

Research on airframe structure, engine performance, weapon mounting capability of *F-16*

Zhaxidaji*

Huaai Preparatory Academy, Pidu District, Chengdu, China, 611730

charlesleoko@ldy.edu.rs

Abstract. With the progress and development of science and technology, the types and application range of fighter jets have become more diversified, and many aircrafts have been developed to be suitable for specific purposes. However, the multi-mission carrying role of aircraft has been very few, which makes different aircraft have their unique advantages or disadvantages, rather than the elite in all aspects. Herein, to gain a comprehensive understanding of the fighter jets, this paper mainly focuses on the *F-16*, which occupies the dominant position of the third-generation aircraft in the last century. In detail, the airframe structure, engine performance and weapon mounting capacity of *F-16* have been deeply studied and compared with the contemporaneous aircrafts to show the superior performance of *F-16*. Overall, through this analysis of *F-16*, this study also aims to not only gain the better knowledge of this fighter jet, but also may provide some insights for the future development of fighters.

Keywords: *F-16* Airframe Structure, Engine Performance, Weapon Mounting Capacity.

1. Introduction

With the development of human society and the progress of science and technology, people's travel has become more and more convenient. The aircraft in the whole process plays a very important role. Thanks to the aircraft, people can quickly and arbitrarily reach any destination they would like to go without the limitation of distance and time. Therefore, aircraft have played an irreplaceably important role in the contemporary transportation system. There are different classifications of airplanes, which can be divided into two categories depending on their functions – civilian airplanes and military airplanes. Civilian airplanes make it easier for people's daily lives, which is about traveling through countries and regions and efficient goods-delivery systems. Besides, fighters, early-warning airplanes, jet fighters, and bombers can be recognized as military airplanes, which aim to protect the airspace safety of a country and the integrity of the motherland. Importantly, different from the civilian airplane, the development of military-aimed airplanes is closely related to defence science and technology and national security.[1]

In terms of the structure of airplane, the main difference between a jet fighter and a civil airplane is that the aircraft is defined as a fighter because of its ability to mount weapons, fire control system and to carry both air and ground combat weapons. Secondly, because of its fuselage structure and the special characteristics of the engine, fighter jets can do things that other common aircraft cannot do, which can be illustrated with an example of flying at a speed of more than Mach 1.5 [2]. Besides, to adapt to aerial combat and ground strikes, jet fighters will remove a lot of redundant loading. For example, the pilot's seat is equipped with a rocket ejection device, which turns the comfortable seat for pilots into an escape

pod. The ability to provide a huge horsepower of the engine and special structural designs allowed the fighter's fuselage to withstand huge overloads, as well as a certain degree of bullet-proof, waterproof, and fireproof capabilities.

During the latter period of World War II, the United States began to step into the process of the development of new jet fighters. The traditional propeller aircraft in the speed has always been hard, and the height of the aircraft is also a problem [1]. The emergence of jet fighters basically solved the existing problem. The operational principle is that when gas jet nozzles, the jet pushes air backwards, and during the same time the aircraft is pushed forwards by the reverse force. In this way, the stability of the jet fighter can be greatly improved, based on which the speed and mounting capacity are correspondingly enhanced as well.

Early jet fighters - for the second generation and third generation of aircraft, most of the second generation of aircraft were United States of America's F-4 and the Soviet Union MiG series, and most of the third generation in the United States were F-16. YF-16 is the most F-16 prototype. During this development, the fuselage structure of F-16A, F-16B, F-16 block 10, and F-16 block 15 were the following optimized type, which aimed to achieve better aerodynamic effects. The subsequent F-16 block 20 and F-16C/D F-16 block 40/50 were upgraded for radar systems and engine replacements, which purpose was to achieve continuous firepower enhancement and performance upgrades.

This paper analyses in detail the performance of airframe and engine of F-16. Then a comparison of its performance with traditional Soviet fighters of the same period. Specifically, the characteristics and functions of the F-16 have been deeply investigated, which aims to show the superiority of the F-16. Lastly, through this study, the prospects, and personal suggestions for the future development of new jet fighters were stated.

2. F-16 and energy maneuver theory

In the second generation of aircraft, the U.S. Army's *F-4* Phantom and the Soviet Union's *MiG* series of aircraft have been in the dominant stage ref. However, the problem of the U.S. Army's F4 was gradually exposed in the Vietnam battle, which was mainly because the aircraft became extremely heavy when meeting the powerful mounting capacity at the maximum of 15,983 LBS ref. In contrast, this problem did not occur to the *MiG* and other light fighters. Therefore, in terms of the dogfighting ability, the F4 almost lost its competitiveness [3]. In the late 1960s, the U.S. military advocated the official start of the development of the third generation of aircraft [4]. They believed that the determinations of victory in aerial combat were height, speed, firepower, and manoeuvre, which is also known as the most famous energy manoeuvre theory.

Therefore, inspired by the failure of the second generation of ghosts and monsters, the development of the third generation of aircraft began, which adhered to the four major concepts. In January 1972, the U.S. Air Force formally put forward the development of a new fighter aircraft program, the purpose of which was to validate the use of new technologies in the fighter, rather than determine on the development on one specific model. At that time, its main technical requirements were the maximum flight speed of Mach 2, with a lift of 18,000 meters. Under this condition, the fighter could accelerate from Mach 0.9 to Mach 1.5 within one minute at an altitude of 9,000 meters [4]. The other technique developed at the same time is that the aircraft with characteristics of small size, lightweight, and cheap could remain the overload with 3 – 4 G at the speed of Mach 0.9 in the altitude of 12,000 meters, which was a breakthrough at that time [4].

2.1. Motorization, structural characteristics of the airframe

To meet the bidding requirements for the third-generation aircraft, General Electric Company produced the *YF-16* prototype in December 1973. After a one-year test, the *YF-16* has successfully conducted the first flight test in 1974. After this big success, a series of *F-16* aircraft with advanced cross-generation performances formally began their service. This impressive invention broke many traditional restrictions on the fighter, which not only the fire control capacity had been greatly improved, but also the overall shape as well as excellent performance almost behaved the same level as the fourth generation.

The overall weight of *F-16* aircraft is 9,295 kg, and its overall length is 15 meters with the length of wing structure of 9.96 meters [5]. To reduce the overall weight, the component of the structural material of *F-16* is 80.6% of traditional aluminium alloy, 7.6% of alloy steel, 2.8% of composite material, 1.5% of titanium alloy and 7.5% of other materials, respectively. Also, 60% of the structural parts inside the aircraft are alloy plates, which can efficiently make the fighter lighter [5].

Besides, to decrease the manufacturing cost, *F-16* was designed to minimize the use of special materials. The fuselage adopts a conventional structure consisting of spacer frames and longitudinal beams, with the forward process separation surfaces behind the cockpit and the aft separation surfaces ahead of the drogue. The *F-16* adopts a semi-monocoque structure with a short and stubby fuselage profile, which is connected to the wing by the formation of a wing-fuselage. This design effectively makes the fuselage and the wing rounded and smooth, which reduces resistance and improves the ratio of lift-to-resistance. With the rational design, the stiffness is greatly increased, and the fuselage volume is improved by 9%. It is also noticed that the overall weight of the fuselage is reduced by 258 kg, which is also good for reducing the radar reflection area.[6]

2.2. Comparison of *F-16* wind tunnel test data and contemporary aircraft

The information of the *F-16* has been fully disclosed, so we can use the aerodynamic data of the *F-16* aircraft from the low-speed static and dynamic (force oscillations) wind tunnel tests conducted in the wind tunnel facility by Ames and Langley Research Centres in National Aeronautics and Space Administration (NASA) [7]. Through the analysis of the data from the wind tunnel tests, it is shown that the aircraft needs leading edge flaps to increase directional stability at large angles of approach, in which way to increase the lift. Therefore, the leading-edge manoeuvring flaps and trailing edge flap ailerons can reach up to 35° s and change the wing curve degree according to the live aerodynamic requirements. The leading-edge flap improves directional stability and maintains lift at large angles of approach, which reduces jitter. This lifting device allows the *F-16* to adopt a small wing with a short wingspan, in which way reduces the weight of 222 kg for the *F-16*.

Secondly, as shown in the data, the angle of attack and slip angle of *F-16* are $-20^\circ \leq a \leq 90^\circ$ and $-30^\circ \leq b \leq 30^\circ$, respectively, where the parameter a represents the angle of attack which is the angle between the oncoming airflow and the aircraft when the aircraft makes a significant climb or manoeuvring turn. The parameter b represents the angle of sideslip when the aircraft performs a turn concerning its original track and is divided into a left-slip and a right slip. For a fighter, the larger the angle of attack allows the fighter to obtain better combat advantages. The measured slip angle is one of the important data that can be used to allow pilots to determine the attitude of the aircraft [8]. Compared with the third-generation aircraft developed by the former Soviet Union, taking the *MiG 29* and *Su-27* as examples, the initial aim to design *Su-27* was to counterbalance the heavy fighter, such as *F-15*, of United States. Therefore, no matter in aerodynamic or in air, the *Su27* was uncompetitive. The *Su27* has an empty weight of 16,380 kg, and the overall length is 21.9 m with a height of 5.93 m. The wing length is 14.7 m, and the wing area is 62 m². Compared with the data of *F-16*, the *Su27* with 1.63 ton is almost double, making it no longer a rival to the *F-16*. Moreover, compared with the wing area of the *F-16* (27 m²), its oversized wing area is not capable of good slewing performance in dog fighting.

2.3. Altitude, speed, and engine

In John Boyd theory of energy manoeuvring, the higher the specific excess power (SEP) results in the better performance. SEP refers to the residual power of a fighter, which is also recognized as the stored energy [9]. The entire stored energy is determined by the thrust. So, a good engine is a key to providing a good thrust. Taking the most classic *F-16A* as an example, its empty weight is 7,230 kg, and the engines used in *F-16A* are *F-100-PW-200*, as shown in Fig. 3. The static thrust of *F100-PW-200* is shown in Figure 1.

ENGINE RATINGS				
S. L. Static	LB	-	RPM (N ₁ /N ₂)	- MIN
Max:	*23,830	-	10,160/ 12,960	- 5
Intermed.	14,670	-	10,200/ 12,980	- 30
Max Cont:	12,420	-	9810/ 12,560	- Cont

* With Afterburner Operating

Figure 1. Thrust gravity diagram of the F-16 engine [8].

2.4. Comparison of F-16 engine performance and contemporaneous aircraft

When evaluating the performance of the aircraft, we can use the SEP calculation method to carry out the calculation of different loads in different situations, in which way to optimize the accuracy of the data of the aircraft engine. SEP refers to the energy left in the aircraft in a specific condition of the aircraft, and he is calculated by the equation (1), where T = the thrust of the aircraft, D = the drag force on the aircraft, V = speed, G = weight.

$$SEP = (T - D) * V/G \quad (1)$$

As the data shown that the F100-PW-200 added thrust is about 10,795 kg [10]. According to the climb rate data of the F-16A and the SAC files [11] of the F-16A Blocks 1-10 and F-16A Block 15, the SEP values of the F-16A wingtip carrying two Rattlesnake missiles in 20,880 LBS. of weight for 1G level flight can be calculated. At Mach 0.8 at sea level, the SEP of the F-16A aircraft in this state is 900 ft/s (275 m/s), and at Mach 1 at sea level, the SEP is 600 ft/s (183 m/s) (Figure 2). Besides, when the F100-PW-200 thrust of the F-16 aircraft carries two wingtip *AIM-9Js*, the drag coefficients are 0.019 and 0.039 at Mach 0.8 and Mach 1, respectively (based on flight test data). Based on the equation $D = 0.5 \times CD \times p \times S \times V^2$ together with a reference area of 27.87 m² and an air density of 1.225 g/m³ at sea level, it can be calculated that the drag for Mach 0.8 and at Mach 1 are 23996 N and 76960 N [10], respectively. According to equation (1), the mass is 20880 LBS equivalent to 9459 kg. Taking SEP and drag into account, the F100-PW-200 thrust can be calculated as 12012 kg and 12944 kg at the speed at Mach 0.8 and Mach 1, respectively. Meantime, the F100 -PW-200 thrust can be estimated as 12,478 kg at Mach 0.9. Besides, the drag coefficient of the F-16 clean configuration at Mach 0.9 is about 0.017[12]. Taking all these parameters into consideration, with the weight of 8,375 kg, the SEP of the F-16A Block 15 fighter at Mach 0.9 at sea level can be estimated at around 355 m/s.

Compared with *MiG-29* which were invented at the same period with the air weight of 12,800 kg, by the employment of the same calculation, the maximum added thrust of *RD-33* is about 8,300 kg, which is much lower than that of *F100-PW-200*. At the same time, the SEP of a *MiG-29* equipped with two *R73* is 325 m/s [13], which is not good as the result mentioned above for *F-16* (SEP = 355 m/s), showing the superior performance of *F-16* at that time.

WEIGHTS		
<u>Loading</u>	<u>Lb</u>	<u>Max L. F.</u>
Empty	15,961	
Basic	16,326	
Operating	16,695	
Design	24,095	9.0(1)
Max T. O.	35,400(2)	
Max In-Flight	35,400	
Combat	23,768(3)	
Max Landing	19,500(4)	
(1) Air-to-Surface Stores Limit - 5.5g		
(2) Tire Limit		
(3) Air Superiority Mission		
(4) 10 fps Design Rate of Sink		

Figure 2. *F-16A* empty weight [8].

2.5. Firepower, load capacity vs. contemporaneous aircraft

The *F-16A* has nine weapon mounting points (as shown in Figure 3), and two of them are *AIM* air-to-air missile mounting points located on the wing tips of the aircraft. The other six weapon mounting points are on the wings which can support a variety of weapon choices, such as *AIM-7* air-to-air medium-range radar missile, *AIM-9* close-range fighting missile, *AIM-120* air-to-air radar missile, *AGM-65* air-to-ground missiles, and *AGM-88* air-to-ground anti-radiation missiles, *AGM-84* air-to-ground anti-ship bombs, *AGM-119* anti-ship missiles, etc [14]. In addition, *F-16* can also mount the *AGM-154* joint outer defence area (JOADA) weapons *CBU-87/89/97* cluster bombs, *GBU-39* small-diameter bombs, *MK-80* series of unguided bombs, pave the way series of guided bombs, joint direct attack (JDAT) bombs, and the *B61* nuclear bomb.



Figure 3. Nine of payload points of *F-16*.

It is known that the empty weight of *F-16* is 15,961 LBS, and its maximum take-off weight is 35,400 LBS. Therefore, taking into account of the weight of the pilots, guns, and 1,000 kg of fuel, the maximum mounting capacity of *F-16* is 16,600 LBS based on the 18,800 LBS as the base weight of aircraft. In other words, when the *F-16* does not need a secondary fuel tank for long-distance flight, the maximum mounting capacity can reach 16,600 LBS. So, when the *F-16* is deployed in a conventional air-to-air armament configuration (two *AIM 9I* and two *AIM 120* with the weight of 190 and 335 LBS, respectively [15, 16]), the conventional air-to-air armament payload is 1050 LBS. It only accounts for 1050 LBS of the maximum take-off weight of 16,600 LBS, which means that the remaining mounting capability of

the *F-16* is 15550 LBS. When two wing mount points are occupied by two *AIM 120*, the *F-16* will have four weapon drop points remaining, each of which can load 5,000 LBS of mounting capacity. This can be used to mount laser-guided bombs as well as secondary fuel tanks. Compared with the *MiG 29* of the same era, which has a maximum take-off weight of 44,000 LBS, and the aircraft has a take-off weight of 33,000 LBS in normal mounting [5]. Through the calculation, mounting capacity of *MiG 29* is 11,000 LBS, which is only 66% of that of *F-16*.

3. Conclusion

In this study, the *F-16* fighter has been detailed investigated, which shows that *F-16* has obvious advantages over contemporary fighters in aircraft manoeuvrability. Its own lighter body weight and smaller wing area make the *F-16* have better rotation performance and air combat advantages. Secondly, the *F-16* has the strongest thrust engine of its generation, which contributes to gaining a good SEP value and making the air superiority *F-16* of more obvious. Finally, its maximum payload of 16,600 LBS made its ground strike capability significantly superior to that of contemporary fighters. Therefore, through comparative study, the conclusion obtained in this paper can be more conducive to explaining that the development of future fighters should be more inclined to adapt to the multi-role of fighters, rather than giving up other advantages for a specific purpose. In conclusion, the appearance of the *F-16* laid the foundation for all advanced fighter aircraft in the future. But until now, the *F-16* is still in service in many countries thanks to its excellent performance and practical applications. To sum up, this study provides the comprehensive understanding of the performance of *F-16* fighter, which will contribute to the optimization and development of the next generation of fighters in future.

4. References

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