David. "Conditions in the Automotive Industry Abroad," *Transactions of the Society of Automotive Engineers* 14, 1 (1919): 671-680, www.hathitrust.org.

Blake, Robert, ed. *The Private Papers of Douglas Haig 1914-1919*. London: Eyre & Spottswoode, 1952.

Boog, Horst. "Das Problem der Selbstständigkeit der Luftstreitkräfte in Deutschland 1908-1945," *Militärgeschichtliche Mitteilungen* 1 (1988): 31-60.

Boyd, Alexander. *The Soviet Air Force Since 1918*. New York: Stein and Day, 1977.

Bradley, W. F. "The Lorraine-Dietrich Production of Airplane Engines," 42, 7 Feb. 12, 1920, *Automotive Industries*, 449-453.

Bruce, J.M. "The de Havilland D.H. 4", *Flight*, 62, 2282 (17 October 1952): 506-510, www.flightglobal.com/pdfarchive.

Bruce, J.M. "The de Havilland D.H. 9", *Flight*, 69, 2463 (6 April 1956): 385-392, www.flightglobal.com/pdfarchive.

Bruce, J.M. "The de Havilland D.H. 9", *Flight*, 69, 2464 (13 April 1956): 422-425, www.flightglobal.com/pdfarchive.

Brunoff, Maurice de, ed. *L'Aéronautique pendant la Guerre Mondiale*. Paris, 1919, www.hathitrust.org.

Budrass, Lutz. *Flugzeugindustrie und Luftrüstung in Deutschland 1919-1945*. Düsseldorf: Dröste Verlag, 1998.

Carhart, H. A. "Finishing Operations on Liberty Motor Cylinders," *American Machinist* 50, 25 (June 19, 1919): 1197-1201, www.hathitrust.org.

Carhart, H. A. "Operations on the Liberty Motor Cylinders, II," *American Machinist* 50, 21 (May 22, 1919): 985-991, www.hathitrust.org.

Carhart, H. A. "Welding Operations on Liberty Motor Cylinders," *American Machinist* 50, 22 (May 29, 1919): 1019-1025, www.hathitrust.org.

Carr, Charles C. *Alcoa An American Enterprise*. New York: Rinehart & Co., 1952.

Castex, Jean and Louis Laspalles and José Larès. *Général Barès: Créateur et inspirateur de L'Aviation*. Paris: Nouvelles Éditions Latines, 1994, www.books.google.com.

Cather, Willa. *One of Ours*. New York: Vintage Classics, 1991.

Chadeau, Emmanuel. *De Blériot à Dassault: Histoire de l'industrie aéronautique en France 1900-1950*. Fayard, 1987.

Chadeau, Emmanuel. "Le Général Edouard Hirschauer," *Revue d'Histoire des Armées* 192 (1993): 115-120.

Chambre des Députés. *Procès-Verbaux de la commission d'enquète sur le rôle et la situation de la métallurgie en France* (Bombardement de bassin de Briey), No. 6026. Paris: Martinet, 1919, www.hathitrust.org.

Chase, Herbert. "Modern Aeronautic Engines," Transactions of the Society of Automotive Engineers, 13, 2 (1918): 241-265, www.hathitrust.org.

Christienne, Charles and Pierre Lissargue. *A History of French Military Aviation*. Translated by Francis Kianka. Washington, D. C.: Smithsonian Institution Press, 1986.

Churchill, Winston S. *The World Crisis 1916-1918 Volume II*. New York: Charles Scribner's Sons, 1927.

Clarkson, Grosvenor B. *Industrial America in the World War The Strategy Behind the Line 1917- 1918*. Boston: Hohgton Mifflin Co., 1923, www.hathitrust.org.

Clodfelter, Mark. *Beneficial Bombing The Progressive Foundations of American Air Power, 1917-1945*. Lincoln: Univ. of Nebraska Press, 2010.

Coffey, Thomas. Hap: *The Story of the U. S. Air Force and the Man Who Built It, General Henry "Hap" Arnold*. New York: Viking Press, 1982.

Colvin, Fred H. "How Ford Built Liberty Motors," *American Machinst* 51, 23 (Dec. 18, 1919): 1037-1041, www.hathitrust.org.

Colvin, Fred H. "Operations on the Liberty Motor Cylinders," *American Machinst* 50, 16 (Apr. 17, 1919): 757-758, www.hathitrust.org.

Conwell-Evans, T. P. *None So Blind*. London: Harrison & Sons, Ltd., 1947.

Cooper, Matthew. *The Birth of Independent Air Power British Air Policy in the First World War*. London: Allen & Union, 1986.

Corum, James S. “The Development of Strategic Air War Concepts in Interwar Germany, 1919-1939,” *Air Power History* 44, 4 (Winter 1997) 18-35.
Corum, James S. *The Luftwaffe*. Lawrence: Univ. of Kansas Press, 1997.
Cramer, C. H. *Newton D. Baker A Biography*. Cleveland: The World Publishing Co., 1961.
Crane, Henry M. “Possible Effect of Aircraft Engine Development on Automobile Practice,” *Transactions of the Society of Automotive Engineers* 14, 1 (1919): 137-145.
Cronon, E. David, ed. *The Cabinet Diaries of Josephus Daniels* 1913-1921. Lincoln: Univ. of Nebraska, 1963.
Crowell, Benedict. *America’s Munitions 1917-1918*. Washington: G.P.O., 1919.
Cuneo, John R. *The Air Weapon 1914-1916*. Harrisburg: Military Service Publishing Co., 1947.
Daimler-Motoren-Gesellschaft. *Zum 25 Jährigen Bestehen der Daimler-Motoren-Gesellschaft*. Untertürkheim, 1915, www.hathitrust.org.
Daniels, Josephus. *The Wilson Era Years of War and After 1917-1923*. Chapel Hill: The Univ. of North Carolina Press, 1946.
Davis, Burke. *The Billy Mitchell Affair*. New York: Random House, 1967.
Davis, Kenneth S. *FDR The Beckoning of Destiny 1882-1928*. New York: G.P. Putnam’s Sons, 1971.
Dawes. Charles G.. *Journal as Ambassador to Great Britain*. New York: The MacMillan Co., 1939.
Dawes. Charles G.. *A Journal of the Great War*. Boston: Houghton, Mifflin Co., 1921.
Del Fabbro, René. “Internationaler Markt und nationale Interesssen. Die BMW AG in der Aera Castiglioni.” *Sozial Geschichte* 18, 2 (2003): 35-62.
Dempsey, Paul. “Notes on Hispano-Suiza WWI Engine”; Aircraft Engine Historical Society, 2010, www.enginehistory.org.
Dempsey, Paul. “Notes on the Liberty Aircraft Engine [1],” Aircraft Engine Historical Society, www.enginehistory.org.
Dempsey, Paul. “Notes on WWI German Superchargers“, Aircraft Engine Historical Society, www.enginehistory.org.
Dickey, Philip S., III. *The Liberty Engine 1918-1942*. Smithsonian Institution Press, 1968.
Dorand. “L’evolution des avions français pendant la guerre.” In Brunoff, ed. *L’Aéronautique pendant la Guerre Mondiale*, 111-118.
Dubreil, Marie-Catherine. “Le bombardement en 1916 une année charnière,” *Revue d’Histoire des Armées* 203 (1996): 51-62.
Dubreil-Villatoux, Marie-Catherine. “L’Aéronautique Militaire dans la Grande Guerre: Vers L’Institutionalisation.” In Francine de Auer-Véran, *Archives de L’Aéronautique Militaire dans la Première Guerre Mondiale*, 9-39. Château de Vincennes: Service Historique de la Défense, 2008, www.rha.revues,org.
Edwards, Junius David and Francis C. Frary and Zay Jeffries. *The Aluminum Industry*, vol. 1, *Aluminum and Its Production*. New York: McGraw-Hill Book Co., Inc., 1930, www.hathitrust.org.
Ehlers, Robert S. Jr. *Targeting the Third Reich. Air Intelligence and the Allied Bombing Campaigns*. Lawrence: Univ. Press of Kansas, 2009.
Encyclopedia Britannica. 24 vols. Chicago: Encyclopedia Britannica, Inc., 1946.
Erinnerungen 1934-1984. Flugtriebwerkbau in München. München: MTU Motoren-und Turbinen-Union GmbH, 1984.
Facon, Patrick. “1918 , ou l’emploi en masse de l’aviation,“ *Revue d’Histoire des Armées* 212 (1998): 89-110.
Facon, Patrick. “Aperçus sur la doctrine d’emploi de l’aéronautique militaire française,” *Revue d’Histoire des Armées* 172 (1988): 80-90.
Facon, Patrick. “Le comité interalliée de l’aviation ou le problème du bombardement stratégique de l’Allemagne en 1918,” *Revue d’Histoire des Armées* 180 (1990): 91-100.
Facon, Patrick. “La coopération aéronautique franco-italienne pendant la Grande Guerre,” *Revue d’Histoire des Armées* 252 (2008), www.rha.revues.org.
Fearon, Peter. “The Vicissitudes of a British Aircraft Company: Handley-Page Ltd. between the Wars,” *Business History*, 20, 1 (Jan. 1978): 63-86.
Feldman, Gerald D. *Army Industry and Labor in Germany 1914-1918*. Princeton: Princeton Univ. Press, 1966.
Feldman, Gerald D. Iron and Steel in the German Inflation 1916-1923. Princeton: Princeton Univ. Press, 1977.
Feldenkirchen, Wilfried. *Siemens 1918-1945*. München: R. Piper GmbH & Co. KG, 1995.
Ferguson, Niall. *The War of the World Twentieth Century Conflict and the Descent of the West*. New York: The Penguin Press, 2006.
Flink, James S. “Mass Production.” In May, ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, 321-326.
Foch, Ferdinand. *The Memoirs of Marshal Foch*. Translated by T. Bentley Mott. Garden City: Doubleday Doran and Co., 1931.
Foreign Relations of the United States, 1917, supp. 2, vol. 1. Washington: G. P. O., 1932.
Fredette, Raymond H. *The Sky on Fire The First Battle of Britain 1917-1918 and the Birth of the Royal Air Force*. Washington, D. C.: Smithsonian Institution Press, 1976 [reprint, Harcourt Brace Jovanovich, 1966.]
Freudenthal, Elsbeth. *The Aviation Business*. New York: Vanguard Press, 1940.
Furse, Anthony. *Wilfried Freeman*. Staplehurst: Spellmount, 2000.

Genevro, George. "Air-Cooled Aircraft Engine Cylinders An Evolutionary Odyssey Part 1 - From the Past," Aircraft Engine Historical Society, www.enginehistory.org.
Gersdorff, Kyrill v. and Kurt Grasmann. *Flugmotoren und Strahltriebwerke*. München: Bernard und Graefe, 1980.
Gibson, A.H. "Aero-engine Efficiencies," *Aviation*, Feb. 21, 1921, 238-240.
Gibson, A.H. "Theories and Practices in the Air Cooling of Engines," *Automotive Industries* 42, 21 (May 13 and 20, 1920): 1109-1113, 1154-1157, www.hathitrust.org.
Gilbert, Martin. *Winston S. Churchil*l, vol. 4, 1916-1922 The Stricken World. Boston: Houghton Mifflin Co., 1975.
Gilles, J. A. *Flugmotoren 1910 bis 1918*. Herausgegeben vom Militärgeschichtliche Forschungsamt. E. S. Mittler & Sohn GmbH, 1971.
Grey, C. G., ed. *All the World's Aircraft, 1919*. London: Sampson, Low, Marston & Co., Ltd., 1919.
Guignard, Georges. "Les Fabrications de l'Aviation militaire pendant la Guerre mondiale." In Brunoff, ed. *L'Aéronautique Pendant la Guerre Mondiale*, 384-412.
Gunston, Bill. *The Development of Piston Aero Engines*. Sparkford: Patrick Stephens, Ltd., 1993.
Haglund, P.E. "The Reminiscences of Mr. P.E. Haglund," April 1955, Accession 65, Ford Motor Company Archives, Oral History Section, Benson Ford Research Center, www.oclc.org.
Harbord, James G. *The American Army in France*. Boston: Little, Brown, and Co., 1936.
Hartmann, Gérard. "L'Aluminum Historique," 2004, www.hydroretro.net.
Hartmann, Gérard. "Ca a Commencé le 23 Mars," 2006, www.hydroretro.net.
Hartmann, Gérard. "Les Errements de la IIIe République," 2007, www.hydroretro.net.
Hartmann, Gérard. "Les Moteurs d'Aviation Lorraine," 2003, www.hydroretro.net.
Hartmann, Gérard. "Les Moteurs d'Aviation Renault," 2009, www.hydroretro.net.
Hartmann, Gérard. "Les Premiers Appareils Breguet," 2005, www.hydroretro.net.
Hartmann, Gérard. "La Societé des Moteurs Salmson," 2004, www.hydroretro.net.
Heinkel, Ernst. *Stürmisches Leben*, ed. Jürgen Thorwald. Stuttgart: Mundus Verlag, 1953.
Heron, S.D. "Aircraft-Engine Practice as Applied to Air-Cooled Passenger-Car Engines." *Journal of the Society of Automotive Engineers* 12, 21 (January 1923): 31-38.
Heron, S.D. *History of the Aircraft Piston Engine. A Brief Outline*. Detroit: Ethyl Corporation, 1961.
Hicks, Harold. "The Reminiscences of Mr. Harold Hicks," July 1952, Accession 65, Ford Motor Company, Oral History Section, Benson Ford Research Center, www.oclc.org.
History of the Ministry of Munitions, vols. 2, 7, 12. [H. M. S. O., 1922], www.hathitrust.org.
Hoeppner, [Ernst W. H.] v. *Deutschlands Krieg in der Luft*. Leipzig: Verlag von K. F. Koehler, 1921, www.hathitrust.org.
Holley, Irving B., Jr. *Buying Aircraft – Material Procurement for the Army Air Forces*. Washington: Office of the Chief of Military History, 1964.
Holley, Irving B., Jr. *Ideas and Weapons*. Office of U.S. Air Force History, 1983. [reprint, Yale Univ. Press, 1953.]
House War Expenditures Hearings – *Aviation*, 1919: see U.S. House. Hearings.
Hudson, James J. *Hostile Skies A Combat History of the American Air Service in World War I*. Syracuse: Syracuse Univ. Press, 1968.
Hunt, O. E. "Probable Effect on Automobile Design of Experience with War Airplanes," *Transactions of the Society of Automotive Engineers* 14, 1 (1919): 154-161, www.hathitrust.org.
Huston, John W. ed. *American Airpower Comes of Age General Henry H. "Hap" Arnold's World War II Diaries*. Maxwell Air Force Base, Alabama: Air University Press, January, 2002, www.afhra.af.mil.
Huth, Fritz. „Luftfahrzeugmotoren." In Neumann, ed. *Deutschen Luftstreitkräfte*, 149-159.
Hyde, Charles Cheney. "Charles Evans Hughes," in *The American Secretaries of State and Their Diplomacy,* vol. 10, ed. Samuel Flagg Bemis (New York: Cooper Square Publishers, 1963), 221-401.
Hyde, Charles K. "Packard Motor Car Company." In May, ed. *Encyclopedia of American Business History and Biography*, 375-381.
Hyde, H. Montgomery. *British Air Policy Between the Wars 1918-1939*. London: Heinemann, 1976.
Isenberg, H. O. C. "Hispano-Suiza Aircraft Engine Production Problems," *Transactions of the Society of Automotive Engineers* 13, 2 (1918): 487-490, www.hathitrust.org.
Jakobs, Fred and Robert Kröschel and Christian Pierer. *BMW Flugbetriebwerke*. München: BMW Group Classic, 2009.
Jones, E. T. "The Development of the Wright Whirlwind Type J-5 Aircraft-Engine." *Journal of the Society of Automotive Engineers* 19, 3 (Sept. 1926): 303-309.
Jones, H. A. *The War in the Air*, vol. 6. Oxford: Clarendon Press, 1937, https://archive.org.
Jones, Neville. *The Origins of Strategic Bombing*. London: William Kimber, 1973.
Keegan, John. *The First World War*. New York: Alfred A. Knopf, 1999.
Kennet, Lee. *A History of Strategic Bombing*. New York: Charles Scribner's Sons, 1982.
Kessler, Harry. *Walter Rathenau His Life and Work*. Translated by W.D. Robson-Scott and Lawrence Hyde. New York: Harcourt, Brace and Co., 1930.

Knappen, Theodore MacFarlane. *Wings of War*. New York: G.P. Putnam's Sons, 1920.
Knauer, Manfred. *Hundertjähre Aluminumindustrie in Deutschland (1886-1986)*. München: Oldenbourg Wissenschaftwissenschaft Verlag, GmbH, 2014, www.books.google.com.
Kossmann, Wilfried. *Uber die wirtschaftliche Entwicklung der Aluminumindustrie. Druckerei und Verlagsantalt*, 1911, www.hathitrust.org.
Kothe, Robert J. "Howard E. Coffin." In *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, ed. George S. May, 103-105. New York: Bruccoli, Clark, Layman, Inc. 1990.
Kotelnikov, Victor. *Russian Piston Aero Engines*. Ramsbury: Crowood Press, 2005.
Krempp, Thérèse. "Le commandant de Rose," *Revue Historique des Armées* 245 (2006), www.rha.revues.org.
Kroll, Richard. "The Reminiscences of Mr. Richard Kroll," October 1953, Accession 65, Oral History Section, Ford Motor Company Archives, Benson Ford Research Center, www.oclc.org.
Lagana, Marc. "A propos de l'interdependence des mileux d'affaires et des mileux politiques: Le Cas des Tréfileries et Laminoirs du Havre de 1901 à 1918," *Revue Françise d'Histoire d'Outre-mer* 66, 242-243 (1979): 59-71, www.persee.fr.
Lamont, Edward M. *The Ambassador from Wall Street*. *The Story of Thomas W. Lamont, J.P. Morgan's Chief Executive.* Lanham: Madison Books, 1994.
Lenz, Rudolf. *Der Kupfer Markt unter dem Einflusse der Syndikate und Trusts*. Berlin: Verlag für Fachliteerateur G.m.b.H., 1910, www.hathitrust.org.
Levine, Isaac Don. *Mitchell Pioneer of Air Power*. New York: Duell, Sloan and Pearce, 1958.
Lewis, Cleona. *America's Stake in International Investments*. Washington, D.C.: Brookings Institution, 1938.
Link, Arthur S. *Wilson The Road to the White House*. Princeton: Princeton Univ. Press, 1947.
Link, Arthur S., ed. *The Papers of Woodrow Wilson*, vol.s 42-49. Princeton: Princeton Univ. Press, 1984-1985.
Link, Werner. *Die amerikanische Stabilierungspolitik in Deutschland 1921-32*. Düsseldorf: Droste Verlag, 1970.
Lloyd, Ian. *Rolls-Royce The Growth of a Firm*. London: The MacMillan Press Ltd., 1978.
Lloyd George, David. *Memoirs of the Peace Conference*, 2 vols. New Haven: Yale Univ. Press, 1939.
Lucke, Charles E. "Steel in Aeroplane Engine Construction," *Aerial Age*, 5, 14 (June 18, 1917): 460-461.
Ludvigsen, Karl. *Ferdinand Porsche Genesis of Genius*. Cambridge: Bentley Publishers, 2008, 226-254, Aircraft Engine Historical Society, www.enginehistory.org.
McAdoo, William G. *Crowded Years*. Boston: Houghton Mifflin Co., 1931.
McCutcheon, Kimble D. "Curtiss OX-5," Aircraft Engine Historical Society, www.enginehistory.org.
McCutcheon, Kimble D. "Wright J-5 'Whirlwind'," Aircraft Engine Historical Society, www.enginehistory.org.
Marcosson, Isaac F. *Anaconda*. New York: Dodd, Mead & Co., 1957.
Marcosson, Isaac F. *Colonel Deeds Industrial Builder*. New York: Dodd. Mead & Co., 1948.
Marks, Lionel S. *The Airplane Engine*. New York: McGraw-Hill Book Co., Inc., 1922, www.hathitrust.org.
Marmon, Howard. "A Comparison of Airplane and Automobile Engines," *Transactions of the Society Of Automotive Engineers* 14, 1 (1919): 149-152.
Marvin, Charles F., Jr. "Combustion Time in the Engine Cylinder and Its Effect on Engine Performance." *National Advisory Committee for Aeronautics, Report* 276. Washington [1927].
Mauer, Mauer. ed. *The U.S. Air Service in World War I*, 4 vols. U.S. Air Force Historical Study 147. Washington: Office of Air Force History, 1978.
May, George S. "Childe Harold Wills." May, ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, 458-461.
May, George S. ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*. New York: Bruccoli, Clark, Layman, Inc. 1990.
Mead, George J. "Wasp and Hornet Radial Air-Cooled Aeronautic Engines." *Journal of the Society of Automotive Engineers* 19, 6 (December 1926): 609-615.
"A Metallurgical Report on Materials Used in Foreign Aeronautical Engines," *Air Service Information Circular*, 3, 222 (Apr. 30, 1921) Washington: G.P.O., 1921, Aircraft Engine Historical Society, www.enginehistory.org.
Miller, Roger G. *Billy Mitchell "Stormy Petrel of the Air."* Washington, D.C.: Office of U.S. Air Force History, 2004.
Mingos, Howard, ed. *Aircraft Yearbook 1919-1939*. New York: Aeronautical Chamber of Commerce, 1919-1939.
Ministry of Munitions. Technical Department – Aviation Production. *The 12 Cylinder Liberty Aero Engine*. September 1918, www.hathitrust.org.
Mitchell, William. *Memoirs of World War I*. New York: Random House, 1960.
Mixter, G. W. and H. H. Emmons. *United States Army Aircraft Production Facts*. Washington: G.P.O., 1919.
Mönnich, Horst. *BMW. Eine deutsche Geschichte*.Wien-Darmstadt: Paul Zsolny Verlag, 1989.

Mooney, Chase C. and Martha E. Layman. *Organization of Military Aeronautics, 1907-1935 (Congressional and War Department Action)*. U.S. Air Force History Study No. 25. Assistant Chief of Air Staff, Intelligence Historical Division, December 1944, www.afhra.af.mil.
Morris, Alan. *First of the Many The Story of Independent Force, R.A.F.* London: Arrow Books, 1968.
Morrow, John H., Jr. *German Air Power in World War I.* Lincoln: Univ. of Nebraska Press, 1982.
Morrow, John H., Jr. *The Great War in the Air from 1909 to 1921*. Washington: Smithsonian Instiution Press, 1993.
Munson, Kenneth. *Bombers Between the Wars 1919-1939*. New York: Macmillan Company, 1970.
Munson, Kenneth. *Bombers Patrol and Reconnaissance Aircraft 1914-1919*. New York: The MacMillan Co., 1968.
Neal, Robert. *A Technical and Operational History of the Liberty Engine Tanks, Ships and Aircraft 1917-1960*. North Branch, MN: Specialty Press, 2009.
Neumann, Georg Paul. ed. *Deutschen Luftstreitkräfte im Weltkriege*. Berlin: Ernst Siegried Mittler und Sohn, 1920, www.hathitrust.org.
Nevins, Allan and Frank Ernest Hill. *Ford Expansion and Challenge 1915-1933*. New York: Charles Scribner's Sons, 1957.
Nourse, Edwin G. *America's Capacity to Produce*. Washington, D. C.: The Brookings Institution, 1934.
Nowarra, Heinz. *Die Deutsche Luftrüstung 1933-1945*, 4 vols. Koblenz: Bernard & Graefe Verlag, 1993.
O'Callaghan, Timothy J. *The Aviation Legacy of Henry & Edsel Ford*. Ann Arbor: Proctor Publications, LLC, 2000.
O'Callaghan, Timothy J. *Ford in the Service of America Mass Production for the Military During the World Wars.* Jefferson, NC: McFarland and Co., Publishers, 2009.
Orde, Anne. British Policy and European Reconstruction after the First World War. Cambridge: Cambridge Univ. Press, 1990.
Palmer, Frederick. *Newton D. Baker America at War*, 2 vols. New York: Dodd, Mead & Co., 1931.
Parrini, Carl P. Heir to Empire United States Economic Diplomacy 1916-1923. Univ. of Pittsburgh, 1969.
Patrick, Mason M. "Final Report of Chief of Air Service, American Expeditionary Forces." In *United States Army in the World War 1917-1919*, vol. 15, *Reports of Commander-in-Chief, Staff Sections and Services*, 225-290. Washington, D.C.: Center of Military History, United States Army, 1991.
Penzer, Norman Mosley. "Nickel – Production." In *Encyclopedia Britannica*, vol. 16, 425. Chicago: Encyclopedia Britannica, Inc., 1946.
Perrini, Mrs. Victor J. "The Reminiscences of Mrs. Victor J. Perrini," *October 1956, Accesssion 65*, Ford Motor Company – Oral History Series, Benson Ford Research Center, www.oclc.org.
Pernot, François. "Barès, 1914-1917 ou l'aviation à l'epreuve de la Grand Guerre," *Revue Historique des Armées* 192 (1993): 3-14.
Pershing, John J. *My Experiences in the World War*, 2 vols. New York: Frederick A. Stokes, 1931.
Pierer, Christian. *Die Bayerischen Motoren Werke bis 1933*. München: Oldenbourg Verlag, 2011.
Pogue, Forrest C. *George C. Marshall Ordeal and Hope 1939-1942*. London: MacGibbon & Kee, 1968.
Porte, Rémy. "Mobilisation industrielle et guerre totale: 1916, année charnière," *Revue Historique des Armées* 242 (2006), www.rha.revues.org.
Pusey, Merlo J. *Charles Evans Hughes*. New York: Macmillan Co., 1951.
Rae, John B. "Henry Martyn Leland." In May,ed. *Encyclopedia of American Business History and Biography: The Automobile Industry 1890-1920*, 296-306.
Raymond, Robert J. "The Liberty Engine and Torsional Vibration," July 17, 2008, Aircraft Engine Historical Society, www.enginehistory.org.
Report of the Amalgamated Copper Company for the Sixteen Months Ending April 30, 1915, www.hathitrust.org.
"Report on Tests of A. B. C. 'Dragonfly' Cylinder," *Air Service Information Circular* 3, 265 (July 21, 1921): 1-6. Robert Neal, Aircraft Engine Historical Society, www.enginehistory.org.
Report of the Military Board of Allied Supply. Washington: G.P.O., 1925, www.hathitrust.org.
Rickenbacker, Edward V. *Rickenbacker*. Englewood Cliffs: Prentice-Hall, Inc., 1967.
Ristuccia, Cristiano Andrea and J. Adam Tooze, "The Cutting Edge of Modernity: Machine Tools in the United States and Germany 1930-1945," CWPE 0342, September 2003, www.econ.cam.ac.uk/research/repec/cam/pdf/cwpe0342.pdf.
Ritchie, Sebastian. *Industry and Air Power*. Portland: Frank Cass, 1997.
Robinson, H. J. "The Reminiscences of Mr. H. J. Robinson," January, 1956, Acc. 65, Ford Motor Company – Oral History Series, Benson Ford Research Center, www.oclc.org.
Roosevelt, Elliott, ed. *The Roosevelt Letters. Volume Two. 1905-1928*. London: George G. Harrop & Co., Ltd., 1950.
Schacht, Hjalmar. *The End of Reparations*, trans. Lewis Gannett. New York: Jonathan Cape & Harrison Smith, 1931.
Schlaifer, Robert and S. D. Heron. *Development of Aircraft Engines and Development of Aviation Fuels*. Boston: Harvard Univ. Press, 1950.
Schwager, Otto. "Neuere Bestrebungen und Erfahrungen im Flugmotorenbau,“ *Technische Berichte* 3, 5 (1918): 133-150, www.hathitrust.org.

Senate Aircraft Production Hearings, 1918: see U.S. Senate. Hearings.
Senate War Department Hearings, 1918: see U.S. Senate. Hearings.
Sherbondy, E. H. "Details of German Aviation Engines," 5, 16 *Aerial Age* (July 2, 1917): 524-532.
Sherbondy, E. H. and G. Douglas Wardrop. *Textbook of Aero Engines*. New York: Frederick A. Stokes Co., 1920, www.hathitrust.org.
Siegert, [Wilhelm.] "Bomben- und Nachtflüge." In Neumann, ed. *Deutschen Luftstreitkräfte im Weltkriege*, 428-450,
Smith, Herschel. *Aircraft Piston Engines*. New York: McGraw-Hill, 1981.
Sparrow, S.W. "Performance of B.M.W. 185-Horsepower Aeroplane-Engine." *National Advisory Committee on Aeronautics Report No. 135*. Washington [1923].
Squier, George O. "Details of Liberty Motor Development," *American Machinist* 50, 3 (Jan. 16, 1919): 130-131, www.hathitrust.org.
Stocking George W. and Myron W. Watkins. *Cartels in Action. Studies in International Business Diplomacy*. New York: The Twentieth Century Fund, 1947, www.hathitrust.org.
Stubbs, Kevin D. *Race to the Front The Materiel Foundations of Coalition Strategy in the Great War*. Westport: Praeger, 2002.
Sweetser, Arthur. *The American Air Service*. New York: D. Appleton and Co., 1919, www.hathitrust.org.
Syon, Guillame de. "Faded Memories The Wright Brothers and Germany 1909-1913." www.corescholar.wright.edu.
Taulbet, Derek S. *Eagle Henry Royce's First Aero Engine*. Derby: The Rolls Royce Heritage Trust, 2011.
Taylor, C. Fayette. *Aircraft Propulsion. A Review of the Evolution of Aircraft Piston Engines*. Washington: Smithsonian Institution Press, 1971.
Taylor, John W. R., ed. *Combat Aircraft of the World From 1909 to the Present*. New York: G.P. Putnam's Sons, 1969.
Technische Berichte, Band I-III. Herausgegeben von der Flugmusterei der Inspektion der Fliegertruppen. Charlottenburg, 1917-1918, www.hathitrust.org.
Timmons, Bascom. *Portrait of an American Charles G. Dawes*. New York: Henry Holt and Co., 1953.
Trade Information Bulletin. See: United States Department of Commerce. Bureau of Foreign and Domestic Commerce.
United States Army in the World War 1917-1919, vols. 8, 9, 15. Washington, D.C.: Center of Military History, United States Army, 1991.
U.S. Department of Commerce. Bureau of Foreign and Domestic Commerce. *Trade Information Bulletin* [1922-1939], www.hathitrust.org.
U.S. Department of the Interior. U.S. Office of Patents. *Annual Report of the Commissioner of Patents 1904*. Washington: G.P.O., 1905, www.books.google.com.
U.S. Department of the Interior. U.S. Office of Patents. *Annual Report of the Commissioner of Patents 1913*. Washington: G.P.O., 1914, www.books.google.com.
U.S. House. Hearings. Select Committee on Expendiures in the War Department, Subcommittee No.1 (Aviation.) 66th Congress, 1st Session, Serial 2, Volume I. Washington, D. C.: G. P. O., 1919 [*House War Expenditures Hearings – Aviation, 1919*], www.books.google.com.
U.S. House. Reports. Select Committee on Expenditures in the War Department, Subcommittee No. 1 – Aviation, 66th Congress, 2nd Session, No. 637, Parts 1 and 2. Washington: G.P.O., 1920 [*House Report 637*, *1920.*]
U. S. Senate. Hearings. Committee on Military Affairs. Investigation of the War Department. 65th Congress, 2nd Session, Part 6, Jan. 30 – Feb. 2, 1918, 2142-2187 [*Senate War Department Hearings, 1918*].
U. S. Senate. Hearings. Committee on Military Affairs, Aircraft Production Subcommittee. 65th Congress, 2nd Session, Vol. I, June, 6, 1918, 313-323, 741-767 [*Senate Aircraft Production Hearings, 1918*].
Valluy, J. E. *La Première Guerre Mondiale Tome Second 1916-1918*. Paris: Librarie Larousse, 1968.
Villatoux, Marie-Catherine and Patrick Facon. "La coopération franco-américaine en matière d'aèronautique 1917-1918," *Revue d'Histoire des Armées* 246 (2007), www.rha.revues.org.
Vincent, Jesse G. "The Liberty Aircraft Engine," *Transactions of the Society of Automotive Engineers* 14, 1 (1919): 385-426, www.hathitrust.org.
Vincent, Jesse G. "Reasons Behind the Liberty Aviation Engine," *Transactions of the Society of Automotive Engineers* 13, 1 (1918): 96-106, www.hathitrust.org.
Vorreiter, Asbert. "Konstruktionsprinzipen der Motoren für Flugapparate," *Zeitschrift für Flugtechnik und Motorluftschiffbau* 1, 2 (1910): 11-16, www.hathitrust.org.
Wagner, Dieter. "Chemische Fabrik Griesheim – Pioneer of Electrochemistry," *Journal of Business Chemistry* 3, 2 (May 2006): 31-38.
Waggoner, J. M. "The Reminiscences of Mr. J. M. Waggoner," Aug. 1955, Accession 65, Ford Motor Company Archives – Oral History Section, Benson Ford Research Center, www.oclc.org.
Wagoner, Harless. *The Machine Tool Industry from 1900 to 1950*. Cambridge: The M.I.T. Press, 1966.

Wark, Wesley K. “British Intelligence on the German Air Force and Aircraft Industry, 1933-1939,” *Historical Journal* 25, 3 (Sept. 1982): 627-698.
Wark, Wesley K. *The Ultimate Enemy*. Ithaca: Cornell Univ. Press, 1985.
White, C. M. *The Gotha Summer The German Air Raids on England May to August 1917*. London: Robert Hale, 1986.
Wilkins, Mira. *The Maturing of Multinational Entrerprise. American Business Abroad from 1914 to 1970*. Cambridge: Harvard Univ. Press, 1974.
Williams, George K. *Biplanes and Bombsights British Bombing in World War I*. Maxwell AFB, Montgomery, Alabama: Air University Press, 1999, www.dtic.mil.
Williams, George K. “‘The Shank of the Drill’: Americans and Strategical Aviation in the Great War,” *Journal of Strategic Studies* 19, 3 (Sept. 1996): 381-431, www.oclc.org.
Wood, Derek and Derek Dempster. *The Narrow Margin The Battle of Britain and the Rise of Air Power 1930-1940*. New York: McGraw-Hill Publishing Co., 1961.

Periodicals

Aerial Age
Aérophile, www.hathitrust.org
Aeroplane
Air Power History
Air Service Information Circular, www.enginehistory.org
Air Service Journal, www.hathitrust.org
American Machinst, www.hathitrust.org
Automotive Industries
Aviation
Deutsche Zeitschrift für Luftschifffahrt, www.hathitrust.org
Engineering and Mining Journal, www.hathitrust.org
Flight, www.flightglobal.com
Frankfurter Allgemeine Zeitung, www.faz.net
Historical Journal
Journal of the Society of Automotive Engineers
Militärgeschichtliche Mitteilungen
New York Tribune, http://chroniclingamerica.loc.gov
New York Times
Revue Française d’Histoire d’Outre-mer, www.persee.fr
Revue Historique des Armées, www.rha.revues.org
Sozial Geschichte
Technische Berichte, www.hathitrust.org
Transactions of the Society of Automotive Engineers, www.hathitrust.org
Washington Evening Star, http://chroniclingamerica.loc.gov
Zeitschrift für Flugtechnik und Motorluftschiffbau, www.hathitrust.org