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Performance Analysis and Tactics of Fighter Aircraft from WWI

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Abstract

On June 6, 2004, the Museum of Flight in Seattle, WA opened their Personal Courage Wing, a collection of 28 WWI and WWII fighter aircraft. This paper discusses performance and tactics of the 18 fighters in the WWI part of the collection. During the first one hundred years of flight great advances were made in fighter performance. However, fighter tactics developed in the early years of WWI are still in use today. A retrospective analysis of the Museum of Flight collection of WWI fighters will show why certain aircraft were successful, where others weren't. Climb and turn performance of these airplanes are compared and the tactics they fostered will be discussed. Speed, handling and stall speeds will be discussed in relation to the utility of these aircraft.

1. Introduction

As we enter the second century of fight, and reflect on the first, it can be difficult to accept that the pilots, designers and mechanics that flew, designed and maintained the fighters of WWI are gone. Now, we must rely on historians and records to recall the lessons learned almost 90 years ago.

Although much is written to preserve the memories, there is little performance analysis available in the open literature. A wonderful synopsis, published by NASA's history office, covers a great deal of performance data on select airplanes from pre-WWI to modern jets.[1] John Anderson, in another exceptional coverage of technical development in aerodynamics during the first part of the century,[2] gives detailed information on design innovations during this period.

The motivation for pursuing this study was to provide an aeronautical engineering tour of the new Personal Courage Wing at Seattle's Museum of Flight (MOF). The author served as a Personal Courage Wing Consultant from Dec, 2003-June 2004 with the task of developing VIP tours that tell "people" stories. The author's interest in the technology of these airplanes led to this side-study.

For this paper analysis involved finding data from various sources and backing out aerodynamic parameters, such as C_{D_o} and e, the Oswald efficiency factor. Then, climb, turns, stall and other performance parameters can be backed out. In many cases, data is scarce and of dubious origin. Nevertheless, a fair amount can be learned if the data is accepted in the spirit for which it is intended.

This paper is organized as follows. First, an overview of the historical context for which these airplanes entered service is presented. Next, the method used to back out aerodynamic parameters is shown. Then, performance characteristics of the airplanes in the collection are presented, along with the tactics they fostered, followed by concluding remarks. The airplanes in the collection are listed in Table 1.

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Artifact	Year	
Caproni Ca.20	1914	Original
Fokker Eindecker E.III	1915	Reproduction
Curtiss JN-4 Jenny	1916	Reproduction
Sopwith Pup	1916	Reproduction
Sopwith Triplane	1916	Reproduction
Albatros D.Va	1917	Reproduction
Sopwith Camel	1917	Reproduction
Aviatik	1917	Restoration
Nieuport 24	1917	Reproduction
Nieuport 27	1917	Reproduction
Fokker Dr.1	1917	Reproduction
RAF S.E.5a	1917	Reproduction
Nieuport 28	1917	Restoration
SPAD XIII	1917	Reproduction
Fokker D.VII	1918	Reproduction
Pfalz D.XII	1918	Restoration
Fokker D.VIII	1918	Reproduction
Sopwith Snipe	1918	Reproduction

Table 1: Artifacts in the Personal Courage Wing

2. Historical Context

Aerial combat began in the first year of the "Great War". The first combat occurred using pistols, grappling hooks and other devices were fired or thrown from flimsy observation planes. Observers, or even pilots trying to control the airplane while firing, could not mount effective attacks with such an unstable gun platform. A fundamental problem occurred when firing forward: an observer might hit the wing, or worse, the propeller. It was not unheard of that airplanes were lost because the pilot shot off his own wooden propeller.

Airplanes designed to shoot down enemy observation planes didn't hit the scenes until 1915. A notable exception was the Italian Caproni CA.20, which was designed with a forward-firing machine gun mounted on a wing-post to avoid shooting through the propeller. From 1914-1917, Italy was involved in the First ItaloSanusi war, a colonial war in Libya. Gianni Caproni, known for designing large bombers, conceived of the aerial fighter in combat. He designed and patented the first airplane with a forward firing machine gun, the Caproni Ca.20. Only the prototype was built: it was ahead of its time. The Museum of Flight Caproni CA.20 is shown in fig. 1.

Anthony Fokker, using a 1913 patent of Franz Schneider, designed an interrupter gear for his Eindeckers, after the Germans captured Roland Garros and his bullet-deflector equipped propeller. As a stable gun platform, the otherwise inferior Eindecker E.III gained dominance in the skies for a period lasting from August 1915 to June 1916, a period known as the Fokker Scourge. The Eindecker was actually anything but stable, by modern terms. It was tricky to handle and employed wing-warping rather than ailerons. The Eindecker is shown in Figure 2.

German pilots Oswald Boelcke and Max Immelmann developed fighter tactics still used today in the Eindecker. Boelcke wrote his "dicta" (table 2), which outlined rules for fighter pilots. Immelmann was the first to do the maneuver that took his name.

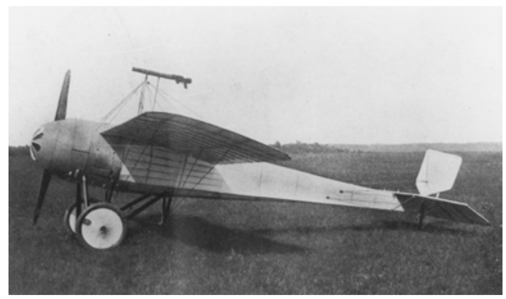

Fig. 1 Caprini S.20
(Photo Courtesy Museum of Flight)

The Allies eventually responded with the Nieuport 11 Bebe and the Sopwith Pup. The Nieuport used machine guns mounted above the propeller arc and the Sopwith Pup used a primitive, and somewhat unreliable, interrupter gear, but was far superior in performance to the Eindecker and ended the Fokker Scourge.

Figure 2**.** Fokker Eindecker
(Photo courtesy of the Museum of Flight)

Many new designs were attempted, with varying success. The Sopwith Triplane, built in 1916, was highly maneuverable, which impressed the Germans. They countered with several triplane designs, such as the well-known Fokker Dr.1 Tripane. These highly maneuverable aircraft were superior in dogfights, but tactics began to show that speed and climb capability was more important then maneuverability. None of the triplanes were built in the large numbers seen in other aircraft.

The Fokker Dr.1, shown in fig. 3 made use of the latest discoveries from Ludwig Prandtl at Gőttingen University in Germany.[3] It is interesting to note that the first Fokker Triplanes did not use interplane struts. The thick Gőttingen airfoil allowed for fully cantilevered wings. Pilot reaction to the independently flexing, non-strut-braced triplane was not positive, so interplane struts were added. It didn't help that the top wing frequently separated from the triplane in flight. The Dr.1 was best known as Manfred Von Richthofen, the Red Baron's, airplane, although he only scored 19 of his 80 victories in this his famous red Dr.1.

Society Anonyme des Establissments Nieuport pioneered the "sesquiplane" concept where the bottom wing has half the chord as the top. Direct descendents of the Nieuport 11 Bebe, were the Nieuport 24bis and the Nieuport 27. The German Albatros DIII and D.Va copied the Nieuport sesquiplane design and added a monocoque fuselage, where a plywood skin added strength to the structure. The Albatros, flown by such pilots as Baron Von Richthofen (the Red Baron), helped the Germans attained parity with the Allies in the air. Unfortunately, these "sesquiplanes" suffered from torsional weakness in the lower wing, where the strut attached to only the single forward spar.

Boelcke "Dicta"

1. *Always try to secure an advantageous position before attacking. Climb before and during the approach in order to surprise the enemy from above, and dive on him swiftly from the rear when the moment to attack is at hand.*
2. *Try to place yourself between the sun and the enemy. This puts the glare of the sun in the enemy's eyes and makes it difficult to see you and impossible for him to shoot with any accuracy.*
3. *Do not fire the machine guns until the enemy is within range and you have him squarely within your sights.*
4. *Attack when the enemy least expects it or when he is preoccupied with other duties such as observation, photography or bombing.*
5. *Never turn your back and try to run away from an enemy fighter. If you are surprised by an attack on your tail, turn and face the enemy with your guns.*
6. *Keep your eye on the enemy and do not let him deceive you with tricks. If your opponent appears damaged, follow him down until he crashes to be sure he is not faking.*
7. *Foolish acts of bravery only bring death. The Jasta must fight as a unit with close teamwork between all pilots. The signal of its leaders must be obeyed.*

Table 2: Boelcke's "Dicta"

Figure 3: Fokker Dr.1 Triplane
(Photo courtesy of the Museum of Flight)

The Albatros used a water-cooled in-line engine. This was a departure from the rotary engines dominant in fighter designs previously. The rotary engine had a higher power to weight ratio for its time. But, rotaries had limitations that eventually led to their disappearance from the scene at the end of WWI.

The famous Sopwith Camel developed from the Sopwith Pup and became the leading airplane of the war in terms of victories. Improvements in the interrupter gear and warming the gun breech with warm engine air solved the frequent jams experienced by the Pup. Placing the gun breach under the cowl led to the characteristic hump that gave the camel its name. The Camel was notoriously difficult to handle. Half of the losses and fatalities were due to takeoff and landing accidents. Contrary to popular myth, the culprit was not the rotary engine, with its gyroscopic effects, but a marginally stable airplane with unforgiving landing gear. The rotary engine, however, resulted in very different left turn and right turn characteristics.

The By 1918 better airplanes, with more power, were reaching the front. Even the Sopwith Camel was being replaced with the Sopwith Snipe, which despite its large, 230 hp Clerget rotary was a docile airplane. The Allies had the RAF S.E.5a, flown by Major Edward "Mick" Mannock, Capt.

James McCudden, and Col. William "Billy" Bishop, the Nieuport 28, which dropped the sesquiplane configuration in favor of a traditional biplane, and the SPAD XIII**,** flown by Capt. René Fonk and Capt. Eddie Rickenbacker, shown in fig. 4. The S.E.5a and SPAD made use of the water-cooled, in-line 200-220 HP Hispano-Suiza, "Hisso". The in-line design allowed for a tighter cowling, which substantially lowered the airplane's drag.

Figure 4: SPAD XIII
(Photo Courtesy of the Museum of Flight)

The Central Powers had their aces flying the Aviatik, Pfalz D.XII, Fokker D.VII powered by 160-185 HP water-cooled, in-line Mercedes engines. The Fokker D.VII and late-coming Fokker D.VIII used the thick Gőttingen airfoil for cantilevered wings. Figure 5 shows the lack of supporting interplane wires in the Fokker D.VII. This, plus its sturdy structural design and easy handling made the Fokker D.VII the only airplane given special mention in the Treaty of Versaille.

Figure 5: Fokker D.VII
(Photo Courtesy of the USAF Museum)

In 1918, Prandtl developed his lifting-line theory, which demonstrated the span efficiency of high aspect-ratio wings. The Fokker D.VIII was the first airplane of note to make use of all the innovations from Gőttingen University. The D.VIII sported a single, high aspect-ratio cantilevered wing, shown in fig. 6. Unfortunately for Fokker, who was a Dutch citizen, building airplanes for the Central Powers, the Germans would not free up their larger Mercedes and BMW in-line engines for his new design. Therefore, he was stuck using a 110 HP Oberursal rotary, which greatly limited its capabilities.

Figure 5: Fokker D.VIII
(Photo Courtesy of the Museum of Flight)

The American contribution to fighters in the First World War was extremely limited. The most notable American airplane of the era was the Curtiss JN-4 Jenny, which was used as a trainer. Before the Americans entered the war there was a skirmish against Poncho Villa of Mexico, whose troops raided U. S. soil in Columbus, New Mexico. General "Blackjack" Pershing used Curtiss "Jennies" to scout. Major Dargue was forced to land with engine trouble and was stoned by a hostile Mexican crowd as he tried to fix the engine. None of the eight Jennies returned to the US. The Curtiss JN-4 Jenny became the primary trainer for the United States Air Service in WWI and later made fame as a barnstormer.

3. Analysis

The retrieval of aerodynamic coefficients was obtained following the procedures outlined in Loftin.[i] First, the total drag comes from the power required for straight and level flight at maximum cruise. Assumed is that the engine is performing at maximum power at altitude. The drag coefficient, C_D, is

$$C_D = \frac{550\eta_p HP}{\frac{1}{2}\rho V^3 S} \tag{1}$$

where η_p is the propulsive efficiency, HP is the engine horsepower at altitude, with

$$HP = \frac{\rho}{\rho_o} HP_o \tag{2}$$

.

HP_o is the rated engine horsepower at sea-level, ρ is density at altitude, ρ_o is the density at sea-level, V is velocity in feet per second, and S is the wing area. Drag is the sum of parasite and induced drag. Thus, the parasite drag is thus

$$C_{Do} = C_D - C_{Di} \tag{3}$$

The induced drag coefficient is proportional to the lift coefficient squared in the form of

$$C_{Di} = \frac{C_L^2}{\pi e AR} \tag{4}$$

where e is the Oswald efficiency factor and AR is the aspect ratio, defined as follows:

$$AR = \begin{cases} \dfrac{b^2}{S} & \text{monoplanes} \\ K\dfrac{b^2}{S} & \text{biplanes/triplanes} \end{cases} \tag{5}$$

K is Monk's span factor and a value of 1.1 is used for biplanes and 1.22 for the two triplanes in the collection. The lift coefficient, C_L, comes from the weight, i.e.

$$C_L = \frac{W}{\frac{1}{2}\rho V^2 S} \tag{6}$$

.

Once C_{Do} is obtained it can be used to find the maximum L/D as follows:

$$\left.\frac{L}{D}\right|_{\text{Max}} = \frac{1}{2}\sqrt{\frac{\pi e AR}{C_{Do}}} \tag{7}$$

.

Finally, $C_{L\max}$ is obtained from airfoil data obtained from various sources, such as references 4, 5, and 6.

Now that the important aerodynamic design parameters are obtained they can be used to find stall speeds and climb and turn performance of these aircraft. These three performance characteristics will be related to the tactics and successes of the aircraft in the results section.

The stall speed is determined from $C_{L\max}$.

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_{L\max}}} \tag{8}$$

Climb performance is obtained by determining the excess power. Excess power is defined as the power available minus the power required for straight and level flight. So,

$$\Delta P = 550\eta_P HP - P_{req} \tag{9}$$

where

$$P_{req} = \frac{1}{2}\rho V^3 S C_{Do} + \frac{W^2}{\frac{1}{2}\rho V S \pi e AR} \tag{10}$$

in ft-lb/sec. ΔP is related to climb as follows:

$$\Delta P = W\frac{dh}{dt} \tag{11}$$

The theoretical speeds for the fastest and tightest turns for these aircraft fall below the stall speeds. Therefore, the maximum turn rate and tightest turn is calculated at the stall speed in a turn, which, when the load factor is taken into account is given by,

$$V_{s,t} = \left[\frac{1100\eta_p HP}{\rho S\left(C_{Do} + \frac{C_{L\max}^2}{\pi \mathrm{eAR}}\right)}\right]^{1/3} \tag{12}$$

.

At this condition, the load factor is

$$n = \frac{\rho V_{s,t}^2 S C_{L\max}}{2\mathrm{W}} \tag{13}$$

and is used to find the maximum turn rate,

$$\dot{\chi} = \frac{g\left(n^2 - 1\right)^{1/2}}{V} \tag{14}$$

and the turn radius

$$r = \frac{V}{\dot{\chi}} \tag{15}$$

.

In surveying published data, it is easy to find multiple values for the weight, W, wing area, S, and cruise speed, V. However, these can generally be reconciled. The propulsive efficiency, η_p, and the Oswald efficiency factor, *e*, are another story. Following Loftin's lead, estimates were made, which gave η_p between 0.68 and 0.8 and *e* between 0.6 and 0.8. Loftin used slightly higher values then those used here. Where possible, known climb data was used to validate the selection of η_p and *e*. Note that the parasitic drag of the airplanes in this collection is so high that the effect of span efficiency is negligible to the total drag.

There are four anomalies in the resulting data that cannot be explained by choices of η_p and *e*. One is the Caproni, whose performance calculations show an airplane way ahead of its time. But, it should be noted that the Caproni was a prototype with a 110 HP engine where contemporary LeRhone and Oberursel engines were 80 HP. This anomaly could be a result of development of the airplane through time, a fact illustrated by its conversion from wing warping to ailerons after the war.

A second anomaly is the Austrian Aviatik that has an unusually large engine for the time. The Aviatik was not built in large numbers, so there is not much in the literature to support or detract from the unusual performance characteristics found.

The other two anomalies will be discussed when they are relevant to the discussion that follows.

4. Results and Discussion

The data obtained here is intended to illustrate the development of the fighter and fighter tactics during WWI. The presented data is not claimed to be accurate beyond what is required for its intended purpose. Given the nature of the data required and the uncertainty of the propeller efficiency and span efficiency, only relative trends and relations are supported. Airplanes in the collection that do not add anything to the conclusions made here are not presented.

Today's vision of WWI aerial fighting was dogfights with aircraft maneuvering for advantage. The reality was that successful pilots learned to surprise the enemy, make a quick attack and an equally quick exit. These tactics are directly from Boelcke's dicta and are still true today.

The best way to start is to compare fighters towards the end of 1916, which corresponds to the end of the Fokker Scourge. Figure 7 shows the big jump in climb performance of the Sopwith Pup and Triplane over the Eindecker E.III. Note that the Eindecker hasn't reached its best climb rate before the wing stalls. This illustrates the relatively small power loading and high stall speed of the Eindecker.

Climb performance of both the Pup and Sopwith Triplane are far superior to the Eindecker. For its time, the Sopwith Triplane had incredible performance. This also shows up in turns as illustrated in fig. 8.

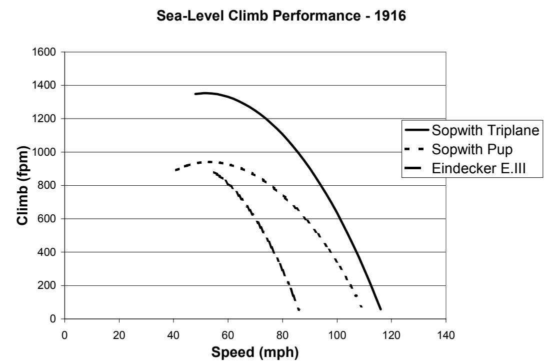

Figure 7. Sea-Level climb performance at end of Fokker Scourge

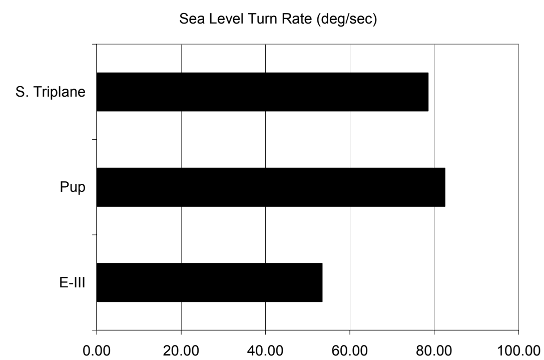

Fig. 8. Turn rate at end of Fokker Scourge

The performance of the Sopwith Triplane was so dramatic the German military asked all of the German manufactures to design triplanes. At this time in the war, there was still a sense that close in combat was necessary. Fokker answered the call with the Fokker Dr.1.

By the end of 1916 engine technology started to take off with the improved in-line, water-cooled engines. The big rotaries were a high source of drag and, with bigger engines, airplane speeds increased.

Next, we compare five airplanes in the MOF collection that were introduced during 1917. Figure 9 shows the climb performance at 10,000 ft and fig. 10 the turn rate.

Climb performance brings up two of the four anomalies found in this study. The first is the Nieuport 27's tremendous climb rate at low speeds, about which the author has never uncovered in the literature. The high climb at low speeds, and abrupt fall off, suggests a very high drag airplane. The figure also suggests a high stall speed. Perhaps pilots rarely experienced the high climb rate because they didn't care to fly close to stall.

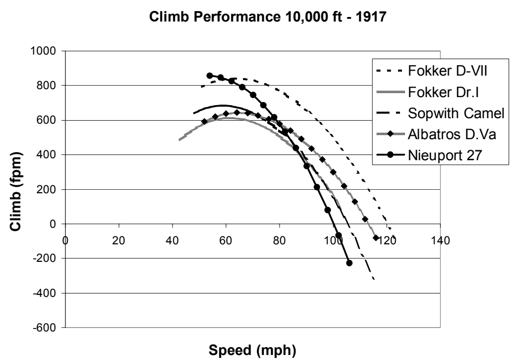

Figure 9: Climb performance - 1917

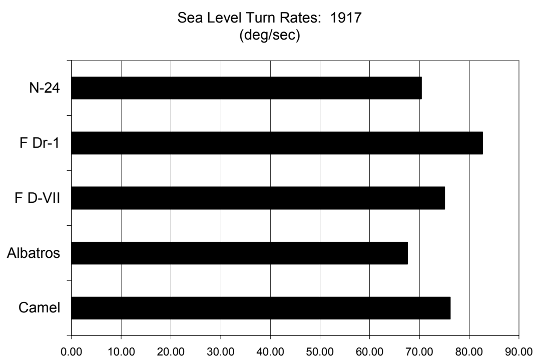

Fig. 10: Turn Performance – 1917

The second anomaly is the Fokker Dr.1, which has a reputation for superior climb and maneuverability. "[It] climbed like a monkey and maneuvered like the devil:" Manfred von Richthofen. The figures show that while the Dr.1 was superior in turn, it was poor in climb, relative to contemporary fighters. It is possible that Richtofen's opinion of the Dr.1's climb was due to its 19 degree climb angle which was 20% greater than the airplane he had flown previously, the Albatros D.III.

It is also worth noting that the Dr.1 had a fairly low stall speed. The thick airfoil section used gave it a lower stall and thus a greater climb angle and turn rate.

The data also demonstrates one reason the Fokker D.VII was such a successful weapon. It had great climb and turn performance. It also has the highest speed of the group and a fairly low stall speed. (In reality, the D.VII should be in the next group, since it fought mostly in 1918. Thus, it will also be presented in the next series of airplanes.)

If we consider the Boelcke Dicta, which suggests a pilot should get in and out and not dogfight, superior climb and speed would be a greater asset then superior maneuvering. The Dr.1 clearly excels in maneuvering but could not compete with its contemporaries in terms of speed and climb. Perhaps it is telling that only about 300 were built compared to the thousands of D.VII's and Sopwith Camels.

The figures show that the Sopwith Camel and Fokker Dr.1 were fairly evenly matched. They shared similar top speeds and climb and turn rates. However, in climb and speed, the Camel had the slight edge. This may be why the Camel was successful while the Dr.1 was not.

As the war moved into 1918 performance continued to increase. Figure 11 shows climb performance and fig. 12 turn rate for a selection of airplanes that saw service in 1918. The Fokker D.VIII came so late it barely saw action while the Snipe was delivered barely a month before the end of the war. The two are contrasts in performance. The Snipe, behind its 230 Bentley rotary is a stellar performer, and served the RAF through 1927. The D.VIII, on the other hand, was a poor performer behind its 110 HP Oberursel rotary. Behind a 145 HP Oberursel III the D.VIII faired far better when compared to its 200+ HP rivals. However, few Oberursel III's were available.

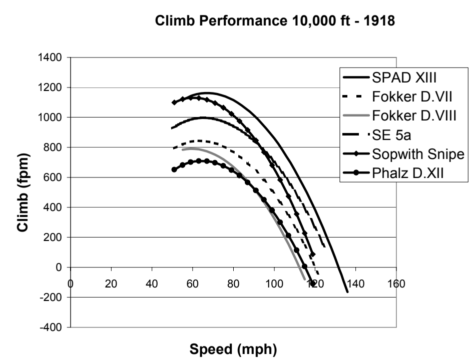

Figure 11: Climb performance – 1918

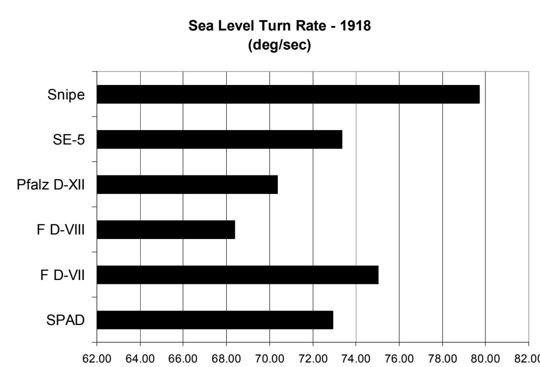

Fig. 12: Turn Performance – 1918

The Snipe illustrates that the Allies hadn't progressed in aerodynamic knowledge as far as the Germans. The Snipe used external wire bracing and, from the climb chart, demonstrates a fairly high drag coefficient ($C_{Do} = 0.048$). The big rotary also contributes to high drag. In contrast the SPAD and SE 5a both had water-cooled in-line engines, with tight-fitting cowls. The SPAD, with its 220 HP "Hisso" was probably the best Allied fighter during 1918. The SE 5a, behind a 200 "Hisso," or equivalent, came close but couldn't beat the bigger engine SPAD.

Both SPAD and SE 5a pilots knew that they should climb or dive away from an attack. None of the German airplanes could out-climb or out-dive these airplanes. It was a foolish pilot in these airplanes that attempted to stick around and fight in a tight dogfight for the Fokker D.VII could out-turn both allied airplanes.

The D.VII had another advantage over its counterparts. It was an easy-handling airplane. New pilots could master the D.VII with very little training. The thick Gőttingen airfoil helped prevent sharp, unexpected stalls. $C_{L\max}$ of the D.VII was 25% higher than for the SPAD and 12% higher than the SE 5a. This could be used to great advantage in close quarters.

The Pfalz D.XII also made use of the work at Gőttingen, but did not have the performance numbers of the Fokker D.VII. The Pfalz was slightly heavier than the Fokker. So, despite using the same engine, and roughly equivalent C_{Do}, the Pfalz could not climb or turn quite as well.

By this time in the air war tactics had developed to where formations of fighters would go "hunting" for the enemy. The Allies took back air superiority with the SPAD and SE 5a so the Central Power airplanes would seldom challenge these formations.

5. Concluding Remarks

Using contemporary performance analysis on historical WWI airplanes the capabilities written about each airplane in WWI literature is confirmed. The Eindecker E.III, was an early airplane whose performance was extremely limited. However, it was the first airplane to have a fixed machine gun that could fire through its propeller, leading to the first true fighter tactics developed by pilots like Oswald Boelcke and Max Immelmann. Success with this airplane led to an explosion of new designs and mass production of fighters.

During 1916 fighter design focused maneuverability. By 1917 this was giving way to climb and speed as the central focus of airplane design. The famed Fokker Dr.1, was a highly maneuverable airplane, which was superior in close-in dog-fighting, but had a low top speed and poor rate of climb.

The progress in engine performance cannot be ignored. Since climb is a function of excess power larger engines made the later airplanes far superior. The success of the SPAD XIII can be attributed to its great performance in "slash and dash" tactics due its large excess power and relatively low drag. Had the war continued, it would have been interesting to see how the Sopwith Snipe and a re-engined Fokker D.VIII would have performed.

A great deal of data on the 18 artifacts in the Personal Courage Wing at the Museum of Flight was generated. This paper represents a summary of the work using the most important fighters of the time. Only performance data was analyzed for this paper. Handling properties would be another interesting study, since some of these airplanes were notorious for having terrible handling properties.

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