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How the Mustang trampled the Luftwaffe: the role of the P-51 in the defeat of the German air force in World War Two

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HOW THE MUSTANG TRAMPLED THE LUFTWAFFE: THE ROLE OF THE P-51 IN THE DEFEAT OF THE GERMAN AIR FORCE IN WORLD WAR TWO

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ABSTRACT

The purposes of this study were to trace the evolution of the North American P-51 Mustang as an escort fighter in World War Two and to enumerate the reasons why it played a leading role in the extension of the American strategic bombing campaign into Germany and the ultimate defeat of the German Luftwaffe.

The Mustang prototype was built in 1940 in response to a British request for a fighter to help repel German invaders. The original model, powered by an Allison engine and three-bladed propeller, was fast and maneuverable at low altitudes, but its performance deteriorated rapidly at altitudes above 12,000 feet. In an experiment to improve its high-altitude performance, the British installed a Rolls Royce Merlin engine in the Mustang, and the resulting high altitude performance of the airplane was exceptional. However, at that time neither the British nor the Americans opted to pursue further development and production of the airplane.

After America entered the war following the Japanese attack on Pearl Harbor in 1941, the Allied powers agreed that the main war effort should be to "Defeat Germany First." A principal aspect of the war plan was a daylight strategic bombing campaign against German forces in Continental Europe by American bombers. The bombing campaign from bases in England began in July of 1942. As the program progressed and targets were attacked that were beyond the range of escorting Allied fighters, it became apparent that the bombers could not adequately defend themselves against defending German fighters. A desperate

effort was made to develop a high-performance escort fighter that could accompany the bombers to all targets of interest. The Merlin-powered Mustang with a four-bladed propeller proved to be that airplane.

This thesis discusses the technical reasons why the Mustang was a superior escort and air combat fighter. The energy maneuverability analysis is used to explain how the fighter gained an air combat advantage over the principal Luftwaffe fighter aircraft. The roles of bomber escort doctrine, pilot training and aircraft production in bringing the Mustang into its position of superiority are also indicated.

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CHAPTER 1

INTRODUCTION

When Japanese bombs fell on Pearl Harbor in December of 1941, ushering the United States into World War Two, the war had already been raging in Europe for over two years. Within three days after the attack, both Germany and Italy, as partners with Japan in the Tri-partite Pact, also declared war against America. The American military had been expecting a confrontation with the Japanese in the Pacific, but now the instant loss of most of the Pacific battle fleet left them with severely weakened forces. Initially, much confusion reigned, but after a period of resource and threat assessment within the American government and by leaders of other Allied nations, a plan for retaliation was formulated. Though the Japanese attack produced an outcry from the American public for an immediate military response to the Japanese treachery, the leaders of the Allied powers opposing Axis aggression unanimously adopted a policy to "Defeat Germany first." Great Britain had, with courage, fortitude and sacrifice, thwarted a German invasion attempt in the Fall of 1940, and it now stood as a potential staging area for military action against the German military colossus. However, German forces were far too strong to allow a cross-channel invasion until America's manpower and industrial might could be brought to bear. America had been surreptitiously involved in the European war against Germany, almost from the start; it had provided Great Britain with supplies and the implements of war. Now it became a full partner in the war effort.

The Royal Air Force had begun operations against German forces on September 4, 1939. Early bombing operations were confined primarily to shipping and coastal military targets. It did not actually bomb Germany itself until August of 1940, and that raid on Berlin was in retaliation for a German bombing of London.[1] Finding daylight attacks too costly, the RAF quickly opted to pursue the air war with night-time raids. The inaccuracies inherent in bombing at night led British Chief of Air Staff Charles Portal to suggest that "area" bombing, rather than bombing a specific target, would be an effective way of ensuring that at least some of the bombs dropped would hit a critical target. This policy was not followed in totality, however, until 23 February 1942, when Air Chief Marshal Sir Arthur Harris was appointed Director of Bomber Command. Harris insisted on a doctrine of "area bombing" that emphasized saturation bombing of populated areas, and he proceeded to launch frequent raids on industrial and strategic centers on the Continent.[2]

The official American Army Air Force presence in the European war began in February of 1942 with the arrival in England of a cadre of officers led by Brigadier General Ira Eaker, commander of Eighth Bomber Command and a passionate supporter of precision daylight bombing. Eaker was charged with spearheading the organization of an American air campaign against Germany. Ultimately, the Eighth Air Force, commanded by Major General Carl Spaatz, began operations against "Fortress Europe" on 17 August 1942, with a twelve-plane raid against railroad marshaling yards at Rouen, France.[3]

From the outset of America's air war in Europe the United States Army Air Force (USAAF) pursued a program of daylight precision bombing. The Air Force leadership was confident that the Norden bombsight promised the accuracy required to place bombs dropped from high altitude on the target without endangering the civilian population. Furthermore, they felt that in a carefully designed flying formation that could provide covering fields of defensive firepower, the Boeing B-17 Flying Fortress, armed with ten .50 caliber machine guns, could survive in the hostile European skies, even on missions beyond the range of escort fighters.[4] They learned the hard way that their suppositions were wrong. First, the illusion of accuracy was put to rest, primarily by frequent cloud cover that prevented visual acquisition of the target and, even in clear weather, by ground-based defensive fire that upset accuracy. Then the illusion of all-encompassing defensive fire collapsed under a hail of cannon and machine gun fire from hordes of fast and maneuverable German fighters.

As the war progressed the American bombers ranged deeper into the Continent, and eventually into Germany itself. However, targets within the boundaries of Germany were beyond the range of escort fighters, and bomber losses to the German defenses mounted steadily. In July of 1943, in a coordinated raid on Schweinfurt and Regensburg, sixty Fortresses fell to the German guns. Then, the following October 14th, on a raid that was later to be labeled *Black Thursday*, another sixty bombers went down, forcing the Americans to curtail missions deep into Germany.[5] During that time the USAAF had been using American P-38 Lockheed Lightnings and P-47 Republic Thunderbolts as escort fighters. Though both of these aircraft had better range than the British front-line fighters, the Hawker Hurricane and the Supermarine Spitfire, and they had good high altitude performance, they still were unable to provide escort support to the borders of Germany. Thus, though the American bombers continued the bombing campaign on the Continent, targets deep in Germany became virtually off limits until a long-range escort fighter could be developed.

Another American fighter aircraft, the North American P-51 Mustang, entered service with the RAF as a reconnaissance fighter just after America entered the war. Subsequently, it was pressed into service by the USAAF in Africa in a ground attack role as the A-36, where it was briefly given the name, Apache. It was responsive and fast, and its internal fuel capacity gave it a better range than the other Allied fighters, but its performance deteriorated drastically at high altitude, the environment of the bomber stream, making it unsuitable as an escort fighter. However, in the Fall of 1942, Rolls Royce test pilot Ronald Harker, noting the good qualities of the Mustang and being intimately familiar with the excellent high altitude performance of the Spitfire, suggested that the Allison engine in the P-51 be replaced with the Spitfire engine, the Rolls-Royce Merlin.[6] The USAAF allocated two aircraft for the experiment. Extensive flight tests confirmed that the Merlin-powered Mustang was a superior airplane with outstanding high altitude performance. Redesign to accommodate the new engine was immediately performed, and by November of 1943 the re-engined fighter was being mass-produced and a squadron was in training for combat with the "new" machine.

In the same time frame the USAAF experimented with external auxiliary fuel tanks that could be employed to extend the range of fighter aircraft. Ultimately, a suitable 108-gallon tank was designed and fitted to all escort aircraft. This addition to the P-51 increased its combat range to well over 700 miles, sufficient to allow the fighter to accompany the bombers to all targets in Germany.[7] This capability not only guaranteed the resumption of the Allied air attack on Germany's war industries, but it also proved to be the necessary instrument for victory in the air war.

The formula for Allied victory in the air war over Europe was *almost* complete. However, it was necessary for four critical areas of comparison to weigh in the Allies favor in order for final victory in the air to be achieved. First, an attack doctrine would need to be in place that would give the Allied forces an advantage. Second, Allied aircrews in sufficient numbers would need to be trained in tactics that would take full advantage of the performance potential of the aircraft they flew in comparison with their German adversaries. Third, the industrial might of the Allies would need to supply enough airplanes and crew to ensure numerical superiority over the enemy. Finally, the aircraft itself must have performance capabilities that exceed those of the enemy aircraft. Any deficiency in any one of these areas would have to be compensated for by excellence in the others.

The objective of this thesis is to demonstrate how the North American P-51 Mustang played a decisive role in implementing favorable resolution of these four conditions in favor of the Allied forces. The first three areas of comparison can be qualitatively determined from the organizational and operational records of the opposing air forces, although the comparisons will be subjective and open to some interpretation. The fourth area focuses on the comparison of airplane combat performance for the opposing air forces. Though this comparison is necessarily based on detailed aspects of aircraft engineering, the comparison of the performance of competing airplanes is accessible by analytical methods that can be graphically displayed in a way that can easily be understood by the layman. One method of evaluating airplane performance capabilities is through the *energy-maneuverability* (E-M) analysis.[8] Such an analysis makes use of graphs of turning rate versus airspeed and altitude versus airspeed to map the combat performance envelope of an aircraft. By overlaying the performance envelope of one aircraft on that of another, regions of aircraft superiority can be determined. In this way successful combat strategies can be identified and an assessment of the requirements for probable combat success can be made. It is proposed in the present work to compare the E-M graphs for the principal combat fighter aircraft in the Allied and Luftwaffe inventories to show probable combat outcomes. The discussion will necessarily include speculative comments on the influence of pilot training on these outcomes. The analysis will be supported where possible with available combat attrition statistics for both Allied and German forces. Throughout most of 1944 only the P-51 was capable of ranging deep into Germany. However, following the invasion of France in June of 1944, bases on the Continent became available, and as the conflict wore on and bases closer to Germany became available, another Allied fighter, the Republic Thunderbolt, became a major player in the skies over Germany. For this reason the performance of the P-47 will be included with the P-51 in the analysis. The German fighters considered are the Messerschmitt 109G and the Focke-Wulf 190, the mainstays of the Luftwaffe fighter corps. Other fighter aircraft certainly participated in air combat over Germany, but they played a lesser role than the four aircraft just mentioned. The Lockheed P-38 was an able participant for the Americans, but it was plagued with engine problems that limited its service in the cold, damp climate of Western Europe. For the Germans, the Messerschmitt 110 and Junkers 88 aircraft were present in large numbers, but they were thoroughly outclassed by the American fighters. The Tank 152a and the Messerschmitt 262 jet fighter were highly competitive with the Americans (the 262 was the outstanding fighter aircraft of the war), but they were available in such small numbers that they didn't present a significant obstacle for the American fighters

In order to put these developments in proper perspective with respect to America's involvement in World War Two, this narrative begins with a brief survey of American air power developments leading up to America's entry into the war. This is followed by the evolution of the strategic bombing program in Europe leading up to the introduction of the P-51 as an escort fighter. A description of the development of the P-51 to undertake the escort fighter role is followed by the discussion of the four conditions mentioned above and why the American air force was able to achieve the upper hand over the Luftwaffe in each area of contention.

CHAPTER 2

THE EARLY AMERICAN BOMBING CAMPAIGN IN EUROPE

America was unprepared for war; particularly a war in both Europe and Asia. However, America's potential for producing and manning the implements of war, long sought after by the British as the German threat continued to grow, was almost limitless. Now that the battle was joined, it was imperative that this potential be used to its fullest advantage. A careful assessment of the Axis military threat by Allied strategists convinced them that, because of its manpower, material and technological resources and its geographical position, Germany was a far stronger adversary and more immediate danger to national security than was Japan. As 1942 began, Germany was firmly positioned on the European Continent, making advances in Africa and threatening Russia across a broad front to the east. The Italians exhibited potential military strength in support of the Germans in the Mediterranean and in Africa.[9] England's position was precarious. An Allied invasion of what had become *Festung Europa* was out of the question at this juncture. The essential question that had to be answered was: "How do the Allied powers make inroads into the Axis stronghold?"

Shortly after the end of World War I the role of the airplane in warfare was under debate in America. While most of the military leadership viewed the airplane strictly as a reconnaissance tool, others had a broader view of its application to warfare. The most vocal of these air power proponents was General Billy Mitchell. In 1921 he demonstrated the effectiveness of the airplane as an offensive weapon when he led a flight of bombers to sink the retired German battleship Ostfriesland that was anchored seventy miles off the Atlantic coast. The publicity from this stunt and subsequent animated exchanges between Mitchell and the military leadership ultimately led to court martial proceedings in which Mitchell was cited for insubordination and conduct contrary to the preservation of good order and military discipline . He was ultimately convicted, and he retired from the military, though he continued to promote military aviation as a necessary safeguard for the nation. Among the Army men who testified on Mitchell's behalf were Colonel Henry H. "Hap" Arnold, Major Carl "Tooey" Spaatz and Major Ira Eaker, men who were destined to become leaders in the ascendancy of the air force as a front line military unit.[10]

During the 1930's in America the debate over the place of air power in modern warfare became more heated. The Air Corps Tactical School had been established in 1920 at Langley Field in Virginia to provide a forum for discussion of air power issues. However, it was not until the early 1930's that its staff, under the leadership of Commandant Colonel John Curry, broadened the scope of the Air Corps mission to consider strategic objectives. Drawing on the ideas of Billy Mitchell in America, Giulio Douhet in Italy and Liddell Hart in Great Britain, the school staff laid out the basic principles and doctrine of modern strategic air warfare. They were expounded in five general statements:

(1) In a modern society there are certain fundamental industrial and economic systems on which the war-making capability and social stability of a nation depend. Disruption or stagnation of these systems paralyzes the capability and desire of a nation to fight.

(2) These systems have inherently weak points that can be exploited through aerial bombardment, and current bombardment technology is sufficiently advanced to permit accurate placement of bombs on specific targets.

(3) It is possible for massed air forces to perform such bombardment missions with acceptable losses and still destroy selected targets.

(4) Selection of appropriate targets and their subsequent destruction by aerial bombardment can fatally weaken the enemy such that victory can be achieved through air power.

(5) In the event that victory cannot be achieved solely by targeting military objectives, then, as a last resort, air power must be applied to the bombardment of cities with the intent to fatally weaken the will of the populace to continue the war.[11]

The remainder of the decade was devoted to developing the organization and equipment essential to carrying out this mission, should it be required.

In 1938 Major General Hap Arnold was named Chief of the Army Air Corps, and he accelerated his efforts to have the Air Corps take on equal status with the Army and the Navy in America's military future. His principal subordinates in this effort were the aforementioned "no-nonsense, get the job done" Brigadier General Carl Spaatz and the diplomatic, "smooth as silk", Colonel Ira Eaker.[12] The German invasion of Poland in September of 1939 propelled Europe into a full scale war and precipitated in the United States a movement to formulate war plans of its own in the event that the war would escalate to include America. (Of course, neighboring Canada, being an integral part of the British Empire, was automatically drawn into the conflict at the outset.) At the forefront of the war planning brain trust for the Air Corps were the team of Lt. Col. Harold L. George and Majors Haywood S. Hansell, Jr., Laurence S. Kuter and Kenneth N. Walker who drafted the Air War Plans Division - 1 document, the blueprint for the Air Corps[*] role in the defense of the United States, protection of Pacific interests and offensive action against Germany.[12] General Arnold presented this document to President Franklin Roosevelt in September of 1941. The specific primary objectives for the air offensive against Germany were to:

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[*] The U. S. Army Air Corps became the U. S. Army Air Force on June 20, 1941.

(1) Destroy and disrupt the German electric and transportation systems and the petroleum industry, and (2) Undermine the morale of the German citizenry. A secondary objective was to neutralize the Luftwaffe. Thus, when America was thrust into the war some three months later, the air plan was already in place, and General Arnold and his staff set about to put it into motion. The unique feature of the plan was that it was based on the premise that a daylight bombing campaign could be carried out effectively and with acceptable losses. The British initially attempted such a tactic early in the war, but mounting aircrew losses at the hands of the German defenses convinced them that only under the cover of darkness could a bombing campaign succeed. The Americans based their opinion that daylight bombing would succeed on the defensive firepower of the B-17 Flying Fortress and on their bomber formation design that ensured overlapping fields of fire for defensive armament. The Fortress had four Wright Cyclone engines, each of which was rated at 1,200 horsepower. The bomber could carry a 6,000 pound payload over a combat radius of 1,000 miles at a cruise speed of 215 mph and altitude of over 30,000 feet, and it initially had ten 0.50 calibre machine guns as defensive armament. Figure 2.1 is a diagram showing the positions and fields of fire of the machine guns mounted on the B-17.[13] The Air Force strategists designed an airplane formation that optimized the effectiveness of this defensive armament. Figure 2.2 shows the positioning of aircraft for a bomber group (a fully manned group initially consisted of three squadrons with six aircraft per squadron). As can be seen from the figure, each group was positioned with high, middle and low squadrons. There was roughly a 300 foot separation in altitude between the squadrons with the lead squadron being positioned in the middle of the group. The groups were correspondingly positioned for large formations

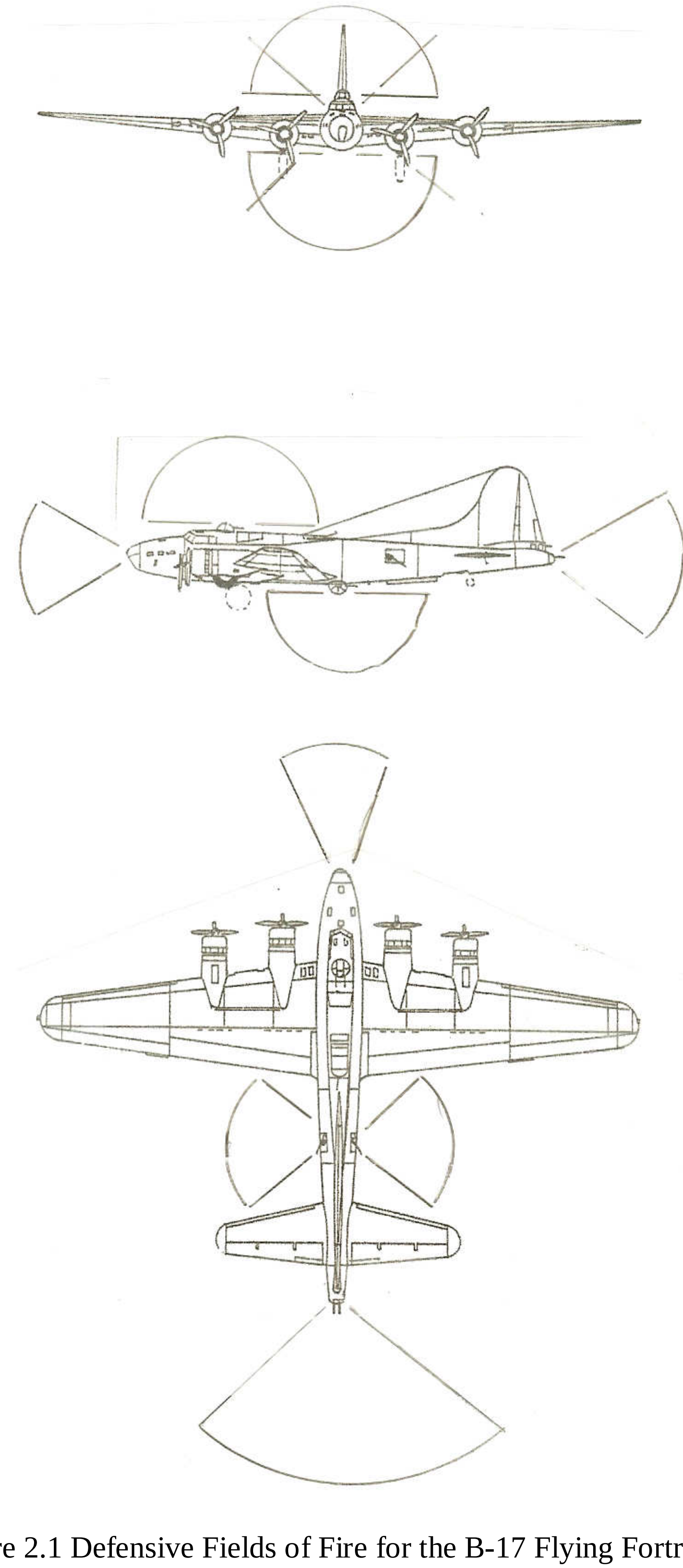

Figure 2.1 Defensive Fields of Fire for the B-17 Flying Fortress (Ref. 13)

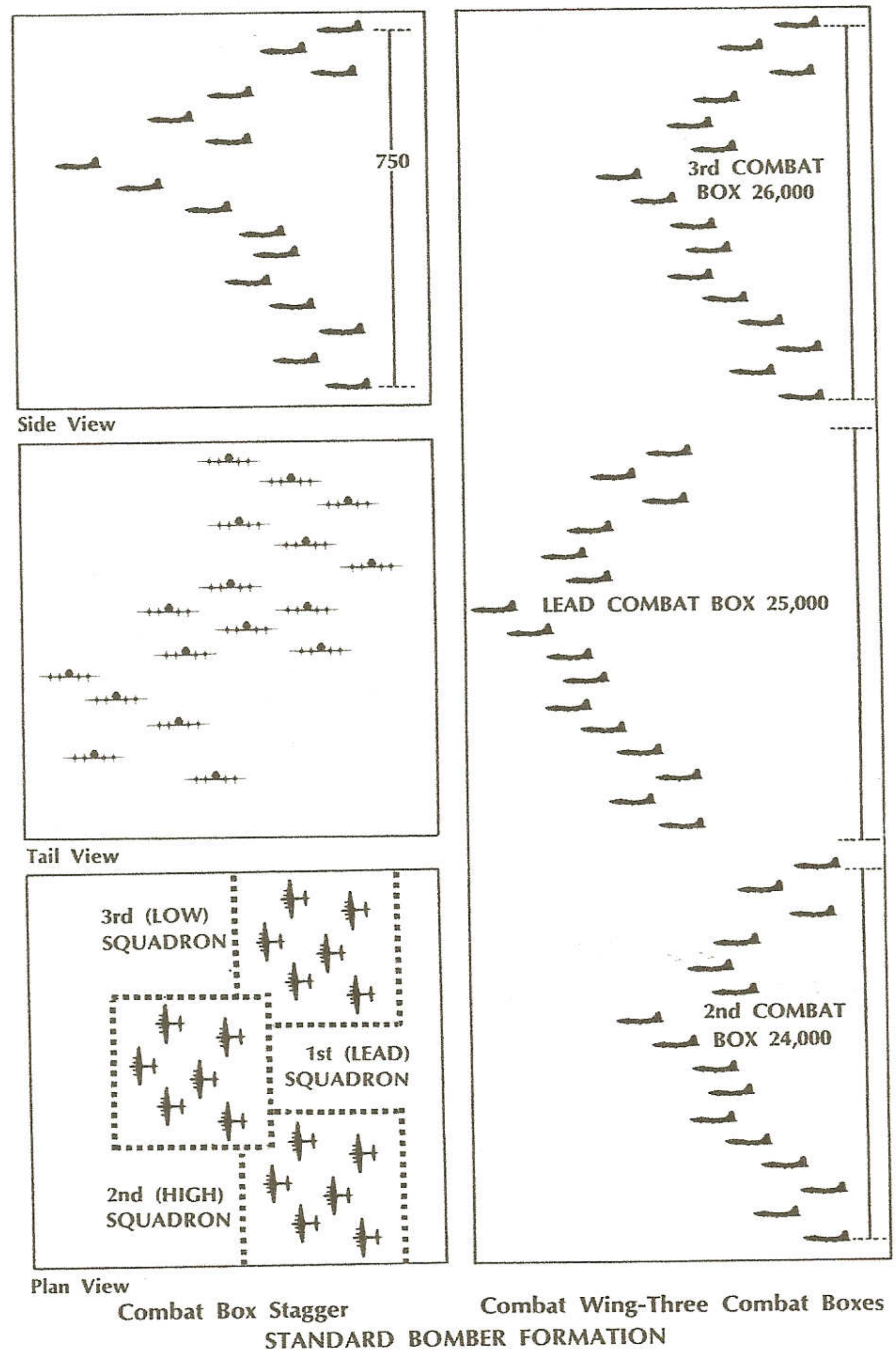

Figure 2.2 USAAF Bomber Formation Geometry (Ref. 14)

into a wing, usually three groups to a wing and three wings to a division.[14] The size of attacking formations increased as the war continued, and eventually, one division followed another, in train, to the target. In some cases, however, groups or divisions followed disparate paths to the target in an attempt to disperse the Luftwaffe opposition.

The Eighth Bomber Command, destined to become the backbone of the American assault on Nazi Germany, was activated at Langley Field, Virginia, on 1 February 1942, with Brigadier General Ira Eaker commanding. Three weeks later, Eaker went to Great Britain with six staff officers and ultimately established his headquarters in Wycombe Abbey, High Wycombe, about thirty miles northwest of London. Later, in the Spring of 1942, Hap Arnold made additional command assignments. In April, he named Brigadier General Frank O'D. Hunter commander of Eighth Fighter Command and, finally, in May, he chose Major General Carl Spaatz to command the entire Eighth Air Force.[15]

In the United States during the Spring, the Air Force began assembling aircraft and crews for transfer to Great Britain. By June, sufficient elements of the 97th Bombardment Group had made the trans-Atlantic flight to England via Greenland and Iceland to commence training for missions against Occupied Europe.* In preparation for their first combat, the group practiced intensely for six weeks on such fundamentals as formation flying, navigation, gunnery and bombing before they were deemed ready for action. Finally, on 17 August 1942, with Commanding General Ira Eaker aboard a bomber appropriately named *Yankee Doodle*, a flight of twelve Flying Fortresses embarked on the first American bombing mission against Occupied Europe. The bombers, escorted by four squadrons of British *Spitfire* fighters, bombed the railroad marshalling yards in the Rouen-Sotteville region of

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* Initially, a bomber group consisted of 18 aircraft; 3 squadrons, 6 aircraft to a squadron. Later in the war, the bomber group was expanded to 48 aircraft. Fighter groups normally were made up of from 52 to 56 aircraft with 12 to 15 aircraft to a squadron and four squadrons to a group.

France, located about 50 miles east of the coastal port of Le Havre. The moderate damage inflicted on the target, disruption of traffic on ten rail lines and destruction of some rolling stock and several buildings, was hailed by Eaker as a great success that demonstrated the potential of daylight bombing to inflict damage on the resources of the enemy. There were no American losses, but a B-17 gunner, Sgt. Kent R. West, shot down a German fighter to claim the first victory over the Luftwaffe for an Eighth Air Force bomber crewman. An interesting sidelight to the mission is that one of the bombers was piloted by Major Paul Tibbets who, almost three years later, would pilot the *Enola Gay* on its mission to drop the first atomic bomb on Hiroshima.[16]

In October, another long range strategic bomber was added to the combat inventory of the Eighth Air Force: the Consolidated B-24 Liberator . Four Pratt and Whitney Wasp engines, each producing 1200 horsepower, drove the Liberator at a cruise speed of 200 mph at an altitude of 25,000 feet. The plane could carry a payload of 8,800 pounds over a combat range of 1,400 miles. It carried ten 0.50 caliber machine guns, and its defensive firing patterns were similar to those of the B-17. As with the B-17, the first models to go into combat had only a single gun in the nose. Though it first flew in 1939, developmental problems beset the Liberator, delaying its combat appearance in Western Europe until October of 1942.

During the Fall of 1942, two conditions prevailed that delayed the growth of the bombing campaign against Nazi-held Europe. First, the bomber production programs took awhile to ramp up to their full potential because satellite aircraft fabrication plants had to be constructed, staffed and tooled to supplement the main Boeing B-17 *Flying Fortress* plant in

Seattle and the San Diego plant for the Liberator.* Second, at the Arcadia Conference in Washington in late December of 1941, President Roosevelt strongly supported Prime Minister Churchill's suggestion that the U. S. effect a military landing in North Africa to get American ground troops involved in the war against Germany and Italy and to put some pressure on the German military effort in Africa. Strong Air Force support was required for this campaign, and, at least temporarily, the Air Force effort in North Africa took precedence over an aerial campaign against Occupied Europe.

Nevertheless, the Eighth Air Force bombing campaign from England against Occupied Europe did continue in 1942, albeit on a small scale. In fact, for the entire year only 793 sorties† on 25 missions were flown by Eighth Air Force B-17 and B-24 strategic bombers. The largest raid for the year was carried out against Lille on 9 October by a total of 79 B-17 and B-24 bombers. For the year, the Eighth lost forty aircraft shot down by enemy action (ground-based anti-aircraft artillery or fighter opposition), with 29 airmen being killed, 130 wounded and 291 missing in action. During that same period the Eighth Air Force gradually grew in size so that by 1 January 1943, eight bomber groups and two fighter groups were regularly attacking German installations in Occupied Western Europe.[17]

From the beginning, America's strategic air war against Germany was directed against military targets and against those industries and that infrastructure that helped to maintain the enemy war machine. Particularly in the campaign against the occupied

* Ultimately, B-17s were built in Seattle, Burbank and Long Beach, and B-24s were built in San Diego, Willow Run (near Detroit), Fort Worth, Dallas and Tulsa.

† A sortie is a bomber that attacks the target. A bomber that aborts a mission at any time prior to target contact is not counted as a sortie.

countries, care was taken to avoid civilian casualties and to minimize damage to areas around the targets.

Throughout 1942 and into early 1943, the bombers of the Eighth flew missions primarily into France and the Low Countries against shipyards, railroad centers, aircraft maintenance facilities and storage depots as well as against actual military facilities such as airfields, submarine bases, unit headquarters and barracks. For these early missions the bombers were escorted by Supermarine Spitfires flown mostly by American pilots. American-built Lockheed P-38 Lightning fighters participated in reconnaissance flights along the English Channel beginning in August of 1942 (in fact, a Lightning pilot achieved the first kill of a German aircraft in an American-built airplane on August 14th). The P-38 was a twin engine, twin tailed fighter with four nose-mounted machine guns and a cannon, and it could fly at 390 mph with a range in excess of 350 miles. It was also the first fighter designed and built in America to participate in the war in Europe. Beginning in August of 1942, P-38s participated in defensive patrols along the English Channel and in fighter offensive sweeps (called *rodeos*) over the coastal regions of the Continent seeking combat with German fighters. On the 2nd of October Lightnings participated as escorts for the first time for a major raid on Meaulte in northern France. However, near the end of that month, all P-38s were withdrawn from escort service in England and sent to the Mediterranean with the Twelfth Air Force to support the Allied landings in North Africa. This was done not only to take advantage of the Lightning's long range capabilities and to show an American-made air presence in the African campaign, but also because the Lightning performed very well in the warm dry heat of the desert while its engines were unreliable in the damp, cold climate of England, resulting in a high abort rate. They did not fly with the Eighth again until

November of 1943. With the departure of the Lightnings, the notoriously short-ranged Spitfire once again took on all bomber escort duties for the Eighth Air Force. At this juncture, by initiating missions for the bombers that stretched beyond the range of their escorts, the American air leaders put to the test the theory that the bombers could defend themselves in the hostile skies defended by the Luftwaffe.

Initially, the unescorted forays were tentative, partly because the strength of the bomber force had been depleted by the demands of Operation Torch, the Allied invasion of North Africa, and partly because the commanders wanted to extend the combat range gradually to give the crews an opportunity to gain experience in close formation flying and in applying interlocking fields of defensive fire. Eighth Air Force strategic bomber losses for 1942 totaled forty aircraft; the deadliest single mission (eleven bombers were lost) surprisingly occurred over Rouen which, at 150 miles, was still within the combat range of the *Spitfire* escorting fighters. Nevertheless, such losses were acceptable in the overall scheme of the air war.

As 1943 began, the battle lines for the air war in Western Europe were drawn. The Allies sent increasingly larger formations of B-17s and B-24s across the English Channel and deep into France and the Low Countries on missions to weaken the Nazi military machine and to weaken the resolve of the Germans to continue the war. The limited ranged Spitfire escorts could provide protection only for coastal targets. Beyond their escort range, the German fighter squadrons waited to pounce on the bombers in the air, and the deadly 88 mm anti-aircraft artillery that ringed the German installations awaited the arrival of the bombers over the target. The principal German fighters were the Messerschmitt 109 and the Focke

Wulf 190. The ME 109G was a formidable opponent with a top speed of 395 mph, a service ceiling of 39,300 feet and armament consisting of two machine guns and one 20 mm cannon. The predominant model of the Focke Wulf aircraft, the FW 190A6, was rated at 400 mph and 35,000 feet, and it mounted two machine guns and four cannons. Two other aircraft, the Junkers 88 and the Messerschmitt 110 were effective against the unescorted bombers by lobbing unguided missiles at them while outside the range of their defensive fire. They were too slow to effectively challenge the bombers with direct attacks.[19*]

In early January of 1943 the American strategic bombing campaign was in jeopardy … not from the Germans, but from Winston Churchill and most of his RAF commanders. The Americans had been in the air war for over four months and had yet to make a significant contribution to the strategic war. With England's lifeline to America in peril from the U-boat threat, the English leaders desperately wanted American bombers to devote their efforts toward defeating the underwater raiders - at their construction sites, at their bases of operation and at sea. However, the Americans insisted that they be allowed to continue what they had started, and they had two allies in the upper echelons of the British military structure: Air Vice-Marshal John Slessor, assistant chief of air staff, and Sir Archibald S. M. Sinclair, secretary of state for air. They cautioned Churchill and the RAF leadership not to be too harsh with the Americans in the early going lest they decide to devote more of their resources to the Pacific war if their strategic efforts in Western Europe were curtailed. Desperately, General Eaker presented the American case, one on one, to Mr. Churchill himself, and he was sufficiently convincing to gain Churchill's support for the American strategic program. A few days later, at a conference of Allied leaders at Casablanca

[*] Published performance data vary for these aircraft. Representative nominal values are used in analyses to follow.

(including both Churchill and Roosevelt), the Combined Chiefs of Staff of the Allied forces announced the creation of the Combined Bomber Offensive, around-the-clock bombing of German installations by American and British air forces, the British at night and the Americans during the daylight hours. Priority targets were listed as submarine construction sites, the aircraft industry, transportation and oil production facilities.[20]

Throughout 1942 the Nazi U-boats had been wreaking havoc with the seaborne supply lines from America to England, and American strategic bombers had taken on a tactical role to repeatedly hit the U-boat bases at St. Nazair, Brest and Lorient on the west coast of France. However, they had little effect on the hardened concrete pens from which the subs operated. It appeared that the submarines would have to be attacked where they were built. Thus, since the strategic role of the American bombers had been confirmed at Casablanca, Air Force planners chose as the target for the Eighth's first foray into the skies over Germany itself the shipyards and naval base facilities at Wilhelmshaven on the North Sea. On 27 January 1943 a formation of fifty-five B-17s and B-24s of the 306th Bomb Group, commanded by General Frank Armstrong, carried out the attack. The Germans were caught by surprise and put up very light opposition to the raid. Only three bombers were shot down, but three crewmen in the returning bombers were killed and forty three men were wounded. Unfortunately, bombing accuracy on the mission was poor because of cloud cover, and little damage was done. However, the precedent had been set, and from that time on, targets in the German homeland appeared with increasing regularity on the raid schedule.[21]

Early in 1943 an aircraft was added to the American inventory that would initially provide extended protection for the strategic bombers and later prove to be the premier ground attack aircraft of the tactical air force: the Republic P-47 *Thunderbolt*. First flown in May of 1941, it was a seven ton behemoth, the largest fighter in the world at the time, that was powered by a 2000 hp super-charged Pratt and Whitney Double Wasp 2800 engine and had a top speed in excess of 400 mph. With a ceiling of 40,000 feet, armament consisting of eight 0.50 caliber machine guns and a very high dive speed, the Thunderbolt was a very effective escort fighter. However, the aircraft had its fair share of teething problems, and it was not until 8 April of 1943 that the "Jug", as it was nicknamed, participated in its first escort mission with the Eighth Air Force. The aircraft initially had a combat range of only 175 miles, just 20 percent more than that of the Spitfire, but that range was doubled by July with the installation of a 75-gallon external fuel tank, as illustrated in Figure 2.3.[23]

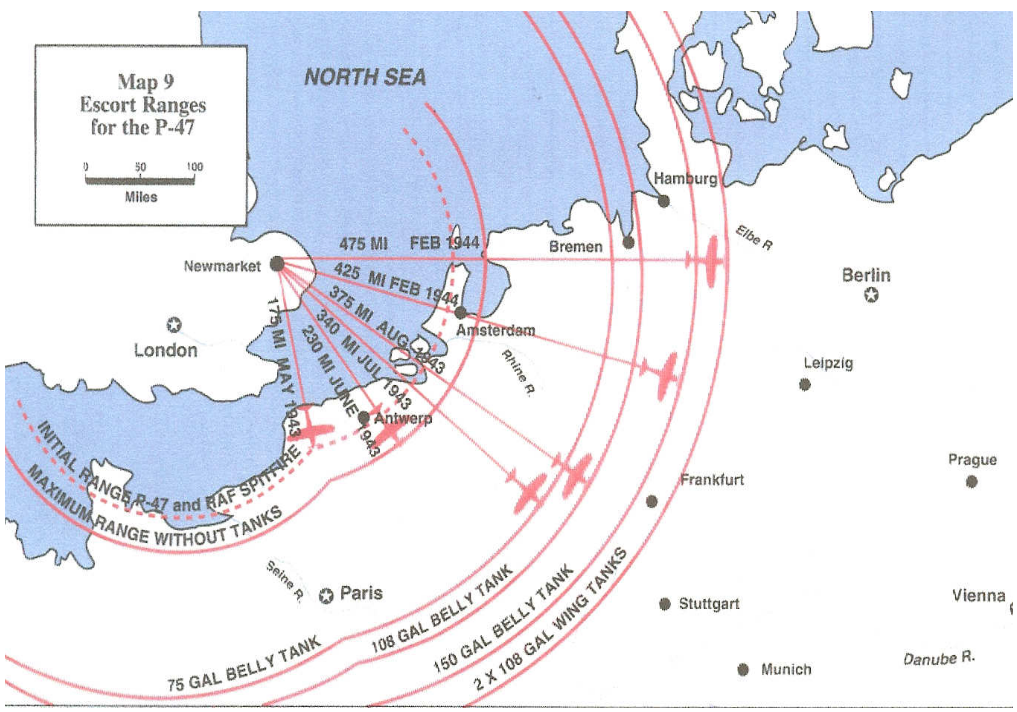

Figure 2.3. P-47 Thunderbolt Combat Range (Ref. 23)

Throughout the Spring of 1943 Eighth Air Force bombers pushed the boundaries of their strategic efforts deeper into Germany. On 17 April the Americans mounted their first 100-plane raid when 107 B-17s attacked Bremen some 350 miles east of London. By this time the German fighter forces had perfected their intercept and attack techniques. Once the track of the bombers had been determined by ground-based radar installations, the fighter forces were staged at bases positioned along the track. Then, as soon as the American Thunderbolt escort turned for home when the bombers were about halfway to the target, the Germans pressed home their attacks. They favored a head-on attack in groups of from six to ten aircraft to take advantage of the weak defensive fire offered from the nose of the bombers. The fighters that attacked the bombers as they approached and left the target area and the anti-aircraft barrage inflicted while the bombers were on their actual bombing run took the heaviest toll of American bombers to date … sixteen bombers shot down and thirty nine heavily damaged.[24] But worse was yet to come.

For the next three months the Eighth mounted almost 5,000 sorties over Western Europe with a loss rate of just under 6 percent. In that time the size of the raids expanded such that in some cases over 300 bombers were involved. At the same time, the range of the P-47 escorts improved to about 375 miles with the addition of 108 gallon external fuel tanks. By the late summer of 1943 the Combined Bomber Offensive was in full swing and submarine construction and transportation targets had been given a work-over, The time had come to mount a significant effort against the aircraft industry deep within Germany itself. The targets selected were the ball bearing plant at Schweinfurt, almost 400 miles from England, and the Messerschmitt ME 109 plant at Regensburg, eighty miles farther into Germany The path to these targets was lined with German fighter bases, but the risk was worth the effort since it was estimated that destruction of the production capability of these plants would account for thirty percent of Germany's 109 production and put a severe setback on production of the vast array of the war-making machinery that used ball bearings. In fact, it was even hinted that a successful raid could shorten the war by six months. The two attacking forces were to cross the Channel together and then take different paths to their respective targets, hopefully confusing the defending German fighter forces in the process. The Regensburg group was to continue on to North Africa after the attack since it had to travel considerably farther to the target than the other group, and the Schweinfurt group was to return to England. The morning of the scheduled attack, 17 August 1943, exactly one year after that tentative first raid on Rouen, greeted the assembled bombers with thick fog. Nevertheless, the 150 plane bomber group bound for Regensburg, having been pushed through extensive blind flying training by its tough commander, Col. Curtis LeMay, lifted into the sky on the way to its target on schedule. General Robert. Anderson, the commander of the second group, elected to wait out the fog before sending his 250 bombers on their way to Schweinfurt. The delay allowed German fighters that attacked the first group to refuel and rearm in time to be waiting for the second group. By this period of the war, the German fighter forces had fine-tuned their attack tactics against the bombers. While the speedy ME 109 and FW 190 single engine fighters pressed home their head-on attacks, the slower twin-engine ME 110s lobbed rockets into the bomber stream from just outside the range of defensive fire and the Junkers 88 medium fighter-bombers dropped bombs from above. The results of these attacks and those from ground-based anti-aircraft artillery were devastating. Sixty bombers and their crews, almost twenty percent of the force that actually made it to Germany, had been blasted out of the sky! In addition, about one hundred and fifty of the bombers that did make it back to base suffered battle damage, and eleven of those had to be scrapped. The bombing results at Regensburg were excellent, the Messerschmitt facilities being so heavily damaged that the Germans accelerated a program to disperse their manufacture and assembly facilities. Schweinfurt's bearing works fared much better, suffering only limited damage that left production virtually unaffected. Though there was no doubt that the German war machine was hurt by the raids, the cost to the American forces was crippling. Post-mission analysis blamed the high losses on the lack of coordination caused by the weather delay and the exceptional distance traveled on the mission resulting in the bombers' flying unescorted by fighters for an extended time in airspace saturated with hordes of tenacious enemy fighters.[25]

The German attacking forces did not escape from these aerial confrontations unscathed. A few attacking German fighters fell prey to American escort fighters, though they usually delayed their attacks until the Americans turned for home at the German border. However, each American bomber had ten 0.50 caliber machine guns that could be brought to bear on the attacking fighters, and they gave a good account of themselves. Throughout the summer of 1943 the American defenses were able to knock down over 17 percent of the attacking Luftwaffe fighter force, and on this mission they conformed to the norm. Since the combat was taking place over Axis-controlled territory, however, some of the downed Luftwaffe pilots were able to return to combat in short order.

The shock of the Regensburg-Schweinfurt mission resonated through the USAAF high command. A loss rate of almost 20 percent of the attacking bomber force could not long be tolerated. An urgent call was issued to the airframe industry to accelerate design and construction programs for an escort fighter that could accompany the bomber stream all the way to targets in Germany and back to England. The call would be answered before the end of the year, but in the meantime, the Air Force brass opted to continue what they had started. Following a six week period of short range missions confined to locales in France, the Low Countries and near the western border of Germany which allowed for fighter escort for most of the missions, the generals decided to try more missions deeper into Germany. Forty five bombers were shot down at Stuttgart in early September. Then, over six days in mid-October, 178 bombers fell to the fierce Luftwaffe opposition. The crowning blow was the loss of sixty B-17s during a second mission to Schweinfurt on October 14, 1943, a day that thereafter was to be called *Black Thursday*. On that mission two hundred and twenty nine B-17s ran the fighter gauntlet to hit the ball bearing works. Only 20 percent of the bombers made it back home without sustaining some kind of battle damage. Unfortunately, as with the first Schweinfurt mission, few of the American bombs found their targets. With these costly and discouraging results, the USAAF brass finally called a halt to raids much beyond the range of the escort fighters.

There was no doubt that the Luftwaffe ruled the skies over Germany, and until that situation could be reversed, the wings of the Eighth Air Force had been clipped. Fortunately, the help that the bomber boys so desperately needed was only six weeks away, and it came in the form of an airframe that had been fighting in Europe with the RAF since early 1942: the North American P-51 Mustang. The evolution of this first Mustang model into the aircraft that became the scourge of the Luftwaffe in service with the USAAF is a story of technological innovation and serendipity. That story, told with some attention to technical details, follows.

CHAPTER 3

THE BIRTH AND REBIRTH OF THE P-51 MUSTANG

The American inventory of combat aircraft when the war began consisted primarily of types that had been developed during the 1930's. The Boeing B-17 Flying Fortress and the Consolidated B-24 Liberator were the front line strategic bombers, and the leading pursuit (later designated "fighter") aircraft were the Bell P-39 Airacobra, the Lockheed P-38 Lightning and the Curtiss P-40 Tomahawk. The bombers were clearly superior to any similar aircraft in the Axis inventories. In fact, the Luftwaffe had no long range, high payload bombers. The German military philosophy was one of "lightning war", or *blitzkrieg*, in which the air force was used for close air support of ground operations. Hence, the Luftwaffe was a tactical air force. This philosophy called for a stable of superior tactical airplanes which included agile and deadly fighters to eliminate the enemy air force, medium bombers to soften hardened defenses and cut off reserves and dive bombers to take out mechanized units and disrupt troop movements. At the beginning of the war the Messerschmitt 109E filled the fighter role admirably. Then, in 1941, an even better fighter entered the combat inventory - the Focke-Wulf 190. Together, these two fighters were formidable air-to-air adversaries for the Allied air forces.

Early in the conflict, Great Britain bore the brunt of the German onslaught. Following the initial attack on Poland in September of 1939 that plunged Europe into war, the Nazi war machine rumbled through the Low Countries, took Norway, Denmark, Belgium and France and was poised to attack Great Britain. Hitler ordered an all-out air assault on the air fields of the British homeland to eliminate RAF opposition to his impending invasion. The Royal Air Force that stood in the way was stocked primarily with two defensive fighter types: the sturdy Hawker Hurricane, which joined the inventory in 1936, and the agile Supermarine Spitfire, which first appeared in 1938. By the Spring of 1940, twenty-two squadrons of Hurricanes and 19 squadrons of Spitfires were available for service, and the factories that fabricated these aircraft were in full production. Royal Air Force Chief Air Marshal Sir Hugh Downing designed a defense of the island based on careful allocation of Hurricane and Spitfire fighters, utilization of a clever radar-assisted early warning and tracking system and a network of ground-based anti-aircraft batteries. Still he felt that, even with the homeland factories operating around the clock, the RAF would be under-equipped in the impending conflict, so he sent a team to the United States to buy some fighters for the RAF.

The British procurement team went to the Curtiss Aircraft Company with an offer to buy 400 P-40 fighters. The P-40 Warhawk seemed to be the appropriate choice for the job at hand. It had better performance than the Hurricane, was adequately armed with four machine guns and had excellent ceiling and dive performance that would allow it to "hit and run" and not be forced to dogfight with the better ME 109. The Curtis Company, however, was in full production for the United States and could not begin to manufacture their P-40 for the British until much later in the year. Reluctant to accept such an extended manufacturing schedule, the delegation took their proposal to North American Aviation, manufacturer of the very successful *Harvard* advanced trainer that the RAF used extensively to train fighter pilots. When North American was offered that option, company president James "Dutch" Kindelberger deflected the proposal to build P-40's by saying that his company could design and build a prototype of a fighter that would be superior in performance to the P-40. The British delegation, though skeptical, offered to consider the proposal pending study of drawings of the proposed design. Several days later North American Vice-President Lee Atwood[*] laid out the detailed design drawings for the proposed fighter, and, after some negotiation, on 29 May 1940 a contract for 320 of the fighters was signed.

In early October, just over 120 days later, the prototype airplane, designated NA-73X, was rolled out of the factory in Inglewood, California. The British gave it the name, *Mustang*. Later that month, on 26 October, test pilot Vance Breese settled into the roomy cockpit of NA-73X, advanced the throttle, roared down the Mines Field runway and lifted the sleek fighter into the air on its maiden flight. It was powered by an Allison V-1710 liquid-cooled, in-line engine that developed 1150 shaft horsepower and turned a three-bladed Hamilton Standard propeller. The test flight showed the airplane to be stable, easy to handle and at least 25 mph faster than the P-40 that the British originally wanted to buy. Its widely spaced landing gear made it much easier to land and operate on the ground than the famous Spitfire, which, with its narrow landing gear, was subject to ground looping. The only problem for the pilot was the long cowling housing the in-line engine which made seeing ahead difficult while taxiing on the runway. Subsequent test flights convinced the British to order an additional 300 of the spirited mount for the RAF.[26]

The Mustang had several unique design features that contributed to its success. It mounted an in-line engine that was contained within a fuselage nose shape that displayed a very small frontal cross section area, and the fuselage contours were blended at wing and tail with fillets that ensured smooth airflow and minimum drag force. In fact, the Mustang had the lowest drag force of any fighter aircraft that participated in World War II. The wing chord-wise cross-section was a so-called laminar flow airfoil which had its maximum

[*] Mr. Atwood was the roommate of the author's father, John W. Courter, at the University of Texas. He ultimately became Chief Executive Officer of North American Rockwell Corporation.

thickness much farther aft than the quarter-chord position used by conventional airfoils. This was advantageous because the thin layer of air next to the wing surface (the boundary layer) remained smooth (laminar) to a position aft of the maximum thickness point, producing much less friction drag than would be produced by a conventional airfoil that would usually produce a turbulent boundary layer. The air induction system used to remove heat from the engine liquid coolant also had some drag-reducing features. Since the cooling requirement was a function of the engine rpm and the airspeed, an aft variable-position bleed door was installed so that just the right amount of airflow for adequate cooling could be achieved without paying the high drag penalty incurred by a fixed airflow system. Using this system allowed the fixed inlet to be smaller than that required for a fixed duct exit area. In addition, the inlet scoop surface adjacent to the fuselage was positioned so that it was displaced from the fuselage surface by a small gap that prevented the slow-moving boundary layer air on the forward fuselage surface from entering the cooling duct, thus permitting a smoother duct inlet flow with resulting higher ram efficiency and concomitant lower drag.

The first British Mustang, labeled the Mark 1, arrived in England on 1 November 1941. Subsequent testing by the RAF revealed that the fighter could dive at 500 mph and achieve just over 380 mph in level flight. The only deficiencies the British noted were that the aircraft's climb performance was poor and that its over-all performance deteriorated rapidly as the airplane altitude exceeded 12,000 feet. Still, the British were generally delighted with the performance of the new fighter, and they pressed it into service in April of 1942 in a tactical reconnaissance role where it excelled at photographic surveillance and at strafing of targets of opportunity for the remainder of the war.

Shortly after the new fighter went into production for the British, the U. S. Army selected airframes numbers 5 and 10 off the assembly line, assigned them the model designation XP-51 and transported them to Wright Field in Ohio where they were stored for later evaluation. With the Lockheed P-38, Republic P-47, Curtiss P-40 and Bell P-39 fighters all in production at that time, the Army felt no urgency to spend resources on a fighter for which there was, as yet, no perceived need. However, the Japanese attack on Pearl Harbor and their subsequent success in the following weeks against American front line fighters induced the Army to resurrect the XP-51 and put it through an extensive performance analysis program. The results of the tests corroborated those of the British, and the Army immediately diverted some of the airframes ordered by the British into the U. S. Army Air Force inventory. These first fifty units were assigned a photo-reconnaissance role and given the designation F-6A and the name Apache, a sobriquet that soon gave way to the original Mustang. As America's involvement in the war became more intense, the Air Force expanded the role of the P-51 to utilize its excellent low-level performance. The basic Mustang airframe was strengthened, dive brakes and bomb shackles were added and a dive-bomber version of the Mustang, labeled the A-36, was born. Five hundred of these aircraft were eventually produced, with the first becoming operational in September of 1942 and seeing action in Africa in the late spring of 1943. The aircraft was very successful in the ground attack role; so much so that its pilots elected to call it the Invader, a name better fitted than Mustang to the role it was playing. During 1942, North American began a production run of 310 P-51A fighters for the USAAF. The first of these aircraft joined the inventory in the Spring of 1943. Thus, the North American P-51 officially entered operational service for the United States in three different variants - as a fighter, a dive bomber and a photo-reconnaissance airplane. All of these Mustang variants were powered by the Allison V-1710 liquid-cooled engine turning a three-bladed Hamilton Standard propeller.[27]

Early in the operation of the Mustang by the RAF, Rolls Royce test pilot Ronald Harker noted that the airframe had superior performance that was only degraded above 12,000 feet altitude by the inferior output of the un-supercharged Allison engine. Being intimately familiar with the British Spitfire and its excellent high-altitude performance, Harker suggested that the Mustang be fitted with the Spitfire's Rolls Royce *Merlin* engine to determine any performance benefits. Four aircraft, designated *Mustang X*, were set aside for this purpose, and a rigorous performance evaluation program ensued. Concurrently, American Assistant Air Attaché Thomas Hitchcock[*] suggested to Air Force Chief "Hap" Arnold that the Air Force also effect and test the conversion. The test results were astounding! The Merlin 61 engine, manufactured in the United States by Packard, delivered 1030 horsepower at about 6,000 feet altitude, but its real value was realized at altitudes over 20,000 feet. At 19,000 feet a two stage blower automatically cut in that provided the additional high-density air required for the engine to maintain its power level to very high altitudes. In order to fully utilize the power provided, the aircraft was fitted with a 4-bladed Hamilton Standard propeller that could take a bigger "bite" out of the air than the three bladed prop and thus produce more thrust. The resulting American pre-production version of the aircraft, designated XP-51B, first flew on 30 November 1942, and a contract was let on 28 December for full production of the P-51B. By summer, Merlin-powered Mustangs were beginning to trickle off the assembly lines and enter the operational inventory. Ultimately, almost 2,000 B-model fighters were built, but seventy one of these were configured as photo-

[*] Hitchcock was the famous "Ten Goal Tommy", the international polo star of the Thirties.

reconnaissance aircraft and given the designation F-6C. All of these production aircraft used the Packard V-1650 engine (the *Merlin* 61 built in the United States under license by Packard).[28]

The "new" North American P-51 Mustang could now operate on an equal footing with the Spitfire at any altitude. It was faster in level flight by about thirty five mph and far superior in a dive. The Spitfire was more maneuverable and had a better climb rate, but the Mustang could hold its own in those categories at all altitudes. However, the two attributes that gave the Mustang a huge advantage over the Spitfire were range and endurance. The Spitfire, having been designed as a home defense fighter to defend Allied installations, had a very short combat range -- about 150 miles -- and its design had very little internal volume to accommodate additional fuel tanks. There was also no provision for carrying external wing tanks. Only a small "slipper" tank attached to the fuselage could be accommodated. This small fuel supply limited the Spitfire to less than two flight hours per flight. On the other hand, the Mustang had enough room for internal fuel storage to give it a combat range in excess of 300 miles and a flight duration of over twice that of the Spitfire.

In the Spring of 1943, while production of the P-51B was just getting under way and following the departure of the P-38 Lightning from England to the Mediterranean Theater, the P-47 *Thunderbolt* inherited the role of principal American fighter in Western Europe and took up the task of escorting the strategic bombers on the campaign to weaken the resources and resolve of Nazi Germany. Unfortunately, the combat range of the P-47 was little more than that of the Spitfire, and as the bombers ranged ever deeper into hostile territory and far beyond the range of the P-47, they suffered losses at an ever-increasing rate. The supporters of daylight strategic bombing quickly realized that their original premise that their bombers could survive unescorted daylight raids with only nominal losses was flawed. The USAAF immediately instituted a program to develop external fuel tanks that could be added to existing fighters to enable them to accompany the bombers on long missions. The tanks were designed so that they could be jettisoned before impending combat so as not to hamper the combat capabilities of the aircraft. By August, Thunderbolts fitted with a 108 gallon external tank mounted on the fuselage centerline were ranging as far as 375 miles, far enough to accompany the bombers to some targets on the borders of Germany. Unfortunately, the brutal Schweinfurt raids of August and October gave vivid testimony that even this improvement in escort range was not enough.

CHAPTER 4

THE ROLE OF THE MUSTANG IN THE DEMISE OF THE LUFTWAFFE

The disaster at Schweinfurt in October of 1943 and the subsequent cessation of American raids deep into Germany highlighted the urgency of the need for escort fighters that could accompany the bomber force to all parts of Germany. The range extension of the Thunderbolt, effected by the development and installation of wing-mounted external fuel tanks, had improved the situation, but it still was not enough to provide bomber escort to all targets in Germany. General Hap Arnold, in his ceaseless effort to prove the capabilities and value of the Air Force to the total war effort, renewed his pressure on the American aviation industry to accelerate development of the aircraft that appeared from early tests to be the solution to the escort problem: the P-51 Mustang. A year had passed since the early British experiment to marry the Rolls Royce engine with the Mustang airframe. Subsequent testing had proved that the resulting aircraft was superior to any combat fighter then in the sky, but development had lagged, mainly because the need for such a plane had not been realized until the bomber losses began to mount during the summer of 1943. Now the need was critical, and Arnold pushed hard to accelerate production. Industry responded. Tooling for the aircraft had been completed earlier in the year, and production had begun, but at a leisurely pace. By the Fall of 1943, Mustangs were moving down the assembly lines in Inglewood, California (P-51B) and Dallas, Texas (P-51C)* at an accelerated rate. Eventually, over 14,500 Mustangs of various models would be built.[29]

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* The B and C models of the Mustang were identical. The letter designation was used simply to indicate the location of the plant where the aircraft was assembled.

The first Merlin-powered Mustangs were fabricated with only the internal fuel tanks. Fortunately, the original Mustang design was easily adapted to accommodate the addition of a single 85-gallon disposable centerline fuel tank mounted on the underside of the fuselage. This extended the combat range of the Mustang to just over 400 miles, enough to allow the fighter to accompany the bombers from their English base all the way to Berlin and back. The B-model Mustang is pictured in Figure 4.1 in two versions.

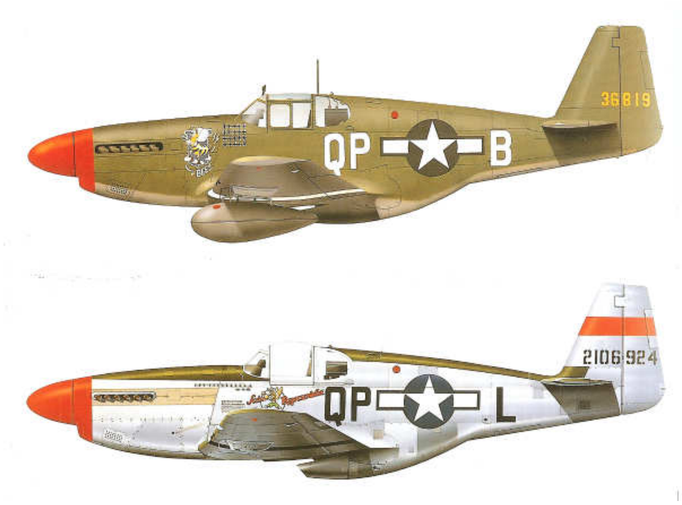


Figure 4.1 Two Versions of the P-51B Mustang (Ref. 30)

The top sketch shows the original configuration with the so-called "bird-cage" cockpit canopy. The rearward visibility of the pilot was restricted in this design though the craft was fitted with a rear-view mirror. The lower sketch illustrates a field modification that was applied by some units -- installation of the Malcolm hood similar to that used on the Spitfire. This design allowed the pilot better visibility to the rear. Only the B- and C-models of the P-51 were in action during the first nine months of 1944, the period in which the Mustang eventually eliminated the Luftwaffe as a threat to the Allied victory in Europe. However, evolution of the Mustang continued, resulting in the final production model, the P-51D, which dominated the skies over Europe and finally, over Japan.

Operational and combat experience gained during the early months of 1944 exposed some deficiencies in the B-model Mustangs that were immediately addressed by the North American design engineers. Solutions to these problems all came together in the P-51D, which appeared in the combat zone in the Fall of 1944 (See Figure 4.2). Almost 8,000 of this model were produced. The D-model was still a Mustang, but it looked different from the earlier models. The visibility problem of the B-model was solved with the installation of a bubble canopy which allowed complete 360-degree visibility. It also had provisions for

Figure 4.2 The P-51D Mustang (Ref. 31)

mounting two 108-gallon external, disposable fuel tanks, one under each wing, which gave the P-51D a combat range of over 700 miles. The new model had a ceiling of almost 42,000 feet, armament consisting of six 0.50 caliber machine guns and a top speed of 437 mph at 25,000 feet altitude. The D-model was also equipped with the K14 computing gun sight that afforded the pilot a quantum improvement in tracking accuracy over the original reflecting gun sight. Aerial gunnery accuracy and formation station-keeping were also improved when an annoying lateral stability problem encountered with early Mustang versions was rectified with the installation of a vertical tail chord extension. One major design feature of all *Mustang* models posed a potential problem for the combat pilot. The powerful *Merlin* engine was liquid cooled, and a stray bullet that punctured the cooling system could put the plane out of action in a hurry. This feature made the Mustang particularly vulnerable during low level attacks where the density of anti-aircraft fire was high. Fortunately, the range benefits and air combat capabilities of the Mustangs made them ideal in the high-altitude bomber escort role, and they gradually replaced the P-47 squadrons, releasing the rugged, air-cooled *Thunderbolts* to enhance their "train busting" and ground attack reputations.

By January of 1944 the USAAF was ready to resume what they had started in the Fall of 1943 -- an all-out attack on the Luftwaffe. By this time air bases throughout the Reich were well stocked with ME 109 and FW 190 fighters. Nevertheless, the presence of an ever growing number of Mustangs, encouraged by General Doolittle to aggressively hunt down the Luftwaffe, made the prospects for an Allied success favorable.

The first England-based operational fighter group equipped with Merlin-powered Mustangs was the 354th Group on loan from the Ninth Air Force (Mustang units of the Eighth Air Force were just being formed). They moved into their quarters at Boxted, England, in mid-November of 1943, and on 1 December they took to the air on their first mission, a sweep over the French coast. Legendary fighter leader Col. Don Blakeslee led the group on their first escort mission on 13 December when they shepherded a raid of 649 Fortresses and Liberators to plaster the shipyards at Kiel. Only five bombers fell to the German defenses on that raid. From that time on the arrival of Mustangs accelerated until, by the end of the war in Europe, eleven Mustang fighter groups, each consisting of about fifty aircraft, were quartered on English soil. Other Mustang groups operated with the Fifteenth Air Force out of Italy.[32]

As 1944 began, General Arnold moved to take advantage of the performance benefits offered by the Mustang. Ira Eaker, the passionate, dependable and steady proponent of strategic bombing, had led the Eighth Air Force bomber force from the very beginning. His escort strategy was to protect the bombers, both to ensure that the maximum number of bombers would drop their loads on the target and to preserve the bomber force and crew for continued action against the enemy. He did this by insisting that the fighters stay with the bomber stream to ward off attackers. Arnold sensed that a much more aggressive strategy was called for. To win the air war, the German fighter corps had to be eliminated. To do this job he called on the proven dynamic leader, Jimmy Doolittle. Eaker was shipped to the Mediterranean to take over the 15th Air Force, and Doolittle assumed command of the Eighth on 4 January 1944. Immediately, he issued the order for the escort fighters to hunt down and destroy the German fighters wherever they could be found … in the air, on the ground and in the factories. With that order, backed by the superior Mustang in the hands of superbly trained and aggressive pilots, the battle for air supremacy in Europe was joined.[33]

At this stage of the war, early 1944, the German air defenses were still very strong. Under the command of General Gunter Korten, the Luftwaffe pulled back many of its far-flung fighter squadrons to defend the Reich. The carefully dispersed fighter fabrication and assembly plants were turning out completed airplanes at an astonishing rate. The important military centers of production and operation were ringed by hundreds of the deadly 88 millimeter anti-aircraft guns. Contrary to the opinion of the Allied bomber boys who thought that the merciless pounding their air power could deliver would induce the German citizenry to give in, those citizens simply worked harder to provide arms to repel the invaders.

The one chink in the German armor was the pilot corps. It was still fully manned, but it had suffered grievous losses during the ferocious air battles of the previous summer and fall. Many of the seasoned veterans were lost during the struggle, and the replacement pilots, though plentiful in number, were not well trained. In fact, the Luftwaffe training program had never been geared for a protracted conflict. In the Thirties, German pilots trained secretly until 1935 when the Luftwaffe was officially revealed to the outside world. By the opening of the global conflict in September of 1939, the German air arm was fully manned and primed with combat experience from the civil war in Spain. A ready reserve of trained pilots numbering about a third of the operational force was available. The typical Luftwaffe pilot had been through two years of training prior to entering an operational unit. This amounted to about 200 hours of flight training. The fighter pilots went to war in the Messerschmitt ME 109E, a superior and deadly instrument of war in the hands of a seasoned pilot.[34]

Early in the war the task of the fighter corps was to eliminate the opposing air forces. In Poland and in Russia this was done with little effort and few losses because of superior equipment and training. Even the numerically superior and supposedly excellent French air force was no match for Goering's airmen. These early confrontations served as a combat training ground second to none, allowing the pilots to hone their skills of interception, attack and gunnery while vanquishing the opposing air forces. Then came the effort to subdue the RAF in the Battle of Britain, and the Luftwaffe was never the same. Though the Luftwaffe bomber corps suffered the bulk of the battle losses, the fighter squadrons were also affected.

The battle had a profound influence on the Luftwaffe training program which had been predicated on the operational concept of the Blitzkrieg: aerial campaigns would be rendered short and decisive by rapid and massive application of air power. It was reasoned that such a strategy would allow ample time for replenishment of manpower and supplies before embarking on the following phase of the war. Certainly, such had been the case as Hitler's aerial minions romped through Poland, the Low Countries, Norway and France.

The erosion of that concept began with the losses over Great Britain, and it accelerated dramatically following the launching of Operation *Barbarosa*, the invasion of Russia, on 22 June 1941. At the beginning of the war, the Luftwaffe was organized into several *Luftflotten*, each consisting of administration, communication, flak and operations units. The operations unit was, in turn, made up of several *Fliegerkorps*, each of which was made up of bomber, dive bomber, ground attack, single-engine fighter, twin-engine fighter, night fighter, reconnaissance and transport *Geschwaders*. Each Geschwader was comprised of four *Gruppen*, three being operational and the fourth being an operational training unit.[35] By early 1942, the Germans had lost so many trained pilots that they had to dip into their training units for instructors and advanced students to fill out their operations ranks. Then, in the summer of 1942, the Luftwaffe high command opted to eliminate the operational training units altogether, leaving each Geschwader with three operational Gruppen. As time went on, the number of flying hours allocated for training gradually decreased, partly because of the accelerated need for more pilots in the operational units caused by combat attrition and partly because of fuel shortages imposed by Allied attacks on fuel production and storage facilities.

The year 1943 was crucial for the Luftwaffe's far-flung units as the fortunes of war turned against the Nazi regime. The stiffened Russian resistance in the East had become an offensive, and the Wehrmacht was forced out of Africa by the British and American forces. The American landings on Sicily and the following thrust up the "boot" of Italy supplied pressure from the south. In the meantime the British and American air campaigns of strategic bombing were putting pressure on the homeland, threatening the source of arms and manpower. In this milieu the Luftwaffe was experiencing an acceleration of attrition, both of pilots and aircraft, that had begun with the Battle of Britain. Figure 4.3 illustrates the loss of fighter aircraft of all types over the year. While this situation was troubling, the deficiencies it caused were being made up by the increased production schedule designed by Director of Armament Erhard Milch.

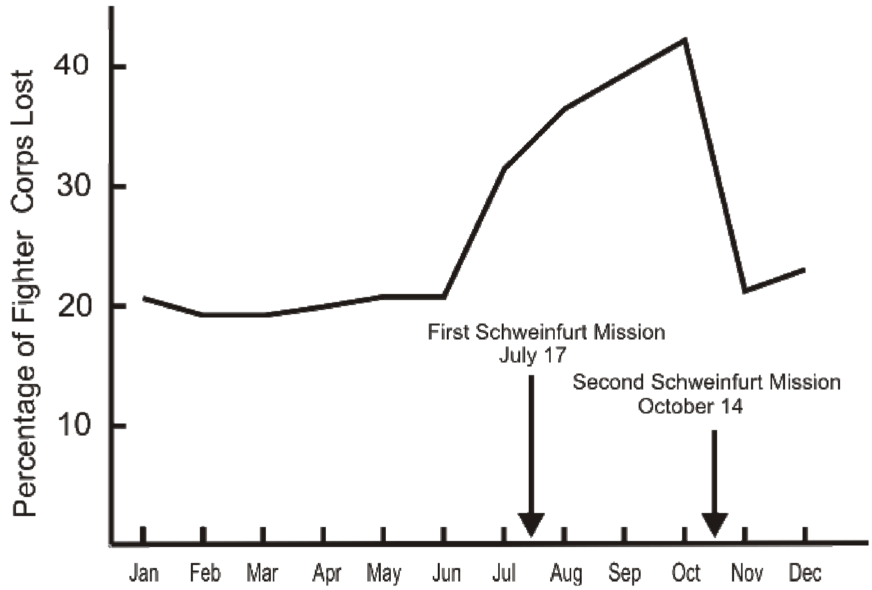


Figure 4.3 . German Fighter Attrition for 1943 (Ref. 36)

A much more critical statistic was that of pilot attrition as shown in Figure 4.4. This graph gives a very clear picture of the cost to the fighter corps of the burgeoning Allied bombing campaign in the late summer and fall of 1943. The graphs also illustrate the temporary respite from catastrophic losses earned by the victory at Schweinfurt. During this period the Luftwaffe training programs were continuing to produce pilots to man the planes, but the quality of those pilots was on a downhill slope for the remainder of the war. By the summer of 1944, with their combat veterans falling to the guns of superior and numerous American fighters and poorly trained pilots taking their place and falling at an ever faster rate, the Luftwaffe was essentially finished as an aerial threat.[38]

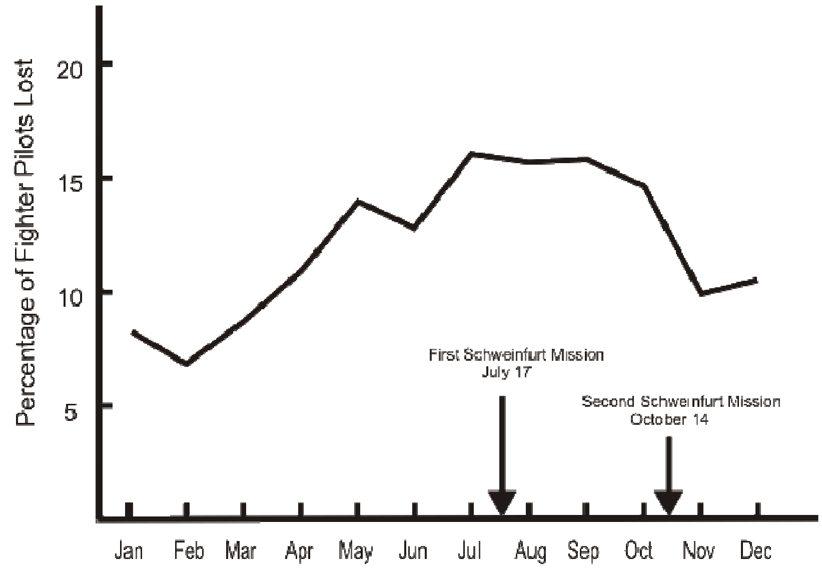


Figure 4.4 Luftwaffe Fighter Pilot Losses for 1943 (Ref. 37.)

Over the same period that the Luftwaffe program was in decline, the American training program was burgeoning. In January of 1940 with hostilities reduced to the so-called "phony war"* in Europe, President Franklin Roosevelt asked the American Congress to appropriate $1.8 billion for national defense, this in addition to the $190 million that had just been approved the previous summer. Part of this funding was put into an expanded pilot training program. Until 1939, pilot training had been a leisurely and relaxed proposition in the United States. Now it took on a more determined image with emphasis on uniformity, quality and volume. The goal of the training program was superior preparation for combat. By the time America was pulled into the war in late 1941, a pilot training program promising 30,000 graduates a year, to be distributed among eighty four combat groups, was in place.

The wartime training program consisted of three nine-week courses, primary, basic and advanced, followed by another nine weeks of transition training in the graduates'

* The "phoney war" was that period following the fall of Poland during which virtually no land action occurred. The period ended on 9 April 1940 with the German invasion of Denmark and Norway.

assigned combat aircraft. The primary course consisted of introductory classroom instruction in aerodynamics, weather, airplane systems, flight safety and fundamental flight maneuvers. Sixty hours of flight instruction, about thirty hours with the instructor and thirty hours of solo work, covered fundamental maneuvers, takeoffs and landings, and stall and spin recoveries. The training aircraft employed were slow, docile and very forgiving of mistakes.
The open-cockpit Fairchild PT-19 and Ryan PT-22 were commonly used in the primary program.

The aircraft used in the basic training course were faster, heavier and, though stable, considerably more difficult to fly. In particular the stall and spin characteristics of these aircraft were more violent and required more skill for recovery. The Vultee BT-15, nicknamed the "Vultee Vibrator" for its post-stall and spin behavior, was commonly used in this part of the program. It had a 450 HP engine and an enclosed glass cockpit. Flight training included considerable cross country navigation, night flying and instrument flying. Fundamental aerobatic maneuvers were also taught in dual flight and practiced in solo flight. Near the end of the course, the trainee received a short introduction to the advanced training aircraft, usually the North American AT-6.

The advanced course was the part of the training program in which pilots were channeled into single-engine or multi-engine classes. The single-engine pilots generally became fighter pilots, and the multi-engine pilots transitioned into transport or bomber assignments. The single-engine course stressed instrument flying, navigation, night flying, formation flying and combat maneuvers, and it was modified frequently during the war as useful combat techniques from experienced and successful pilots filtered back from the war zones. Aircraft identification was stressed in the classroom. The multi-engine course commonly used the Beechcraft AT-11 aircraft. Instruction included an extensive dose of instrument and formation flying. Teamwork between the pilot trainees and other crew members, which could include pilot, navigator and bombardier trainees, was stressed in later stages of the training.

Following completion of the advanced course the graduate pilot, whether he be single- or multi-engine trained, went through an additional nine weeks of transition training to his assigned combat aircraft type before he was given an operational assignment. His first operational assignment was to a continental unit for an indeterminate period before he and his unit were assigned to an overseas base. Thus, a new recruit could expect to spend eighteen to twenty-four months in training before going into combat. Of course, throughout the war American pilots had the luxury of training in an environment that was consistent, thorough, free of distractions, and, most of all, free of hostile aircraft trying to shoot them down. Conversely, German pilots trained from 1942 onward had to face abbreviation of their training regimen, fuel shortages and, ultimately, enemy bullets.[39]

When the fighter conflict was joined on a big scale from the first days of 1944, there were several different aircraft types that were involved, but four fighter types dominated the air to air combat scene, two from each side. On the American side were the recently introduced P-51 Mustang and the dependable warhorse from the early days of the bomber war, the P-47 Thunderbolt. With 108-gallon auxiliary fuel tanks installed, the Mustangs could accompany the bombers on raids to anywhere in Germany, and the Thunderbolts could range well within its western borders. The Germans countered with only two fighter types with performance that could be competitive with the Americans and in sufficient numbers to be a formidable threat: the Messerschmitt 109 G and the Focke Wulf 190 A. The 109 was actually well past its zenith as a fighter, but there were large numbers of the G model available, and, in the hands of an experienced pilot, it could still make a good account of itself. The 190 was agile, easier to fly than the 109 and well armed, making it a good combat platform even for a pilot with limited experience. Late in the war the Germans introduced the rocket-powered Messerschmitt 163 and the twin-turbojet-powered Messerschmitt 262, both of which could outperform the Allied fighters they encountered as they sought to break up the bomber formations, but they appeared so late and in such small numbers that they represented no enduring threat to the bombing campaign or the advancing Allied armies. The 262 was especially vulnerable during takeoffs and landings when it could not use its superior speed to escape attack. The 163 rocket plane had usable thrust for only about seven minutes, and after rocket burnout, it became a glider, and though it was agile, it was easy prey for the American fighters.

The ferocious battles of "Big Week" in late February of 1944 portended the fate of the Luftwaffe. Huge formations of Allied bombers attacked the German fighters on three fronts: at the factory, at the air bases and in the air.[40] Then, in the early days of March, Eighth Air Force commander Gen. Jimmy Doolittle, hoping to deliver a knockout blow to the Luftwaffe, ordered a temporary suspension of bomber raids on the Luftwaffe infrastructure in favor of missions designed solely to draw the German fighter corps into battle. He figured that the Germans would defend Berlin with everything they had in their aerial arsenal. He was right. The raids on the 6th, 8th and 9th were costly. One hundred and fifteen bombers were shot down, but the bombers severely damaged a ball bearing plant and dropped some bombs on government facilities in the center of the city. More importantly, however, the escort fighters knocked down 160 German fighters.[41] This all out effort to Berlin together with missions elsewhere during the month of March paid big dividends in the fighter attrition sweepstakes. Almost 60% of the German fighters available for combat on 1 March had been knocked out of action by 1 April.

By May of 1944, with the Allied invasion of the Continent just weeks away, the Luftwaffe as a threat to the invasion had been eliminated. This does not mean to imply that the German fighters disappeared from the scene of action, but the Allied fighter forces had depleted the German air force to the extent that Allied invasion commander, General Dwight D. Eisenhower, could say with conviction that any aircraft sighted over the invasion battle field would be part of the Allied forces. Though the war in Europe continued for another year, the Luftwaffe had forever lost its opportunity for victory over the Allies.

The demise of the Luftwaffe was certainly hastened by the superior training of American pilots and the increasing number and combat range of American fighters. However, the battle could not have been won without the superior combat performance of the P-51 Mustang in the hands of pilots who had been trained to use it. The combination was devastating to the Luftwaffe. Certainly there are examples in the annals of the air war in which the underdog in aerial warfare emerged as the victor. For example, the famous Flying Tigers, operating the cumbersome P-40 Tomahawk against the quick and agile Japanese Zero, achieved victory after victory over the superbly trained veteran Japanese pilots by using hit and run tactics. But the Luftwaffe never really had a chance against the Mustangs. There was just no place to hide.

The technical reasons for the superiority of the Mustangs in air combat with the Luftwaffe can be explained graphically for the layman using a unique formulation of the fundamental principles of aircraft performance that was actually developed after World War Two. An explanation of this method of analysis and its application to the air war that took place in Europe in the Spring and Summer of 1944 is presented in the following chapter.

CHAPTER 5

THE MUSTANG AERIAL VICTORY EXPLAINED: ENERGY MANEUVERABILITY ANALYSIS

It is one thing to say that the appearance of the Mustang over Germany heralded the end of the Luftwaffe as an effective fighting force. It is another to provide the technical reasons why this occurred. In the last chapter the influence of pilot training, aircraft range and aircraft numbers on this result were explained. Now an explanation of the technical reasons involving aircraft performance and combat tactics is provided.

In the early 1960's at Eglin Air Force Base in Florida, John Boyd, a dynamic and unconventional U. S. Air Force fighter pilot, began to formalize a theory of combat maneuver analysis he had begun thinking about while serving in an F-86 squadron in MiG Alley during the Korean War.[42] In that war the North Koreans (and, undoubtedly, also some Soviets) flew the MiG 15, a small, swept-wing fighter with exceptional performance. The airplane was more than a match for the F-86 in many respects, but the Americans still finished the war with a ten to one kill ratio advantage. While Boyd conceded that part of that advantage could have been because of differences in pilot training, he felt that much of it had to do with tactics that emphasized the strengths of the F-86 and minimized those of the MiG. Thus began his quest to quantify these tactics. The result, developed after many months of performance comparisons and calculations, he called Energy Maneuverability Analysis, or E-M.[43]

The question that immediately comes to the mind of the reader is: What does a theory developed twenty years *after* the end of World War II have to do with the influence of the P-51 Mustang on the victory over the Luftwaffe in Europe in that war? The answer is that with the E-M analysis can one properly *quantify* one of the reasons for that victory, the aerodynamic superiority of the Mustang over the principal German fighter types.

The Energy Maneuverability Method

Though E-M method is analytical in nature, it can be represented graphically in a way that can easily be understood by the layman. However, some simple algebraic expressions must be introduced to adequately explain what is shown on the E-M graphs. The energy-rate or power of a system (e.g., airplane) can be expressed as

$$P = (T - D)\,V \qquad (5.1)$$

where P = Energy rate (or power)

T = Thrust force, the driving force generated by the aircraft power plant. This can be produced directly by a gas turbine (jet) engine or by a reciprocating engine-propeller combination

D = Drag force, the force resisting forward motion. For an airplane, it is produced by friction, flow separation and wing-tip vortices

V = Velocity, the magnitude and direction of the rate of change of forward motion

Now, the *specific energy rate*, *Ps*, the energy rate per unit weight, is given by:

$$P_s = \frac{P}{W} = \frac{(T - D)V}{W} \qquad (5.2)$$

where W = Aircraft weight

Notice that P_s is zero when the thrust and drag are equal. This is a steady-state condition in which the airplane is flying at constant velocity, neither accelerating nor decelerating. Thus, when the specific energy rate is *positive*, the airplane is *accelerating*, and when the specific energy rate is *negative*, the aircraft is *decelerating*. Hence, the instantaneous dynamic condition of the aircraft can be instantly assessed by monitoring the magnitude and sign of the specific energy rate. The question remains, however: How does this information translate into an assessment of favorable air combat tactics? The answer to this question can best be provided for the layman in graphical terms.

For each altitude in level flight an aircraft has a minimum speed for which controlled level flight can be maintained, the stall speed, and a maximum speed produced when the drag force is just equal to the maximum thrust that can be produced. These speeds change with altitude and are theoretically equal when the aircraft is flying at its maximum altitude (its ceiling). Figure 5.1 is a depiction of typical thrust (T) versus velocity and power (P = T V)

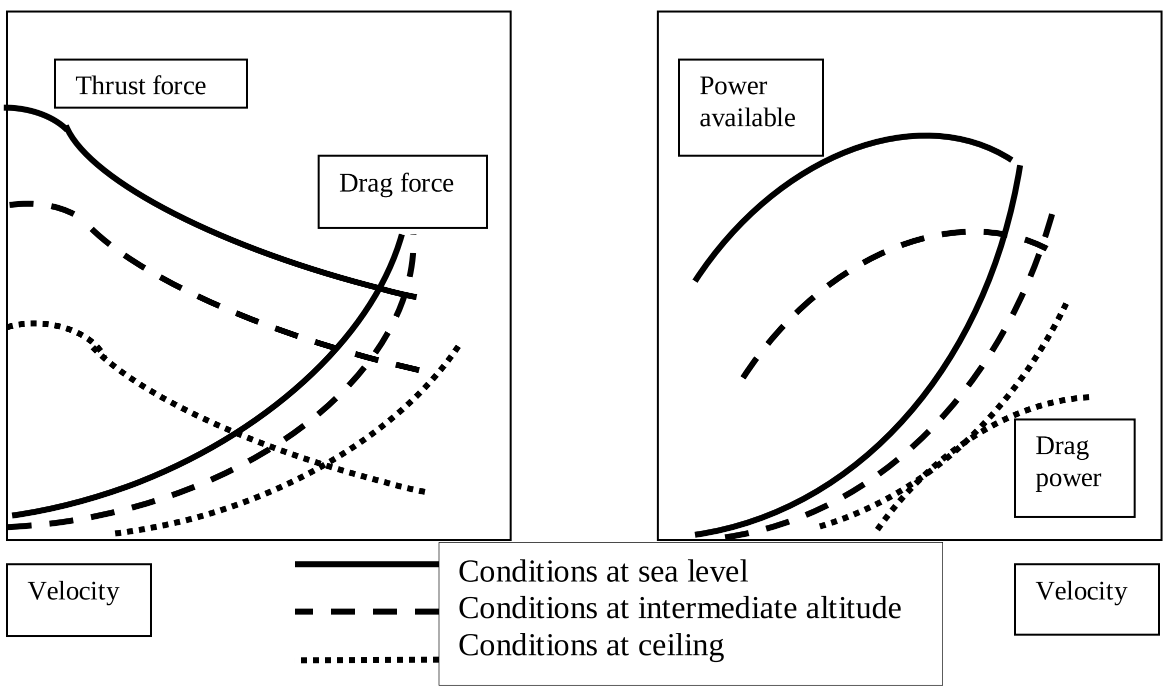


Figure 5.1. Variation of Thrust, Drag , Power and Drag Power with Velocity as a Function of Altitude for a Propeller-driven Aircraft

versus velocity graphs for an airplane in level flight for three different altitudes: sea level, intermediate altitude and ceiling. Also shown on the graphs are the drag force (D) and the drag power (DV).

It is from these fundamental relationships that the instantaneous performance of the aircraft can be determined. It is obvious from the curves that this performance is a function of altitude. However, the aircraft turning performance is not sensitive to small changes in altitude, so a reasonable assessment of combat performance can be made by analysis of turning performance at fixed altitude on the one hand and climbing and diving performance as a function of attitude on the other. Such an approach allows for generalized analysis on a quasi-static basis, thus alleviating the necessity for analyzing each maneuver in a time-dependent reference frame. Incidentally, while it is obvious that the weight of an aircraft changes continuously with the expenditure of fuel, and, for a combat aircraft, instantaneously, with the use of various weaponry, the changes are small with respect to the maneuvering time frame; hence, the weight is considered constant in the combat performance analysis.

In order to put these aerodynamic characteristics into the Energy-Maneuverability framework, it is necessary to show a typical specific energy graph for an airplane. (see Figure 5.2 on page 51). In this figure, in addition to the steady-state value of specific energy rate ($P_s = 0$) only positive values of P_s are shown (i.e., curves for an accelerating aircraft). Of course, negative values of the specific energy rate occur when the aircraft is decelerating. Since a value of specific energy rate can be computed for every flight condition of an aircraft, P_s becomes a parameter that can be used to assess airplane performance.

Furthermore, it is also a convenient and revealing parameter that can be used to *compare* the maneuvering performance of various aircraft. The mathematical details of this method are

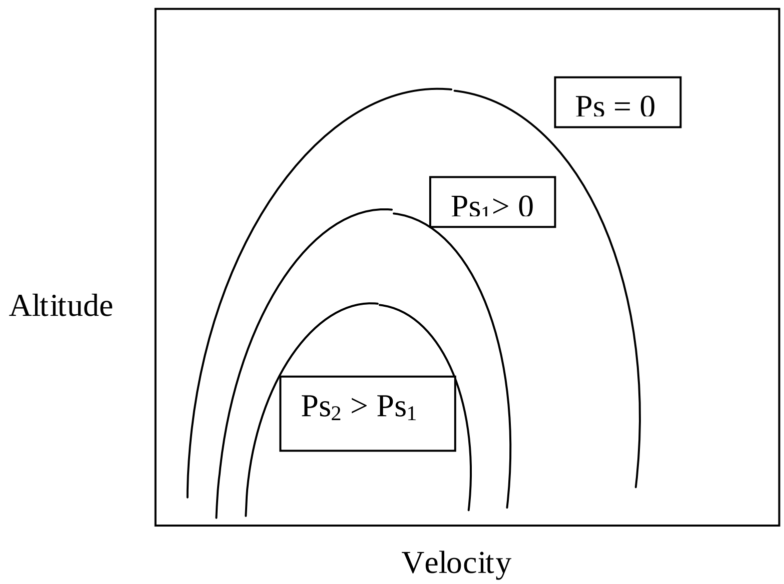


Figure 5.2. Specific Energy Rate for Typical Fighter Aircraft

given in Appendix B. The conceptual application of the method to comparative combat performance assessment can now be explained graphically in the following paragraphs.

The detailed maneuvering between two adversary aircraft to gain a position favorable for aerial victory is commonly called "dogfighting". The instantaneous "dogfighting" capability of an airplane can best be described in terms of its turning capability at each value of its airspeeds. Thus, the variation of turn rate with velocity is of primary importance in determining flight conditions that will give one fighter an advantage over another. Figure 5.3 is a diagram showing the forces acting on an aircraft that is undergoing a constant velocity coordinated turning maneuver in the horizontal plane. The angular rate at which the airplane is turning, $\dot{\psi}$, and the angle at which it banks, ϕ, depend on the value of the specific energy rate. This information can be revealed in a graph which is known as a

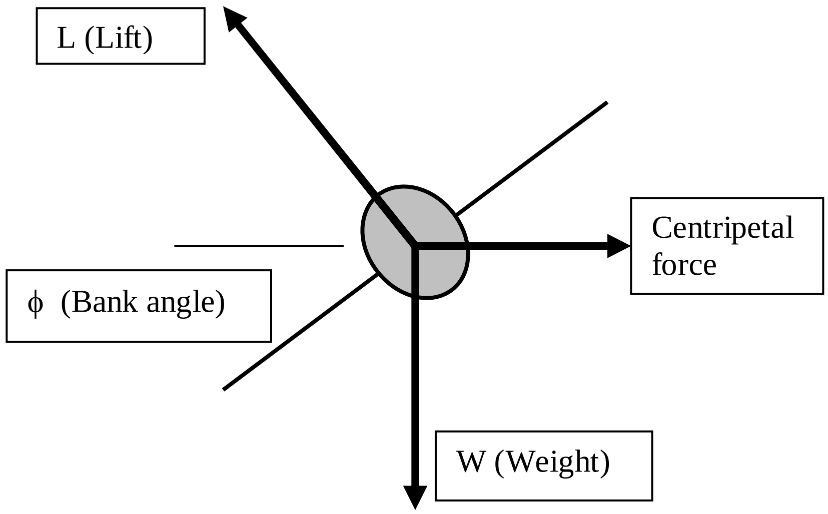


Figure 5.3. Force Vectors on an Airplane in the Horizontal Plane

"doghouse plot" (because it looks somewhat like a doghouse, and there is a semantic connection with the term "dogfight"). This graph shows the maneuvering envelope of the subject airplane. That is, the airplane can fly for all those conditions inside the doghouse, and it cannot fly at conditions outside the doghouse. The flight restrictions may be imposed because of airplane aerodynamic limitations (loss of control because of stall), structural limitations (actual structural failure) or pilot effectiveness limitations (loss of consciousness because of excessive g-loading). A typical doghouse plot is shown in Figure 5.4. The salient features of the aircraft's turning performance (and, hence, of it's "dogfighting " capability) are indicated on the plot.[44]

It is easily seen now that by plotting the performance of all aircraft on the same graph scale, the performance of these aircraft can be analytically compared. A typical comparison is shown in Figure 5.4 between hypothetical aircraft "A" and hypothetical aircraft "B". In fact, Aircraft "B" has a definite advantage at low speed (gray area) because it can turn at a

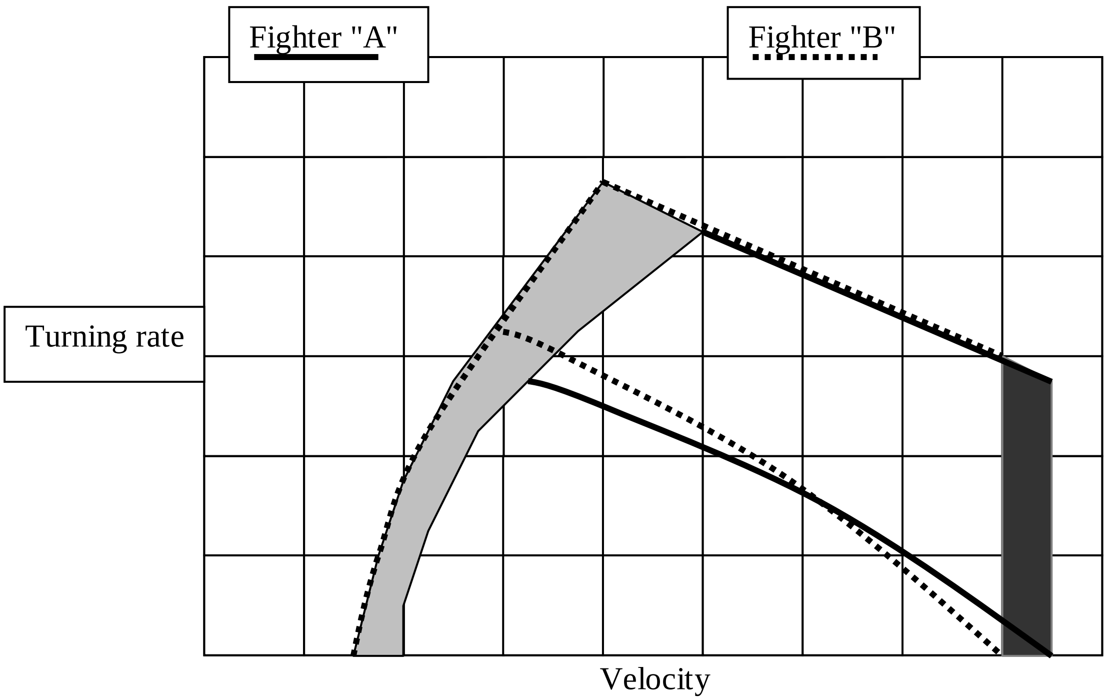


Figure 5.4. Horizontal Plane Performance Comparisons (The "Doghouse" Plot)

higher rate at any speed up to the "corner" speed (the corner speed is the speed at which the aircraft has its highest turn rate at the highest "g" loading). Note that the maximum "g" loading is determined by the loading for which the pilot remains capable of controlling the aircraft, and it is less than the loading at which the loss of structural integrity of the aircraft occurs. On the other hand, Aircraft "A" has an advantage at high speed (black area) because it can go faster than Aircraft "B". Therefore, a "hit and run" tactic would be preferred by Aircraft "A" and a "dogfight" tactic would be preferred by Aircraft "B".

Note that the doghouse plot is constructed for a constant altitude. The plots do change with altitude, but the general relationship of the plot of one aircraft versus another does not change significantly. Thus, the service ceiling of the aircraft, that altitude at which the aircraft can maintain controlled flight at a climb rate of 100 feet per minute, is important primarily because it gives the pilot of the aircraft with the higher ceiling the option of whether or not to engage in combat. Obviously, if the service ceilings of two aircraft are significantly different, the aircraft that can fly at the higher altitude has a greater potential energy that can be converted into a high kinetic energy in a dive. Of course, all energy exchange situations are limited by structural, control and pilot biological constraints.

The intermediate line on the graph between the maximum "g" line and the zero turn rate axis is the line for which the subject aircraft can make a sustained turn without losing altitude or airspeed.. As would be expected, aircraft "B", the dogfighter, has an advantage at low speeds, but it loses that advantage to the "hit and run" fighter (Aircraft A) at high speeds. A well trained and capable pilot will know where his airplane stands relative to his opponent's in the energy-maneuverability arena and, thus, he will be able to capitalize on his advantages and avoid disadvantageous situations. It should be noted that in regions where the turn rate graphs overlap (i.e., in the white space between the gray and black regions in Figure 4.4) the aircraft have essentially equal capability, and a combat outcome depends on the relative combat skills of the competing pilots.

It is obvious from the preceding discussion that a highly maneuverable aircraft has a combat advantage at constant altitude over an aircraft that is less maneuverable, but what advantages accrue to an aircraft that has superior dive performance or superior climb performance? Figure 5.5 is a graph of altitude versus velocity for Aircraft "A" and Aircraft

"B". The closed figure is bounded on the left side by the stall condition for the aircraft and on the right side by the maximum speed. The sloped line in the center of the graph shows the locus of all points for which the rate of climb is a maximum. The graph shows that Aircraft "A" has superior high altitude performance, whereas Aircraft "B" has speed

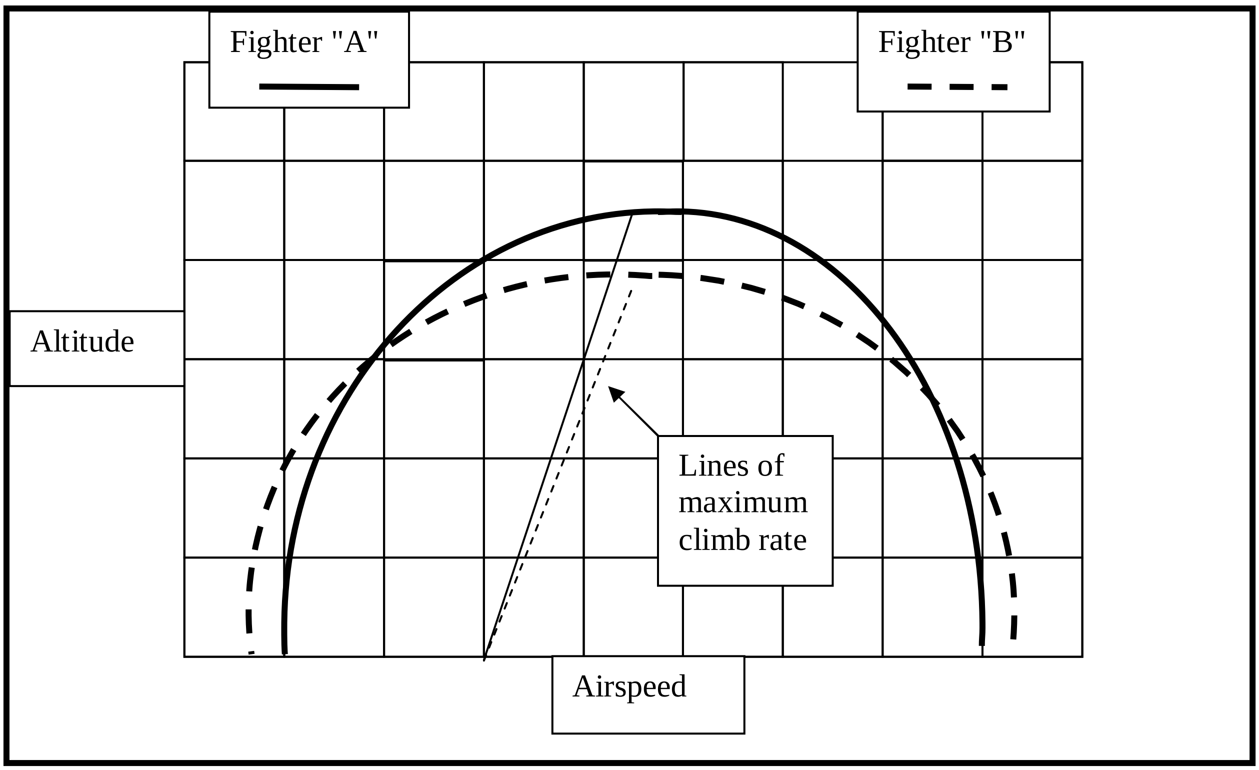


Figure 5.5. Vertical Plane Performance Envelope Comparisons
for Airplane "A" and Airplane "B"

advantages (both high and low) at lower altitudes. These graphs also show that Aircraft "A" has a higher rate of climb at all altitudes. In practice, then, if the two aircraft confront each other at the same altitude, aircraft "A" has a definite advantage because it can climb away from Aircraft "B" to its maximum altitude and loiter there, out of reach of Aircraft "B", until it is advantageous either to fly away or to dive to the attack. Aircraft "B" has little advantage in this confrontation unless he can lure his adversary into a dogfight, though he can "run for it" in level flight at most altitudes.

The preceding analysis can be applied to both the American and German combat fighter inventories identified in Chapter 4 to determine probable outcomes of combat among the adversaries. A comparison of probable results with attrition statistics will testify to the accuracy of the assumptions inherent in the present approach to combat analysis. Using this approach, regions of performance dominance of one aircraft type over another can be identified, and an educated conjecture can be made regarding probable combat outcomes. When this type of analysis is made within the framework of pilot training and combat order of battle that existed over Germany in early 1944, the final outcome can be explained with some confidence.

Four aircraft are considered in the analysis: the P-47 Thunderbolt and P-51 Mustang for the Americans and the ME 109G Gustav and FW 190A Butcherbird for the Germans. The horizontal plane analysis can be made by presenting turning performance data on the same scale for each of the aircraft so that an overlay method may be used to readily demonstrate regions of superiority of one fighter over another. Vertical plane analysis will consist only of comparing appropriate tabulated data. Speculative conclusions regarding possible combat strategies and outcomes can be supported by actual combat order of battle and attrition data.

Consider first the P-47 in comparison with the German fighters. Figure 5.6 compares the horizontal plane maneuvering capabilities (i.e., "dogfighting") of the Thunderbolt and the ME 109G. This graph shows that the P-47 is by no means a dogfighter. At constant altitude the Gustav can easily out-turn it, except at high speed. Thus, if the Thunderbolt pilot were not in a favorable attack position at constant altitude, he would not initiate combat. However, the P-47 does have a sufficient speed advantage at constant altitude to pull away from the 109, though in most cases the Thunderbolt pilot would opt to dive away from the Gustav until he is out of danger, and then again climb to high altitude for another attack. Data in Appendix A provide a comparison of the vertical plane performance of the two fighters via the ceiling, power and weight parameters. This clearly indicates that in combat with the 109 the best strategy for the P-47 is to loiter at high altitude until a combat opportunity presents itself. Then the Thunderbolt could swoop down at high speed on the

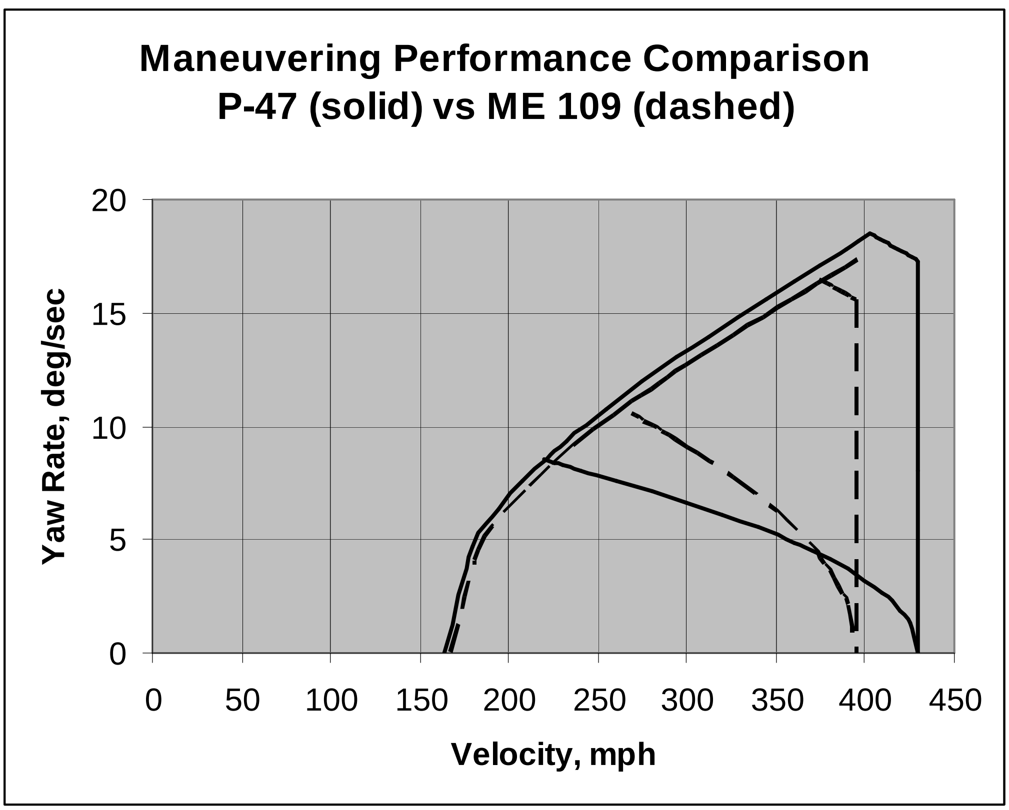


Figure 5.6 Maneuvering Performance Comparison
P-47C Thunderbolt vs ME 109G Gustav
Altitude = 25,000 feet

attack in a "hit and run" maneuver. In many cases, particularly late in the war, the German fighter pilot under attack would perform a split-S maneuver to dive away from combat, a maneuver that worked very well against opposing fighters early in the war. Such an action against a Thunderbolt, however, would be a deadly choice because the P-47, being very heavy and powered by a 2,000 horsepower engine could out-dive any other fighter in the sky. Fighter Group 56, which flew the P-47 throughout the war and achieved more air-to-air victories than any other unit in Europe, was particularly adept at this strategy. The top scoring ace in the European Theater, Col. Frances Gabreski of the 56th, brought down 28 German aircraft with his Thunderbolt. He survived the war, stayed in the Air Force and became a jet ace during the Korean war.[45]

Figure 5.7 shows the comparative performance of the Thunderbolt and the FW 190A Butcherbird. The P-47 can hold its own in turning with the Butcherbird, and it even has an advantage with increasing airspeed. However, the diagram is somewhat misleading because it does not account for the difference in inertia of the two fighters, nor does it consider climb performance. A dogfight seldom takes place at constant altitude, and the P-47, because of its inferior climb performance and high weight and inertia suffers in the type of climbing, twisting encounter that the FW 190 pilots preferred. Thus, again, unless the Thunderbolt pilot were presented with an advantageous position at constant altitude, he would opt to dive away to fight another day. In the case of the P-47 this most often meant taking part in a "train-busting" mission. The Thunderbolt was very rugged, and its air-cooled radial engine could take a great deal of punishment before it failed. Once the long-range Mustangs appeared on the scene the Thunderbolt squadrons gradually deployed away from the escort role into that of interdiction and ground support. It is interesting to note that some famous

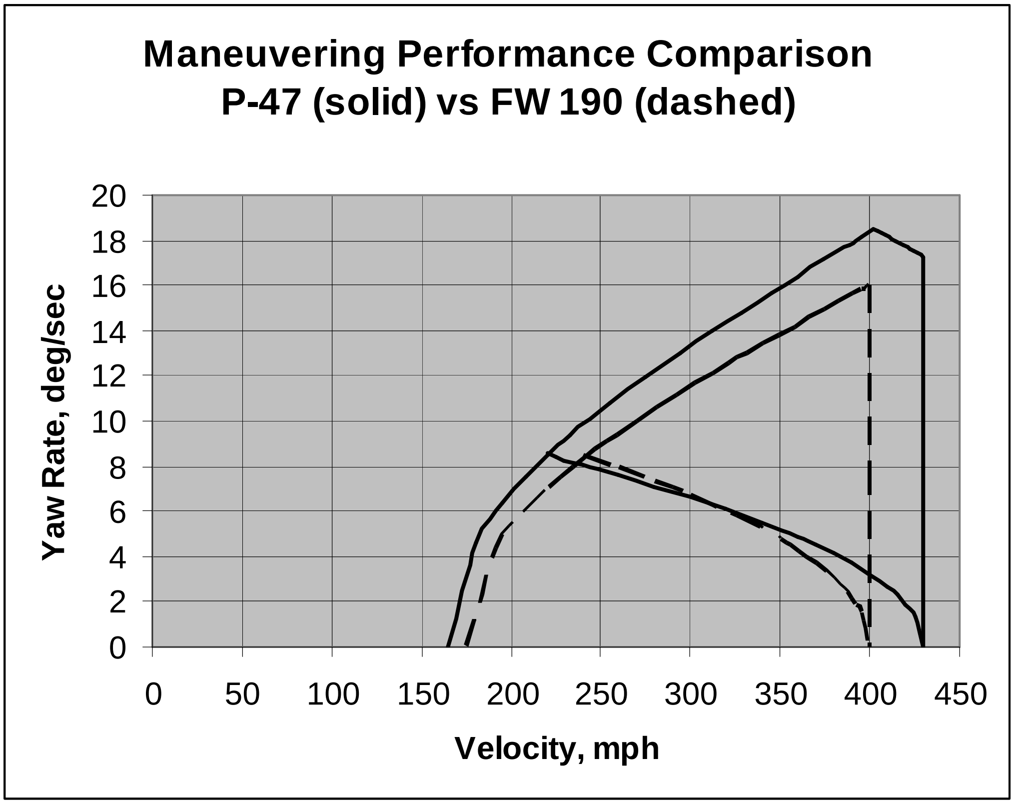


Figure 5.7 Maneuvering Performance Comparison
P-47 Thunderbolt vs FW 190 Butcherbird
Altitude = 25,000 feet

P-47 pilots were shot down during the war, including Col. Gabreski and the brilliant leader of the 56th Fighter Group, Col. Hubert "Hub" Zemke, but they and many other "Jug" pilots survived in large measure because of the sturdy construction of the airplane.

Now consider the performance of the P-51 in its struggle with the Luftwaffe. Certainly the most important feature of the Mustang in the European air war is that it was *there* … there being wherever the Luftwaffe happened to be. However, it would not have survived very long if it had not had outstanding air combat attributes.

The Mustang performance comparison against the ME 109 is shown in Figure 5.8, and it is seen to be quite similar to that of the P-47. The 109 is simply more agile than the

Mustang at low- to-moderate speeds. However, the main difference between this confrontation and the same one involving the P-47 is that the Mustang has a lower inertia and, hence, a quicker response. A P-51 pilot would opt to stay in the fight if he were in that part of the performance envelope where turn rates were of the same order. In this regard, unlike the P-47 pilot, his equal climb performance (see Table A.1) would also enable him to

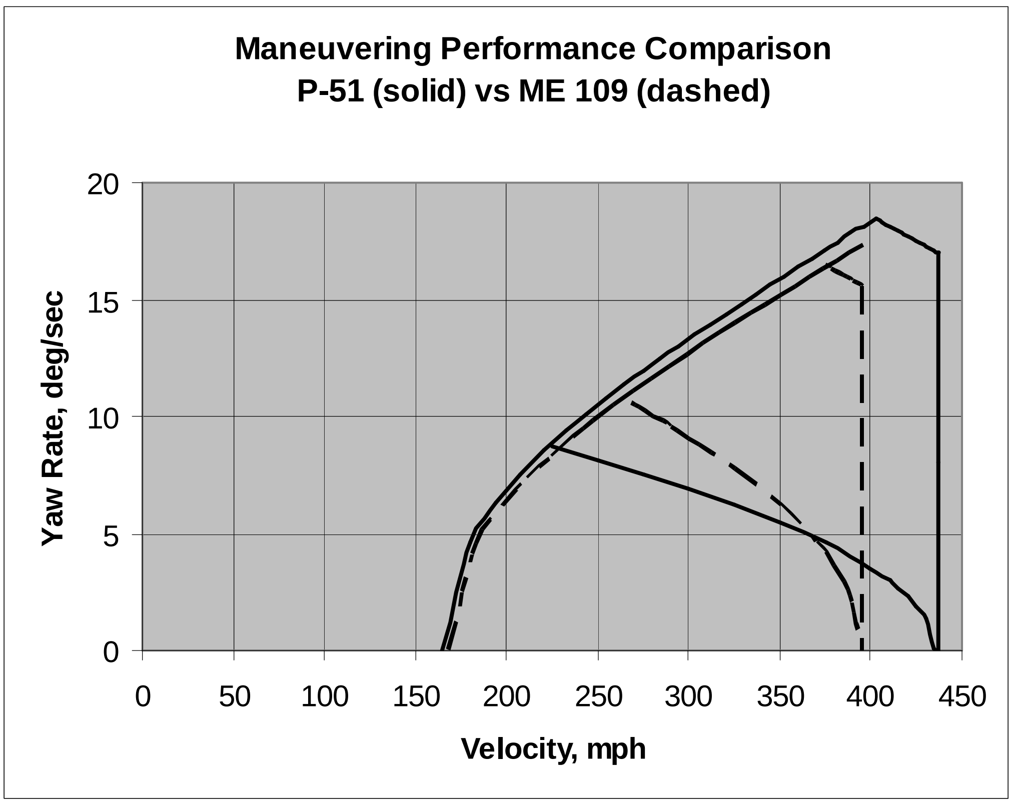


Figure 5.8 Maneuvering Performance Comparison
NA P-51 Mustang vs ME 109G Gustav
Altitude = 25,000 feet

stay in the combat arena on an equal basis. The E-M graph shown in Figure 5.9 illustrates that the Mustang also has a performance edge over the Butcherbird. There is no doubt that at this stage of the war the Mustang pilot was the *hunter* and in the majority of combats his superior training allowed him to use the Mustang's attributes to their fullest extent. In air combat in the vertical plane the Mustang was superior to both the ME 109 and FW 190. This can be surmised from Table A.1 in Appendix A. The American airplane had the edge over both German fighters in stall speed, maximum speed, rate of climb and ceiling. Thus, the Mustang pilot was able to choose the milieu in which he would fight. More often than not, because of his superior training, he was able to make a productive choice.

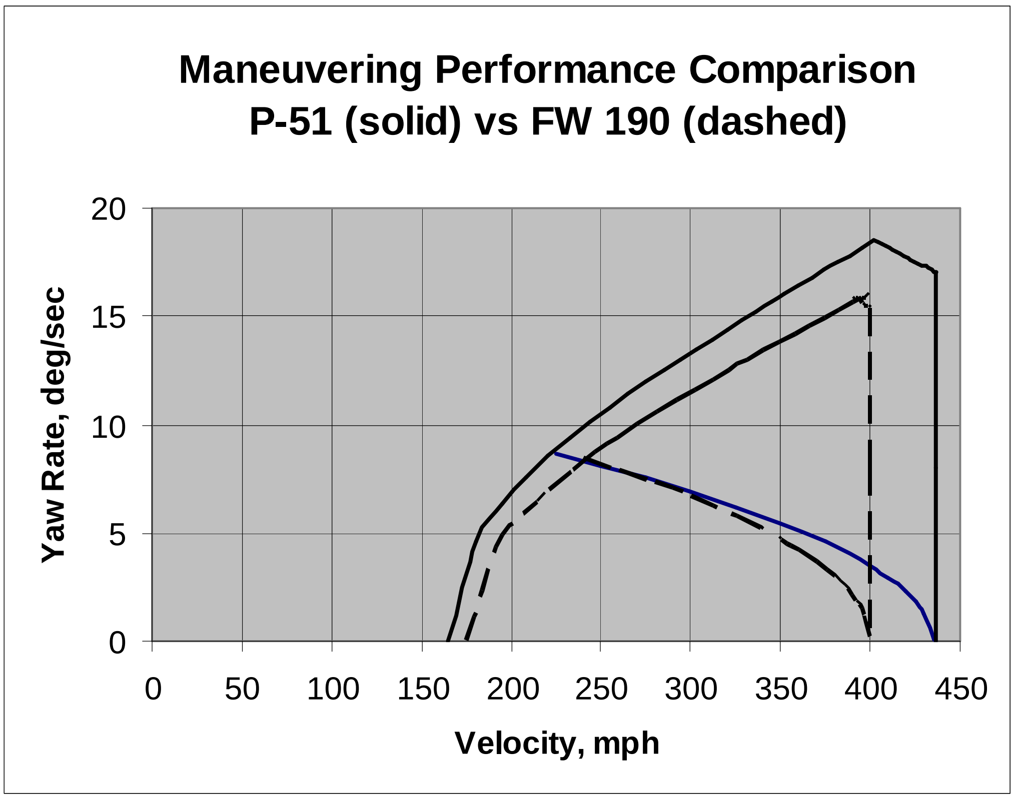
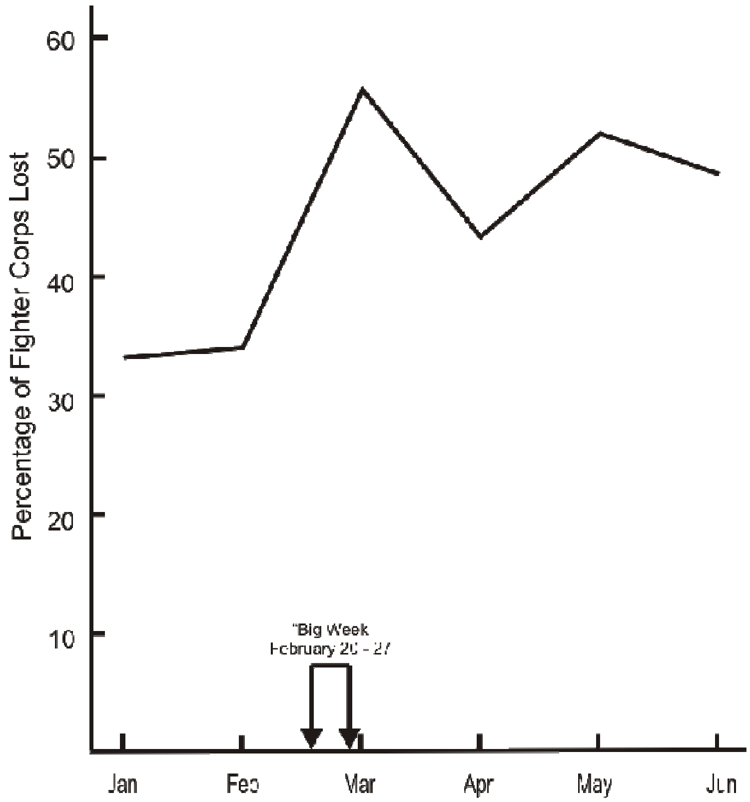


Figure 5.9 Maneuvering Performance Comparison
NA P-51B Mustang vs FW 190 Butcherbird
Altitude = 25,000 feet

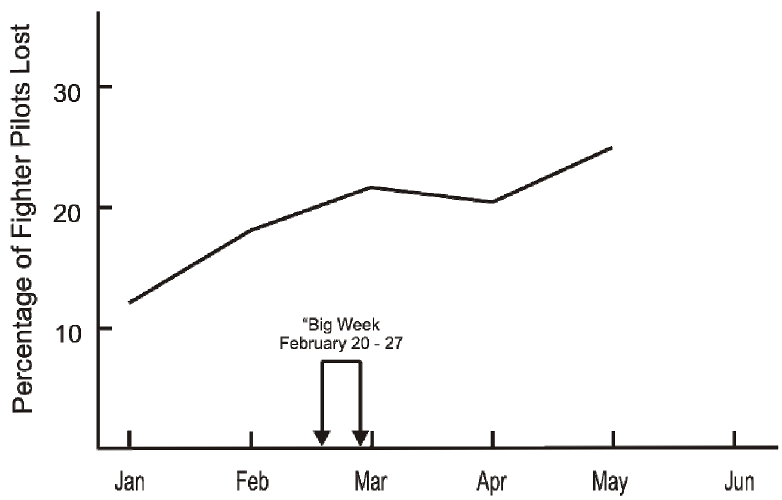
The leading Mustang ace of the European war was Maj. George Preddy of the 352nd Fighter Group who flew his Mustang named *Cripes a Mighty* to 26 victories over Luftwaffe fighters. The most formidable combat fighter team of the European Theater, the 4th Fighter

Group's Captain Don Gentile and his wingman, Captain John Godfrey, destroyed 36 German aircraft.[46] The very first Mustang ace of the war was Major James Howard of the 354th Fighter Group. But that was not Howard's only claim to fame as a fighter pilot. He began the war in China and became an ace as a volunteer flying with the famed Flying Tigers (American Volunteer Group) against the Japanese. After resigning from the AVG in 1942, he joined the USAAF and took an assignment as a P-51 squadron leader in Europe. In January of 1944 while on an escort mission over Germany he single-handedly held off a swarm of German fighters that were attacking a B-17 squadron. For his actions he became the only fighter pilot in the European Theater to be awarded the Congressional Medal of Honor.[47] Howard survived the war and went on to become a lieutenant general in the USAF. Gentile and Godfrey also survived the war, but Preddy was killed by Allied ground fire during a low level mission on Christmas Day of 1944.[48]

The Energy Maneuverability graphs for the four aircraft chosen for analysis are not conclusive in their own right in predicting the combat outcomes between the fighters. However, when viewed in the light of the combat milieu during those spring months of 1944, they offer a revealing insight into why the air war transpired the way it did. Figure 5.10a shows the attrition of fighter aircraft for the first half of 1944. Figure 5.10b shows the pilot attrition for the same period. The Germans were out-trained and out-numbered, their veteran pilots were worn out and their number was diminishing by the day. The German first line fighters were up against aircraft that were equal or better in the important qualities of air combat and manned by American pilots who always had an avenue of escape from an



a. Attrition of Fighter Aircraft



b. Attrition of Fighter Pilots

Figure 5.10 Attrition of the Luftwaffe Fighter Force in Early 1944 (Ref. 48) unfavorable situation because of these airplane qualities and the pilots' superior training. Worst of all for the German pilots, there was no refuge; no respite from the daily grind. For them the war was here, there, … everywhere.

CHAPTER 6.

CONCLUSION

The fierce air battles over Germany in the Spring of 1944 may have signaled the death knell of the Luftwaffe's domination of the European sky, but it by no means meant that the air war in Europe was over. Following the invasion of Normandy in June of 1944, the Eighth Air Force gradually turned their major efforts from tactical support of the invasion through disruption of enemy transportation activities to strategic attacks on the Third Reich. In this case, the principal objective was the synthetic oil production and storage system. Thirteen percent of the bomb tonnage dropped during the war was directed at the oil supply, and the bulk of this effort took place in the last seven months of the war.[50] Seventy percent of the Luftwaffe fighter force (almost 2,000 aircraft) was allocated to protect the oil production and storage facilities, and they seldom failed to respond in force to attacks against this life blood of their war machine. It is indicative of the Germans' desperate oil situation that a single refinery and storage complex around Leuna was guarded by over 460 heavy anti-aircraft guns.[51]

The final desperate measures of the Luftwaffe to stem the tide of the overpowering Allied air forces occurred late in 1944. Fighter Commander Adolph Galland instructed his forces to be conservative in their defense efforts for a few weeks in order to build up the number of the fighter forces so that the Luftwaffe could make a series of large-formation attacks against the American bombers to seriously decimate their ranks. (He named this effort was *Der Gross Schlag*, "The Big Blow"). Three such attacks were carried out between the 2nd and the 25th of November, and a total of seventy three bombers were brought down, but only about 25% of those fell to the German fighters.

The last gasp of the Luftwaffe came on New Year's Day, 1945. A force of over 750 fighters attacked sixteen Allied air fields on the Continent, destroying 134 aircraft and damaging 62 more. The loss of equipment was barely felt by the Allies, but the attacking German force lost 220 aircraft in the attack, and, more importantly, about an equal number of pilots. The loss was just too much to expect the Luftwaffe to be able to put up much resistance for the remainder of the war. Indeed, the Eighth Air Force flew eighty four bombing missions against the Reich in 1945, the last on 25 April against Pilsen and Salzburg. Four hundred thirteen bombers were shot down by the flak batteries and the few Luftwaffe fighters that made it through the numerous American fighter escorts, an average of about 5 per mission, or about 0.5% of the attacking force. Recall that the American attrition for the *Black Thursday* Schweinfurt raid was about 26%. Truly, the Luftwaffe was *kaput*.

What had started out as the most powerful and modern air force in the world just six years previously was now all but gone. Why? Since the development and deployment of the P-51 *Mustang* had such a profound impact on the Allied prosecution of the air war in Europe, it is instructive to review Luftwaffe technological developments to determine how they might have influenced the outcome of the war had they been aggressively pursued from the outset. It is beyond the scope of the present work to discuss these developments in detail. Here they will simply be listed with a comment on their possible effect on the outcome of the war.

1. Development of the external fuel tank for the ME 109 fighter. During the Battle of Britain, the turning point of the early air war, the German fighter escorts had only ten minutes of combat time over England before they had to turn for home. Greater

endurance would certainly have improved the survival rate of the bombers. Incidentally, such a tank became available for the ME 109E7 in 1941.

2. Development of a long range heavy bomber with large payload. At the outset of the war the German bomber corps was equipped with tactical medium bombers and dive bombers. All of these aircraft had a small payload and they were relatively slow and lightly armed for self defense. The German attempt to develop a long range bomber, the Heinkel 177, was beset with design and fabrication flaws which delayed its appearance in combat until 1943, too late to have an impact on the war. In view of the slender margin of victory for the British in the Battle of Britain, it is likely that the presence of the heavy bomber and range-enhanced escort fighter over Britain would have turned the tide in favor of the Luftwaffe.

3. Development of the jet propelled fighter. There is no doubt that earlier development of the ME 262 jet fighter would have had a profound effect on the air war over Western Europe. Design of the airplane and its radical new power plant, the gas turbine engine, began in 1938, but the first aircraft did not fly until March of 1943. Finally, in the late Fall a few of the aircraft began to trickle off the assembly line, but it was too late for them to make a difference. Much has been written in the post war literature that Hitler's decision to use the ME 262 as a bomber rather than as a fighter was crucial to the outcome of the war. Though it was certainly a stupid decision when American bombs were raining on Germany, the ME 262 arrived too late to have made a difference anyway. However, if it had been available in large numbers as a fighter in the summer of 1943, the balance of power in the air war would have swung to the Germans.

The preceding is simply idle speculation. As long as the war continued and the enemies of Germany were steadfast, Germany was certain to lose it because of the preponderance of assets arrayed against it. However, had the Germans developed key advanced concepts in the field of aeronautics early in the war, they may have made the cost of continuing the war so high that the Allies would have sued for peace.

It is untrue to say that the Mustang won the war in Europe for the Allied forces. It is even untrue to say that the Mustang won the air war in Europe for the Allied forces. It is certain that the war would have ended without the Mustang's presence at all. However, if the war had continued without it to the same conclusion on the track it was taking in 1943, there is *no doubt* that the cost of victory would have been much higher …in time, in money, in lives lost, and in futures changed. On the other hand, if the Mustang had entered service a year earlier, the pressure that Mustang-escorted bomber raids deep into Germany would have placed on the Reich might have induced Hitler to sue for peace. Such speculation is intriguing, but pointless. What *is* certain is that the appearance of the Merlin-powered Mustang in Europe changed the face of air combat there and hastened the demise of the Luftwaffe as an effective aerial fighting force.

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APPENDIX A

TABULATED AIRPLANE PERFORMANCE DATA

In the present work the performance characteristics of four aircraft are considered, two from the American Army Air Force (USAAF) and two from the German Air Force (GAF - the Luftwaffe). The aircraft considered for detailed analysis herein are the North American P-51D Mustang and the Republic P-47D Thunderbolt for the Americans and the Messerschmitt 109G Gustav and the Focke Wulf 190A Butcherbird for the Germans. Physical and performance characteristics of these aircraft are shown in Table A.1 on the next page. Sources for these data are found in the Bibliography as follows: Books by Land (1981), Perkins (1948), and Hoerner (1958) and Internet Addresses www.luftfahrtmuseum.com, www.warbirdresourcegroup.org and www.acepilots.com. The data for propeller and airframe efficiencies can only be acquired through comprehensive testing. Appropriate test data were not available to the author, so arbitrary values of 0.85, which are typical, were selected for these efficiencies. The engine efficiency relating shaft power to brake power is usually high, so a value of 1.0 was assumed. Variations in the listed horsepower for subject engines compensates for the small errors incurred by this assumption. At any rate, the values of these quantities are not sufficiently critical in the energy maneuverability analyses to affect the comparative outcomes.

Table A.1

Characteristics of Fighter Aircraft Considered

Airplane Parameter	NA P-51 Mustang	Rep. P-47C Thunderbolt	ME 109G Gustav	FW 190A Butcherbird
Wingspan b (ft.)	37.00	40.75	32.74	34.46
Planform area S (sq. ft.)	272.30	332.20	176.10	197.00
Aspect Ratio $AR = b^2/S$	5.03	5.00	6.09	6.03
Drag area $f = C_{Do} S$	3.85	6.33	5.65	5.11
Combat weight W (lbf.)	10,100	14,600	6,700	9,650
Engine power P (HP)	1,675	2,000	1,500	1,500
Drag area f (ft.^{2})	3.85	6.50	5.65	5.88
S.L. Stall speed V_s (mph)	110	110	112	118
Max. speed V_m (mph)	437	430	395	400
Service ceiling h_s (ft.)	41,900	42,000	38,550	37.400
Rate of climb $\dot{h}_{SL}$ (ft./min.)	3,455	2,800	3,345	3,450
Range (mi.)				
June 1943	200	340		
Jan 1944	475	375		
March 1944	650	425		
April 1944	850	475		

Note: Propeller and airplane efficiencies are assumed to be 0.85 for the four aircraft considered in this analysis.

APPENDIX B

AIRPLANE PERFORMANCE ANALYSIS METHODS

Horizontal plane analysis

In order for the reader to understand the performance comparisons for combat in the horizontal plane using the "doghouse" plot described in Chapter 4, it is necessary to present the functional relationships involved. Thus, we must show the relationship between turning rate and velocity in terms of aircraft characteristics. This is given by Equation (B.1) below:

$$\dot{\chi} = \frac{g}{V}\sqrt{n^2 - 1} = \frac{g}{V}\sqrt{\left(\frac{C_L \rho V^2 S}{2W}\right)^2 - 1} \qquad \text{(B.1)}$$

where

n	=	load factor, the ratio of lift to weight
g	=	gravitational acceleration
V	=	aircraft forward velocity
W	=	aircraft weight
S	=	wing planform area
C_L	=	airplane lift coefficient
ρ	=	air mass density

Now, the left-hand arc of the plot up to the *maximum g* line is determined by the stall characteristics of the airplane. For this case the lift coefficient, C_L, is a maximum, and it is a quantity determined by the shape of the airplane wing, independent of the flight trajectory or of the atmosphere. The so-called roof of the doghouse plot is the locus of points that represent a limiting g-force on the pilot. For purposes of this analysis a value of 6.0 is selected here to be consistent with the accepted standards for World War Two combat in which the pilots did not wear modern "g"-suits to alleviate the blood-pooling problem endemic in high-g maneuvers. The limiting g-loading line is, thus, given by the equation

$$\dot{\chi}_{g_{limit}} = \frac{g\sqrt{35}}{V} \qquad \text{(B.2)}$$

Other lines of constant g-loading are also shown on the graph. Finally, the right hand limit of the doghouse plot is fixed by the maximum speed of the aircraft at the specified altitude.

$$V = V_{max} \tag{B.3}$$

The lines defined by equations (B.1) through (B.3) form the boundaries of the "doghouse" plot, and they are shown in red in Figure 4.4. The diagonal black line with negative slope in this figure gives the value of maximum turning rate as a function of velocity that the aircraft can achieve without experiencing a loss or gain of altitude. A point on this line is determined for a given velocity by first calculating the load factor, n_m, with the equation:

$$n_m = \frac{1}{\left(W/S\right)} \left\{ \left[\frac{550\, \eta_p\, \rho\, HP}{2\left(\frac{1}{\pi\, e\, AR}\right) S} \right] V - \frac{C_{D_o}\, \rho^2}{4\left(\frac{1}{\pi\, e\, AR}\right)} V^4 \right\}^{1/2} \tag{B.4}$$

where
η_p = propeller efficiency
HP = engine horsepower
C_{D_o} = zero lift drag coefficient = $2\,D/\rho\,V^2\,S$
e = airplane efficiency factor
AR = wing aspect ratio = $(\text{span})^2/S$

Then, the corresponding best turn rate is calculated for the same velocity with the equation:

$$\dot{\chi}_m = \frac{g\,\sqrt{n_m^2 - 1}}{V} \tag{B.5}$$

Other lines that are helpful in analyzing the aircraft performance from the doghouse plot are lines of constant turning radius, R, and constant load factor, n. The turning radius is given by Equation (B.6) as follows

$$R = \frac{V}{\dot{\chi}} \tag{B.6}$$

Finally, the constant load factor line is calculated for a given turn rate and velocity by the equation

$$\dot{\chi}_g = \frac{g\sqrt{n^2 - 1}}{V} \tag{B.7}$$

Note that the turn rate depends on the airplane drag force and g-loading. The drag force, in turn, depends on the friction and flow-separation drag and on the lift force produced in the turn. These characteristics can be calculated for each aircraft configuration. In the present work this is done for each aircraft considered using the same reference data and methods. Tabulated values of these physical and performance quantities for the aircraft considered for comparison in Chapter 5 are shown in Appendix A. Results of the above analyses for the four subject test aircraft of this thesis are shown in Chapter 5, Figures 5.6 through 5.9.

Vertical plane analysis

The determination of .climb performance considered here is a quasi-steady-state analysis. That is, the aircraft is assumed to be in wings-horizontal flight, and its performance at each altitude is determined from instantaneous values of important parameters at that altitude. The characteristic chart that can be used for performance comparisons in this case is the altitude - versus velocity graph shown in Figure 4.5. The left-hand branch of the curve is locus of points representing the slowest speed that the aircraft can fly as a function of altitude. This is simply the stall speed, and it is given by the equation:

$$V_{stall_{altitude}} = V_{stall_{sealevel}} \sqrt{\sigma} \qquad \text{(B.8)}$$

The right-hand branch of the curve represents the maximum velocity attainable by the aircraft as a function of altitude. Since the power output of a given engine-propeller combination is not generally linear with altitude, an equation similar to equation (A.7) cannot be used to determine power output as a function of altitude. In fact, the power output of an engine-propeller combination at a given airplane velocity can be made almost independent of altitude over a large range of altitudes with the use of a supercharger. It will be recalled from Chapter 2 that the use of the supercharged Rolls Royce engine in place of the Allison engine in the Mustang produced a dramatic change in the performance of the airplane. Appropriate supercharged engine data are available for use in the present analysis. In any case, the right-hand branch of the vertical performance curve which represents the maximum velocity attainable by the aircraft is determined when the maximum power put out by the engine-propeller combination at a given altitude is exactly equal to the airplane drag power at the same altitude.

Important performance parameters for flight in the vertical plane, in addition to stall speed and maximum speed, are the maximum rate of climb, the maximum angle of climb and the time to climb between altitudes. In the analysis of combat performance, the rate of climb is the most important of these parameters, and it is the only one considered in the present study.

The rate of climb for an aircraft depends on the excess power it can generate at a given altitude. The excess power is the difference between the power generated by the engine-propeller combination (P_A) and the resistive power generated by friction and flow separation on the airplane (P_R = D V). Thus, the rate of climb is determined by the following equation:

$$\dot{h} = \frac{P_A - P_R}{W} = \frac{k\eta_p\ SHP\ -\ DV}{W} \qquad \text{(B.8)}$$

where $\dot{h}$ = rate of climb usually given in units of feet per minute
SHP = shaft horsepower available
k = unit conversion factor
η_p = propeller efficiency
D = airplane drag force
V = airplane velocity
W = airplane weight

Tabulated values of these parameters for the American and German aircraft of interest are shown in Appendix A. Also shown is the maximum rate of climb available to the subject fighters at an altitude of 25,000 feet. As the aircraft approaches it ceiling, the rate of climb decreases to zero. The *service ceiling* is a standard used to define the useful ceiling of an aircraft. It is the altitude for which the aircraft achieves a rate of climb of 100 feet per minute. It should be noted that the dive speed for the World War Two aircraft considered here was often limited by structural rather than performance considerations. In this regard, the Republic P-47 was by far the most structurally rugged of the four aircraft considered. It is no surprise that, since it was also the heaviest and had the most powerful engine, it could out-dive any of the other aircraft considered. On the other hand, it can be seen from Table A.1 that the P-47 also had the poorest climbing performance.

The computational algorithms and tabulated results of the horizontal plane analyses for the P-51 *Mustang*, P-47 *Thunderbolt*, ME 109 *Gustav* and FW 190 *Butcherbird* are given in the following pages. These tables constitute the four curves that make up the maneuverability graphs presented in Figures 5.6 through 5.9 in Chapter 5. The four curves are as follows:

1. The stall line. This is the left-hand boundary line on the graph given by Equation (B.1).

2. The limit load factor line. This is the top line on the graph given by Equation (B.2)

3. The maximum velocity line. This is the right-most boundary of the graph given by Equation (B.3)

4. The coordinated turn line. This is the intermediate line on the graph with a negative slope that emanates from the stall line and terminates at maximum velocity on the zero-turn line. This line is determined from Equation (B.5) after computing the load factor from Equation (B.4)

These results are calculated with the computer software, MATHCAD 14.0. The computational algorithm for each calculation is presented prior to the presentation of the tabulated results.

Calculations for the P-51B Mustang
Altitude = 25,000 feet

1. The stall line

Load Factor	Yaw Rate (deg/sec)	Velocity (mph)
1.0	0.00	164.36
1.2	4.64	180.05
1.4	6.34	194.48
1.6	7.56	207.90
1.8	8.54	220.52
2.0	9.37	232.44
2.2	10.11	243.79
2.4	10.78	254.63
2.6	11.39	265.03
2.8	11.96	275.03
3.0	12.50	284.68
3.2	13.01	294.02
3.4	13.49	303.07
3.6	13.95	311.86
3.8	14.39	320.40
4.0	14.82	328.73
4.2	15.24	336.84
4.4	15.64	344.77
4.6	16.02	352.52
4.8	16.40	360.10
5.0	16.77	367.53
5.2	17.13	374.80
5.4	17.48	381.94
5.6	17.82	388.95
5.8	18.16	395.84
6.0	18.49	402.60

Calculations for the P-51B Mustang
Altitude = 25,000 feet

2. <u>The load factor limit line (n = 6.0)</u>

Velocity (mph)	Yaw Rate (deg/sec)
374	16.47
376	16.38
378	16.30
380	16.21
382	16.13
384	16.04
386	15.96
388	15.88
390	15.79
392	15.71
394	15.63
396	15.56
398	15.48
400	15.40
402	15.32
404	15.25
406	15.17
408	15.10
410	15.02
412	14.95
414	14.88

3. <u>Maximum velocity line (Valid for all yaw rates)</u>

$$V = V_{max} = 437 \text{ mph}$$

Calculations for the P-51B Mustang
Altitude = 25,000 feet

4. Constant altitude coordinated turn

Velocity (mph)	Load Factor	Yaw Rate (deg/sec)
140	1.53	10.45
160	1.63	10.10
180	1.71	9.69
200	1.78	9.27
220	1.84	8.82
240	1.88	8.37
260	1.92	7.91
280	1.93	7.42
300	1.93	6.92
320	1.91	6.38
340	1.86	5.80
360	1.78	5.16
380	1.67	4.44
400	1.51	3.56
420	1.28	2.37
437	1.00	0.00

Calculations for the P-47C Thunderbolt
Altitude = 25,000 feet

1. The stall line

Load Factor	Yaw Rate (deg/sec)	Velocity (mph)
1.0	0.00	164.36
1.2	4.64	180.05
1.4	6.34	194.48
1.6	7.56	207.90
1.8	8.54	220.52
2.0	9.37	232.44
2.2	10.11	243.79
2.4	10.78	254.63
2.6	11.39	265.03
2.8	11.96	275.03
3.0	12.50	284.68
3.2	13.01	294.02
3.4	13.49	303.07
3.6	13.95	311.86
3.8	14.39	320.40
4.0	14.82	328.73
4.2	15.24	336.84
4.4	15.64	344.77
4.6	16.02	352.52
4.8	16.40	360.10
5.0	16.77	367.53
5.2	17.13	374.80
5.4	17.48	381.94
5.6	17.82	388.95
5.8	18.16	395.84
6.0	18.49	402.60

Calculations for the P-47C Thunderbolt
Altitude = 25,000 feet

2. The load factor limit line (n = 6.0)

Velocity (mph)	Yaw Rate (deg/sec)
402.6	18.49
404.6	18.39
406.6	18.30
408.6	18.21
410.6	18.13
412.6	18.04
414.6	17.95
416.6	17.87
418.6	17.78
420.6	17.70
422.6	17.61
424.6	17.53
426.6	17.45
428.6	17.36
430.6	17.28

3. Maximum velocity line (Valid for all yaw rates)

$$V = V_{max} = 430 \text{ mph}$$

Calculations for the P-47C Thunderbolt
Altitude = 25,000 feet

4. <u>Constant altitude coordinated turn</u>

Velocity (mph)	Load Factor	Yaw Rate (deg/sec)
140	1.49	10.45
160	1.59	10.10
180	1.67	9.69
200	1.73	9.27
220	1.79	8.82
240	1.83	8.37
260	1.86	7.91
280	1.87	7.42
300	1.86	6.36
320	1.82	5.81
340	1.76	5.20
360	1.66	4.51
380	1.52	3.69
400	1.31	2.61
420	1.08	0.09
430	1.00	0.00

Calculations for the ME 109G Gustav
Altitude = 25,000 feet

1. <u>The stall line</u>

Load Factor	Yaw Rate (deg/sec)	Velocity (mph)
1.0	0.00	167.35
1.2	4.51	183.32
1.4	6.17	198.01
1.6	7.36	211.68
1.8	8.31	224.53
2.0	9.12	236.67
2.2	9.84	248.22
2.4	10.59	259.26
2.6	11.09	269.85
2.8	11.64	280.03
3.0	12.17	289.86
3.2	12.66	299.37
3.4	13.13	308.58
3.6	13.58	317.53
3.8	14.01	326.23
4.0	14.43	334.70
4.2	14.83	342.97
4.4	15.22	351.04
4.6	15.60	358.93
4.8	15.96	366.65
5.0	16.32	374.21
5.2	16.67	381.62
5.4	17.01	388.89
5.6	17.34	396.02
5.8	17.67	403.03
6.0	17.99	409.92

Calculations for the ME 109G Gustav
Altitude = 25,000 feet

2. The load factor limit line (n = 6.0)

Velocity (mph)	Yaw Rate (deg/sec)
374	16.47
376	16.38
378	16.30
380	16.21
382	16.13
384	16.04
386	15.96
388	15.88
390	15.79
392	17.71
394	15.63
395	15.60

3. Maximum velocity line (Valid for all yaw rates)

$$V = V_{max} = 395 \text{ mph}$$

Calculations for the ME 109G Gustav
Altitude = 25,000 feet

4. Constant altitude coordinated turn

Velocity (mph)	Load Factor	Yaw Rate (deg/sec)
140	2.07	16.26
160	2.19	15.29
180	2.29	14.38
200	2.37	13.50
220	2.43	12.65
240	2.46	11.80
260	2.47	10.94
280	2.45	10.05
300	2.39	9.11
320	2.29	8.08
340	2.12	6.92
360	1.87	5.54
380	1.49	3.67
395	1.00	0.00

Calculations for the FW 190 Butcherbird
Altitude = 25,000 feet

1. <u>The stall line</u>

Load Factor	Yaw Rate (deg/sec)	Velocity (mph)
1.0	0.00	174.82
1.2	4.32	191.51
1.4	5.91	206.85
1.6	7.04	221.13
1.8	7.96	234.55
2.0	8.73	247.24
2.2	9.42	259.30
2.4	10.04	270.83
2.6	10.61	281.89
2.8	11.15	292.53
3.0	11.65	302.80
3.2	12.12	312.73
3.4	12.56	322.36
3.6	13.00	331.70
3.8	13.41	340.79
4.0	13.81	349.64
4.2	14.19	358.28
4.4	14.57	366.71
4.6	14.93	374.95
4.8	15.28	383.02
5.0	15.62	390.91
5.2	15.96	398.66
5.4	16.28	406.25

Calculations for the FW 190 Butcherbird
Altitude = 25,000 feet

2. <u>The load factor limit line (n = 5.0)</u>

Velocity (mph)	Yaw Rate (deg/sec)
390.9	18.49
392.9	18.39
394.9	18.30
396.9	18.21
398.9	18.13
400.0	18.09

3. <u>Maximum velocity line (Valid for all yaw rates)</u>

$$V = V_{max} = 400 \text{ mph}$$

Calculations for the FW 190 Butcherbird
Altitude = 25,000 feet

4. Constant altitude coordinated turn

Velocity (mph)	Load Factor	Yaw Rate (deg/sec)
140	1.59	11.06
160	1.68	10.61
180	1.76	10.11
200	1.82	9.60
220	1.88	9.07
240	1.91	8.52
260	1.92	7.95
280	1.92	7.35
300	1.89	6.71
320	1.83	6.00
340	1.73	5.21
360	1.58	4.26
380	1.36	3.03
400	1.00	0.00

VITA

Robert W. Courter was born in Denver, Colorado, in June, 1935, to the late John Wayne and Martha Virginia West Courter. He attended public schools in Colorado, California, and Texas, and was graduated from Arlington Heights High School in Fort Worth, Texas, in June of 1953. He studied aeronautical engineering at the University of Texas in Austin and earned a bachelor of science degree and master's degree. Following two years in industry with the McDonnell Aircraft Corporation in St. Louis, Missouri, he returned to the University of Texas as an instructor in the Department of Aerospace Engineering. He earned the doctoral degree in 1965 and began an academic career at the University of Wyoming. In 1968 he took a position as an assistant professor in the Department of Mechanical, Aerospace and Industrial Engineering at the Louisiana State University in Baton Rouge. He retired from that department as an associate professor in 2001. That same year he began studies toward a master's degree in the Department of History at the Louisiana State University. He has been married to Georgia Wall Courter for fifty two years. They have three children, Stephen Mark, Brian Lee, and Amy Lynne Palmer, and five grandchildren.