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**NAVAL POSTGRADUATE SCHOOL**  
**Monterey, California**



**THESIS**

**MODERNIZATION OF THE CZECH AIR FORCE**

by

Vaclav Vlcek

June 2001

Thesis Advisor:  
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Raymond Franck  
Gregory Hildebrandt

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**MODERNIZATION OF THE CZECH AIR FORCE**

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Captain, Army of the Czech Republic  
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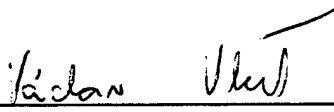
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requirements for the degree of

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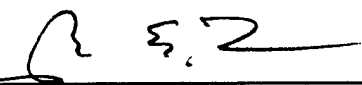
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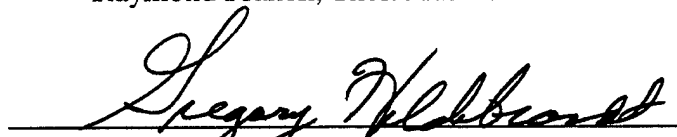
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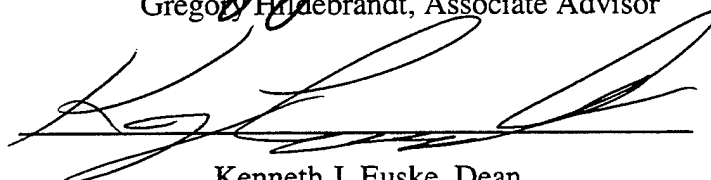
  
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## ABSTRACT

This research explores the decision-making problem for the purchase of modern fighter aircraft for the Czech Republic. This represents a specific case of a complex issue of military hardware acquisition.

The author starts with a general overview of Czechoslovak and Czech Air Force's (CAF) history and the major stages of its development. This historical overview is followed by a description of the present situation of the CAF with the emphasis on current problems. The CAF operates obsolete second-generation aircraft, rapidly approaching the end of their operational life. A partial solution would be a purchase of 72 L-159 Advanced Light Combat Aircraft to supplement 36 front-line fighters.

The aircraft under consideration are F/A-16, F/A-18, Mirage 2000-5, JAS-39, and Eurofighter. The MiG-29 SMT is included for comparison. The main contribution of this study is a prediction of Life Cycle Costs (LCC) for each aircraft together with an estimate of quality or relative effectiveness based on TASCFORM-AIR model. These should be the most important criteria for proper decision-making.

The study includes a brief description of the Czech economy, military budget, a summary of world industrial base, and future military aircraft developments. A final recommendation is provided.

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## I. INTRODUCTION

### A. BACKGROUND

In 1799 Sir George Cayley invented the concept of the fixed-wing aircraft. He conducted experiments with kites to understand how things fly. One of his great contributions was to separate the ideas of lift, propulsion, and control. Everything what he learned helped him to build a glider. In 1850s many imaginative people tried to build steam-powered flying machines, but the engines were either too weak or too heavy. Mankind had to wait until the world's first successful, piloted, powered flight was made achievable. On December 17, 1903 Orville and Wilbur Wright flew a gasoline-powered flying machine about 120 feet [Ref. 1]. That short flight is widely considered the starting point of modern aviation. Following years were filled with competition like who will fly faster, higher, longer etc. In 1909 in France Louis Bleriot flew a small aircraft over the Channel from France to England [Ref. 1].

The beginning of WWI brought the idea of using aircraft for the military purposes. They were at first used for observation and the planes on either side were unarmed. Soon pilots began carrying rifles and pistols into the air and traded shots. Little later the problem of perfecting a machine gun that would synchronize its firing with the rotation of the propellers was solved. This is the beginning of the evolution of military aircraft.

The Czechoslovak Air Force was established at the end of WWI on October 30, 1918. A French military aviation mission assisted in the formation of the Czechoslovak Air Force (CAF). The Air Force expanded rapidly and became a large and well-equipped force in Europe with an inventory of 1,000 aircraft in 1938. Because of the Munich Agreement and political decisions, these aircraft were never used against the enemy. All of them were confiscated by Nazi Germany. Most pilots escaped to other countries and fought on both East and West fronts against two Axis Powers.

After the end of WWII the CAF was reestablished. As the Communists consolidated power in 1948, most of the pro-Western military personnel were forced to leave. The Air Force was reorganized along Soviet lines. In 1989, after the fall of the Iron Curtain in Europe, democratic processes expanded in Czechoslovakia. The following years were focused on the transformation of the Czechoslovak Armed Forces. The split of Czechoslovakia into the Czech and Slovak Republics interrupted this process. The military inventory was divided up in the ratio two to one in favor of the Czech Republic, based on population. A few years later the government of the Czech Republic approved the new concept of its Armed Forces with the focus on the European security structures and the ultimate goal to become a member of NATO.

This new concept is associated with the modernization of the Czech Armed Forces. Major part of this program is the procurement of modern military aircraft. Most of the 2<sup>nd</sup> generation aircraft will be at the end of their life cycle by 2005. The government of the Czech Republic therefore decided to procure 72 Advanced Light combat Aircraft produced domestically. The government has to decide about the purchase of 36 supersonic military aircraft, which will become the backbone of the CAF.

This thesis reviews the history, evaluates the present, and analyze possible future courses of the Czech Air Force.

## **B. PURPOSE**

The purpose of this thesis is to utilize methods learned at the Naval Postgraduate School to analyze a complex decision-making issue. The purchase of 36 supersonic aircraft is a decision which will determine the nature of the CAF for the next 20 years. Therefore, I want to focus my attention on possible courses of action by considering all influential factors.

### **C. RESEARCH QUESTIONS**

- What is the history of Czech Air Force?
- What is the current state of the Czech Air Force, what are the major deficiencies and needs?
- What aircraft is available nowadays and what are its life cycle costs?
- What are the economic capabilities of the Czech Republic?
- What is the Czech military budget?
- Does the Czech Republic have enough resources to sustain modern military aircraft throughout its life cycle?
- What is the current world industrial base for aircraft and its future?
- What are the new aircraft developments?



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## II. HISTORY OF THE CZECH AIR FORCE

### A. 1918 – 1938

During WWI, the Czechs served in the Austro-Hungarian Army, but most of them deserted. Later Czechoslovak Legions were formed in France, Italy and Russia to fight for Czechoslovak independence from Austria-Hungary. On October 28, 1918 the Czechs and the Slovaks proclaimed their independence and established their own state, Czechoslovakia. Two days later a group of air officers under the leadership of Captain Jindrich Kostrba established "The Air Corps", which is generally considered as the establishment of the Czechoslovak Air Force (CAF). The lack of aircraft and insufficient infrastructure were of major concern to the newly established CAF. The only airfield was in Cheb with a small repair shop located in Prague. The major armament at that time was formed by 11 aircraft type Hansa Brandenburg I (Fig. 1).

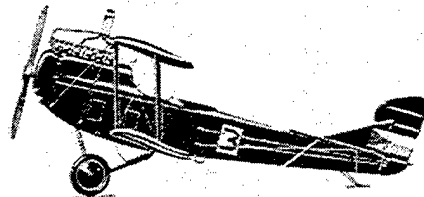


Figure 1. Hansa Brandenburg C.1 Aircraft. From Ref. [3].

In January 1919 the representatives of Czechoslovakia and France signed an agreement to provide help with the buildup of the Czechoslovak Armed Forces. The French military mission was led by Division General Pelle. Soon after, this process was interrupted by the attack of Hungarian Communists on the Slovak territory soon after. This situation forced the Czechoslovak President, Tomas G. Masaryk to assign General Pelle as a Commander in Chief of the Czechoslovak Armed Forces. He was responsible not only for the buildup of the Czechoslovak Armed Forces, but also for the combat operations in Slovakia. Under the leadership of French officers on June 6, 1919, the

Czechoslovak Aeronautics Command was established. After the establishment of the Czechoslovak Aeronautics Command, new plans were drawn for 23 air squadrons with a total of 312 aircraft. The first modern aircraft of the CAF were French SPAD S. VII (Fig. 2) and SPAD XIII [Ref. 2].

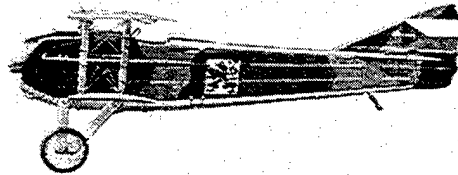


Figure 2. SPAD S. VII. Aircraft. From Ref. [3].

Some aircraft were delivered by France for free and the rest for discount prices. The Air Corps and the Czechoslovak Aeronautics Command were unified during the summer of 1919. The CAF Command was then the central institution, which supervised the further development of the CAF.

A new round of reorganization took place during the last months of 1920; in January 1921 the CAF Command was dissolved. At that time the CAF was organized in three regiments with the inventory of 165 aircraft [Ref. 2]. Since that time, the CAF was commanded by the 13<sup>th</sup> Department of Czechoslovak Department of Defense (DOD). The Czechoslovak industrial base soon satisfied the growing demand of the CAF for military aircraft. The most important companies were Aero, Avia, and Letov, which began to supply new military aircraft for the CAF by 1921. Among the first Czechoslovak military aircraft were Letov S-1 (Fig. 3), Avia BH-3, BH-9, BH-11, and BH-21.

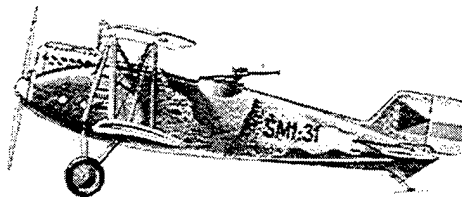


Figure 3. Letov S-1 Aircraft. From Ref. [3].

The French military mission fulfilled advisory tasks during the first months of 1919. Lack of senior Czechoslovak officers was the major reason for assignment of high-ranking French officers to the higher levels of command in the CAF, beginning with General Pelle, who was assigned as a Chief of the General Staff. During 1926 French officers handed over all command positions to Czechoslovak officers [Ref. 3].

In the following years, the French military mission performed the role of an advisory body. Without its help the modernization of 1930's would have been impossible. During the first ten years of the Air Force's existence, nine airfields were built [Ref. 2]. The major role in modernization of the CAF was played by the Czechoslovak industrial firms, which supplied new aircraft for the CAF. The CAF procured aircraft like Avia B-534, Letov S-328, Aero A-100, and Aero MB-200 [Ref. 4].

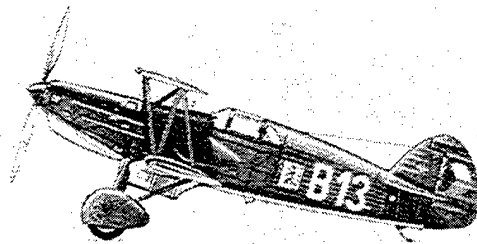


Figure 4. Avia B-534 Aircraft. From Ref. [3].

The change of German political orientation led to an urgent need to reinforce the frontier with Germany. The strategic plan was to build up a row of fortifications including small bunkers. This plan was financially very demanding and left only a few resources to modernize infantry divisions and the CAF. The aircraft company Avia developed Avia B-135, which was fully comparable with the German Messerschmitt Bf-109 [Ref. 3].

## 1. Avia B-135

The fighter aircraft Avia B-135 (Fig. 5) was based on the third prototype of the Avia B-35 aircraft. The first flight took place in June 1939. The design of the aircraft represented the peak of the Czechoslovak aircraft design school. The aircraft was introduced at the air show "Salon l'Aeronautique" in Brussels. Final developments were finished in 1940 and Avia was offered for export to countries approved by Germany. The only customer was Bulgaria, which purchased 12 aircraft including the license to produce it, but no more aircraft were produced [Ref. 3].

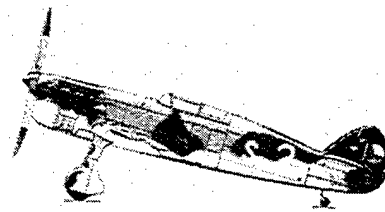


Figure 5. Avia B-135 Aircraft. From Ref. [3].

## 2. Messerschmitt Bf-109

The development of this aircraft began in 1934. The maximum use was made of features, which had proved successful in the Bf-108 Taifun touring four-seater. The first flight occurred in September 1935. In 1936 the Messerschmitt Bf-109 (Fig. 6) was selected (although it was not the outright winner of the competition) as a standard fighter for Luftwaffe. It became the backbone of the German Luftwaffe from 1936 to 1942 [Ref. 3].

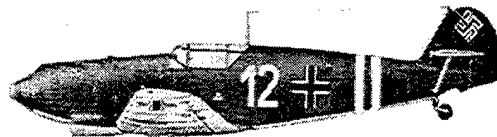


Figure 6. Messerschmitt Bf-109 aircraft. From Ref. [3].

	Avia B-135	Messerschmitt Bf-109
Wing span	10.85m	9.9m
Length	8.5m	8.7m
Height	2.6m	2.59m
Empty weight	2.063kg	1.900kg
Operational weight	2.447kg	2.660kg
Maximum speed	535km/hr	560km/hr
Service ceiling	9,500m	10,500m
Range	940km	1,050km
Armament	Two 7.92mm guns One 20mm cannon	Two 7.92 guns Two 20mm cannons

Table 1. Basic Comparison of Avia B-135 and Messerschmitt Bf-109 Aircraft.

At the beginning of German occupation of Czechoslovakia, the CAF had the following organization structure [Ref. 4].

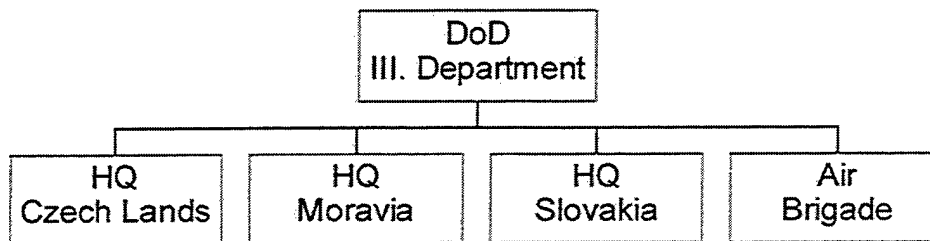


Figure 7. The Organization Structure of the CAF in 1938.

On September 29 and 30, 1938, the British prime minister and the French prime minister met with Adolf Hitler at Munich. The Munich Agreement was reached on Nazi Germany's territorial claims against democratic Czechoslovakia. The Czechoslovak government was not represented at the Munich conference. The most serious loss was the German acquisition of the mountains, which had provided Czechs with a natural protective barrier, together with a line of carefully built fortifications and bunkers. In effect, this annexation guaranteed that Czechoslovakia could not effectively defend itself against Germany.

## B. 1939 – 1945

Six months later, on March 15, 1939 – German troops marched into Czechoslovakia and Czechoslovak Armed Forces were ordered to offer no resistance. The German annexation of the rest of the Czechoslovak territory ended the activity of the Czechoslovak Armed Forces as well as the CAF. The Slovaks established their own Slovak state and cooperated with the Germans. The Munich Agreement and the political capitulation of the Czechoslovak government brought almost 1,100 front line aircraft to the hands of Germans. Most of the aircraft were sold, some were operationally employed like Letov S-328, and some were used for experiments [Ref. 3].

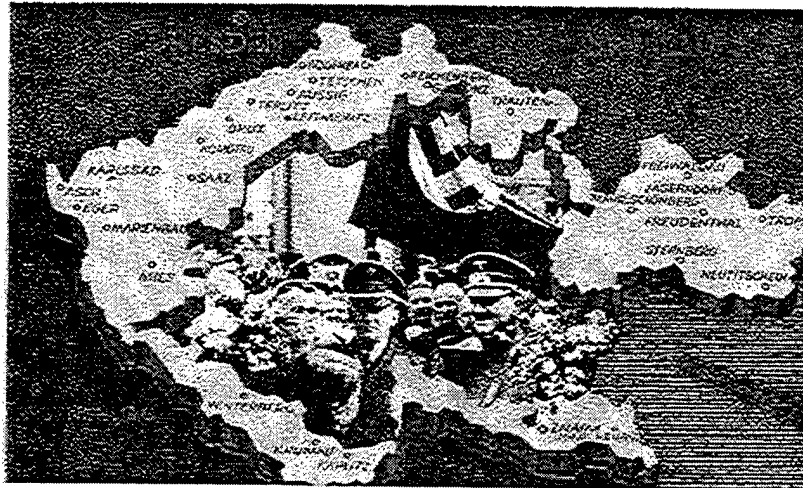


Figure 8. Occupation of Czechoslovakia. From Ref. [4].

Most of the Czechoslovak pilots did not wait for persecutions and escaped abroad, where they joined the Polish and French Air Forces. The Czechoslovak pilots fought to defend Poland when attacked by Germany in September of 1939. The Polish Air Force was not equal to the German Luftwaffe and the goals of the “Blitz Krieg” were soon achieved. When the Soviet Union attacked Poland, a group of Czechoslovak soldiers was captured by the Soviets and transported to the Soviet Union.

A second group of Czechoslovak soldiers escaped to France, where they were forced initially to serve in the French Foreign Legion. When Germany attacked France

they were transferred into the French Air Force and fought the short-lived Battle of France. After Germany defeated France, the surviving Czechoslovak pilots escaped to Great Britain and joined the Royal Air Force. Politically, however, they were the responsibility of the Czechoslovak government in exile. In 1940 the Anglo-Czechoslovak Agreement was reached, which legally permitted the Czechoslovak Air and Land Forces to operate in Britain. Further developments led to the creation of the Czechoslovak Air Inspectorate in Britain. On 12 July, 1940, 310 Fighter Squadron was raised at Duxford. This was followed by 311 Bomber Squadron, 312 Fighter Squadron and 313 Fighter Squadron. These squadrons worked under direct supervision of British officers and the flying and operational training of Czech personnel was carried out in British flying schools and in Canada. The three Czech fighter squadrons were brought together in the Czech Fighter Wing, which operated as part of the 2<sup>nd</sup> Tactical Air Force. The Czechoslovaks tried several times to gain the fully independent status of their Air Force; this, however, was refused. Between August 1940 and January 1945, Czech airmen flying with the Royal Air Force recorded 326 victories [Ref. 2].

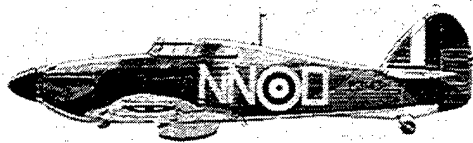


Figure 9. Spitfire Mk. I. From Ref. [3].

Czechoslovak pilots also took part in the fight against the Luftwaffe on the Eastern Front. In February 1944, 21 Czech veterans of RAF squadrons were brought to the Soviet Union, where they became the nucleus of the Czechoslovak air units in the East. Their first base was in Ivanovo, where they trained on the Lavochkin La-5 fighter (Fig. 10). In May 1944 this group moved to the Kubinka airfield and joined ground crew personnel, then officially became the 128<sup>th</sup> Independent Fighter Squadron. Meanwhile the Soviet Union had decided to form an Independent Czechoslovak Fighter Regiment within



the framework of the Soviet Air Force. This regiment consisted of three squadrons and the personnel were drawn from those already in training at Soviet flying schools and from those who fled from the Slovak State. The regiment became operational in July 1944 and moved forward to the front line. One month later, the Slovak National Uprising began and part of the regiment was moved to the Slovak territory, behind enemy lines. Late in the October of 1944 the Soviet authorities agreed to the establishment of the 2<sup>nd</sup> Czechoslovak Air Regiment and the 3<sup>rd</sup> Czechoslovak Battle Regiment. These regiments were later brought together in the 1<sup>st</sup> Czechoslovak Mixed Division, which operated within the framework of the 8<sup>th</sup> Soviet Army. The division became operational in April 1944 and took part in fighting in Northern Moravia [Ref. 5].

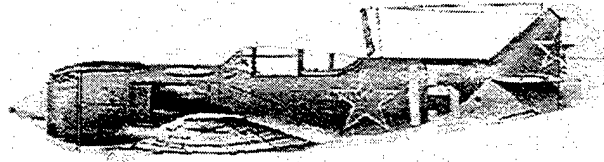


Figure 10. Lavochkin La-5 Aircraft. From Ref. [3].

### C. 1945 – 1989

The Czechoslovak soldiers fighting on both West and East Fronts returned after the end of WWII. They returned with their aircraft and formed the backbone of the reestablished Czechoslovak Air Force. The build up of the CAF had to begin once again. Fortunately, it did not have to start from level zero like in 1918. At the end of the war, the Czechoslovak Air units had about 2,300 personnel and more than 200 combat aircraft. Both the command structures and combat units were available. The combat units were formed in one fighter wing, one bomber squadron (created in the Great Britain), and one mixed air division (created in the Soviet Union). These combat air units were subordinated to the Air Force Command, but formally they were subordinated to the

British and Soviet commands. The Czechoslovak air units created in Britain existed as Royal Air Force units up to February 1946 [Ref. 6].

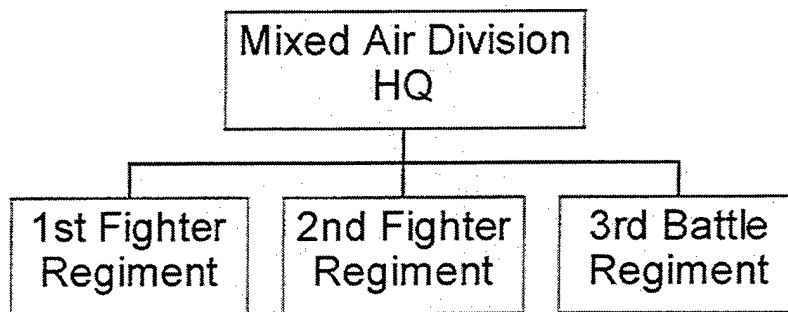


Figure 11. The Organization Structure of the 1<sup>st</sup> Czechoslovak Mixed Air Division.

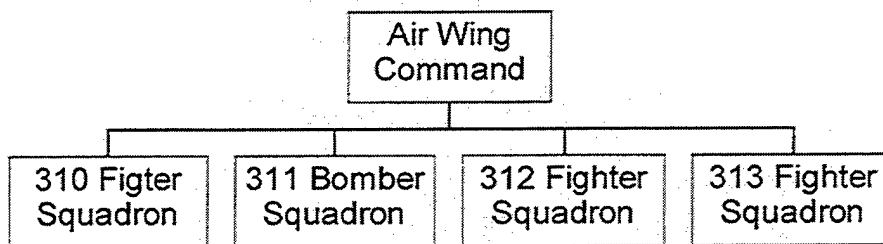


Figure 12. The Organization Structure of the Air Wing.

Czechoslovak pilots brought with them huge variety of aircraft like Arado Ar-96B, Siebel Si 204D, La-5FN, Petjakov P-2, Spitfire Mk IX, Mosquito B-36, Il-2, and others. This caused later problems with logistics and training [Ref. 4].

The only solution was to procure or develop a standard aircraft for the CAF. The Czechoslovak industry then produced the Avia S-199 fighter aircraft, based on the German Messerschmitt Bf-109. The time period between 1945 and 1950 can be described as a transition period, when ideas about organization structure of the CAF were changing very rapidly. Generally, the plans were focused on robust organization, which did not reflect real capabilities of available financial and human resources. The whole of Czechoslovak territory was divided into four military areas, which were supported by an appropriate structure of the CAF (Fig. 13). The CAF was divided into two major parts: combat AF and intelligence AF [Ref. 3].

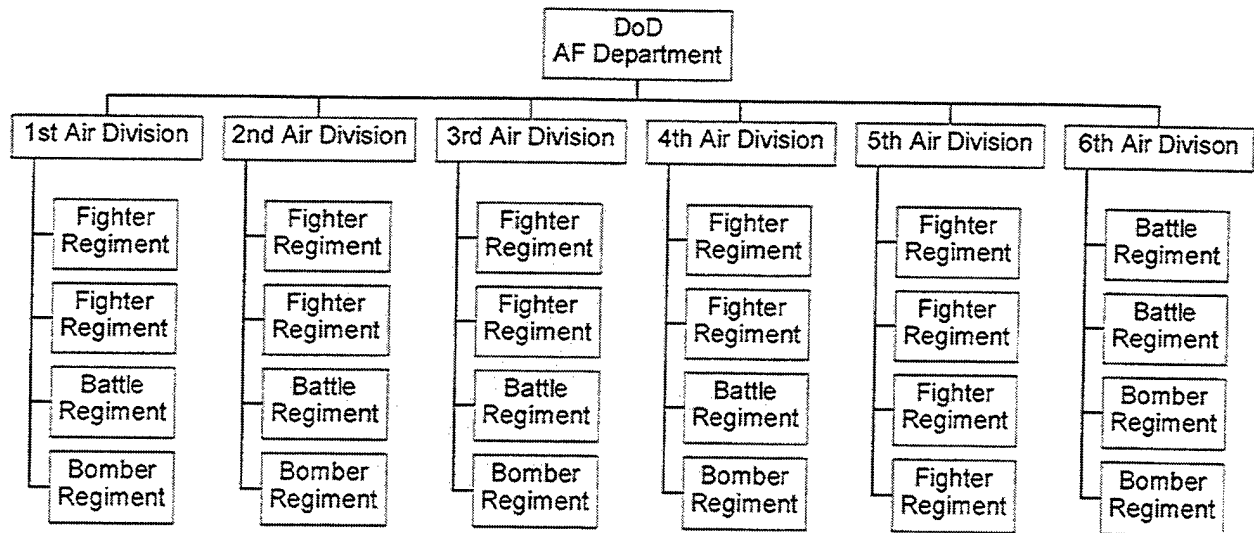


Figure 13. Temporary Organization Structure of the Combat Air Force in 1946.

The total number of aircraft would reach more than 1,300. This build up of the CAF temporary organization soon struggled due to lack of resources and was therefore changed several times. When the Communists consolidated power in 1948, most of pro-Western and ex-RAF personnel were forced to leave the CAF [Ref. 7]. That year also brought cuts in manpower and aircraft. The Communists began the reorganization of the CAF along Soviet lines, which was partially completed by October 1949. New organization structure of the CAF was as follows (Fig. 14):

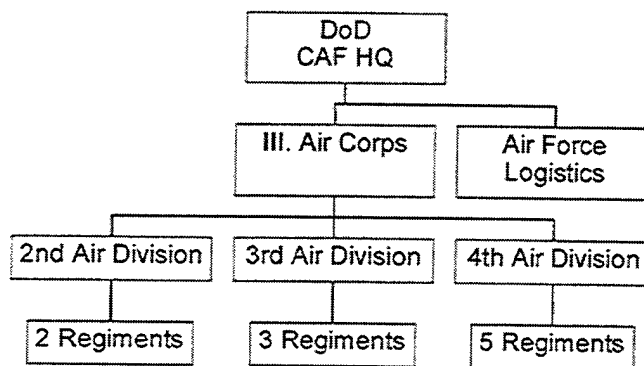


Figure 14. The Organization Structure of the CAF in 1949.

Massive removal of personnel caused a lack of manpower and increased a demand for the Air Force educational institutions. The lack of affordable aircraft

stimulated the recovery of Czechoslovak aircraft companies, which started to work on new projects. The Germans had used the Czechoslovak aircraft companies during WWII for the production of German aircraft. The first success was the construction of Avia S-199 that was based on Messerschmitt Bf-109G; spare parts were readily available in many aircraft companies. Because of the destruction of an engine factory, engine Jumbo 211 was used later. This unique mixture gave birth to the Avia S-199. This change of engine caused a lot of troubles and this aircraft received soon nicknamed "mule". Stability was not very good, which caused many accidents during take off and landing. Although the Avia S-199 became the standard aircraft of the CAF, it was less preferred for the reasons mentioned above. 25 aircraft were sold to Israel, where it was used during combat operations after Israel proclaimed its independence in 1948. The aircraft was used by the CAF up to 1955, later mostly for the training of new pilots. Other plans focused on the completion of German jet aircraft that were coproduced by Czech companies during WWII. One aircraft was the jet Messerschmitt Me-262 Schwalbe. Most of the spare parts were left in the Avia factory; therefore this company was able to complete this aircraft. It was produced under the marking S-92 and CS-92 (Fig. 15) [Ref. 7].

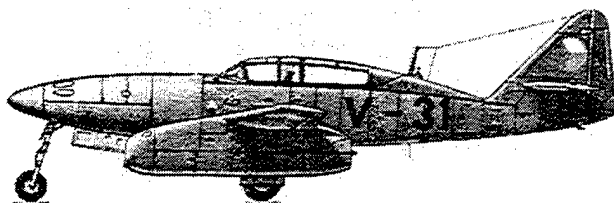


Figure 15. Avia CS-92 Aircraft. From Ref. [3].

Lessons learned from this aircraft were used later in the development of Letov L-52 aircraft. At this time it was obvious that the CAF would be armed with Soviet jet aircraft. The Soviet aircraft delivered was based on the JAK-23; but in 1951 it was decided to procure MiG-15 Fagot (Fig. 16). This decision stopped development of the Czechoslovak designed jet aircraft. The Czechoslovak industrial base for aircraft was

modified for the production of Soviet jet aircraft. Czechoslovak industry produced almost 3,500 of MiG-15 aircraft. Czechoslovak pilots used the MiG-15 for 30 years.

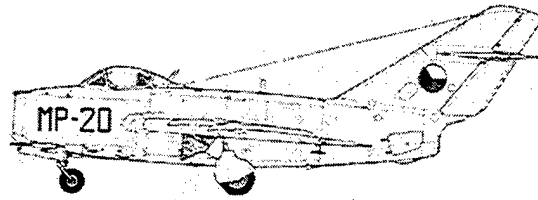


Figure 16. MiG-15 Aircraft. From Ref. [3].

Growing numbers of modern military jet aircraft led to the establishment of the Jet Training Center to provide training for MiG-15 pilots. At the same time the Czechoslovak government announced the "Three-year Armament Program 1951-1953". The ultimate objective of this program was to accelerate the armament of the Czechoslovak Armed Forces [Ref. 8].

The CAF was based on air regiments (with four squadrons) and air divisions. Many squadrons and higher units were moved from one location to another, according to change of the CAF's organization structure. Fighter regiments located on the western part of the country were responsible for the protection of the western frontier. In 1955, a new aircraft was introduced. It was the MiG-17 Fresco, the first aircraft with radar in the CAF. The MiG-17 was considered a transition type with only 26 aircraft purchased. The transition from early jet aircraft to advanced jet aircraft called for the build up of new airfields with appropriate logistic infrastructure. Further development of the technical infrastructure led to the procurement of MiG-19 Farmer. First squadrons were equipped with MiG-19 in 1958. This was the first supersonic aircraft used by the CAF. In 1959, the Czechoslovak industrial base developed the famous jet trainer aircraft Delfin L-29 (Fig. 17). A few months later Delfin was chosen as a standard jet trainer for the Warsaw Pact countries [Ref. 10].

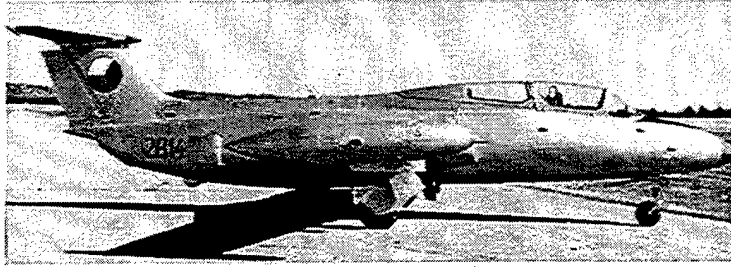


Figure 17. L-29 Delfin Training Aircraft. From Ref. [3].

The time period from 1958 to 1961 was marked by huge reorganization of the CAF, which split the fighter air units into Air Defense and a Tactical Air Force. A new organization element was created during this era, the Air Army, which supervised Air Divisions. All of the Tactical Air Force was organized under the 10<sup>th</sup> Air Army, which had primary tasks to provide close air support for the Ground Forces and a secondary task to protect the Czechoslovak airspace. The second element was the 7<sup>th</sup> Air Defense Army, which had under its command three divisions and was fully responsible for the protection of Czechoslovak airspace. The air defense divisions consisted of fighter regiments and air defense regiments equipped with surface-to-air missiles. Soon after the reorganization a new aircraft began its long service with the CAF. It was the second-generation 2 Mach aircraft, the MiG-21 Fishbed (Fig. 18). Imports began in 1962 with Czechoslovakia later gaining the license to produce this aircraft [Ref. 8].



Figure 18. MiG-21 Aircraft. From Ref. [3].

The MiG-21 has remained the backbone of the CAF up to the present. Various models were used for the intercept, ground attack, and fighter reconnaissance roles. Although employed in large numbers by all air regiments, the MiG-21 has been the least reliable aircraft ever used by the CAF. After long years of using MiG aircraft, the Soviet Union introduced to the CAF an aircraft from SUCHOJ design office. The first such aircraft was Su-7 Fitter, used for the fighter bombing missions. The first Su-7 was introduced in 1965 [Ref. 8].

The Six Day War between Israel and its Arab neighbors in 1967 clearly demonstrated the vulnerability of unprotected aircraft on the ground and also the ease with which runways could be made unusable. After this experience, European military airfields began to build hardened shelters and bunkers to protect aircraft against a direct hit from a heavy bomb. This was also the case of the CAF, which began massive shelter construction on every airfield, beginning with those airfields which were located close to the western frontier.

In 1968, the high standard of morale and readiness within the CAF was affected by political developments inside the Czechoslovak Communist Party. This era is referred to as "Prague Spring". The Czechoslovak Communist Party, as well as Czechoslovak society was split into two camps. The first one supported the old order while the second one favored the Reform movement and called for "Liberal Socialism". This development affected the military establishment and led to the same division among officers and warrant officers. This process was observed with maximum attention in the Soviet Union, which later decided to stop the reform movement in Czechoslovakia. On August 21, 1968, the Soviet Union together with other members of the Warsaw Pact invaded Czechoslovakia. All military airfields and garrisons were surrounded by Warsaw Pact forces to ensure no armed resistance of the Czechoslovak Armed Forces. Training was eliminated and political discussion inside military units reflected the emotions of the Czechoslovak public. The Czechoslovak Armed Forces suffered from the apathy that seemed to infect the entire society after crushing of the Prague Spring. The failure to

resist the invasion undermined the prestige of the military in its own eyes and in the eyes of the public, which contributed greatly to its demoralization, and to the loss of operational effectiveness.

An agreement was reached in October 1968 regarding withdrawal of Warsaw Pact Forces from Czechoslovakia. However, the Soviet units were to remain as "temporary stationing". This element of Soviet Forces later evolved into the Soviet Central Group of Forces in Czechoslovakia. For the Czechoslovak Armed Forces it meant transfer of many garrisons in order to house Soviet units. Once the hard line Communists consolidated political power, they sought to re-establish party control over the Armed Forces. This was the era of "normalization", which was marked by purges of possibly "unreliable" military personnel. The manpower of the Czechoslovak Armed Forces was reduced and the purge was fully completed in 1975. Direct consequence of this process was a lack of experienced officers and warrant officers. There was an urgent need to train new pilots and technicians.

In 1973, the CAF purchased a new fighter-bomber aircraft Su-22 Fitter for the Tactical Air Force. Major deficiencies of MiG-21, like limited payload and short range led to the development of the third-generation aircraft MiG-23 Flogger. This variable geometry fighter was procured for the CAF beginning in 1978, but the backbone of the CAF was still the MiG-21.

In the meantime, the Czechoslovak company Aero Vodochody developed new jet trainer L-39 Albatros, which has been as successful as its predecessor the L-29 [Ref. 10].

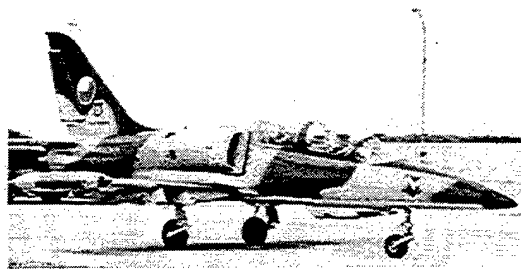


Figure 19. L-39 Albatros Training Aircraft. From Ref. [3].



During the early 1980s' the CAF took part in many Warsaw Pact military exercises to prove combat readiness and ability to manage new kinds of aircraft. At the end of 1984, training began for a battle aircraft with the close support mission, the Su-25K Frogfoot. This was only part of the modernization program, which included replacement of Su-7 and MiG-21 by the Su-22 and MiG-23. Rotary wing squadrons were also modernized. They were equipped first with Mi-24D helicopters and after later Mi-24V's after the establishment of the second rotary wing regiment. The peak of CAF modernization was the purchase of MiG-29 Fulcrum. The first aircraft was delivered in April 1989 and the total number of MiG-29 aircraft reached 20, greatly enhancing the combat capability of the CAF.

**D. 1989 – 1999**

Year 1989 represented the peak of the CAF development measured in armament and combat readiness. The organization structure of the CAF at that time was as follows.

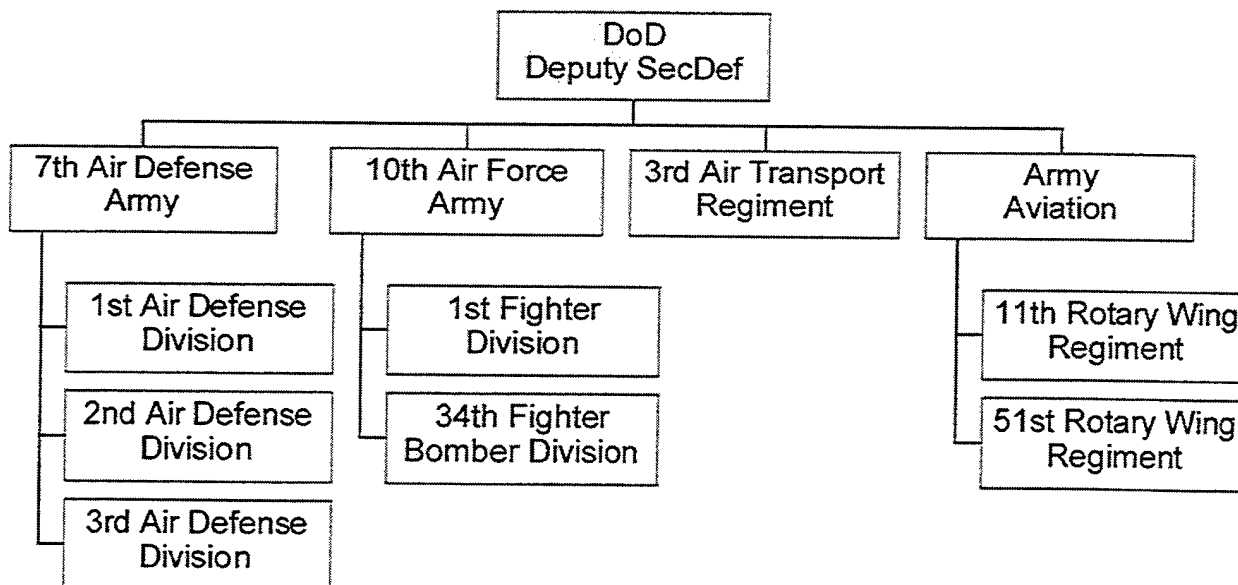


Figure 20. The Organization Structure of the CAF in 1989.

The change of the political environment in Europe and the start of "perestroika" in the Soviet Union led to the fall of the Iron Curtain and ended the Cold War. This new political environment accelerated democratic developments in the East-European countries. It started in Czechoslovakia with the Velvet Revolution on November 17, 1989. The Czechoslovak Communist Party dropped its claims to "a leading role", which later led to free democratic elections. The Czechoslovak Armed Forces were conceived as Communists' tool of power; therefore civilian control over the Armed Forces was the order of the day. It was considered very important to create totally apolitical Armed Forces with numbers of personnel and equipment appropriate to the political and military environment in Europe. However, there was no clear vision of the future for the CAF; therefore, major attention was focused on downsizing. Some cities even sent petitions to the Czechoslovak government, requesting the closure of those military airfields, which were very close to city boundaries. Cancellation of air squadrons and air regiments led to withdrawal of many experienced pilots and technicians. Other factor, which contributed to this exodus, was the permanent move of many air units from one airfield to other. Lack of the conceptual work and permanent changes released a huge wave of resignations among young officers.

After the reduction in numbers of air units, new system of command and control was established. In 1990, the Air Force and Air Defense Command was established to oversee activities of both the 10<sup>th</sup> Air Army and 7<sup>th</sup> Air Defense Army. The oldest aircraft were offered for sale and later destroyed – most of them were MiG-21. Few months later, the 10<sup>th</sup> Air Army was reorganized into the 1<sup>st</sup> Mixed Air Corps.

Another important event which further influenced the fate of the CAF, was the split of Czechoslovakia into the Czech and Slovak Republics. It was decided to split the Czechoslovak Armed Forces in the ratio 2:1, based on the population. Most of the planed aircraft transfers to the Slovak side were complete by the end of 1992. The year 1993 was not only the first year of the Army of the Czech Republic, but also the year of further

downsizing. New plans of the CAF organization structure (Fig. 21) were drawn and 1/3 of the aircraft were determined for destruction [Ref. 9].

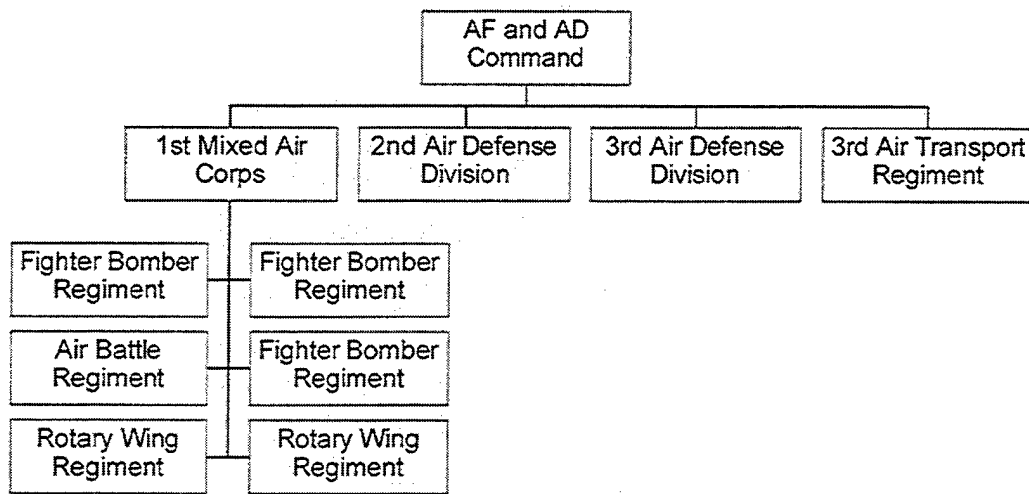


Figure 21. The Organization Structure of the CAF in 1993.

Decreasing numbers of military personnel and major weapon systems necessitated a new reorganization of the remaining CAF. The Air Force and Air Defense Command and 1<sup>st</sup> Mixed Air Corps were deactivated and replaced by 3<sup>rd</sup> Tactical Air Force Corps and 4<sup>th</sup> Air Defense Corps in 1994. At the end of 1994, the Inspector of the Air Force and Air Defense decided to further reduce number of combat aircraft. The major reason for this decision was technical obsolescence and inability to provide financing for the purchase of necessary spare parts. Among those aircraft were even MiG-23s. Approximately at the same time the Czech DoD prepared “The acquisition plan for years 1995 – 2005”. Part of this plan is a purchase of 72 Advanced Light Combat Aircraft L-159 ALCA, produced by the Czech company Aero Vodochody. At the end of 1994, it was also decided to stop training on MiG-29 (Fig. 22) – the best aircraft of the CAF available at that time. One year later they were exchanged for Polish helicopters W-3 Sokol in ratio 1:1. This “trade of the century” had been the subject of discussion for many years [Ref. 9].

Further development led to the establishment of the Air Force Command, by joining 3<sup>rd</sup> Tactical Air Force Corps and 4<sup>th</sup> Air Defense Corps. Air units were stabilized on five Air Force bases.

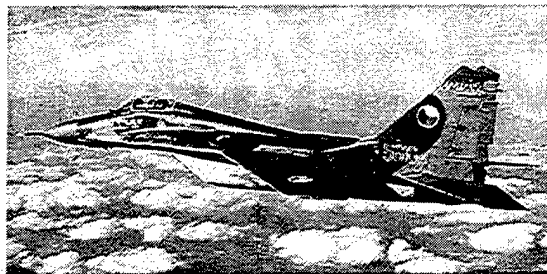


Figure 22. Mig-29 Aircraft. From Ref. [3].

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### III. PRESENT STATE OF THE CZECH AIR FORCE

#### A. TASKS AND MISSION

The CAF together with the Ground Forces are the main combat arms of the Army of the Czech Republic. The CAF was established in 1997, after joining the 3<sup>rd</sup> Tactical Air Force Corps and the 4<sup>th</sup> Air Defense Corps. The primary mission of the CAF is to ensure the sovereignty of the Czech Republic's airspace.

The CAF fulfils the following tasks:

- Provide permanent command and control of subordinate units as well as combat readiness for the transition from peace time to war time.
- Maintain surveillance of the Czech Republic's airspace.
- Provide the sovereignty of the Czech Republic's airspace by maintaining the combat readiness of specified air and air defense units.
- Provide training of pilots, ground crews, and Air Defense specialists as well as training of conscripts for the needs of the CAF.
- Provide the full range of Search and Rescue capabilities.
- Provide the air traffic control of military aircraft coordinated with civilian authorities.
- Provide Close Air Support for the Ground Forces and coordinate joined activities.
- Provide airlift capabilities.
- Provide units for NATO's Immediate and Rapid Reaction Forces.
- Provide long-range reconnaissance and air survey photography.
- Provide units to augment civil protection forces in the case of natural disasters and accidents.

## B. STRUCTURE

The CAF consists of two major components – Tactical Air Force and Air Defense.

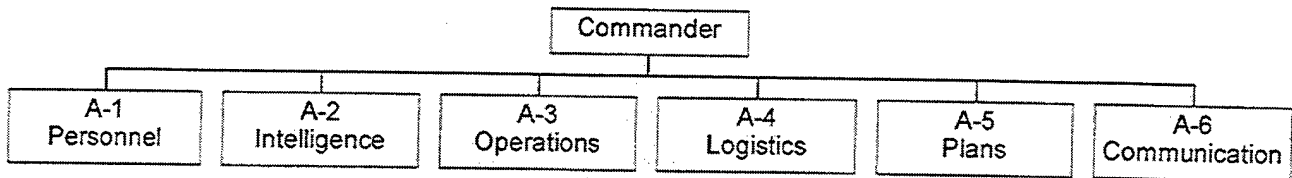


Figure 23. The Organization Structure of the CAF Command.

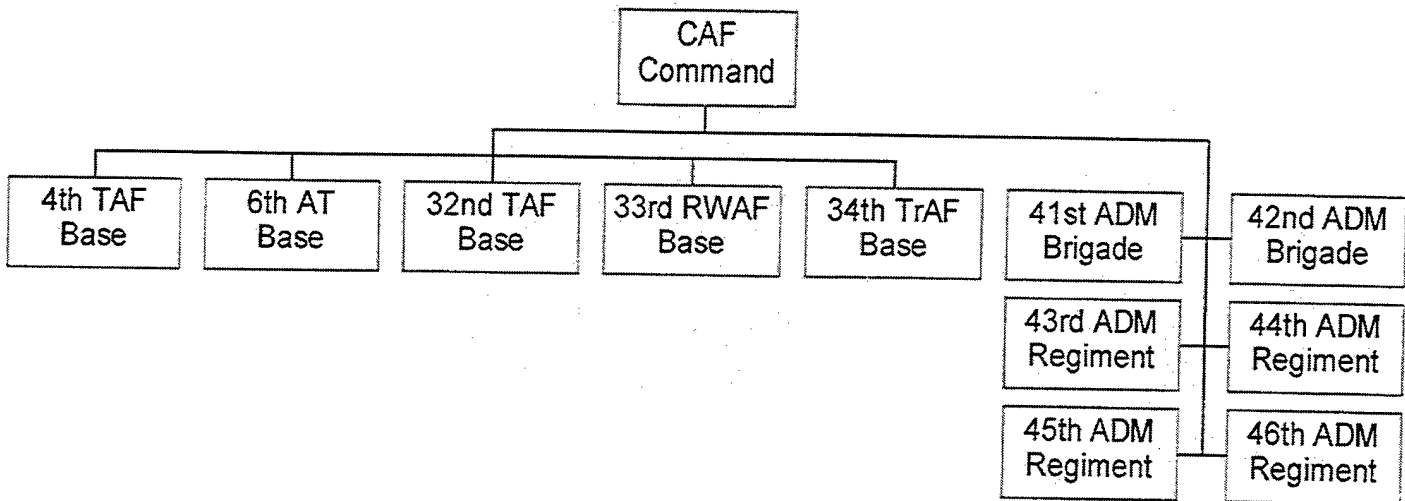


Figure 24. Current Organization Structure of the CAF.

TAF – Tactical Air Force

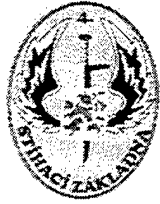
RAAF – Rotary Wing Air Force

TrAF – Training Air Force

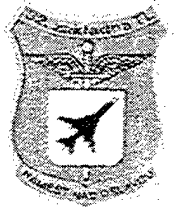
ADM – Air Defense missile

AT – Air Transportation

4<sup>th</sup> Tactical Air Force Base – Caslav



32<sup>nd</sup> Tactical Air Force Base – Namest nad Oslavou



33<sup>rd</sup> Rotary Wing Air Force Base – Prerov



34<sup>th</sup> Training Air Force Base – Pardubice



6<sup>th</sup> Air Transport Base – Praha - Kbely





## C. MAJOR ARMAMENT

The total numbers of aircraft as well as the numbers of kinds of aircraft were radically reduced during the last ten years. For the purpose of this work we will split the aircraft into following categories:

- Combat aircraft
- Training aircraft
- Transport aircraft
- Helicopters

### 1. Combat Aircraft

#### a. *MiG-21 Fishbed*

Developed in the Soviet Union in the mid 1950's, based on the experience from the Korean War. Lessons learned from the Korean War called for a lightweight fighter. The MiG-21 was the first Soviet design with delta-shaped wing. The first delivery to Czechoslovakia occurred in 1962. Currently, the CAF employs 40 MiG-21MF. Major armament of this aircraft is 30mm cannon and short-range air-to-air missiles. This Mach 2 second-generation aircraft can be also used for the close air support of the Ground Forces. Life cycle ends in 2005.

#### b. *Su-22 Fitter*

At the beginning of 1960s' the Soviets began experiments with variable geometry aircraft. Major advantages were shorter take off, shorter landing, and longer range. The result of such developments was the Su-7 and its modification Su-17. Export versions of this aircraft were the Su-20 and Su-22. Although this aircraft was designed for fighter-bomber missions, proper designation would be bomber. Major armament of this aircraft is two 30mm cannons, plus 10 pylons for bombs, missiles and guided missiles. Su-22 is equipped with EW countermeasures equipment. First delivery to Czechoslovakia

was in 1973. The CAF has now 33 Su-22 M4 modification, including five trainers UM-3K. Life cycle ends in 2009.

*c. Su-25 Frogfoot*

The youngest aircraft in the CAF fleet. The Su-25 was developed in the Soviet Union in 1975 as a jet attack aircraft. It is a very agile, subsonic, close air support aircraft. This lightly armored attack aircraft is designed for battlefield and low-altitude performance, featuring 30mm twin barreled cannon plus 10 pylons for an assortment of missiles and bombs. Many self-defense features were also added. First Su-25's were delivered to Czechoslovakia in 1984. The CAF operates 24 Su-25K.

**2. Training Aircraft**

*a. L-29 Delfin*

Czechoslovak jet trainer aircraft developed in the second half of 1950's. In 1961, it won the competition for the standard trainer aircraft of the Warsaw Pact countries. This mid-wing aircraft with a T-tail was widely admired for its reliability and stability. The CAF still employs 24 L-29.

*b. L-39 Albatros*

Second-generation jet trainer aircraft developed to replace the L-29. Serial production began in 1972 with first aircraft was operational in the CAF in 1974. The aircraft's primary mission is basic and advanced training, with external armament stores that would enable it to fulfill operational training in ground attack roles. Nowadays the CAF uses 34 L-39 aircraft including L-39 ZA, which is a combat version of the L-39 armed with 23mm cannon.

### 3. Transport Aircraft

#### *a. L-410 Turbolet*

The L-410 was designed and produced in Czechoslovakia with first flight occurring in 1969. It was designed as flexible, high wing, light and small transport aircraft. The CAF operates 14 L-410.



Figure 25. L-410 Turbolet Aircraft. From Ref. [5].

#### *b. An-24 Coke*

A high-wing turboprop transport aircraft designed as a commuter passenger/cargo aircraft. This aircraft may be easily converted from passenger to cargo configuration. Navigation and communication equipment allows operating day or nighttime, under any weather conditions. It has been produced since 1961.

#### *c. An-26 Curl*

Serves as a medium size military transport aircraft. The An-26 has a rear loading ramp and decreased number of cabin windows. In addition to carrying cargo, it is equipped with side benches to accommodate personnel or paratroopers. It has been produced since 1969. The CAF operates 7 AN-24/26 aircraft.

*d. Tu-134*

The development of this aircraft began in 1961, based on the requirement for new jet-powered airplane. It is a civilian aircraft used for the passenger transport. The CAF operates only one Tu-134.

**4. Helicopters**

*a. Mi-24 Hind*

An assault helicopter carrying a large weapon load and capable of transporting up to eight troops. It is still considered one of the fastest assault helicopters in the world. Developed in the Soviet Union in 1968 and later produced in many modifications. Capable of providing full scale missions to support Ground Forces. The CAF operates 35 Mi-24 modifications D and V.

*b. Mi-2 Hoplite*

Light combat/transport helicopter. It can be equipped with anti-tank missiles as well as air-to-air missiles, but it can also be used as transport helicopter carrying up to 8 passengers. The CAF has 32 Mi-2's in its inventory.

*c. Mi-8,9,17*

Medium size transport and passenger helicopter based on Mi-4 design. Developed and produced in the Soviet Union since 1962. Mi-9 and 17 being modifications of Mi-8 HIP. The CAF operates 41 of them.

*d. W3-A Sokol*

The newest helicopter in the CAF fleet. This twin-engine helicopter was developed in Poland in 1979. Its design is based on the Mi-2, which was produced in Poland. It is designed for transport of up to 12 personnel or cargo. The helicopter has modern avionics, which allows operations in all weather conditions. The CAF operates 11 Sokols, primarily for Search and Rescue mission.

## D. TRAINING

The training of new pilots is accomplished at the Military Academy in Brno. All students have to finish basic military training first. After this, they attend standard academic assignments, which meet educational standards similar to civilian universities. Part of their curricula is adjusted to meet the specific needs of their future occupation. Theoretical preparation is basically finished at the end of third year. At the beginning of fourth year, they are dispatched to the 34<sup>th</sup> Air Force Training Base in Pardubice, where all students start their practical preparation. They begin training in the Z-142 propeller driven aircraft, which is especially designed for training and acrobatics. Students usually fly about 50 hours with a given number of specific assignments and flight tasks. Each flying assignment is evaluated in great detail. After completion of this training, the students are divided into three groups: jet aircraft, rotary wing, and transport aircraft. Students, who fail this training are offered other positions within the CAF.

Jet aircraft students then continue their training with L-29 Delfin aircraft. During this stage they have to complete 100 hours. Students' performance is again closely observed. After careful evaluation, they are sent to the next stage with L-39 Albatros aircraft. Their training schedule is planned for 100 hours, which includes live fire exercises. All students have to finish air-to-ground missions using unguided missiles and standard bombs. After completion of this training, they finish their academic assignments and graduate from the Military Academy at the rank of lieutenant and as pilots of 3<sup>rd</sup> class. They are then assigned to Air Force Bases, where further training is focused on a particular type of aircraft.

## **E. PROBLEMS**

The specific problems of the CAF can be divided into three areas: equipment, training, and quality of life.

### **1. Equipment**

Several decisions left Czech pilots with second-generation aircraft, which are obsolete most notably in avionics. The only fighter aircraft is the MiG-21, which was excellent in the 1970's but now lacks appropriate avionics and weaponry. A similar assessment can be made about the Su-22, which is more advanced than the MiG-21. The weaponry of Su-22 is sufficient for the fighter-bomber missions, but the avionics is also outdated. The newest aircraft in the fleet, the Su-25 is excellent for its close air support tasks and could be used by the CAF for an extended period. The life cycle of Mig-21's ends in 2005 and the Su-22 in 2009. A partial solution for this obsolescence is procurement of 72 Advanced Light Combat Aircraft L-159. The CAF is still waiting for the Czech government decision about purchase of 36 modern supersonic aircraft.

### **2. Training**

This problem is closely connected to equipment obsolescence. Lack of spare parts for the obsolete aircraft causes decreasing of combat readiness as well as decreasing flight hours per pilot. This is coupled with the exodus of skilled technicians and ground crews. A major concern is the flight safety, because of decreased flight hours per pilot. The combat training of pilots is also limited because of the unavailability of aircraft firing ranges for air-to-air missions. Most of pilot training is focused on air-to-ground training. Fighter pilots usually complete their air-to-air missions over the Baltic Sea; this training is organized once a year.

### 3. Quality of life

Permanent move of air squadrons and air regiments as well as substantial downsizing has drastically decreased the quality of life of CAF personnel. The biggest issue in this area is certainly housing. The move of air units from one place to another causes separation of families, which live together only during weekends. Adequate and affordable housing is not readily available and will take many years to provide.

Another concern is compensation and benefits. The growing gap between private and government sectors is the major cause of the inability to attract, retain, and motivate quality personnel.

#### F. L-159 ALCA

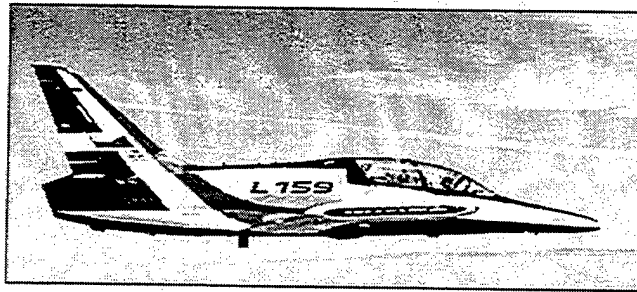


Figure 26. L-159 ALCA Aircraft. From Ref. [10].

The L-159 ALCA (Advanced Light Combat Aircraft) is based on the previous line of military jet trainers like L-39, L-59, and L-139. Discussion of the concept with the CAF started in 1992. At the end of 1992, the Czech government issued requirement specifications. The development of a completely new design would cost billions of U.S. dollars and would last approximately 15 years; therefore it was agreed to use an old and proven design. Final specifications were issued in the second half of 1993 and development work began in 1994. Rockwell North American (now Boeing) was awarded the avionics contract in late 1994. In April 1995, the Czech government committed to a 25% financing of the development and declared its intention to buy 72 aircraft as the

future backbone of the CAF. The contract was officially signed on July 4, 1997. The first flight took place on August 2, 1997. In the 50-minute sortie it reached the altitude of 5000 meters and speed of 670 km, and performed maneuvers of up to 4.5g. Aero Vodochody company developed two modifications, L-159A – single-seat aircraft and L-159B – two-seat aircraft. L-159A made its maiden flight on August 18, 1998. It achieved 6g and -1g maneuvers without problems. After completing the first part of gun firing tests, the L-159B was sent to northern Norway for several weeks of weapons tests. The tests took place at the Nordic Sea Test Range and as of May 28, 1999 a total of 78 sorties were completed. The sorties tested operations with Plamen cannon, unguided rockets CRV-7, air-to-air missiles AIM-9 Sidewinder, and air-to ground missile AGM-65 Maverick. The first delivery of five aircraft was due in late 1999, but it was delayed until June 2000. 27 domestic and 40 foreign companies cooperate on the project [Ref. 10].

**L-159 main features:**

- Latest generation AlliedSignal/ITEC F124-GA-100 turbofan engine (Max. thrust 28 kN) with dual-redundant FADEC (Full Authority Digital Engine Control)
- 7 pylons - 6 under wing and 1 under the fuselage centerline
- Head-Up and, Head-Down Displays, Multi mode pulse Doppler Grifo L Radar, which has nine air-to-air and air-to-ground modes each and can track up to eight targets
- Honeywell H7646 ring laser gyro inertial navigation system with embedded GPS
- GEC Marconi Sky Guardian 200 Radar Warning Receiver and Countermeasures Dispensers
- Two Rockwell Collins ARC-210 UHF/VHF radios
- AN/APX-100 IFF
- HOTAS Controls (Hands On Throttle And Stick)
- OBOGS (On-Board Oxygen Generating System), OBIGGS (Fuel tanks inerting system)
- APU, 0-0 Ejection Seat



Wing span	9.45 m
Length	12.73 m
Height	4.77 m
Max. level speed	935 km/hr
Max. rate of climb	48 m/s
Load factor	+8g/-4g
Max. ramp weight	8,000 kg
Service ceiling	13,200 m
Internal fuel	1,551 kg
External fuel	1,382 kg
Max. range (int. fuel)	1,570 km
Max. range (int. & ext.)	2,530 km
Max external load	2,340 kg
Armament:	AIM-9M Sidewinder
	AGM-65 Maverick
	Plamen 20 mm cannon pod
	Bombs, cluster bombs
	Rocket pods
	ECM pods, recce pod

Table 2. L-159 ALCA Specifications.

Operational roles of L-159 include Close Air Support, Air Defense, border patrol, lead-in fighter training, tactical reconnaissance, counter insurgency, anti-ship missions, and weapons training.

The primary mission of the L-159 aircraft will be close air support; therefore, the CAF needs other aircraft for the interceptor mission. The National Security Council, well aware of this deficiency, proposed purchase of 36 new supersonic fighter aircraft. The government requested bids from contemporary aircraft producers. All bids are currently under consideration of a special commission, created for this purpose.

## IV. SELECTED CONTEMPORARY FIGHTER AIRCRAFT

### A. F/A-16 FIGHTING FALCON

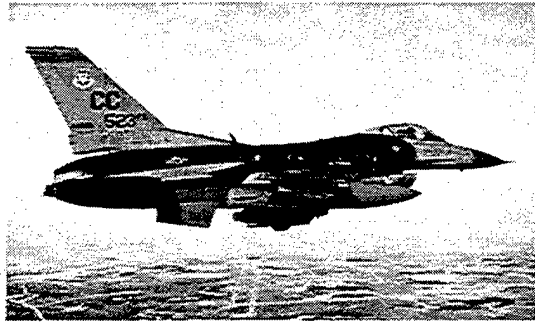


Figure 27. F/A-16 Fighting Falcon Aircraft. From Ref. [23].

The F-16 Fighting Falcon is a compact, multi-role fighter aircraft. It is highly maneuverable and has proven itself in air-to-air combat and air-to-surface attack. It provides a relatively low-cost, high-performance weapon system for the United States and allied nations. In an air combat role, the F-16's maneuverability and combat radius (distance it can fly to enter air combat, stay, fight and return) exceed that of all potential threat fighter aircraft. It can locate targets in all weather conditions and detect low flying aircraft in radar ground clutter. In an air-to-surface role, the F-16 can fly more than 500 miles (860 kilometers), deliver its weapons with superior accuracy, defend itself against enemy aircraft, and return to its starting point. An all-weather capability allows it to accurately deliver ordnance during non-visual bombing conditions [Ref. 11,12, and 13].

#### 1. Development

Development started in 1972 as the Lightweight Fighter Program to produce a true air superiority lightweight fighter. General Dynamics and Northrop built prototypes as technology demonstrators. Northrop produced the twin-engine YF-17, using breakthrough aerodynamic technologies and two high-trust engines. General dynamics countered with the compact YF-16, built around a single F100 engine. In 1975 the U.S.

Air Force announced that the YF-16 was the winner of its Air Combat Fighter competition. The YF-16 had generally shown superior performance over its rival from Northrop.

The original F-16 was designed as a lightweight air-to-air day fighter. Air-to-ground responsibilities transformed the first production of F-16s into multi-role fighters. The A in F-16A refers to a Block 1 through 20 single-seat aircraft. The B in F-16B refers to the two-seat version. The letters C and D were substituted for A and B, respectively, beginning with Block 25. Block number is an important term in tracing the F-16's evolution. Basically, a block is a numerical milestone. The block number increases whenever a new production configuration for the F-16 is established. Not all F-16s within a given block are the same. They fall into a number of block subsets called mini blocks. These sub-block sets are denoted by capital letters following the block number (Block 15S, for example). From Block 30/32 on, a major block designation ending in 0 signifies a General Electric engine; one ending in 2 signifies a Pratt & Whitney engine.

The F-16A, a single-seat model, first flew in December 1976. The F-16B, a two-seat model, has tandem cockpits that are about the same size as the one in the A model. Its bubble canopy extends to cover the second cockpit. To make room for the second cockpit, the forward fuselage fuel tank and avionics growth space were reduced. During training, the forward cockpit is used by a student pilot with an instructor pilot in the rear cockpit.

The F-16C and F-16D aircraft, which are the single- and two-seat counterparts to the F-16A/B, incorporate the latest cockpit control and display technology. All F-16s delivered since November 1981 have built-in structural and wiring provisions and systems architecture that permit expansion of the multi-role flexibility to perform precision strike, night attack and beyond-visual-range interception missions.

## 2. Structure

80 percent of the airframe structure of the F-16 is of conventional aluminum alloy, and about 60 percent of the structural parts are made from sheet metal. An attempt was made to minimize the amount of exotic material used in the construction of the F-16 in the interest of saving cost. About 8 percent is steel, composites are 3 percent and titanium is 1.5 percent. The F-16 is built in 3 major subsections, nose, center and aft. In order to save money, the fuselage structure is fairly conventional in overall configuration, being based on conventional frames and longerons. The forward manufacturing breakpoint is just aft of the cockpit, while the second is forward of the vertical fin.

The wing platform of the F-16 is effectively that of a cropped delta with a 40-degree leading edge sweep. The wing has 4 percent thickness/chord ratio. The wing structure incorporates five spars and 11 ribs. Upper and lower wing skins are one-piece machined components. From left to right, the wing gradually blends with the fuselage, making it impossible to tell where the wing begins and the fuselage ends. This wing/body blending made it possible to increase the internal volume, enabling more fuel to be carried. In fact, 31 percent of the loaded weight of an F-16 is fuel, accounting for its long range. Gradually increasing the thickness of the wing in the region of the root resulted in a stiffer wing than would have been possible with a conventional design. In forward-to-aft platform, the wing leading edge blends smoothly with the fuselage by means of leading edge strakes. At high angles of attack, these strakes create vortices, which maintain the energy of the boundary air layer flowing over the inner section of the wing. This delays wing root stalling and maintains directional stability at low speeds and high angles of attack. Vortex energy also provides a measure of forebody lift, reducing the need for drag-inducing tail trim. By keeping the inner-wing boundary layer energized, the strakes allowed the wing area to be kept smaller, saving about 500 pounds in weight.

### 3. Power Plant

The development of the Pratt & Whitney F100 turbofan began in August of 1968 when the USAF awarded contracts to both P & W and General Electric for the development of engines to be used in the projected F-X fighter, which was later to emerge as the F-15 Eagle. The F100 is an axial-flow turbofan with a bypass ratio of 0.7:1. There are two shafts, one shaft carrying a three-stage fan driven by a two-stage turbine, the other shaft carrying the 10-stage main compressor and its two-stage turbine. For the F100-PW-200 version, normal dry thrust is 12,420 pounds, rising to a maximum thrust of 14,670 pounds at full military power. Maximum afterburning thrust is 23,830 pounds.

In recent years, the USAF became interested in acquiring an alternative engine for the F-16, partly in a desire to set up a competitive process between rival manufacturers in an attempt to keep costs down, as well as to develop a second source of engines in case one of the suppliers ran into problems. In search of a source for an alternate engine for the F-16 and for the Navy's F-14 Tomcat, in 1984 the Department of Defense awarded General Electric a contract to build a small number of F101 Derivative Fighter Engines (DFE) for flight test. The DFE was based on the F101 used in the B-1 but incorporated components derived from the F404 engine used in the F/A-18. The Navy decided to adopt the DFE as a replacement for the Tomcat's TF30 turbofan, but the USAF announced that they were going to split future engine purchases between Pratt & Whitney and General Electric. GE was given a contract for full-scale development of its new engine, which was to be designated F110.

The General Electric F110 is similar in size to the Pratt & Whitney F100. The F110 has a three-stage fan leading to a nine-stage compressor, the first three stages of which are variable. The bypass ratio is 0.87 to 1. The single-stage HP turbine is designed to cope with inlet temperatures as high as 2500 degrees F (1370 C). Blades are individually replaceable without rotor disassembly. An uncooled two-stage LP turbine

leads to a fully modulated afterburner. When afterburning is demanded, fuel is injected into both the fan and core flows, which mix prior to combustion.

In an attempt to make the F100 more competitive with the General Electric F110, Pratt & Whitney introduced the more powerful F100-PW-229 version in the early 1990s. This engine is rated at 29,100 pounds of thrust with full afterburner. It has higher fan airflow and pressure ratio, a higher-airflow compressor with an extra stage, a new float-wall combustor, higher turbine temperatures, and a redesigned afterburner. It has about 22 percent more thrust than previous F100 models. The first F-16s powered by the -229 engines began to be delivered in 1992. However, the degree of mechanical changes introduced in the -229 makes it impractical to rebuild -200 engines to -229 standards.

#### **4. Flying Controls**

Leading-edge maneuvering flaps are programmed automatically as a function of Mach number and angle of attack. The increased wing camber maintains lift coefficients at high angles of attack. These flaps are one-piece bonded aluminium honeycomb sandwich structures actuated by a Garrett drive system using rotary actuators. The trailing edges carry large flaperons, which are interchangeable left with right and are actuated by National Water Lift integrated servo-actuators. The maximum rate of flaperon movement is 80 degrees per second. Interchangeable, all-moving tail plane halves. The split speed brakes are located inboard of rear portion of each horizontal tail surface to each side of nozzle, each deflecting 60 degrees from closed position.

#### **5. Accommodation**

Main features are as follows: pilot only in F-16A; air conditioned cockpit; McDonnell Douglas ACES II zero/zero ejection seat; transparent bubble canopy made of polycarbonate advanced plastics material. The windscreen and forward canopy is an integral unit without a forward bow frame, and are separated from the aft canopy by a simple support structure that serves also as the breakpoint where the forward section

pivots upward and aft to give access to the cockpit. A redundant safety lock feature prevents canopy loss. Windscreen/canopy design provides 360 degrees all-round view, 195 degrees fore and aft, 40 degrees down over the side, and 15 degrees down over the nose. To enable the pilot to sustain high g forces, and to improve comfort, the seat is 30 degrees aft and heel line is raised. In normal operation the canopy is pivoted upward and aft by electrical power. The pilot is also able to unlatch the canopy manually and open it with a back-up hand crank. Explosive unlatching devices and two rockets provide emergency jettison. A limited displacement, force-sensing control stick is provided on the right-hand console, with a suitable armrest, to provide precise control inputs during combat maneuvers. The F-16B has two cockpits in tandem, equipped with all controls, displays, instruments, avionics and life support systems required to perform both training and combat missions. The layout of the F-16B second station is essentially the same as that of F-16A, and is fully systems-operational.

## 6. Systems

Main aircraft subsystems are as follows: Hamilton Standard regenerative bootstrap air cycle environmental control system, using engine bleed air, for pressurization and cooling; two separate and independent hydraulic systems to power operation of the primary flight control surfaces and the utility functions; electrical system powered by engine-driven Westinghouse 40 kVA and Lear Siegler 5 kVA generators; and ground control units with Sundstrand constant speed drive. Four dedicated, sealed cell batteries provide transient electrical power protection for the fly-by-wire flight control system. Application of the Control Configured Vehicle (CCV) principle of relaxed static stability produces a significant reduction in trim drag, especially at high load factors and supersonic speeds. The aircraft center of gravity is allowed to move aft, reducing both the tail drag and the change in drag on the wing due to changes in lift required to balance the download on the tail. Relaxed static stability imposes a requirement for a highly reliable, full-time operating, stability augmentation system, including reliable electronic, electrical

and hydraulic provisions. The signal paths in the quad-redundant system are used to control the aircraft, replacing the usual mechanical linkages. Direct electrical control is employed from pilot controls to surface actuators.

## **7. Avionics and Equipment**

Westinghouse APG-66 pulse Doppler radar and angle track radar with planar array in nose (APG-68 in F-16C/D). The radar has a lookdown range in ground clutter of 23 to 35 miles, and look up range of 19 to 46 miles. The forward avionics bay immediately forward of cockpit contains radar, air data equipment, inertial navigation system, flight control computer, and space and structural provisions for a radar altimeter. Rear avionics bay contains Collins AN/ARN-108 ILS, Tacan and IFF, with space for future equipment. A Dalmo Victor ALR-69 radar warning system is installed. Communications equipment includes Magnavox AN/ARC-164 UHF transceiver; provisions for a Magnavox KY-58 secure voice system, Collins AN/ARC-168 VHF AM/FM transceiver, AN/AIC-18/25 intercom, and Novatronic interference blanker. Sperry Flight Systems central air data computer. Singer-Keafott modified SKN-2400 inertial navigation system, Collins AN/ARN-108 ILS, Collins AN/ARN-118 Tacan, Teledyne Electronics AN/APX-101 air-to-ground IFF transponder with a government furnished IFF control.

## **8. Provisions Armament**

A General Electric M61 A1 20mm multi-barrel cannon is installed in the port side wing/body fairing with 515 rounds of ammunition. There is a mounting for an air-to-air missile at each wingtip, one under fuselage centerline hardpoint and six under-wing hardpoints for additional stores. There are mounting provisions on each side of the inlet shoulder for carriage of sensor pods (electro-optical, FLIR, and so on). Typical stores loads can include two wingtip-mounted AIM-9J/L Sidewinders, with up to four more on the outer under-wing stations; Sargent-Fletcher 370 gallon drop tank on the inboard



under-wing station; 300 gallon drop tank or 2,200 lb bomb on the under-fuselage station; a Martin Marietta Pave Penny laser tracker pod along the starboard side of the nacelle; and single or cluster bombs, air-to-ground missiles, or flare pods, on the four inner under-wing stations. Westinghouse AN/ALQ-19 and AN/ALQ-131 ECM pods can be carried on the centerline and two under-wing stations.

## **9. Combat Record**

During the operation Desert Storm, F-16s flew approximately 13,500 sorties with about 4,000 at night. The average sortie duration was 3.24 hours. Almost every mission involved air refueling. F-16s performed the following tasks: combat air patrol, suppression of enemy air defenses, battlefield air interdiction, close air support, and deep air interdiction. Very few sorties were lost to attrition or aborts. No air-to-air kills were scored by F-16s during Desert Storm.

Many more sorties were generated during peacekeeping operations Deny Flight and Deliberate Force. During the operation Allied Force, F-16s flown by US and Dutch pilots downed several Serbian Mig-29s. Despite thousands of sorties flown, only one F-16 was lost to a surface-to-air missile.

## B. F/A-18 HORNET

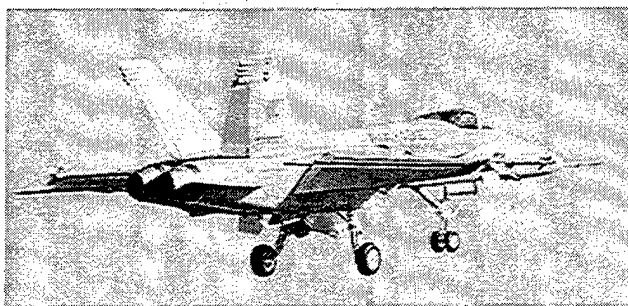


Figure 28. F/A-18 Hornet Aircraft. From Ref. [15].

The F/A-18 Hornet is a single- and two-seat, twin engine, multi-mission fighter/attack aircraft that can operate from either aircraft carriers or land bases. The F/A-18 performs a variety of roles: air superiority, fighter escort, suppression of enemy air defenses, reconnaissance, forward air control, close and deep air support, and day and night strike missions. The F/A-18 Hornet replaced the F-4 Phantom II fighter and A-7 Corsair II light attack jet, and also replaced the A-6 Intruder as these aircraft were retired during the 1990s [Ref. 14,15, and 16].

### 1. Development

The F/A-18 Hornet is a modern jet fighter built by McDonnell Aircraft Company (now Boeing). The F/A-18 is based upon the experimental YF-17 designed and built by Northrop Corporation during the 1970's under contract with the U.S. Air Force. In a tight competition, General Dynamics' F-16 Falcon was ultimately chosen as the Air Force's mainstay fighter. Later, in an effort to salvage their efforts, Northrop teamed up with McDonnell Douglas to produce a new naval air combat fighter known as VFAX. McDonnell Douglas' experience was useful because of their extensive background in carrier-based fighter design. For this reason, McDonnell Douglas became the primary contractor with Northrop being the major subcontractor. Although the original idea was

to design an F-18 fighter version and an A-18 attack version, it was decided to build a multi-role F/A-18 because the differences between the two versions were so minor.

The original F/A-18A (single seat) and F/A-18B (dual seat) became operational in 1983 replacing Navy and Marine Corps F-4s and A-7s. It quickly became the battle group commander's mainstay because of its capability, versatility and availability. Reliability and ease of maintenance were emphasized in its design, and F/A-18s have consistently flown three times more hours without failure than other Navy tactical aircraft, while requiring half the maintenance time.

Following a successful run of more than 400 A and B models, the U.S. Navy began taking fleet deliveries of improved F/A-18C (single seat) and F/A-18D (two seat) models in September 1987. These Hornets carry the Advanced Medium Range Air-to-Air Missile (AMRAAM) and the infrared imaging Maverick air-to-ground missile. Two years later, the C/D models came with improved night attack capabilities. The new components included a Navigation Forward Looking Infrared (NAVFLIR) pod, a raster head-up display, night vision goggles, special cockpit lighting compatible with the night vision devices, a digital color moving map and an independent multipurpose color display.

## **2. Structure**

The Hornet uses advanced composite materials for large portions of its structure. About half of the weight of the structure is made up of aluminum, while steel contributes about 16.7 percent of the weight. Titanium makes up about 12.9 percent of the structural weight, this metal being used for a considerable fraction of the wings, fin, and horizontal tail attachments as well as the wing-fold joints. About 40 percent of the aircraft's surface area is covered by graphite/epoxy composite material, this material making up 9.9 percent of the aircraft's weight. The remaining 10.9 percent of the weight is made up of various other materials (plastic, rubber, etc).

As compared to the YF-17, the wing of the Hornet had 50 additional square feet of area, with increases in both span and chord in order to improve the low-speed performance. The wing had a trapezoidal planform (swept on the forward edges but straight on the trailing edges) and incorporated variable camber. The variable camber is achieved by using full-span leading edge flaps and hydraulically actuated single-slotted flaps on the inner trailing edges. These surfaces are all under computer control to manage extension and retraction, setting the surfaces to the most desirable angle to give optimal performance throughout the entire performance envelope. The ailerons on the outer portions of the wing trailing edges can double as flaps to enhance low-speed handling qualities, and differential operation of flaps and ailerons can be used for roll control. The outer wing panel is hinged at the inboard edge of each aileron for folding aboard carriers. One 96 US gallon fuel tank is installed in each wing, but most of the internal fuel is housed in the fuselage.

The twin vertical tails of the F-18 were necessary to offset the vortex flows coming off the leading-edge extensions of the wings. The twin tails are mounted far forward in order to close the aerodynamic gap between the trailing edge of the wing and the leading edge of the vertical tail. This results in smooth and drag-free fuselage airflow. The forward position of the tails also reduced airflow interference around the engine nozzles and saved weight by eliminating the need for any major rear fuselage carry-through structure.

### **3. Power Plant**

The 15,000 lb General Electric YJ101 turbofans that powered the YF-17 were replaced by their F404-GE-400 derivatives, rated at 16,000 lb with afterburner. The F404 is a low-bypass turbofan, with a bypass ratio of 0.34, which makes it a true turbofan rather than a "leaky" turbojet, as was the YJ101. The engine has a three-stage titanium fan, with one row of fixed inlet guide vanes and one row of variable guide vanes. The

compressor has seven stages, with the first three stages having variable stators. There are single-stage high and low-pressure turbines.

The F404 engine is fairly simple, with relatively few moving parts. As compared to other recent turbofans, the F404 has experienced relatively few developmental problems. In particular, it is extremely resistant to compressor stalls even at high angles of attack. Even if a stall does occur, the problem corrects itself very quickly, with engine and afterburner relighting themselves automatically. The engine is remarkably responsive, being able to accelerate from idle to full afterburner in only four seconds. However, the time taken to accelerate from Mach 0.8 to Mach 1.6 was originally longer than the required value. Although some progress has been made in improving this response time, this problem has persisted in spite of numerous attempts to fix it.

#### **4. Flying Controls**

Full digital fly-by-wire controls using ailerons and tailerons for lateral control plus flaps in flaperon form at low airspeeds. Leading edge and trailing edge flaps scheduled automatically for high maneuverability, fast cruise and slow approach speed. Both rudders turned in at take off and landing to provide extra nose-up trim effort. Fly-by-wire returns forwards 1g flight if pilot releases controls. Lateral and then directional control progressively washed out as angle of attack reaches extreme values. Height, heading and airspeed holds provided in fly-by-wire system.

#### **5. Accommodation**

Pilot only, on Martin-Baker SJU-5/6 zero/zero ejection seat. Pressured, heated and air conditioned cockpit. Upward opening canopy with separate windscreen on all versions. Two pilots in F/A-18B and F/A-18D.

## **6. Systems**

The Hornet features a single airframe-mounted accessory drive (AMAD) just forward of and below the engines. Hydraulic pumps, generators, fuel pumps, and air starter turbines are all mounted on the AMAD, which is connected to each engine via a drive shaft. The two fully independent hydraulic systems provide power for all flight controls, the speed-brake, the refueling probe, landing gear and brakes, and the M61 cannon. The hydraulic reservoirs contain a level sensing system, which detects leaks and automatically closes the faulty section down, leaving the rest of system fully operative. Sophisticated fire detection and extinguishing system is installed in the engine compartments.

A single AlliedSignal GTC-200 APU is provided for engine starting and ground pneumatic, electric, and hydraulic power. Electrical power system is based on General Electrics GE 40 kW generator.

## **7. Avionics and Equipment**

Raytheon AN/APG-65 multimode digital air-to-air and air-to-ground tracking radar, with air-to-air modes which include velocity search, range while search, track while scan (track 10 targets and display eight to pilot), and raid assessment mode. Improved AN/APG-73 replaced AN/APG-65 in F/A-18C/D. Communication equipment includes AN/ARC-182 UHF/VHF transceiver, AN/ARC-210 SECOS 610 UHF/VHF transceiver, Conrac communications system control, and AN/APX-100 IFF identification system. Navigational systems include AN/ARN-118 Tacan, Litton AN/ASN-130A inertial navigation system, being replaced by AN/ASN-139 ring laser system. Two digital computers AN/AYK-14 are used for data processing and control. Self-defense equipment includes AN/ALR-50 Rear Warning Radar, AN/ALE-39 chaff dispenser, and jammer AN/ALQ-165.

## **8. Provisions Armament**

Nine external weapon stations, comprising two wingtip stations for AIM-9 Sidewinder air-to-air missiles; two outboard wing stations for an assortment of air-to-air or air-to-ground weapons, including AIM-7 Sparrows, AGM-84 Harpoon, AGM-65F Maverick, and Boeing Standoff Land Attack Missile. Two inboard wing stations for external fuel tanks, air-to-ground weapons or IMI ADM-141A TALD tactical air-launched decoys. Two nacelle fuselage stations for Sparrows or Lockheed Martin AN/ASQ-173 laser spot tracker/strike camera. Centerline fuselage station for external fuel or weapons. Air-to-ground weapons include GBU-10 and -12 laser guided bombs, Mk 82 and Mk 84 general-purpose bombs, and CBU-59 cluster bombs. An M61A1 20mm six-barrel gun with 570 rounds is mounted in the nose.

## **9. Combat Record**

The Hornet has been battle tested and has proved itself to be exactly what its designers intended: a highly reliable and versatile strike fighter. The F/A-18 played an important role in the 1986 strikes against Libya. Flying from USS CORAL SEA (CV 43), F/A-18s launched high-speed anti-radiation missiles (HARMs) against Libyan air defense radars and missile sites. On the first day of Operation Desert Storm, two F/A-18s, each carrying four 2,000 lb. bombs, shot down two Iraqi MiGs and then proceeded to deliver their bombs on target. Throughout the Gulf War, squadrons of U.S. Navy, Marine and Canadian F/A-18s operated around the clock, setting records daily in reliability, survivability and ton-miles of ordnance delivered.

F-18s were also used during the operation Allied Force, where they proved its combat readiness and effectiveness. They were not used for air-to-air mission with 75 percent of missions being air-to-ground strikes.

## 10. Remark

The production of the standard F/A-18 was terminated recently and full-rate production of the F/A-18 Super Hornet is scheduled to start in 2001. Most probably this aircraft will be offered to the Czech Republic. Boeing is currently working on a cost reduction program for the Super Hornet to bring its price below \$ 45 million.

The F/A-18 E/F is a completely new design based on the F/A-18 C/D aerodynamic configuration. The aircraft is 25 percent larger than its predecessor but has 42 percent fewer parts. Both the single and two-seat models offer increased range, greater endurance, more payload-carrying ability, more powerful engines, enhanced survivability and renewed potential for future growth.

Structural changes to the airframe increase internal fuel capacity by 33 percent. This extends the Hornet's mission radius by up to 40 percent. There are two additional weapon stations, bringing the total to 11. This allows for increased payload flexibility by mixing and matching air-to-air and/or air-to-ground ordnance. Increased engine power comes from the F-414-GE-400, an advanced derivative of the Hornet's current F404 engine family. The F414 produces 35 percent more thrust and improves overall mission performance.



### C. MIRAGE 2000-5

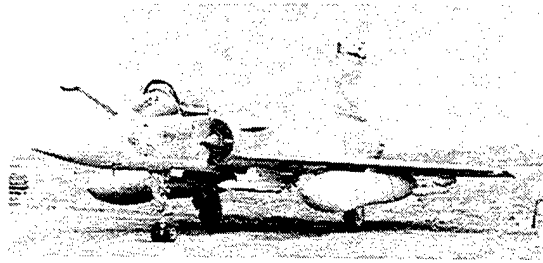


Figure 29. Mirage 2000-5 Aircraft. From Ref. [17].

The Mirage 2000 is very similar to the Mirage III/5 and 50, though it is not a variant of the Mirage III/5 or 50 but an entirely new aircraft with advanced interceptor controls. In its secondary ground-attack role, the Mirage 2000 carries laser guided missiles, rockets and bombs. There is a two-seat version of this aircraft, the 2000N (Penetration) that has nuclear standoff capability. The Mirage 2000-5 is a multi-role single-seater or two seater fighter. It differs from its predecessors mainly in its avionics; it's new multiple target air-to-ground and air-to-air firing procedures linked to the use of RDY radar and its new visualization and control system. As a multi-role combat aircraft with versatile air-to-air mission capabilities, the Mirage 2000-5 integrates the state-of-the-art of the know-how based on the experience gained from the previous Mirage 2000 versions (Mirage 2000 DA, Mirage 2000 E, Mirage 2000 D) and is designed for the most-advanced armaments [Ref. 16,17, and 18].

#### 1. Development

The Mirage 2000 evolved from a series of Dassault design efforts performed from 1965 to 1975. The first in this series was a collaborative project known as the Anglo-French Variable Geometry (AFVG) swing-wing aircraft, begun in 1965. The collaboration was a fiasco, and the French pulled out in 1967. The British stayed with the concept and formed another collaboration with the Germans and Italians, which eventually produced the Panavia Tornado. Dassault then worked on several new aircraft

concepts evolved from their Mirage G variable-geometry experimental prototype, resulting in a sophisticated design with the designation Avion de Combat Futur (ACF), or Future Combat Aircraft. The ACF prototype was almost complete when the French government cancelled it in 1975. The ACF was simply too big and expensive. However, Dassault had been considering other fighter options in the meantime, partly because of limited ACP export potential. These alternatives were smaller, simpler, and cheaper than the ACF, and took the form of a number of "Mini-Mirage", or "Mimi"; concepts developed beginning in 1972 as a "back-burner" project. These concepts congealed into an aircraft known at first as the Super Mirage III, then the Delta 1000, Delta 2000, and finally Super Mirage 2000.

When the ACF was cancelled, Dassault was able to immediately offer the Mirage 2000 as an alternative, and the French Defense Council accepted it. It wasn't exactly an even trade, since the ACF was a strike aircraft first and an interceptor second, while the Mirage 2000 was exactly the reverse. However, the Mirage 2000 was much more affordable. There was another reason for Dassault to push the Mirage 2000. In 1975, four European nations selected the General Dynamics F-16 as their new first-line fighter, rejecting an updated Mirage F1. Marcel Dassault was disgusted with the choice, and felt his company could build a better aircraft. Using the delta wing configuration seemed to many like a backward step. The company had used that configuration on the Mirage III and 5, but abandoned it for the Mirage F1. A delta wing tends to be a good choice in terms of high-speed flight characteristics, simplicity of aircraft construction, relatively low radar signature, and internal volume. It tends to be a poor choice in terms of maneuverability, low-altitude flight, and length of take-off and landing run.

While the delta wing was outdated by that time, Dassault modified the aerodynamics of the new aircraft to ensure a degree of inherent instability, obtained by moving the aircraft's center of lift in front of its center of gravity. Control was maintained by a fly-by-wire control system and automatic, full length, two-segment leading-edge

flaps. This gave the Mirage 2000 a level of agility that the Mirage III and 5 lacked, and the aircraft would become known for its handling. A noticeably taller tail allowed the pilot to retain control at higher angles of attack, assisted by small strakes mounted along each air intake. The versions of MIRAGE 2000 include MIRAGE 2000B,C,D,E, and N.

The old prototype MIRAGE 2000B was extensively modified to fly as MIRAGE 2000-5 in October 1990. In 1995 it was purchased for the French Air Force and later it was also successful in exports.

## **2. Structure**

Dassault was correct in anticipating that the use of the latest CCV (Control Configured Vehicle) concepts in concert with advanced technology would make the Mirage 2000 a warplane offering capabilities enormously superior to those of the Mirage III with basically the same layout. The core of this superior capability was the combination of relaxed static stability, an area-ruled fuselage, a cambered wing carrying automatically scheduled full-span slats on its leading edges and full-span elevons on its trailing edges, and a fly-by-wire control system. The combination offered a huge reduction in trim drag; good turn rate at high altitudes and high speeds, and excellent controllability at low altitudes and low speeds. The delta design was carefully optimized for maximum internal fuel volume. The basic composition is based on following structure: multi-spar metal wing; elevons have carbon fiber skins with AG5 light alloy honeycomb cores; carbon fiber/light alloy honeycomb panel covers avionics bay; most of fin and all rudder skinned with boron/epoxy/carbon; rudder has light alloy honeycomb core.

## **3. Power Plant**

One SNECMA M53-P2 turbofan, rated at 64.3 kN (14,462 lb) dry and 95.1 kN (21,385 lb) with afterburning. Alternative M53-P20, rated at 98.1 kN (22,046 lb) is no longer offered. Movable half-cone centerfold is located in each air intake.

Internal wing fuel tank capacity 1391 US gallons; fuselage tank capacity 660 US gallons in single-seat aircraft, 640 US gallons in two-seat aircraft. Total internal fuel capacity 1,050 US gallons in 2000C and E 1,030 US gallons in 2000B, N, D and S. Provision for one jettisonable 343 US gallon RPL-522 212 lb fuel tank under center of fuselage, and a 449 US gallon RPL-501/502 463 lb drop tank under each wing. Total internal/external fuel capacity 2,291 US gallons; in 2000C and E, 8,604 litres (2,271 US gallons).

Detachable flight refueling probe forward of cockpit on starboard side. (Availability of in-flight refueling on exports aircraft not disclosed, although probes are fitted to Abu Dhabi's 2000RADs.) Dassault type 541/542 tanks of 2,000 liters (528 US gallons) are available for the 2000-5, 2000N, D and S wing attachments (and optional on 2000B/C), empty weight 240 kg (529 lb) each, increasing internal/external fuel to 9,204 liters (2,430 US gallons).

#### **4. Flying Controls**

Full fly-by-wire control with SFENA autopilot; two-section elevons on wing move up 16 degrees and down 25 degrees; inner leading-edge slat sections droop up to 17° 30' and outer sections up to 30 degrees; fixed strakes on intake ducts create vortices at high angles of attack that help to correct yaw excursions; small airbrakes above and below wings.

#### **5. Accommodation**

One or two occupants on Hispano-Suiza license-built Martin-Baker Mk 10Q zero/zero ejection seat(s), in air-conditioned and pressurized cockpit. Pilot-initiated automatic ejection in two-seat aircraft; 500 microseconds delay between departures. Canopy/ies hinged at rear to open upward and, on Mirage 2000D, covered in gold film to reduce radar signature.

## 6. Systems

ABG-Semca air conditioning and pressurization system. Two independent hydraulic systems, pressure 280 bars (4,000 lb/sq in) each, to actuate flying control servo units, landing gear and brakes. Hydraulic flow rate 110 liters (29 US gallons; 24 Imp gallons)/min. Electrical system includes two Auxilec 20110 air-cooled 20 kVA 400 Hz constant frequency alternators (25 kVA in Mirage 2000D and 2000-5), two Bronzavia DC transformers, a SAFT 40 Ah battery and ATEI static inverter. Eros oxygen system.

## 7. Avionics and Equipment

Thomson-CSF RDM multi-mode radar or Dassault Electronique/Thomson-CSF RDY pulse Doppler radar, each with operating range of 54 nm (100 km; 62 miles). (Mirage 2000N/D have Dassault Electronique/Thomson-CSF Antelope terrain-following radar for automatic flight down to 61 m (200 ft) at speeds not exceeding 600 knots (1112 km/h; 691 mph); Antelope 5 in 2000N includes altitude-contrast updating of navigation system; Antelope 50 in 2000D has full terrain-reference navigation facility.) SAGEM Uliss 52 inertial platform (52E in 2000C and B; 52D for export; and two 52P in 2000N/D, plus integrated GPS in 2000D), Dassault Electronique Type 2084 central digital computer and Digibus digital databus (2084 XR in 2000D), Sextant TMV-980 data display system (VE-130 head-up and VMC-180 head-down) (two head-down in 2000N/D), SFENA 605 autopilot (606 in 2000N, 607 in 2000D, 608 in 2000-5), LMT Deltac Tacan, LMT NRAI-7A IFF transponder, SOCRAT 8900 solid-state VOR/ILS and IO-300-A marker beacon receiver, TRT radio altimeter (AHV-6 in 2000B and C, AHV-9 in export aircraft, two AHV-12 in 2000N and AHV-17 in 2000-5), TRT ERA 7000 V/UHF com transceiver, TRT ERA 7200 UHF or EAS secure voice com, Sextant Avionique Type 90 air data computer, and Thomson-CSF Atlis laser designator and marked target seeker (in pod on forward starboard underfuselage station).

## **8. Provisions Armament**

Mirage 2000 has nine hardpoints for carrying weapon system payloads, five on the fuselage and two on each wing. The single seat version is also armed with two internally mounted high firing rate 30 mm guns.

Air-to-air weapons include the MICA multi-target air-to-air intercept and combat missiles and the Magic 2 combat missiles, both from Matra BAe Dynamics (France). The aircraft can carry four MICA missiles, two Magic missiles and three-drop tanks simultaneously. The Mirage 2000-5 can fire the Super 530D missile from Matra BAe Dynamics (France) or the Sky Flash air-to-air missile from Matra BAe Dynamics (UK) as an alternative to the MICA missile.

Mirage 2000 is also equipped to carry a range of air-to-surface missiles and weapons including laser-guided bombs. These include Matra BAe Dynamics BGL 1000 laser guided bomb, Aerospatiale AS30L, Matra BAe Dynamics Armat anti-radar missile, Aerospatiale AM39 Exocet antiship missile, Matra BAe Dynamics rocket launchers, Matra BAe Dynamics Apache stand-off weapon, and the stealthy cruise missile, SCALP. The Mirage 2000-9 aircraft ordered by the United Arab Emirates will carry the Black Shahine missile being developed by Matra BAe Dynamics.

## **9. Combat Record**

French and Abu Dhabi Mirage 2000s saw operational use during the Gulf War, though apparently they did not see much actual combat action. French Mirage 2000s have been prominent participants in UN and NATO air operations over the former Yugoslavia.

## D. JAS-39 GRIPEN

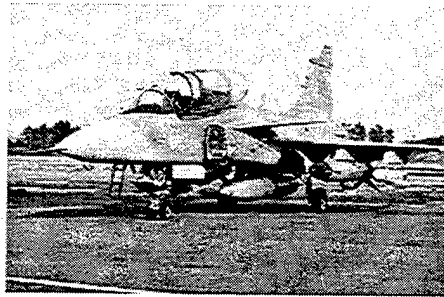


Figure 30. JAS-39 Gripen Aircraft. From Ref. [19].

JAS-39 Gripen is currently the only operational 4<sup>th</sup> generation aircraft in the world. It is a multi-role lightweight combat aircraft. The Gripen fighter combines new knowledge-based software controlled avionics systems, advanced aerodynamical design, a well-proven engine and fully integrated system to produce highly capable multi-role combat aircraft. The JAS-39 is the first Swedish aircraft that can be used for interception, ground attack and reconnaissance and is now replacing the Draken and the Viggen aircraft [Ref. 16, 19, and 20].

### 1. Development

In 1978 the Swedish Government decided that the Swedish Air Force needed a new multi-role aircraft for the turn of the century. At the same time as the Swedish aerospace industry was defining a new project, the Air Force made an evaluation of existing foreign aircraft such as the American F-16 and F-18. After an evaluation process, Parliament decided in June 1982 to go ahead with the Swedish project and the Defense Materiel Administration signed a contract for development of the JAS 39 Gripen. The JAS 39 Gripen is the result of a joint development by Saab Military Aircraft, Ericsson Microwave Systems, Volvo Aero Corporation and Celsius Aerotech.

First of five single-seat prototypes rolled out in April 1987 and made first flight in December 1988 but was lost in a landing accident after fly-by-wire problem. New flights

were renewed in May 1990. All developmental work in the original contract had been completed by late 1996. The first production aircraft for Swedish Air Force made first flight in June 1993, but the aircraft was lost during an accident. As a result flight control software was modified. Thrust-vectoring is under consideration for Gripen.

In 1995 Saab and British Aerospace (BAe) signed an agreement for the joint marketing of the Gripen. Saab thereby gained access to the global sales organization of British Aerospace, as well as to its governmental support in international marketing. British Aerospace will adapt the export version of the Gripen to NATO standards, and also produce certain subsystems for the aircraft. The agreement, which followed on more than a decade of cooperation between the two companies, became the basis for a consolidation between Saab and British Aerospace. It also paves the way for Saab's deepened integration with the European aerospace industry.

Current versions of the JAS-39 include JAS-39A – standard single-seater, JAS-39B – two-seater with primary roles conversion and tactical training, but also combat capable. The JAS-39C and D are new features under consideration with planned improvements. The JAS-39X is the potential export version with fully integrated NATO standard equipment.

## **2. Structure**

The Gripen's canard configuration allows it to exceed the payload and performance targets. The high-lift delta wing is further augmented by the addition of canards. The Gripen has a simple cropped delta wing with 45 degree leading edge sweep. Its canard foreplanes are swept at 43 degrees. The dog-toothed wing is augmented by two leading-edge flaps linked with four drooping elevons through a full authority triplex digital fly-by-wire system. The trailing-edge flaps of the Gripen perform opposite function than those on an inherently stable aircraft. Instead of lowering the nose, the flaps raise the aircraft, increasing the tendency to pitch nose and improve agility.



There are some 60,000 parts and about 40 central processing units in the JAS-39. About 56% of the structure is made of aluminium alloys and 26% is made of composite, including fin, wing, canards, most contact surfaces and many covers and doors.

### **3. Power Plant**

General Electric Aircraft Engines and Volvo Aero Corporation developed the RM12 derivative engine from the F404 to power the JAS 39 Gripen for the Swedish Air Force. The RM12 had a projected dry rating of 12,150 lb (54.04 kN), or 17,800 lb (79.18 kN) with a new Volvo/GE afterburner, which gives the all-altitude supersonic performance even with fixed rectangular intakes. The RM12 (F404-400) is a two-shaft augmented low-bypass ratio turbofan with a three-stage fan and a seven-stage compressor, both incorporating variable stators and driven by single-stage turbines. The afterburner, which boasts a fuel activated, variable-area nozzle is fully modulating from minimum to maximum augmentation. GE to Volvo supplies 60 percent of engine components, but Swedish design input has been such that many RM12 changes are featured in the newest F404-402 engines. The RM12 is optimized for single-engine mission with up to 10 percent increase in fan airflow, 1.1 birdstrike resistance, improved turbine materials and a combat performance rating. A new Full Authority Digital Electronic Control (FADEC) is being incorporated in 2000. The RM12 delivers rapid throttle response, unrestricted throttle movements and smooth afterburner light-offs. In addition, the engine is highly reliable and has exceptionally high tolerance to inlet distortion. South Africa has recently selected the RM12-powered JAS 39.

### **4. Flying Control**

The JAS-39 relies on a series of electrical servos connected to the canards, leading edges, flaps, rudder, and airbrakes to move these control surfaces. A thicker, broader fin, more akin to that of Viggen, replaced the earlier narrow fin seen on models and provisional drawings. The original design was too small to accommodate the necessary

rudder hydraulics or servos. The three-channel digital flight control system has a three-channel analog back up, which kicks in if two of the digital channels malfunction. The back-up system, which can also be activated by the pilot, disables the canards (locking them in neutral position) and makes the Gripen neutrally stable. The mature fly-by-wire system permits roll rates of 250 degrees per second. It also accepts brutal control inputs or abrupt load reversals quite happily and keeps the aircraft in trim at all times.

## **5. Accommodation**

Pilot only in JAS-39A, on Martin Baker Mk 10L zero/zero ejection seat. Hinged canopy (opening sideways to port) and one-piece windscreen by Lucas Aerospace. Two seats in tandem in JAS-39B. Command sequence in two-seat aircraft ejects rear occupant first, simultaneously inflating an airbag between the two cockpits to protect the rear pilot from Perspex splinters.

## **6. Systems**

Hymatic environmental control system for cockpit air conditioning, pressurization and avionics cooling. Two hydraulic systems with Dowty equipment and Abex pumps. Hamilton Sundstrand main electrical power generating system comprises an integrated drive generator, generator control unit and current transformer assembly. Lucas Aerospace auxiliary and emergency power system, comprising gearbox-mounted turbine, hydraulic pump and 10kVA AC generator to provide auxiliary electric and hydraulic power in event of engine or main generator failure. In emergency role, the turbine is driven by engine bleed or APU air. If this is not available, the stored energy mode using thermal energy is selected automatically. Micro turbo APU and air turbine starter for engine starting, cooling air and standby electrical power. Optional On-Board Oxygen Generating System on export aircraft. Lot 3 Gripens have single Ericsson Saab Avionics GECU general electronic control unit, replacing previous three controllers for air, fuel and hydraulic systems.

## **7. Avionics and Equipment**

Communication equipment comprises of Celsius Tech dual VHF/UHF transceivers and IFF. Retrofit planned with tactical radio systems. Export versions will have GUS 1000 audio management system. The aircraft is equipped with Ericsson/BAE PS-05/A multimode pulse Doppler target search and acquisition radar with lookdown – shootdown capabilities. For fighter missions, system provides fast target acquisition at long range, search and multi-target track-while scan, quick scanning and lock-on at short ranges, and automatic fire control for missiles and cannon. In attack and reconnaissance roles, operating functions are search against sea and ground targets, mapping with normal and high resolution and navigation.

The central computing system is Ericsson SDS 80 with three databusses, one of which links flight data, navigation, flight control, engine control and main systems. The self-defense features include EricssonTech rear warning radar and Ericsson Saab Avionics electronic warfare suite EWS-39.

## **8. Armament**

SAAB has chosen two missiles to be the standard armament of the JAS39. For short-range combat the Rb74 Sidewinder (AIM-9L) IR seeking missile has been chosen. The JAS39 carries special target selection equipment enabling it to give the missile a higher performance and accuracy than before. The pylons on the wing tips are constructed for Rb74 and Rb24, which is the older version of the Sidewinder AIM-9.

For medium range combat the Rb 15 AMRAAM (AIM-120) radar-seeking missile was chosen as standard armament. This choice was a surprise since the SAAB 37 Viggen carries Rb71 Sky Flash and it was assumed that the JAS39 would carry the same missile.

The JAS39 has 6 pylons on the wings for carrying weapons and equipment. The two on the wing tips are constructed for missiles. Except for them the JAS39 also has a pylon

under the fuselage for equipment, normally an extra tank. The JAS39 also carries an internal cannon. It is the 27mm Mauser BK27 cannon. It is partially controlled by the radar to increase firing opportunities and improve hit probability.

#### 9. Combat Record

None.

#### E. EUROFIGHTER

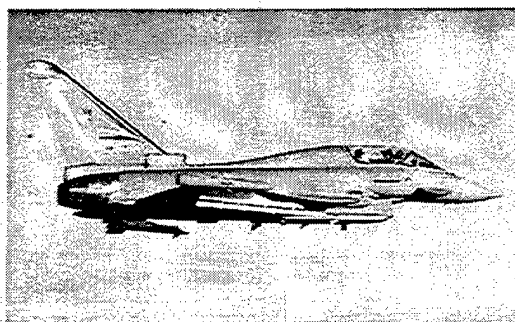


Figure 31. Eurofighter Aircraft. From Ref. [22].

Eurofighter is a single-seat, twin-engine, agile combat aircraft, which will be used in the air-to-air, air-to-ground and tactical reconnaissance roles. The design of the Eurofighter Typhoon is optimized for the air superiority mission with high instantaneous and sustained turn rates, and specific excess power. Special emphasis has been placed on low wing loading, high thrust to weight ratio, excellent all round vision and carefree handling. The use of Stealth technology is incorporated throughout the aircraft's basic design. Eurofighter's air dominance supremacy and versatility as a multi-role combat aircraft is marked by its highly potent and comprehensive air-to-surface attack capability [Ref. 16, 21, 22, and 23].

## 1. Development

The roots of the Eurofighter can be traced back to the early 1970's. The British were thinking about Short Take Off Vertical Landing (STOVL) aircraft to replace Jaguar and Harrier aircraft. In 1972 they changed the plan for an air superiority fighter and STOVL capability was dropped. The British started cooperation with the Germans and the French and together launched a study titled the European Combat Aircraft (ECA). This project aimed to produce an aircraft matching the needs of the tri-national air forces. All three countries began their own developments. By 1981 it became clear that the project was doomed to failure with no aircraft meeting all the diverse requirements. After the failure of the European Combat Fighter (ECF) project in 1981, the three Panavia nations (Britain, Germany and Italy) linked their studies under the Agile Combat Aircraft (ACA) program. The official construction contract was signed in 1983 and a first flight date of mid-1986 was set.

The final solution was a low set cranked canard-delta wing with a single fin powered by twin engines fed via an intake mounted in ventral position. During the developmental phase, Britain, France, Germany, Italy and Spain once again tried to initiate a joint fighter program. The differences in requirements between the member nations threw the project into chaos. In 1985 France went alone to design Rafale and in 1986 the Eurofighter was born as a collaborative project between Britain, Germany, Italy and Spain. The continuing differences in requirements between member nations almost caused Germany to leave the project. In December the Eurofighter 2000 was born. The first flight took place in March 1994 with each nation having its own prototype. During the course of action each nation reduced its orders for aircraft, which caused the work share shift.

In 1998 the Eurofighter 2000 was named Typhoon for export markets. The fully capable Eurofighter should be available as the first squadrons form in 2003. Standard version is single-seater with two-seater as a combat capable conversion trainer.

## 2. Structure

Eurofighter benefits from advances over the twenty years in the fields of metallurgy, polymer science and composites. Over 80% of the airframe is comprised of modern materials. This brings advantages not only in terms of the strength to weight ratio but also has implications for stealth features. Most of the aircraft shell, about 70% is comprised of Carbon Fiber Composite (CFC). The canards, out-board flaperons and engine nozzles are subject to large stresses and/or high temperatures and thus are made of Super Plastic Forming, Diffusion Bonded (SPFDB) Titanium. The wing leading edges, fin leading edges, rudder trailing edge and wingtip ECM pods are made from a Lithium-Aluminium alloy imparting superior strength to weight than standard aluminium alloys. Additionally these areas are also coated in Radar Absorbent Materials (RAM). The canopy seal surrounds are manufactured from a Magnesium alloy. Overall only 15% of the Eurofighter shell is metal while CFC comprises 40% of the structural weight.

Much of the basic design of the Eurofighter was derived from BAe's Experimental Aircraft Program and its preceding projects. However, there are some notable differences between the current Eurofighter and its EAP cousin. For example, while the EAP utilized a cranked delta layout the Eurofighter instead uses a standard delta configuration. Other differences include the inclusion of conformal recessed fuselage weaponry, a wide mouthed curved intake and a bubble type canopy.

Production responsibility for the structure is split amongst the consortium. BAe manufactures the front fuselage, canards, starboard leading wing slats and flaperons, fin and centerline pylon. DASA constructs the center fuselage, Alenia is responsible for the port wing, CASA and Alenia builds the rear fuselage and CASA and BAe build the starboard wing. Each nation maintains its own final assembly line thus ensuring local delivery times can be met but at a likely cost increase due to four-way shipping requirements.

The Eurofighter is a pitch unstable, delta-canard tail-less design with a 53° leading edge sweepback on the main wing. This configuration was found to give an optimal combination of lift and agility. With a wing area of around 50 sqm it has a small loading in a typical combat situation, which implies very good maneuverability. Pitch instability causes the aircraft to point its nose up during flight further increasing agility and helping to reduce drag.

With no tail the all-moving foreplanes, or canards impart pitch and roll control combined with the wing flaperons and rudder. In addition the canards can be used to trim the aircraft through different flight regimes minimizing drag. The canards may also be used as an extra pair of airbrakes when landing by pointing them straight down maximizing drag. Unusually the canards are mounted much nearer the nose than is typically found in similar aircraft. This increases the maximum achievable Angle of Attack (AoA). The drawback to this is a decreased view to the left and right of the pilot. Automatic slats are present on the main wing leading edges, which ensure the correct wing camber is maintained across the flight envelope. A hydraulically operated air-brake is integrated behind the cockpit, moving into a near-vertical position to maximize drag when required.

### **3. Power Plant**

The Eurofighter is powered by two Eurojet EJ2000 turbofans. EuroJet is a consortium of companies from each partner nation. The EJ200 started life in 1982 as the Rolls Royce/British MoD XG-40 Advanced Core Military Engine or ACME demonstrator. This programme, split into three phases; technology (1982-88), engine (1984-89) and assessment (1989-95) developed new fan, compressor, combustor, turbine (including high temperature life prediction) and augmentor systems using advanced materials and new manufacturing processes.

The first full engine commenced rig testing in December 1986 with the final XG-40 running for some 200 hours during 4000 cycles bringing the programme to a close in June 1995. Upon formation of the EuroJet consortium in 1986 much of the continuing XG-40 research was used for the new programme. The requirements were for a power plant capable of higher thrust, longer life and less complexity than previous engines. Overall the EJ200 employs a very low By-Pass Ratio (the ratio of air which bypasses the core engine or compressor stages) of 0.4:1, which gives it a near turbo-jet cycle. Such a low BPR has the benefit of producing a cycle where the maximum attainable non-afterburning thrust makes up a greater percentage of total achievable output. At its maximum dry thrust of 60kN (or 13,500lb) and with afterburning the engine delivers around 90-100kN (or 20,250-22,500lb) of thrust. Compared to other engines, these figures seem relatively high; however, such data must be used with caution and evaluated with all other performance data to be of any use.

The future developments of the engine are focused on the growth potential, which is predicted between 20-30%. As well as the potential for increasing the EJ200's thrust, there are also plans to incorporate a Thrust Vectoring Control, (TVC) nozzle. The EJ200's TVC nozzle is a joint project lead by Spain's ITP and involving Germany's MTU. Preliminary design of the system began in mid-1995 at ITP, the proceeding years involved work by both ITP and MTU to deliver a fully functional EJ200 integrated system. The outcome of this research led to the first 3DTVc equipped EJ200 undergoing rig trials in July 1998. The nozzle requires relatively few modifications or additions to be made to the EJ200; a new hydraulic pump, reheat liner attachment upgrades, casing reinforcement, new actuators and associated feed equipment.

#### **4. Flying Controls**

Two-segment automatic slats on wing leading edges with inboard and outboard flaperons on trailing edges. All-moving foreplanes below windscreen. Hydraulically actuated airbrake aft of canopy forming part of dorsal spine. Liebherr primary flight



control actuators. Full-authority quadruplex active control technology with digital fly-by-wire control system and ENOSA flight control computer combines with mission adaptive configuring and aircraft's instability in pitch to provide carefree handling, gust alleviation and high sustained maneuverability throughout flight envelope. Pitch and roll control via foreplane/flaperon active control technology to provide artificial longitudinal stability. Yaw control is provided via rudder.

## **5. Accommodation**

Pilot only in single-seater and two pilots in two-seater on Martin Baker Mk 16A zero/zero ejection seats. Single-piece Aerospace Composite windscreen and single-piece rear-hinged canopy on both versions. Optional liquid-cooled vest for pilot. Anti-g trousers augmented by pressure breathing system.

## **6. Systems**

The Eurofighter has essentially two electrical systems, the primary power generation and distribution system and the secondary systems (including the auxiliary power unit). Primary power is supplied via the engine turbines through a LucasVarity/BAe Systems supplied distribution and rectification system. Using this electrical power can be supplied at a number of voltages and AC phases as well as supplying a DC output. The DC system is fully redundant with two back-up rectifier units in case the two primaries fail. Additionally a DC battery source is available in emergencies as well as to power up the APU. The secondary system provides a back up using air-driven turbines in case of total engine (or engines) failure or partial (gearbox, turbine, etc.) failure. Since the Eurofighter is designed for autonomous operation the aircraft includes an Auxiliary Power Unit, or APU as part of the secondary system. Before the engines are started the APU generates all the AC/DC power required to operate the aircraft's systems. The engine start systems, supplied by AlliedSignal and Microturbo are also powered by the APU.

The Eurofighter includes two fully redundant hydraulic systems each of which incorporate flight control isolation valves. Both systems are supplied by engine driven gearboxes. Utilities control system is integrated within overall system architecture and provides for continuous monitoring and fault detection. Integrated monitoring and recording system constantly checks status of all other systems.

## **7. Avionics and Equipment**

The CAPTOR ECR 90 radar has been developed by the Euroradar consortium. The multi-mode pulse Doppler radar is the first airborne radar in NATO with three as opposed to two processing channels. The third channel is used in a jamming scenario. To complement the radar, a dual-mode forward looking infra-red (FLIR) sensor is mounted on the port side of the fuselage. In the air-to-air role the sensor, integrated with the radar is used for passive detection and tracking of targets, so called Infra-Red Search and Track (IRST).

Rhode and Schwarz VHF/UHF transceiver especially designed for the Eurofighter will enable open and encrypted communication. Communications and Audio Management unit also provides for the pilot being able to verbally interact with the system.

The Eurofighter is equipped with a Litton Italia LN-93EF laser gyro inertial navigation system and accelerometer package with high accuracy. This system is cross-referenced with the Global positioning system

## **8. Provisions Armament**

As well as an internally mounted 27 mm Mauser gun, the Eurofighter Typhoon has thirteen hard points for weapon carriage, four under each wing and five under the fuselage. An Armament Control System (ACS) manages weapons selection and firing and monitors weapon status.

For air-to-air combat, the standard weapon configuration is four BVRAAM (Beyond Visual Range) air-to-air missiles on semi-recessed fuselage stations and two ASRAAM short-range air-to-air missiles on the outer pylons. A mix of up to ten medium-range and short-range missiles can be carried. The UK RAF has selected Matra BAe Dynamics Meteor for the BVRAAM requirement and Raytheon AMRAAM until Meteor enters service.

Eurofighter can carry a range of air-to-surface weapons, including Brimstone and DWS 37 anti-armour weapons (three under each wing and one under the center fuselage) and laser-guided bombs. Avionics pods can be mounted under each wing, for example a laser designator pod.

#### 9. **Combat Record**

None.

#### F. **MiG-29SMT**

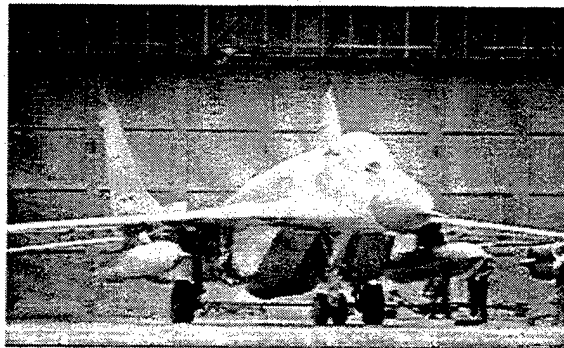


Figure 32. MiG-29SMT. From Ref. [25].

MiG-29M is an advanced multi-role tactical fighter for control of upper airspace, ground attack and naval high-altitude precision weapons control. This aircraft is based on MiG-29 and was designed to remove the weaknesses of the baseline MiG-29A. With its

old-generation radar and weak avionics suite, the MiG-29A was no match for advanced western fighters. Other weaknesses were short range and limited air-to ground capabilities. MiG-29M is sometimes designated as MiG-33 [Ref. 16, 24, 25 and 26].

## **1. Development**

During the late 1960's, the Soviet General Staff launched a study for an Advanced Tactical Fighter, paralleling F-15 development in the USA. The official requirement for development was issued in 1972 to replace MiG-21 and MiG-23 assets in tactical and air defense forces. The new lightweight fighter was to undertake autonomous operations from austere sites to achieve air superiority over the tactical theater and provide limited escort and surface attack capabilities. Detailed design work began in 1974, which resulted in the production of the first prototypes. The first flight took place in 1977 and the first MiG-29UB two-seater flew in 1981. The first deliveries to Soviet fighter regiments began in 1983 and by 1989; it was serving in 12 different countries around the world. In the second half of the 1980's the fighter development proceeded in two directions. One line of modernization, smaller in scope, aimed to enhance the fighter's air-to-air performance characteristics. This line of development led to the designation MiG-29S. Existing MiG-29 fighters will be modified to the MiG-29S configuration.

The second modernization program, which was wider in scope, aimed to extend the aircraft's flight range by increasing its fuel capacity, and to enhance its multifunction capability. These objectives required considerable structural changes, even though the exterior design of the fighter sustained few alterations. This program was designated as MiG-29M with the first flight in 1986. This fighter is available for export as MiG-29ME (sometimes designated as MiG-33).

Other versions of MiG-29 include MiG-29SM, which is modified version of MiG-29S. This is the first version offering simultaneous dual-target engagement capability, first flown in 1995. Further modifications led to MiG-29SMT and MiG-

29SMT-II. The MiG-29 was also modified as a carrier based aircraft. The MiG-29 is primarily single-seat aircraft with the MiG-29UB as a two-seat version.

## **2. Structure**

Approximately 7 percent of airframe, by weight, is made of composite materials. The remainder is made of metal, including aluminium-lithium, which is used for the wing carry-through structure housing fuel tanks. Ailerons and vertical tail surfaces are made of carbon fiber honeycomb. Approximately 65 percent of horizontal tail surfaces are made of aluminium alloy and the rest of carbon fiber. A small vortex generator is built in each side of nose, which helps overcome a tendency for early aileron reversal at angles of attack above 25 degrees.

The MiG-29 is based on all-swept mid wing configuration with wide ogival wing leading-edge root extensions, with 40 percent of lift provided by the lift-generating center fuselage.

## **3. Power Plant**

The first versions used two Klimov/Sarkisov RD-33 turbofans each with 49.4 kN (11,110 lb) dry and 54.9 to 81.4 kN (12,345 to 18,300 lb) with afterburning. Engine ducts are canted at approximately 9 degrees with wedge intakes, and are swept back at 35 degrees under wing root leading-edge extensions. The multi-segment ramp system includes a top-hinged forward door inside each intake that closes the duct while aircraft is taking off or landing, to prevent ingestion of foreign objects.

In 1995, Klimov developed two advanced thrust-vector-control engine designs for use with the MiG-29M, the RD-133 and the RD-333. This became very important after the SU-27 evolved to the SU-35 and then on to the vectored-thrust Su-37. The RD-133 is based on the RD-33 fitted with axis symmetric nozzles while the RD-333 is a new fifth-generation engine. Flight test with the RD-133 began in 1997 while the RD-333 still

require some money for development. The RD-133 is an 81.8 kN thrust class engine with afterburning and the present upgrade of MiG-29M features engines that give 86.3 kN of thrust. The RD-333 is expected to have 98 KN of thrust. Both engines are expected to have design lives of 2,000 hours.

#### **4. Flying Controls**

The MiG-29 incorporates conventional flying controls. The older versions had hydraulically powered surfaces with three-axis autopilot. The modernized versions are now equipped with a full quadruplex fly-by-wire flight control system that combines both analog and digital devices incorporating multiple redundancies for operation with relaxed static stability. Maneuvering performance has been maintained but there has been a substantial increase in permissible angle-of-attack over the present 30 degrees. The design further incorporates computer-controlled, four-section, leading-edge maneuvering flaps over full the span of each wing, (except the tip) and standard trailing-edge flaps. The pilot may override the limiter, with a few demonstration pilots authorized up to +11g.

#### **5. Accommodation**

Fully pressurized and air-conditioned cockpit. Pilot only on 16-degree rearward-inclined K-36DM series 2-zero/zero ejection seat, which affords -14-degree view forward over the nose and under hydraulically actuated rearward-hinged transparent blister canopy in high-set cockpit. Sharply inclined one-piece curved windscreen of electrically de-iced triple glass. Three internal mirrors provide rearward view.

#### **6. Systems**

Variable displacement pumps driven by the engine accessory gearboxes power two independent hydraulic systems. Main system powers one chamber of each control surface actuator while the back-up system powers second chamber of each control surface actuator and can be also powered by an emergency pump.

Electrical system consists of three subsystems. Accessories gearbox drives a 30 kW DC generator and a 12 kW AC generator. Reserve DC power is provided by silver-zinc batteries and reserve AC power is provided by 1.5 kW converter.

Three separate pneumatic systems, with main system powering the wheel brakes, canopy, fuel shut-offs and brake parachute actuator and emergency system operating main wheel brakes, and allowing emergency gear extension.

## **7. Avionics and Equipment**

All avionics is integrated via on-board digital computer with multiple channels and PC-compatible software. Modernized versions feature an upgraded avionics system based around a standard databus. Current MiG-29 versions use 60 percent lighter Phazatron NIIR NO10 (or NO19MP) Zhuk pulse Doppler terrain following and ground-mapping radar. This radar is able to track 10 targets and engage four simultaneously over a range of 50 miles.

Communication equipment is based on R-862 Zhooravl-30 communication radio, R-855UM Komar 2M emergency radio and SPU-9 intercom. IFF system utilizes Parol-2D. Optional IFF communication and navigation systems meets ICAO and/or NATO standards. Navigation systems are based on GPS/GLONASS. Self-defense system is based on the Sirena SPO-15LM 360 degrees radar warning system with sensors on wingroot extensions, wingtips and port fin. Jamming station as well as jamming decoys are available.

## **8. Provisions Armament**

A 30 mm Gryazev/Shipunov GSh-30-1 single barrel cannon with 170 rounds capacity. The MiG-29SMT has 8 hardpoints with the maximum armament load of 5,000 kg. It can carry a variety of weapons based on customer desires. For the air-to-air mission, it can carry following missiles: R-60 IR homing missiles, R-27, R-73 highly

maneuverable dogfight missile employd with helmet mounted sight, and R-77 long-range autonomous missile. To fight against sea-based targets it can use newly developed X-31A air-to-ship missile. Older versions of the MiG-29, which had weak air-to-ground capabilities, can be enhanced by using new avionics which allows armament with following air-to-ground weapons: TV guided KAB-500Kr and KAB-1500Kr, semi-active laser guided bomb KAB-1500L, IR guided bomb KAB-500R, semi-active Kh-25, and anti-radiation bombs.

**9. Combat Record**

None.



Specification parameter	F/A-16	F/A-18	Mirage 2000-5	JAS-39 Gripen	Eurofighter	Mig-29 SMT
Wing span	9.8 m	13.7 m	9.13 m	8.4 m	10.95 m	11.36 m
Length	15.03 m	18.4 m	14.66 m	14.1 m	15.96 m	16.26 m
Height	5.09 m	4.9 m	5.20 m	4.7 m	5.28 m	4.73 m
Wing area	27.87 m <sup>2</sup>	46.45 m <sup>2</sup>	41 m <sup>2</sup>	30 m <sup>2</sup>	50 m <sup>2</sup>	38.06 m <sup>2</sup>
Empty weight	8,600 kg	13,380 kg	7,500 kg	6,500 kg	10,995 kg	10,500 kg
Maximum T/O weight	19,187 kg	28,803 kg	17,500 kg	13,000 kg	21,000 kg	22,400 kg
Internal fuel load	3,162 kg	6,305 kg	3,160 kg	2,400 kg	4,500 kg	4,775 kg
External store load	5,443 kg	8,032 kg	6,300 kg	4,200 kg	6,500 kg	5,500 kg
Engines - dry	65 kN	55.6 kN	64 kN	54 kN	60 kN	62 kN
- with afterburner	104 kN	97.9 kN	98 kN	81 kN	90 kN	98.1 kN
Maximum speed	2,400 km/hr	2,025 km/hr	2,338 km/hr	2,128 km/hr	2,125 km/hr	2,400 km/hr
Service ceiling	15,240 m	13,865 m	18,000 m	15,240 m	16,765 m	17,500 m
G limit	9	9	9	9	9	9
Hardpoints	9	11	9	7	13	8

Table 3. Selected Aircraft Specifications.

GENERATION	Characteristics	Examples
First	radar gunfights; swept wings; early hydro-mechanical flight control system	F-86, F-84 MiG-15, MiG-17
Second	supersonic with afterburning; search and fire control radar; air-to-air missiles, long runway requirements; weather limitations	F-104, MiG-21 Mirage III, F-4
Third	multiple target track radar; highly maneuverable; multi-role; ability to attain supersonic speeds without afterburning; sustained high-g flight	F-15, F-16, F-18 Mirage 2000 MiG-29, Su-27
Three and half	substantially upgraded third-generation aircraft; improved avionics suite with better weapon delivery capabilities; greater range; power plant enhancements	F-16 block 50 Mirage 2000-5 MiG-29SMT
Fourth	advanced aero-dynamical design; optional thrust-vectoring control engines; enhanced self-defense features; high instantaneous and sustained turn rates; composite materials; pitch instability enhancing agility; integrated avionics	JAS-39, Rafale Eurofighter Su-37
Fifth	advanced stealth technology features; internally carried armament; first-look, first-kill capabilities against multiple targets; enhanced supercruise flight; high AoA; active phased-array radar	F-22, JSF MFI, S-37

Table 4. Fighter Aircraft Generations.

Note: Various divisions and definitions specifying generations of fighter aircraft can be found in subject literature. This table represents the author's assessment of a majority view of subject matter experts.

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## V. DECISION CRITERIA

### A. LIFE CYCLE COSTS

The rapidly increasing procurement costs of modern military aircraft connected with decreasing, but still high operating and support costs, have been a major concern to many Air Forces around the world. Finally recognizing that downstream operating and support costs are several times greater than the initial acquisition, defense managers introduced the Life Cycle Cost concept into the decision-making process. The life cycle concept has been recognized for several decades, but real breakthroughs were possible only by using computers and networks.

It is extremely difficult to predict or estimate the LCC of a military aircraft because it involves thousands of variables. The future is always uncertain and things tend to change in the course of time; therefore our LCC estimates will never be perfect. However, experts have to do their best to get costs under control.

The life cycle cost (LCC) is defined as "the total cost of an item or system over its full life. It includes cost of acquisition, ownership (operating, maintenance, support, etc.) and, where applicable, disposal." [Ref. 27].

For purposes of cost estimating, LCC is typically divided into research and development, procurement, operation and support, and disposal phases. The following descriptions provide a brief summary of the costs associated with each life-cycle phase [Ref. 28].

- **R&D.** R&D consists of those costs incurred from program initiation at the conceptual phase through the end of engineering and manufacturing development. R&D costs include the cost for feasibility studies, modeling, tradeoff analyses, engineering design, development, fabrication, assembly and test of prototype hardware and software, system test and evaluation, associated peculiar support equipment, and documentation.

- **Procurement.** Procurement includes the costs associated with producing or procuring the prime hardware, support equipment, training, data, initial spares, and facilities.
- **O&S.** O&S consists of all costs incurred by the DoD to field/deploy the system including personnel, consumable and reparable parts, fuel, shipping, and maintenance.
- **Disposal.** Disposal captures costs associated with deactivating or disposing of a materiel system at the end of its useful life. Disposing of a military hardware can result in additional costs or a salvage value depending on the disposition. This cost is normally insignificant compared to the total LCC. The main exceptions to this include disposal of nuclear waste, missile propellants, and other materials requiring expensive detoxification or special handling.

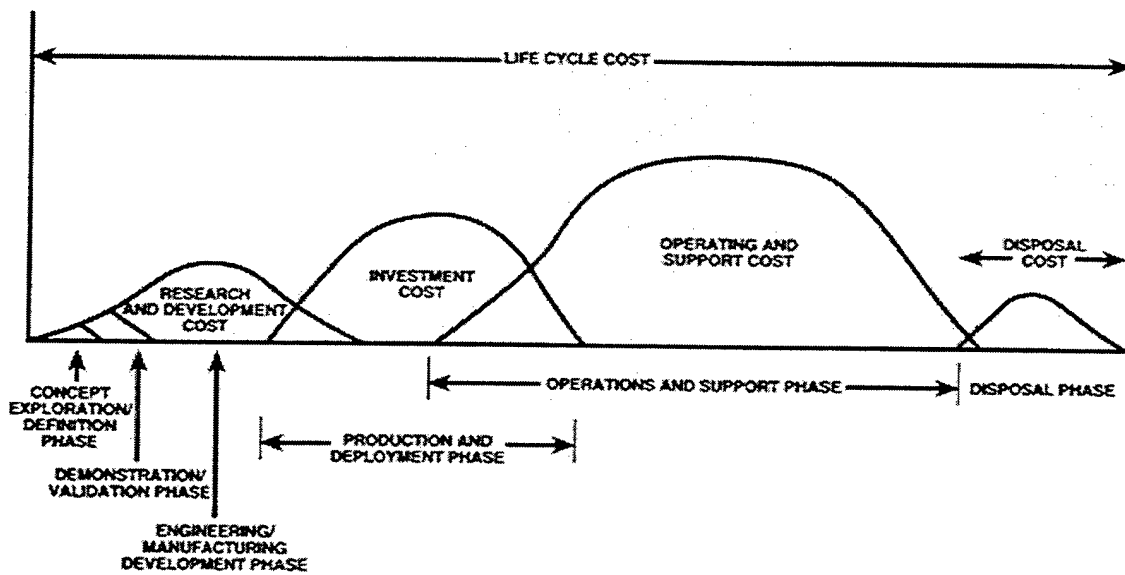


Figure 33. LCC Breakdown. From Ref. [27].

$$\text{LCC} = \text{RDT\&E} + \text{Procurement} + \text{O\&S} + \text{Disposal}$$

Equation 1. LCC Breakdown.

The government of the Czech Republic will incur following costs:

**1. RDT&E**

These costs are not appropriate for the Czech government since it will not conduct RDT&E. This is the case of most countries in the world, which cannot afford to invest huge amounts of money into RDT&E and often lack appropriate industrial base for advanced fighter aircraft.

**2. Procurement**

Analysis of procurement costs can bring a lot of confusion and misunderstanding since there are many costs to be taken into consideration. One has to be very careful when speaking about aircraft cost. Generally, the following four costs are discussed.

Flyaway cost – includes airframe, engine, avionics, non-recurring “start-up” costs, and allowance for changes.

Weapon system cost – includes flyaway cost plus initial support, which is based on data, contractor services, peculiar support equipment, training equipment, and factory training.

Procurement cost – includes weapon system cost plus initial spare parts.

Program acquisition cost – includes procurement cost plus RDT&E portion and military construction.

For the purpose of this study, the procurement cost is an important variable for LCC analysis. Unfortunately, this information is of very sensitive nature and is not easily available. Procurement cost estimates in this study are based on recent sales, and on published articles in aviation magazines. The situation is further complicated by the fact that some aircraft considered have been produced for many years, while others are brand new. An exhaustive search is necessary to locate proper and reliable information about

aircraft procurement costs. The table below represents the best available estimates of selected aircraft procurement costs in millions of US Dollars.

F/A-16C/D	F/A-18E/F	Mirage 2000-5	Jas-39 Gripen	Eurofighter	Mig-29SMT
40	60	55	55	70	30

Table 5. Estimated Procurement Costs.

Notes:

- A) The procurement cost of the F/A-18E/F is based on Boeing's statement to bring the flyaway cost under \$ 45 million to remain competitive on international markets.
- B) Some aircraft companies include RDT&E amortization in procurement cost.

### 3. Operation and Support Costs

This is the biggest part of LCC, usually about 50% of all LCC. In the USA, the O&S costs are based on following cost element structure [Ref. 28].

- 1.0 **Mission personnel**
  - 1.1 Operations
  - 1.2 Maintenance
  - 1.3 Other mission personnel
- 2.0 **Unit-level consumption**
  - 2.1 POL/Energy consumption
  - 2.2 Consumable material/repair parts
  - 2.3 Depot level reparable
  - 2.4 Training munitions/expandable stores
  - 2.5 Other

- 3.0 **Intermediate maintenance (external to unit)**
- 3.1 Maintenance
- 3.2 Consumable material/repair parts
- 3.3 Other
- 4.0 **Depot maintenance**
- 4.1 Overhaul/rework
- 4.2 Other
- 5.0 **Contractor support**
- 5.1 Interim contractor support
- 5.2 Contractor logistic support
- 5.3 Other
- 6.0 **Sustaining support**
- 6.1 Support equipment replacement
- 6.2 Modification kit procurement/installation
- 6.3 Other recurring investment
- 6.4 Sustaining engineering support
- 6.5 Software maintenance support
- 6.6 Simulator operations
- 6.7 Other
- 7.0 **Indirect support**
- 7.1 Personnel support
- 7.2 Installation support

A detailed description of each element is provided in Appendix A.



#### **4. Disposal**

Most LCC studies and analyses simply do not estimate the cost of aircraft disposal, since aircraft are usually in service for at least 20 years and the discounted cost is generally small. Also, recovery of precious metals could cover much of the disposal expense. Therefore, disposal costs will not be considered in this study

#### **5. LCC of selected aircraft**

Czech decision makers will have a limited timeframe to decide about the aircraft purchase. They will have about four months to submit a final decision once all bids have been officially received. One can easily imagine that there will be insufficient time for detailed LCC analyse, which would require extensive staff and databases. Support information is not readily available, and even if it were available, it would be valid only for a specific country or environment. One solution to this problem is to simplify the LCC equation to the following format:

$$\text{LCC} = \text{Procurement} + \text{O\&S costs}$$

Equation 2. LCC Breakdown Simplification.

Procurement costs were estimated in Table 4; therefore, remaining unknown variables are O&S costs. These costs can be based on cost per flying hour. Cost per flying hour is defined as "the cost of owning and operating an aircraft expressed as the cost incurred in a period (week, month, year, etc.) divided by the number of hours the item was operated (in service) in the same period" [Ref. 27]. According to this definition, O&S cost estimates can be based solely on cost per flying hour multiplied by the number of flying hours per year. The NATO standard is 180 flying hours per pilot per year. For the CAF environment, the author will consider two pilots per aircraft each flying 150 hours per year, giving a total of 300 hours per year.

According to Ref. 27, the O&S costs per flying hour (CPFH) for the F-16 is about \$ 8,000. Half of this sum is "mission personnel"; the majority of the other half is repair and condemnation of Depot Level Repairables (DLR); the third significant factor is fuel. U. S. Air Force Instruction (AFI) 65-503 specifies more precisely the total CPFH for the F-16, which is \$ 3,775 not including mission personnel. This number includes consumables, fuel, DLR, and depot maintenance.

The author will exclude mission personnel expenses from all calculations, since each country has different labor and pay rates. The mission personnel portion will be approximately the same for all fighters considered, since the selected Air Force Base will be transformed into a new structure. Our calculation will not then represent total CPFH, but rather it will use the variable portions, which matters most in making a decision. Adding mission personnel costs would therefore not change the total rating.

The LCC will be presented in net present values with inflation rate equal to 4% and discount rate equal to 5%. The following formula will be used for all calculations:

$$\text{LCC (NPV)} = \text{PC} + \text{SUM } \text{AC}/(1+r)^1 + \text{AC}/(1+r)^2 + \dots \text{AC}/(1+r)^{20}$$

Equation 3. LCC Net Present Value calculation.

Where:

PC = procurement cost

AC = annual O&S costs

r = discount rate

The annual O&S costs will be first inflated and then discounted. The results of all calculations are presented in Table 6 and Figure 34.

	F/A-16	F/A-18	Mirage 2000-5	JAS-39	Eurofighter	MiG-29 SMT
CPFH	3,775	5,860	4,800	4,300	6,261	3,557
O&S costs per year	1,132,500	1,758,000	1,440,000	1,290,000	1,878,300	1,067,100
Total O&S costs	20,518,530	31,851,291	26,089,793	23,372,103	34,031,875	19,333,618
Aircraft cost	40,000,000	60,000,000	55,000,000	55,000,000	70,000,000	30,000,000
Total LCC	60,518,530	91,851,291	81,089,793	78,372,103	104,031,875	49,333,618

Table 6. LCC Calculations.

Sample calculation is provided in Appendix C.

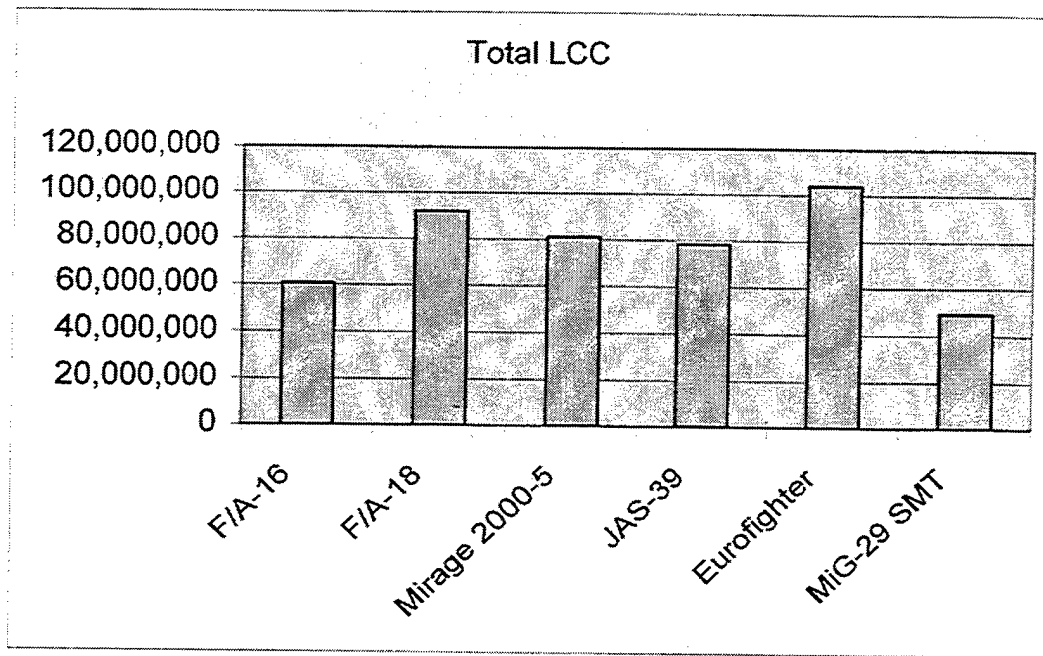


Figure 34. Total LCC.

## B. AIRCRAFT EFFECTIVENESS

The cost of an aircraft and its projected LCC are only part of the information necessary for defense managers to choose among alternative aircraft. Quality or relative effectiveness is the other part of information, which can then be assessed along with the cost of an aircraft. The Analytic Science Corporation (TASC) developed a model for assessing aircraft capabilities and comparative force modernization, TASCFORM-AIR [Ref. 30]. The TASCFORM-AIR methodology recognizes two sets of roles: air combat and surface attack. A number of individual roles are found within each of these sets. The following roles will be considered:

Air combat	Surface attack
Fighter	Close Air Support
Interceptor	Interdiction

TASCFORM-AIR uses basic airframe/propulsion characteristics normalized relative to a baseline aircraft. The F-4B, is the basis for a preliminary figure of merit called Weapon Performance (WP). The model then incorporates a figure of merit called Weapon System Performance (WSP). In order to recognize other factors like relative obsolescence and relative sortie rate generation, the TASCFORM-AIR model can be used to count for the Adjusted Weapon System Performance (AWSP). Finally, the model can establish Designated Force Performance (DFP) and Equivalent Force Performance (EFP). The aircraft technical data summarized in Table 7 were used in this study.

Parameter	F/A-16C	F/A-18E	Mirage 2000-5	JAS-39	Eurofighter	Mig-29 SMT
<b>Air-to-air attack roles</b>						
Hardpoints	9	11	9	7	13	8
Range Hi-Lo-Hi	1800 km	2000 km	1800 km	1600 km	2000 km	2100 km
Basing factor	750 km	750 km	750 km	750 km	750 km	750 km
Missile range	75 km	75 km	50 km 100 km	75 km 100 km	75 km 100 km	110 km
Rate of climb	147 m/s 108 m/s	162 m/s 118 m/s	178 m/s 132 m/s	108 m/s 80 m/s	195 m/s 145 m/s	200 m/s 147 m/s
Max. speed	2 M	1.8 M	2.2 M	2.2 M	2 M	2.2 M
<b>Air-to-ground attack roles</b>						
Payload	5,4443 kg	8,032 kg	6,300 kg	4,200 kg	6,500 kg	5,500 kg
Rate of climb	189 m/s	175 m/s	222 m/s	140 m/s	236 m/s	259 m/s

Table 7. Selected Aircraft Specifications.

## 1. Air Combat Roles

### a. Weapon Performance

$$WP_r = (F_{PL_r} \times PL_r) \div (F_{R_r} \times (R + BF + 2MR)) + (F_{M_r} \times M_r) + (F_{V_r} \times V_r)$$

Equation 4. Weapon performance calculation.

Where:

$PL_r$  = Payload expressed in number of air-to-air ordnance stations, including 1 for an internal gun, divided by 8

$R + BF + 2MR$  = Maximum range for a clean aircraft, using internal fuel only to fly a high-low-high mission profile; plus a basing factor; plus two times missile range, the sum divided by 1800 km

$M_r$  = Maneuverability of the aircraft, represented by maximum excess power at altitudes of 4.5 km and 7.5 km divided by 122 m/s and 92 m/s respectively

$V_r$  = Useful airspeed expressed as best Mach, divided by 2.2

$F_{PL_r}$ ,  $F_{R_r}$ ,  $F_{M_r}$  and  $F_{V_r}$  are weighting factors

**b. Weapon System Performance**

$$WSP_{rt} = ((F_{PL_r} \times PL_r \times PU_{rt}) + (F_{Rr} \times (R + BF + 2MR) \times NAV_r) + (F_{Mr} \times M_r) + (F_{Vr} \times V_r)) \times S_r$$

Equation 5. Weapon System Performance Calculation.

Where:

$PU_{rt}$  = Payload utility factor

$NAV_r$  = Navigation capability factor

$S_r$  = Survivability factor

$$PU_{rt} = (TF_{gmr} \times TA_{gmr} \times GME_{rt} \times CM_{gmr} \times WE_{gmr}) + (TF_{ngmr} \times TA_{ngmr} \times NGME_{rt})$$

Equation 6. Payload Utility Factor Calculation.

**2. Surface Attack roles**

**a. Weapon Performance**

$$WPr = (F_{PL_r} \times PL_r) + (F_{Rr} \times (R + BF + 2MR)) + (F_{Mr} \times M_r) + (F_{Vr} \times V_r)$$

Equation 7. Weapon performance calculation.

Where:

$PL_r$  = Payload, expressed in maximum store station capacity divided by 7250 kg

$R + BF + 2MR$  = Clean range plus basing factor plus twice ASM or ASCM range if appropriate (for the purpose of this study the ASM or ASCM ranges were not considered)

$M_r$  = Maneuverability, expressed as maximum excess power at the altitude of 1.5 km divided by 153 m/s

$V_r$  = Useful speed divided by 2.2

**b. Weapon System Performance**

$$WSP_{rt} = ((F_{PL_r} \times PL_r \times PU_{rt}) + (F_{R_r} \times (R + BF + 2MR) \times NAV_r + (F_{M_r} \times M_r) + (F_{V_r} \times V_r)) \times S_r$$

Equation 8. Weapon System Performance Calculation.

$$PU_{rt} = (TF_{gmr} \times TA_{gmr} \times GME_{rt} \times CM_{gmr}) + (TF_{ngmr} \times TA_{ngmr} \times NGME_{rt} \times CM_{ngmr} \times WE_{ngmr})$$

Equation 9. Payload Utility Factor Calculation.

Mission	F/A-16C	F/A-18E	Mirage 2000-5	JAS-39	Eurofighter	Mig-29 SMT
Fighter	22.89	25.9	23	19.3	29	23.44
Interceptor	25.73	29.7	26.10	21.4	32.9	26.5
CAS	22.54	31.9	24.95	19.2	28.62	21.53
Interdiction	21.70	29.38	23.76	18.95	26.93	21.10
Composite score	23.48	28.34	24.27	19.83	29.76	23.70

Table 8. Effectiveness Scores.

The composite score values are weighted values based on the actual decision making context. The Czech Republic is producing its own aircraft (L-159 ALCA), which will be primarily used for the support of Ground Forces. Although the Czech Republic is looking for a multi-role aircraft, its primary use will be fighter mission. Therefore, the relative weights are as follows:

Fighter – 3

Interceptor – 2

CAS – 1

Interdiction – 1

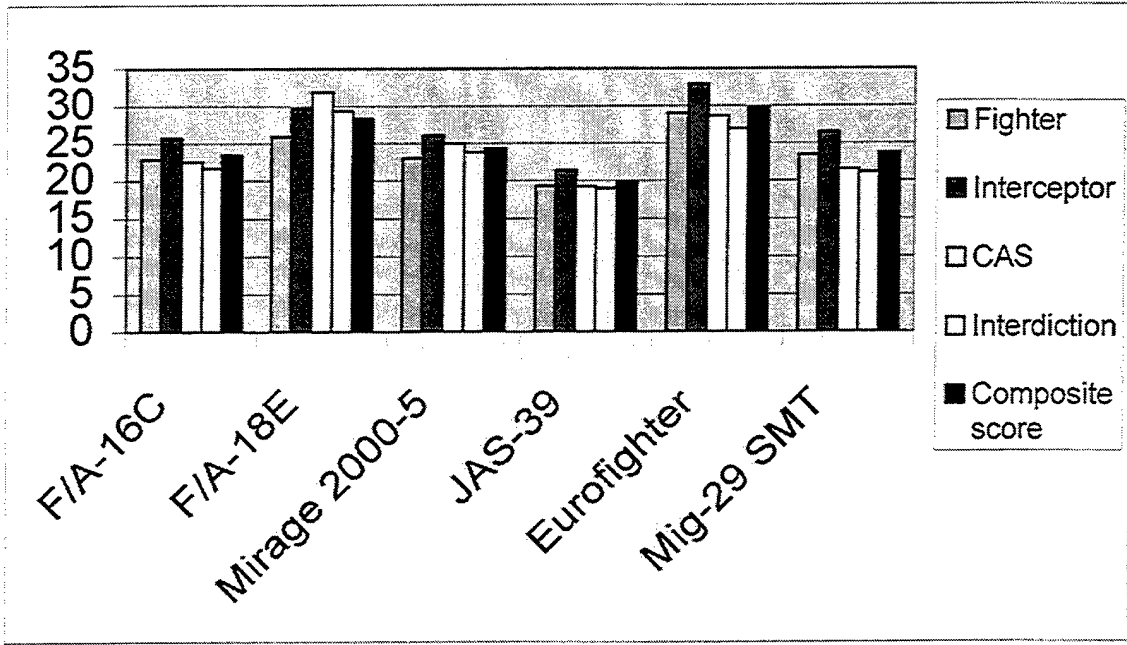


Figure 35. Aircraft Effectiveness Scores.

A detailed sample calculation is provided in Appendix C.



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## VI. CZECH ECONOMY AND MILITARY BUDGET

### A. CZECH ECONOMY

At the beginning of this century, the territory of the Czech Republic was one of the most economically developed parts of Europe and was the most industrialized part of the Austro – Hungarian Empire. Between 1918 – 1938, the Czech lands were listed among the ten most developed states of the world. In 1948, the Czech state came under the Soviet sphere of influence. Industry, agriculture, services, and trade were completely nationalized and centrally controlled. The fall of communism in 1989 initiated the liberalization process and ongoing economic transformation.

Nowadays, the Czech Republic is a small and generally open economy. One government priority has been creation of a free and competitive market. It is a long and complicated process to convert a centralized economy into a free market economy. Small and middle-sized businesses and factories have already finished this process. But the government is working on unfinished structural reforms, mainly in the field of bank privatization, industrial restructuring, legal reform, and improvement of financial market institutions. All the above-mentioned factors are believed to be major cause of the 1998 recession. The Czech economy realized an economic decline of 1% in 1997, which was followed by a 2.2% decline in 1998. In 1999, the Czech economy was recovering from this recession with the economic decline of .2%. The next year was finally marked with positive economic growth of about 2.6%.

One of important objectives of the Czech government was to pursue balanced budgets, which was achieved in 1998, incurring only small deficits on the way. In order to overcome the recession and support wide range of social welfare programs, the Social Democratic government introduced budget deficit of approximately 1.6% of estimated gross domestic product (GDP). The budget for year 2000 was also planned for a deficit.

Budget deficits incurred have traditionally been financed through the issuance of government bonds.

The Czech government seeks to attract foreign investments and it offered a package of incentives to foreign and domestic firms that make a \$ 10 million manufacturing investment through a newly registered company. The package includes tax breaks, duty-free imports of state-of-art equipment, deferral of value-added tax payments (VAT), and job creation benefits [Ref. 31].

The central financial institution is the Czech National Bank (CNB), which is by law responsible for monetary policy. The primary instrument used by the bank to influence monetary policy is the two-week repo rate. Current account imbalances and high inflation rates of 1998 forced the Czech National Bank to implement a series of austerity measures designed to dampen inflation and reduce external imbalances. Monetary policy during most of 1998 remained restrictive, with maintenance of relatively high interest rates designed to reduce inflation and dampen domestic demand, and high compulsory bank reserves to lower the amount of money in the economy. In 1999, after relative recovery of current account, the central bank cut interest rates several times. As a result of this measure, the development of Czech economy took a gradual upturn and the economy moved from decline to stagnation. The average inflation rate in 1999 reached 2.1% after five years of average annual inflation rate of about 10% [Ref. 32]. In 2000 the average inflation rate was about 3.8% and for the next five years it is predicted to stay within the range of 3 – 4%. On the other hand, the political and economical situation in Europe caused weakening of the CZK to USD exchange rate.

The Czech crown is fully convertible for most business transactions. The Foreign Exchange Act provides a legislative framework for full current account convertibility, including all trade transactions and most investment transactions. As of January 1999, all capital account restrictions were removed except for the ability of the Czechs to open bank accounts abroad without a permit issued by the CNB, and the purchase of real estate in the Czech Republic by foreigners. These limitations will disappear by 2002, according

to the Czech Republic's commitments to the Organization for Economic Cooperation and development (OECD).

The Czech Republic sees full membership in the European Union (EU) as one of its highest foreign policy priorities. Relations between the Czech Republic and the EU are currently governed by a EU association agreement of 1991. Detailed accession negotiations began in November 1998. The preparations for full membership in the EU have been slowed by the transformation of regulatory policies and practices to meet EU standards. The Czech Republic has made great progress, but the full membership will probably not be achieved before 2003.

The Czech Republic is a member of OECD and meets most of its standards and regulations. Czech tax codes are generally in line with EU tax policies. In 1998, the government reduced taxes on corporate profits from 38% to 35%. The tax rate for the highest tax bracket for personal income tax stands at 40%. An important part of the government's structural reforms include stricter bankruptcy provisions. Any progress in this area is limited by the three to four year backlog in the bankruptcy courts and by a small secondary market for the liquidation of seized assets.

The Czech Republic maintains a moderate foreign debt and has received investment grade ratings from major international credit agencies. The foreign debt slightly decreased in 2000 due to increased export opportunities. Key economic indicators are summarized in Table 8 [Ref. 31 and 32].

In USD	1997	1998	1999
Nominal GDP	53 bil.	56.4 bil.	54 bil.
Real GDP Growth	- 1%	- 2.3%	-2%
GDP by sector:			
Agriculture	4.6%	5.1%	5.3%
Manufacturing	26.6%	31.4%	31.2%
Services	51.4%	51.9%	52.1%
Government	3.8%	31.2%	31.9%
Per Capita GDP	5,144	5,483	5,196
Labor Force	5 mil	5.17 mil	5.20 mil
Unemployment	5.2%	7.5%	9.4%
Consumer price inflation	8.5%	10.7%	2.2%
Current Account Deficit/GDP	6.1%	1.9%	1.5%
External debt	21.6 bil.	24.3 bil.	24.3 bil.
Debt Service Payments/GDP	10%	10%	7.5%
Fiscal Deficit/GDP	.9%	1.6%	2.1%
Gold and Foreign Exchange Reserves	15 bil.	15.9 bil.	13.2 bil.

Table 9. Key Economic Indicators.

## B. CZECH MILITARY BUDGET

During the Cold War, the Czechoslovak People's Army had an overall strength of about 210,000 personnel. It operated and maintained a huge inventory of weapon systems, which included 4,500 tanks, 4,900 armored personnel carriers, 3,400 artillery systems (100 mm and above), and 687 aircraft. The fall of the "Iron Curtain" and the end of the Cold War brought relaxation of military tensions and consequently Czechoslovakia signed The Treaty on Conventional Forces in Europe.

Practical aspects of this treaty led to drastic reduction of military hardware, which accounted almost for 50% of all equipment operated before 1989. The process of reduction of major weapon systems was linked to reduction of military units and personnel. In 1993, then Czechoslovakia split into the Czech and Slovak Republics, with the armament of the Czechoslovak Army split 2/3 to 1/3 respectively. Transformation of the Czech Armed Forces, destruction of redundant military hardware, and movement of military units required large expenditures, which would otherwise be devoted for acquisition and modernization projects. The Army of the Czech Republic was left without sufficient resources to finance the acquisition of major weapon systems. This process was further complicated by lack of comprehensive strategic vision for the Czech Armed Forces, as well as the general trend of toward lower military expenditures. Military expenditures of the Czech Republic, as a percentage of GDP are expressed in the following table [Ref. 33].

1993	1994	1995	1996	1997	1998	1999	2000
2.6	2.6	2.3	1.8	1.7	1.8	1.9	2

Table 10. Military Expenditures of the Czech Republic.

Based on the Czech government commitment to increase military expenditures during the accession process to NATO, military expenditures began to rise by .1% of GDP per year, reaching 2% in 2000. Financial experts of the Czech DoD are changing the structure of military expenditures in order to free necessary resources to cover financing of new acquisition projects. The objective is to maintain investment outlays at the level of 24% of all military expenditures. The character of the evolution of investment outlays is summarized in Table 10 [Ref. 33].

1993	1994	1995	1996	1997	1998	1999	2000
6.3	12.8	22.9	20.1	20.9	21.5	22.3	23.3

Table 11. Investment Outlays in Percent of Military Expenditures.

Allocation of more money for acquisition projects opened the way for the modernization of the Czech Armed Forces. The Czech government continues implementation of a new force concept with focus on smaller, but more sophisticated and more capable forces. In accordance with this concept, the list of priorities was set up. This list includes investments in following programs:

- Command, Control, Communication, Computer and Intelligence systems,
- Air Traffic control systems,
- Cryptology equipment,
- Air Defense upgrade, and
- Major weapon systems procurement.

As far as the modernization programs for both Air Force and Ground Forces are concerned, the Czech DoD has already finished modernization projects of the T-72 Main Battle Tank as well as the L-159 ALCA aircraft. Deliveries of new military hardware are on the way. This part of chapter will be concluded with prediction of Czech military outlays up to year 2004 [Ref. 33].

Billions of USD	2000	2001	2002	2003	2004
GDP in c.p.	56.4	59	62.3	65	68.9
GDP in 1994 prices	36.3	37.1	38	38.9	39.8
GDP growth	2.1%	2.2%	2.5%	2.3%	2.3%
Inflation	3.6%	3.8%	4%	3.8%	3.9%
DoD expenditures	1.145	1.207	1.288	1.376	1.44
Investment outlays	.305	.354	.367	.370	.390
Customary outlays	.717	.738	.795	.861	.910
Personnel mandatory outlays	.40	.384	.406	.421	.434
O&S	.151	.144	.160	.174	.180
Total military expenditures	1.165	1.228	1.311	1.40	1.47

Table 12. Prediction of Czech Military Expenditures.



### C. OPTIONS TO FINANCE FRONT-LINE FIGHTER PROCUREMENT

The previous section, has shown predicted military expenditures up to year 2004. The Czech government expects to invest between \$ 1.5 – 2 billion into the purchase of 24 – 36 new supersonic fighter aircraft. The current size of military budget is \$ 1.207 billion and investment outlays are set at \$ .354 billion. It is very clear that the purchase of modern fighter aircraft cannot be financed from the military budget, because of insufficient resources. In this case, such a purchase has to be financed from other resources.

From economic point of view, one can find several possibilities of acquiring major weapon systems. Defense economic literature generally speaks about two main options:

- Natural acquisition and
- Financial acquisition.

Natural acquisition during the war is based on confiscation of enemy's weapon systems or as war reparation according to peace agreement. During the peace time, this kind of acquisition generally takes the form of aid to developing countries, or to countries of special interest. The final form of natural acquisition is exchange of military hardware between countries.

More common way of procurement of military hardware is through financial acquisition, which can be divided into the following categories:

- Budget financing.
- Fund financing.
- Debt financing.
- Leasing.

The last two options are probably most suitable for Czech purchase of modern fighter aircraft.

## VII. WORLD INDUSTRIAL BASE AND FUTURE MILITARY AIRCRAFT DEVELOPMENTS

Part of all technical and economic considerations involved in a purchase of modern fighter aircraft should be a brief study of the world industrial base and future military aircraft developments. Not only will it provide ideas about contemporary threats but it would also unveil valuable information about standards of different countries. This is the main objective of this chapter. Military analysts should understand major trends and developments of military aircraft. The final decision about the purchase of certain type of military aircraft will influence the structure and effectiveness of the CAF for the next 20 years.

It is no secret that the aircraft industry is rapidly shrinking and mergers are common. This fact greatly influences the number of military aircraft types. Air Forces around the world are asking for multi-purpose aircraft capable of switching very quickly from one role to another. The cost of military aircraft has risen dramatically, causing general decrease of aircraft total numbers. Our attention has to be firmly focused on the future of a given aircraft. Some aircraft are produced in large batches while others were developed just for a specific market with very limited export opportunities. As a consequence, prices of spare parts and overhauls would be very high since economies of scale would not be achieved. Czech experts and decision makers will make one decision which will last for 20 years, but at this point, there is also necessity to look even further to the future. There are already new projects and developments under way, which will lead to new aircraft programs. It should be useful and advisable to become involved in a specific program, because it would certainly ease similar decision in the future.

The general trend is to maintain one type of air superiority aircraft and one type of air-to-ground optimized fighter. In this part, we will describe the contemporary the situation and ongoing developments in Europe, USA, Russia, and Asia.

## A. EUROPE

Only four companies in Europe are currently capable of producing high-end military aircraft. These companies are EADS (joint venture of Germany, United Kingdom, Spain, and Italy), British Aerospace, SAAB, and Dassault Aviation. European aircraft producers produce the following fourth-generation aircraft:

- Eurofighter – Typhoon
- Rafale
- JAS – 39

The Eurofighter and the JAS – 39 were described in detail in Chapter IV, because both of them are competitors for the Czech market. More time will be devoted to discussion of the Rafale.

### 1. Rafale

The Rafale is a fourth generation multi-purpose aircraft, which will replace five types of French aircraft.

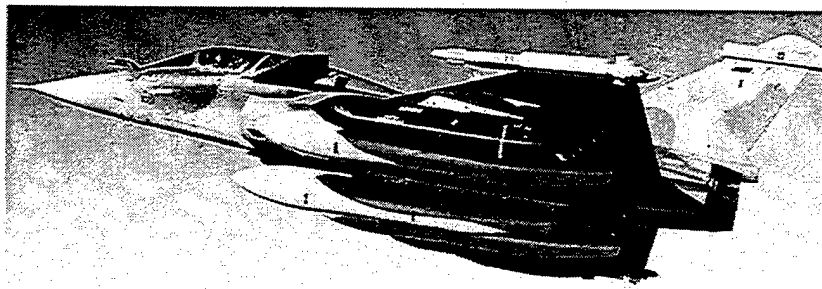


Figure 36. Rafale Aircraft.

The Rafale program started in the mid 1980's when France left a joint European venture that eventually led to the Eurofighter. The flight tests of Rafale technology demonstrator began in 1986. Three versions of the Rafale aircraft were later developed. Single seat Rafale B and two-seat Rafale C for the French Air Force and Rafale C for Navy.

The aerodynamic design includes a swept – back delta wing with high aspect ratio, large active foreplanes and single vertical fin. Composite materials account for more than 35% of the airframe. The aircraft is powered by two SNECMA M88-2 afterburning turbofans with 49 kN maximum dry thrust and 75 kN with afterburning each. The Rafale is comparable to the Eurofighter by its size, but it can carry up to 9,500 kg of external load on its 14 hardpoints, which is impressive performance. It is equipped with the state-of-art fully integrated avionics. Main weapons are expected to be Mica and Magic air-to-air missiles, Apache/Scalp air-to-ground missile, and AS 30 laser guided missiles. The French government has ordered 76 aircraft. Expected procurement unit cost is estimated at \$ 65 – 70 million [Ref. 16, 18, and 34].

## **B. THE UNITED STATES OF AMERICA**

In the United States many mergers have taken place, leaving two major producers of military aircraft, Boeing and Lockheed Martin. The trend is to procure one type of heavy air superiority aircraft and one type of lighter combat aircraft with suitable models for the Air Force, the Navy, and Marine Corps. Lockheed Martin Aeronautics Company and Boeing Defense Space Group's Military Airplane Division are teamed to develop and produce F – 22 as a replacement for the F- 15. A multi – role fighter optimized for air-to-ground role is being developed by both companies under the designation Joint Strike Fighter. Both projects are described below.

## 1. F – 22 Raptor

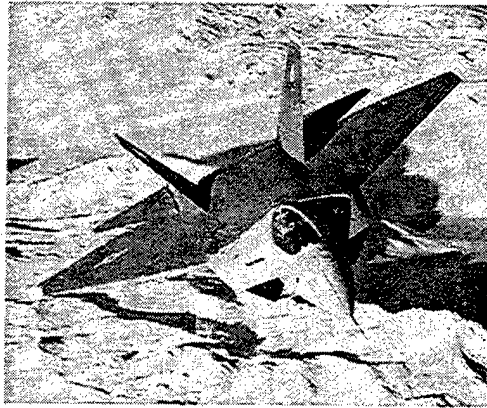


Figure 37. F-22 Raptor Aircraft. From Ref. [13].

The F-22 is a fifth generation air superiority aircraft. The F-22 team was formed in 1986 for the Advanced Tactical Fighter competition. The team built two YF-22 prototype aircraft and won the Air Force's competition in 1991. Lockheed Martin serves as the prime contractor. The F-22 is designed to penetrate enemy aerospace and employ first-look, first-kill capability against multiple targets. The aircraft will carry all armament internally, a contributing factor to stealth characteristics. This will further improve aerodynamic properties and range.

The F-22 has also four hardpoints under wing, each capable of carrying 2,200 kg. The Raptor will be powered by two Pratt & Whitney F119-PW-100 turbofans with integrated flight propulsion controls and two-dimensional thrust-vectoring engine nozzles. It can achieve maximum speed of 2,125 km per hour with a designed supercruise feature. The aircraft will be capable of 60 degrees AoA. The avionics suite will be based extensively on high-speed integrated circuits and integrated from the most technologically advanced subsystems. For air-to-air missions it will carry six AIM-120C and two AIM-9 missiles. For the air-to-ground missions it will carry two 450 kg Joint Direct Attack Munitions internally.

The flight test program began last year and will continue through the 2001. Total number of 339 aircraft will be built and the program should be completed by 2011. Initial operational capability of one operational squadron is scheduled for December 2005. The

F-22 will become the most expensive aircraft ever built with the unit cost in excess of \$ 120 million [Ref. 16 and 35].

## **2. Joint Strike Fighter (JSF)**

The JSF is a fifth generation multi-role fighter optimized for the air-to-ground role. It will become the core aircraft of the Air Force, Navy, and Marine Corps. It was recognized in 1993 that separate Tactical Aviation Modernization Programs conducted by each service are not affordable; therefore, the Multi-role Fighter and Advanced Strike Aircraft programs were cancelled. The Joint Advanced Strike Technology (JAST) program was initiated later. The JSF program has emerged from the JAST in 1995. The JSF program will demonstrate two competing weapon system concepts for all three Services. In the Air Force, the JSF will replace F-16 and A-10 and will complement the F-22. The Air Force version will feature Conventional Takeoff and Landing (CTOL). In the Navy it will complement F/A-18E/F Super Hornet currently in production. The Marine Corps requested a Short Takeoff Vertical Landing (STOVL) aircraft to replace the AV-8B and F-18 Hornet. The total number of 3,038 aircraft are expected to be produced. From this number 2,036 aircraft are to be built for the Air Force. It will certainly become the most produced aircraft in the 21<sup>st</sup> century. The unit flyaway costs are also very promising. It is \$ 28 million for CTOL, \$ 35 million for STOVL, and \$ 38 million for carrier – based version.

The JSF will be primarily powered by one F119-PW-100 turbofan, which also powers the F-22. The JSF Lockheed Martin and Boeing engine configurations both share a common core. An alternate engine program began in 1996 designated as the General Electric F120. The empty aircraft should weigh about 10,000 kg with maximum takeoff weight of 22,700 kg. It will carry approximately 6,800 kg of internal fuel and more than 6,000 kg of internally loaded payload. This will greatly increase combat radius. The JSF will employ the state-of-art integrated avionics with advanced sensors and off board data

fusion. The JSF will have 70-90% commonality for all service variants to reduce development, production, and total ownership costs [Ref. 16 and 36].

Lockheed Martin has designed the X-35 concept and Boeing the X-32 concept.

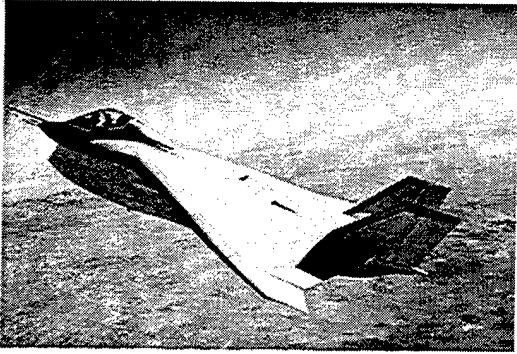


Figure 38. X-32 Concept. From Ref. [15].

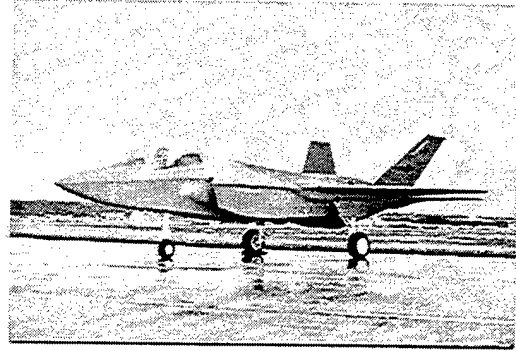


Figure 39. X-35 Concept. From Ref. [13].

### C. RUSSIA

In Russia, three design bureaus are capable of developing and producing a front-line fighter aircraft. These are Mikoyan, Sukhoi, and Yakovlev. Although there is much uncertainty about current aircraft developments, due to lack of necessary financial resources, it can be stated that Russia is following the same path as the USA. Their long-term goal is to develop and procure one type of air superiority aircraft designated as MFI, and one lighter tactical fighter, designated as LFI or LFS. The result of these developments depends very much on financing. Two projects are under consideration for the air superiority aircraft – MiG 1.42/1.44 MFI (Multi-functional Front-line Fighter) and the famous Sukhoi S-37 Berkut. Both have been designated as research vehicles and technology demonstrators. One of those concepts will lead to the procurement of Russia's fifth generation air superiority aircraft, replacing the Su-27 Flanker and its derivatives. As far as the Lightweight Front-line Fighter (LFI) concept is concerned, two concepts will likely compete for it. These are the Sukhoi S-55 and Mig I-2000, with possible involvement of the Yakovlev design bureau to work on the V/STOL concept.

## 1. ANPK MiG (Aviation Scientific – Industrial Complex)

### a. *Mig 1.42/1.44*

The program began in 1983 as a future replacement for Mig-29 and Su-27. Final MFI configuration was adopted in 1991. MiG 1.42 was later selected as the Russian Air Forces' fifth generation fighter. Further developments led to the 1.44 version, which is currently used as a technology demonstrator. The basic design is based around twin-fin delta canard with large movable foreplanes and very widely spaced outward-canted twin tailfins. The composite materials account for about 30% of the airframe. The new aircraft will be powered by two Saturn/Lyulka AL-41F turbofans, each rated at approximately 175 kN with afterburning. Production aircraft will have integrated avionics based on Phazotron N014 Zhuk – RN radar with active phased-array antenna. One of the combat modes will be Beyond Visual Range air combat which will be greatly enhanced by using new – generation air-to-air missile R-37 with a range of about 300 km. Standard armament will probably consist of R-77 Adder air-to-air missiles. The unit cost will probably exceed \$ 70 million [Ref. 37].

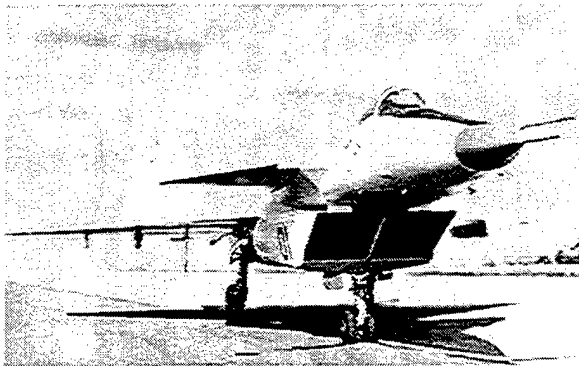


Figure 40. MiG 1.42 Aircraft. From Ref. [24].



*b. Mig I-2000*

The design work on this project probably began at the same time as the MFI concept. The first proposal was powered by single RD – 33 turbofan and was very similar to the F-16. This design was later offered by Mikoyan to China as the FC-1 fighter. The MiG I-2000 is designed in a low-observable configuration with well-shielded diamond shaped engine intakes. Further enhancements consist of supersonic cruise, internal carriage of basic weapons, and possible V/STOL capabilities. Mikoyan is considering both single and two-engine variants. The previous variants were powered by RD-33 and later by RD-133 engines. However, future development will be probably based on a single-engine platform configured with the AL-41F turbofan with a three-dimensional thrust-vectoring nozzle. The aircraft should be noticeable smaller than MiG-29 with maximum takeoff weight of about 16,000 kg [Ref. 16 and 18].

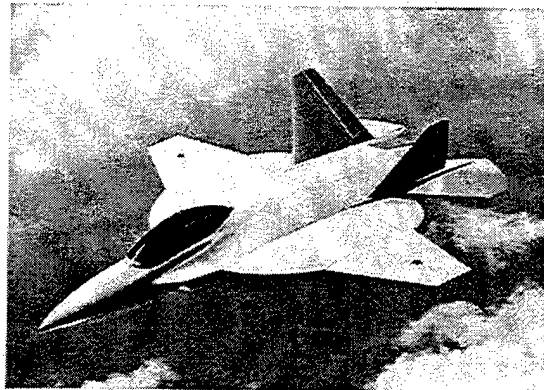


Figure 41. MiG I-2000 Aircraft. From Ref. [24].

## 2. AVPK Sukhoi (Aviation Military – Industrial Complex)

### a. *S-37 Berkut*

Developmental work on this remarkable aircraft began around 1987. It was first designated as S-32. This project started as a research program to explore post-stall maneuverability and super-maneuverability. It had been promoted as an alternative for the MiG 1.42, but this information was denied recently, leaving the S-37 as a research vehicle and technology demonstrator. The aircraft made its maiden flight in 1997. The S-37 incorporates the features and technologies of a fifth-generation fighter aircraft.

The aircraft features forward-swept wings, which promises a range of benefits in aerodynamics at subsonic speeds and should demonstrate 120 degrees of AoA. Major components seem to be standard Su-27 parts. The wings are mostly made of composites. The aircraft has large canards mounted on the intake side, close to leading edge of the wing. The S-37 is powered by two D-30F6 turbofans, each 153 kN with afterburning, but these will be potentially replaced by AL-41F rated at 175 kN with three-dimensional thrust – vectoring. The aircraft does not have fully specified avionics, but it will certainly be built around an active phased-array radar. Some sources report provisions for conformal weapons carriage with a total of 12 hardpoints. The aircraft will employ standard air-to-air missiles like R-77 Adder and R-73 Archer [Ref. 16 and 18].

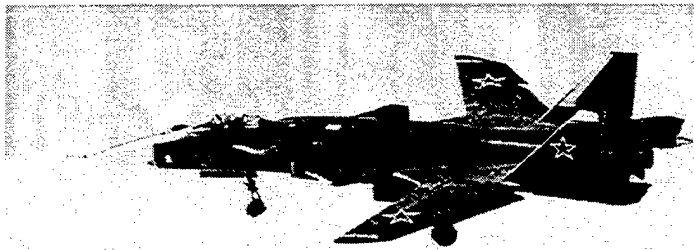


Figure 42. S-37 Aircraft. From Ref. [4].

*b. S-55*

This project is one big unknown since it has been changed several times and further progress is held in secrecy. Its origins go back to 1990, when the Russian Air Force specified a requirement to replace Aero L-29 and L-39 trainer aircraft. The project began as a development of a two-seat advanced jet trainer and light combat aircraft. The Sukhoi design bureau described the new design as a scaled-down development of the Su-27. The basic concept was later understood as a development of a light combat aircraft with secondary advanced training capabilities. The program then led to designation as S-55. The S-55 will be probably powered by one Saturn/Lyulka AL-37FP or AL-37FU afterburning turbofan with a thrust-vectoring nozzle. There are no further details available at this time, but some sources unveiled that the S-55 could be redesigned to incorporate technology from the S-37 project [Ref. 38].

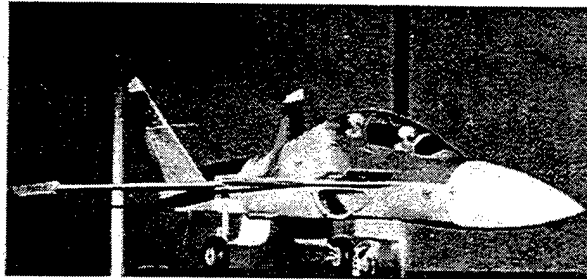


Figure 43. S-55 Aircraft. From Ref. [24].

The following table is a summary of known parameters of the MFI competing projects.

Parameter	MiG 1.42	S-37
crew	1	1
length	20 m	22.6 m
wing span	16.4 m	16.7 m
height	5.6 m	6.4 m
engines	2 x AL-41F 91/175 kN	2 x AL-41F 91/175 kN
max. takeoff weight	34,500 kg	34,000 kg
payload	6,500 kg	-----
service ceiling	18,500 m	18,800 m
Maximum speed	2,600 km/hr	2,200 km/hr

Table 13. Russian MFI Projects Comparison.

#### D. ASIA

Asian countries want to gain independence in developing front-line fighter aircraft. Most of them are turning their attention to the development of indigenous fighter aircraft, with some transfer of technology. Some nations are able to develop light combat aircraft independently, but they usually need assistance with development of advanced multi-role fighter aircraft. This problem was solved in the past by purchasing some types of aircraft. However governments now seek more independence and larger involvement of their industrial base for production of military aircraft. The easiest way is to purchase a license for production, which is connected with transfer of technologies and know-how thus providing more opportunities for future independent developments.

1. **Japan**

a. *F-2*

In 1982, Japan announced a requirement for a new military aircraft, which would replace F-1 fighter support aircraft. This project was later known as FS-X. None of the competing aircraft met specified requirements; therefore the Japanese government decided to develop an indigenous aircraft. In 1986, the Japanese government opened the competition once again and in 1988, the United States and Japan agreed to cooperatively develop the FS-X fighter aircraft.

In 1996, the designation F-2 was officially assigned to the FS-X project with the single-seater designated as F-2A and the two-seater as F-2B. The F-2 configuration is based on Lockheed's F-16 block 40 fighter, but it has 25% larger wing, longer fuselage, and longer horizontal and vertical tails. The aircraft is powered by one General Electric F110-GE-129 turbofan. Avionics is provided by domestic companies featuring an active phased-array radar. Armament can be deployed on 13 external store stations. Production deliveries will continue beyond 2010 [Ref. 16 and 23].

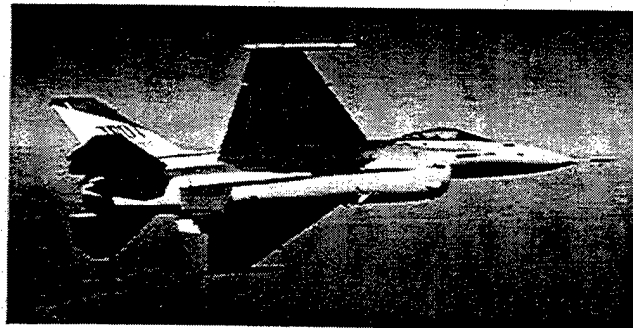


Figure 44. F-2 Aircraft. From Ref. [16].

## 2. China, Peoples Republic

### a. FC-1

The FC-1 (Fighter China) is a single-seat tactical fighter and ground attack aircraft. This project was launched in 1991 after the cancellation of US participation in the development of Chengdu Super 7 aircraft. The FC-1 was most likely developed with some design assistance from the Mikoyan design bureau. Russians might use their experience from the development of single-engined MiG-33.

The aircraft is designed as mid-mounted delta wing with narrow wingroot strakes at the leading edge and conventional servo-operated flying controls with a single analogue FBW system. The FC-1 will be powered by one RD-93 turbofan rated at 81.4 kN with afterburning. The avionics suit is still under consideration. Maximum payload of 3,800 kg can be deployed on 7 hardpoints. Maximum takeoff weight is 12,700 kg. The FC-1 will be produced for the Chinese and Pakistani Air Forces. Projected unit cost is about \$ 15 million [Ref. 39].

### b. J-10

The J-10 is a multi-role tactical fighter with the performance likely matching aircraft like the Mirage 2000. However, sources report that it is in the same performance class like Eurofighter and Rafale fighters. This aircraft was most probably developed in the cooperation with Israel, which used its experience from the cancelled Lavi program. Both developers had problems with the propulsion system. This problem was solved in 1991, when China acquired Russian AL-31F turbofan rated at 122.6 kN with afterburning.

The J-10 features a delta wing canard configuration, which ensures aircraft stability with enhanced static stability active control technology. Avionics as well as armament are still under consideration. Service entry should be in about 2005 [Ref. 23].

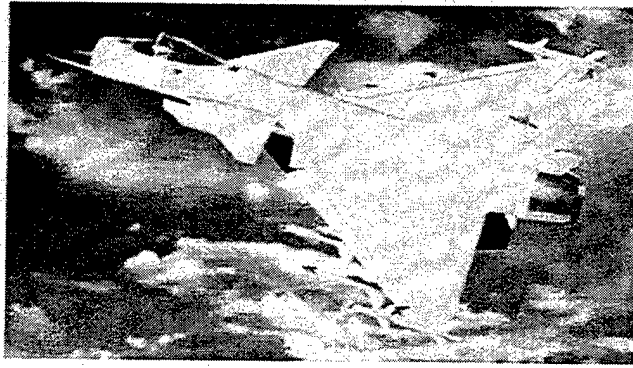


Figure 45. J-10 Aircraft. From Ref. [16].

*c. J-11*

The J-11 is the Chinese designation for the Russian Su-27 Flanker. It is a multi-role fighter-bomber and air superiority aircraft, which can also be used in the maritime strike role. The program started in 1996, when China obtained a license to manufacture 200 Su-27 aircraft. In 1999, Russia agreed to sell about 72 Su-30 front-line fighters to China. This is designated as Su-30MKK, especially modernized to meet Chinese requirements. Licensed production of this aircraft is also under consideration [Ref. 16 and 40].

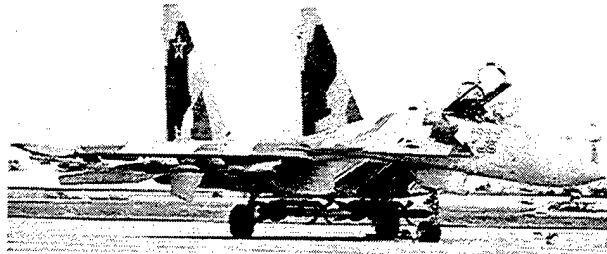


Figure 46. J-11 (Su-27) Aircraft. From Ref. [16].

### 3. India

#### *a. LCA*

In 1983, the Indian government approved the Light Combat Aircraft (LCA) development program. Project definition began in 1987 to develop an aircraft replacing the MiG-21. The program was delayed several times. The aircraft features shoulder-mounted delta wings with compound sweep on leading edges. Great attention is paid to the use of composite materials. The LCA is powered by one General Electric F404-GE-F2J3 afterburning turbofan rated at 80.5 kN. Avionics suit will be equipped by domestic companies. The maximum payload of 4,500 kg can be deployed on seven external store stations. The aircraft can reach maximum speed of 1,850 km per hour at altitude with the service ceiling of 15,200 m. The development has not been completed yet; therefore, the production will begin after 2003 [Ref. 16 and 23].

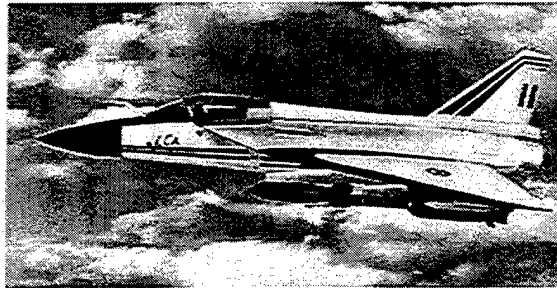


Figure 47. LCA Aircraft. From Ref. [16].

#### *b. MCA*

The Indian government also requested a study of the LCA advanced version, which was designated as Medium Combat Aircraft (MCA). The MCA is a potential replacement for Jaguars and Mirage 2000 aircraft starting in 2008. The twin-engined MCA would embody stealth technology.



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## VIII. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

The Czechoslovak Air Force was established on October 30, 1918, just two days after the proclamation of independence from the Austro-Hungarian Empire. Wave of enthusiasm supported the establishment of Czechoslovak Armed Forces, able to protect new state of the Czechs and the Slovaks. This task was accomplished with the help of French military mission under the leadership of General Pelle. The establishment of the Czechoslovak Armed Forces was be impossible without such help. The Czechoslovak government paid particular attention to the development of the CAF, since aircraft proved to be very useful during WWI.

From the very beginning, Czechoslovak pilots had to use only a few aircraft, which were confiscated after the WWI. The lack of aircraft was solved by the delivery of the French SPAD S. VII. aircraft. The following years were characterized by rapid expansion of the CAF. Growing demand for aircraft led to the establishment of Czechoslovak aircraft companies, which were soon able to develop and produce front-line military aircraft. The peak of the inter-war period was the development of Avia B-135 aircraft, which was comparable to world's best aircraft.

The occupation of Czechoslovakia by Nazi Germany brought destruction of the Czechoslovak Armed Forces and confiscation of all its equipment. Czechoslovak pilots who escaped from Czechoslovakia fought against Germany on both fronts of WWII. After the end of WWII, Czechoslovak pilots returned to their country together with a huge variety of aircraft. It was necessary to create new organizational structure of the CAF based on pilots and aircraft returning from the Soviet Union and Great Britain. New plans suggested robust organization, which did not reflect the availability of necessary financial and human resources. After the Communist revolution of 1948, many ex-RAF pilots were forced to leave the CAF. The lack of personnel then led to immediate establishment of pilot training schools. Czechoslovak aircraft companies recovering from

war trauma began to develop new aircraft. Most of them were able to develop and produce military jet aircraft. The Communist coup de etat terminated such projects, since the CAF was redesigned along Soviet lines and Czechoslovakia received deliveries of Soviet aircraft. Czechoslovak companies then co-produced Soviet military aircraft.

High standard of the morale and readiness of the CAF was affected by political upheaval within the Czechoslovak Communist Party. In 1968, it eventually led to the invasion of Czechoslovakia by armies of the Warsaw Pact. The purge of the Czechoslovak Armed Forces followed soon. In the meantime, the Aero company was able to develop and produce excellent jet training aircraft L-29 and L-39. The peak of the CAF development was achieved in 1980s with deliveries of MiG-29 and Su-25K aircraft.

After the end of the Cold War and the "Velvet Revolution" of 1989, Czechoslovakia began to reduce its Armed Forces to meet the terms of Vienna treaty about conventional forces in Europe. Many pilots retired and many aircraft had to be destroyed. At the end of 1992, the Slovaks decided to leave the Czechoslovak Federation with and the Czechoslovak Armed Forces were split into two parts. Further downsizing and complete reorganizations were necessary to adjust the structure to new environment.

The government of the Czech Republic, busy with extensive economic transformation, paid little attention to its Armed Forces. This caused gradual decline, and left the CAF with obsolete second-generation aircraft and inappropriate infrastructure. The problem of aircraft obsolescence was only partially solved by the development of the L-159 ALCA aircraft with its primary Close Air Support mission. The deliveries began last year and the CAF will operate 72 of them. The Czech Republic does not have sufficient capabilities to develop and produce front-line fighter aircraft; therefore it wants to purchase 36 multi-role fighter aircraft with deliveries starting around 2004.

Five companies and aircraft will compete for this order. These are F/A-16 Fighting Falcon, F/A-18 Super Hornet, Mirage 2000-5, JAS-39 Gripen, and Eurofighter (Typhoon). The author, however, included MiG-29 SMT for wider comparison. This makes sense considering that the CAF operated MiG-29s up to 1995. This should be

benchmark, because the Czech Republic intends to build a quality Air Force. The MiG-29 is a third-generation aircraft, which would not meet contemporary requirements, mostly because of avionics. Therefore, the MiG-29 SMT has been taken into consideration, since it is a modernized and updated version of the MiG-29. The MiG-29 SMT is surely a three and half-generation aircraft and falls in the same category as the F-16 and Mirage 2000-5. These aircraft are competing against forth-generation aircraft represented by the JAS-39 and the Eurofighter.

Chapter V deals with decision criteria, which provide data about LCC of each aircraft and its relative effectiveness or quality. The LCC are based on available information about aircraft procurement costs and costs per flying hour. The author did not include mission personnel costs, because the procurement of new aircraft would certainly require a change of the CAF organization structure regardless of aircraft chosen. Thus, costs per flying hour include costs which really matter. It has to be said that all numbers are based on unclassified information available and appropriate estimates. Perfect information is not readily available in the real world, but decisions have to be made. Table 6 give us approximate LCC in net present values for each aircraft by taking into account its 20-year service.

Relative effectiveness of an aircraft is usually a very controversial matter; therefore, the author used the TASFORM-AIR methodology, which uses basic aircraft characteristics. All aircraft have been compared in both air combat and surface attack missions. Table 8 summarizes all calculations with the last representing composite scores. The greatest weight is given to air combat roles, because the L-159 ALCA was designed mostly for ground attack missions. One would probably wonder, why the JAS-39 performed so poorly, but it has to be understood that it was designed as a small aircraft with limited range and payload. The following graph depicts the TASFORM scores against LCC.

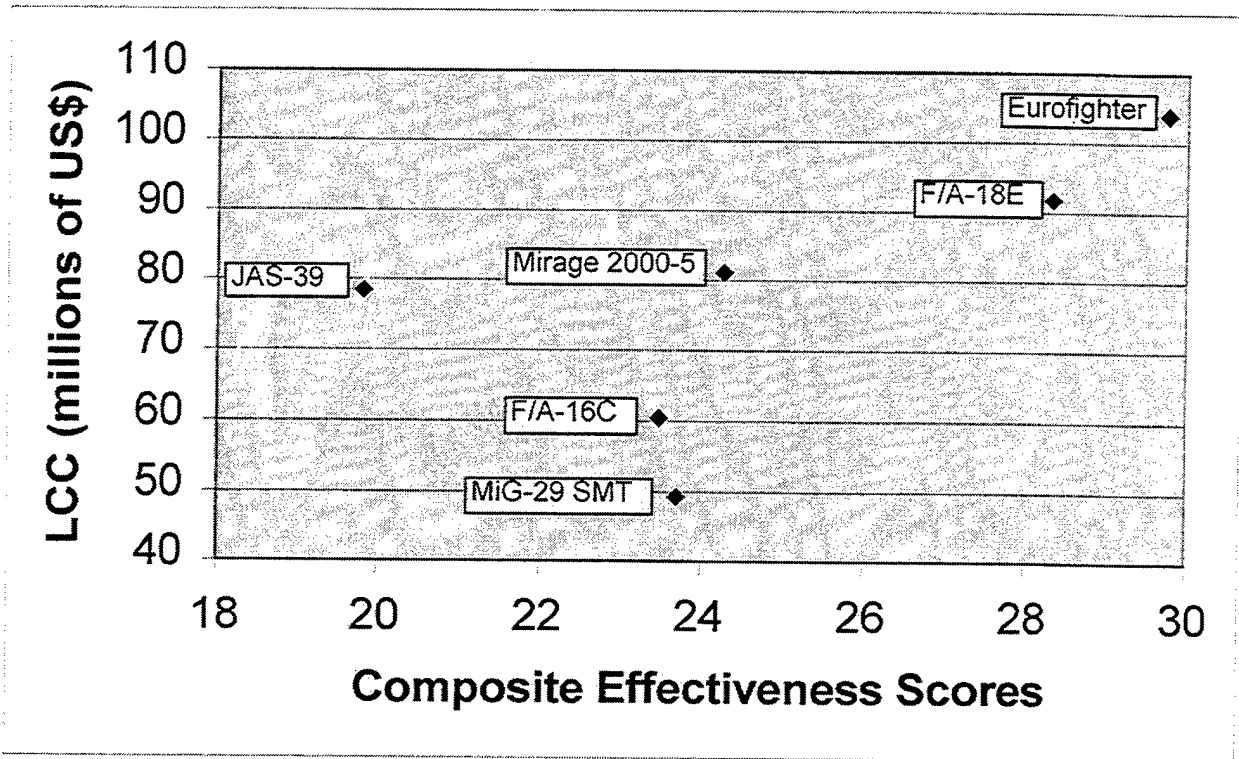


Figure 48. Composite Effectiveness Scores with LCC.

It is clear that quality costs money. While quality is very important, one has to also consider the economic capabilities of the Czech Republic. Although the military budget reached 2% of GDP, the Czech Armed Forces are not able to finance the procurement of modern fighters from that budget. The nominal Czech GDP was about \$ 56.4 billion and military budget about \$ 1.145 billion in 2000. The purchase of 36 fighters could cost up to \$ 2 billion. Czech DoD made substantial changes in the structure of financial outlays to allocate about 24% of its annual budget to investment outlays. Most of investment outlays will be used for the procurement of L-159 ALCA during the next four years. The Czech government can use debt financing or leasing to procure new aircraft. However, it is in government's own interest to limit that debt as much as possible.

At the same time, the Czech government has to be aware of future military aircraft developments throughout the world. The trend is to operate fewer but more capable aircraft. Bigger nations have turned their attention to force structure of one air-superiority aircraft, and one multi-role fighter optimized to air-to-ground missions. Smaller nations, or nations with limited financial resources, clearly pursue one multi-role fighter and one light combat aircraft. Nations like the United States and Russia skipped the development of a fourth-generation aircraft and will acquire directly a fifth-generation aircraft. A fourth-generation aircraft is certainly very expensive; therefore, a three and half-generation aircraft should be considered as a standard.

## **B. RECOMMENDATIONS**

In January, the Czech government announced an official request for the delivery of 24-36 multi-role fighter aircraft in January 2001. Aircraft companies have to submit their specifications in May and the final decision should be made known in October 2001. A commission of 14 members has been established for this purpose, representing Departments of Defense, State, Trade and Industry, and Treasury. Their decision will surely not be one of purely technical and financial considerations. They have to take into account political environment as well as the government's request for offset programs. The Czech government requires a minimum of 150% in offset programs, which are divided into specific categories. The reason for this is to bring more foreign investment into the country and enhance export of Czech products. These matters further complicate already difficult technical and financial considerations. This acquisition can be covered either by debt financing or by leasing agreement, since there are not sufficient resources in the government budget nor in the military.

The history of the CAF shows that there are important milestones repeating every 20 years. One of such milestones will be the acquisition of modern fighters, which will form the backbone of the CAF for the next 20 years. The author has provided important decision criteria in Chapter V. These criteria are LCC and relative effectiveness of each aircraft. The cheapest solution would be the acquisition of the MiG-29 SMT, which also provides very good average TASCFORM score in its category. This aircraft is not taking part in this competition, because it is not politically advisable to purchase aircraft from Russia. Further fate of the MiG-29 SMT is not clear even in Russia, which means

potential problems with spare parts. The Czech Republic had problems with spare parts while operating an older version of the MiG-29. On the other hand, the Czechs could purchase new aircraft by amortizing Russian debt against the Czech Republic, accounting for about \$ 3.7 billion.

The fourth-generation aircraft are too expensive for the Czech environment. The least expensive of them is JAS-39. This aircraft received the lowest TASFORM score although it is clearly a fourth-generation aircraft. One of the explanations is that the Gripen was designed for neutral Sweden; therefore range and payload were adjusted to fit the Swedish environment. Another reason can be that the advantages of a fourth-generation aircraft are difficult to quantify because, we know that its effectiveness is largely based on data fusion for greater situation awareness.

The Czech Republic became a member of NATO in 1999. It should not only benefit from the collective defense, but contribute to it. Therefore, it is necessary to account for the deployment of the CAF air units out of the Czech territory. Making all logical eliminations should leave us with a standard three and half-generation aircraft. The purchase of such a category of aircraft is highly advisable since it not only provides required quality but also limits the size of predictable debt.

A significant consideration should also be future spare parts availability. Some aircraft have clear future with continuing production and deliveries while other will certainly terminate. The author would recommend the purchase of a three and half-generation aircraft with sufficient future production rates. At the same time, the Czech Republic should take part in a major development program of a future aircraft, at least at the level of requirements formulation. This would greatly enhance similar decisions in the future.

## APPENDIX A. AIRCRAFT O&S COST ELEMENT STRUCTURE DEFINITIONS

### 1.0 MISSION PERSONNEL

The mission personnel element includes the cost of pay and allowances of officer, enlisted, and civilian personnel required to operate, maintain, and support a discrete operational system or deployable unit. This includes the personnel necessary to meet combat readiness, unit training, and administrative requirements. For units that operate more than one type of aircraft system, personnel requirements will be allocated on a relative workload basis. The personnel costs will be based on manning levels and skill categories.

**1.1 Operations.** The pay and allowances for the full complement of aircrew personnel required to operate a system. Aircrew composition includes the officers and enlisted personnel (pilot, non-pilot, and crew technicians) required to operate the aircraft of a deployable unit.

**1.2 Maintenance.** The pay and allowances of military and civilian personnel who perform maintenance on and provide ordnance support to assigned aircraft, associated support equipment, and unit-level training devices. Depending on the maintenance concept and organizational structure, this element will include maintenance personnel at the organizational level and possibly the intermediate level. A brief description of these maintenance categories is shown below:

- Organizational Maintenance. Personnel who perform on-equipment maintenance for unit aircraft.
- Intermediate Maintenance. Personnel who perform off-equipment maintenance for unit aircraft. If intermediate-level maintenance is provided by a separate support organization (e.g., a centralized intermediate maintenance support activity) the costs should be reported in element 3.0, Intermediate Maintenance (External to Unit).



- Ordnance Maintenance. Personnel performing maintenance and service functions for aircraft munitions, missiles, and related systems. Also includes personnel needed for loading, unloading, arming, and dearming of unit munitions; inspecting, testing, and maintaining of aircraft weapons and release systems; activation and deactivation of aircraft gun systems; and maintenance and handling of the munitions stockpile authorized by the war reserve material plan.
- Other Maintenance Personnel. Personnel not covered above. Includes those personnel that support equipment maintenance, simulator maintenance, and Chief of Maintenance functions related to the system whose costs are being estimated.

**1.3 Other mission personnel.** The pay and allowances of military and civilian personnel who perform unit staff, security, and other mission support activities. The number and type of personnel in this category will vary depending on the requirements of the particular system. These billets exist only to support the system whose costs are being estimated. Some examples are:

- Unit Staff. Personnel required for unit command, administration, flying supervision, operations control, planning, scheduling, flight safety, aircrew quality control, etc.
- Security. Personnel required for system security. Duties may include entry control, close and distant boundary support, and security alert operations.
- Other Support. Personnel required for staff information, logistics, ground safety, fuel and munitions handling, and simulator operations as well as for special mission support functions such as intelligence, photo interpretation, etc.

## 2.0 UNIT-LEVEL CONSUMPTION

Unit-level consumption includes the cost of fuel and energy resources; operations, maintenance, and support materials consumed at the unit level; stock fund

reimbursements for depot-level reparable; operational munitions expended in training; transportation in support of deployed unit training; temporary additional duty/temporary duty (TAD/TDY) pay; and other unit-level consumption costs, such as purchased services for equipment leases and service contracts.

**2.1 POL/energy consumption.** The unit-level cost of petroleum, oil, and lubricants (POL), propulsion fuel, and fuel additives required for peacetime flight operations. Includes in-flight and ground consumption, and an allowance for POL distribution, storage, evaporation, and spillage. May also include field-generated electricity and commercial electricity if necessary to support the operation of the system.

**2.2 Consumable material/repair parts.** The costs of material consumed in the operation, maintenance, and support of an aircraft system and associated support equipment at the unit level. Depending on the maintenance concept or organizational structure, consumption at the intermediate level should be reported either in this element or in element 3.0, Intermediate Maintenance (External to Unit). Costs need not be identified at the level of detail shown below; the descriptions are intended merely to illustrate the various types of materials encompassed in this element:

- Maintenance Material. The cost of material expended during maintenance. Examples include consumables and repair parts such as transistors, capacitors, gaskets, fuses, and other bit-and-piece material.
- Operational Material. The cost of non-maintenance material consumed in operating a system and support equipment. Examples include coolants, deicing fluids, tires, filters, batteries, paper, diskettes, ribbons, charts, and maps.
- Mission Support Supplies. The cost of supplies and equipment expended in support of mission personnel. Examples include items relating to administration, housekeeping, health, and safety.

**2.3 Depot level reparable.** The unit-level cost of reimbursing the stock fund for purchases of depot-level reparable (DLR) spares (also referred to as exchangeables) used to replace initial stocks. DLRs may include repairable individual parts, assemblies, or subassemblies that are required on a recurring basis for the repair of major end items of equipment.

**2.4 Training munitions/expendable stores.** The cost of expendable stores consumed in unit-level training. Includes the cost of live and inert ammunition, bombs, rockets, training missiles, sonobuoys, and pyrotechnics expended in noncombat operations (such as firepower demonstrations) and training exercises.

**2.5 Other.** Include in this element any significant unit-level consumption costs not otherwise accounted for. The costs identified must be related to the system whose operating and support requirements are being assessed. Possible examples are:

- Purchased Services. The cost of special support equipment, communication circuits, and vehicles, including service contracts for custodial services, computers, and administrative equipment.
- Transportation. The deployed unit transportation cost of moving primary mission and support equipment, repair parts, secondary items, POL, and ammunition to and from training areas. May also include transportation costs for items procured or shipped by the unit. Excluded are transportation costs for reparable acquired through DBOF.
- TAD/TDY. Temporary additional duty or temporary duty (TAD/ TDY) pay. The cost of unit personnel travel for training, administrative, or other purposes such as crew rotations, deployments, or follow-on tests and evaluation. Includes commercial transportation charges, rental costs for passenger vehicles, mileage

allowances, and subsistence expenses (e.g., per diem allowances and incidental travel expenses).

### **3.0 INTERMEDIATE MAINTENANCE (EXTERNAL TO UNIT)**

Intermediate maintenance performed external to a unit includes the cost of labor and material and other costs expended by designated activities/units (third and fourth echelon) in support of an aircraft system and associated support equipment. Intermediate maintenance activities include calibration, repair, and replacement of parts, components, or assemblies, and technical assistance.

**3.1 Maintenance.** The pay and allowances of military and civilian personnel who perform intermediate maintenance on an aircraft system, associated support equipment, and unit-level training devices.

**3.2 Consumable material/repair parts.** The costs of repair parts, assemblies, subassemblies, and material consumed in the maintenance and repair of aircraft, associated support equipment, and unit-level training devices.

**3.3 Other.** Include in this element any significant intermediate maintenance costs not otherwise accounted for. For example, this could include the cost of transporting subsystems or major end items to a base or depot facility.

### **4.0 DEPOT MAINTENANCE**

Depot maintenance includes the cost of labor, material, and overhead incurred in performing major overhauls or maintenance on aircraft, their components, and associated support equipment at centralized repair depots, contractor repair facilities, or on site by depot teams. Some depot maintenance activities occur at intervals ranging from several months to several years. As a result, the most useful method of portraying these costs is on an annual basis (e.g., cost per aircraft system per year) or an operating-hour basis.

**4.1 Overhaul/rework.** The labor, material, and overhead costs for overhaul or rework of aircraft returned to a centralized depot facility. Includes programmed depot maintenance, analytic condition inspections, and unscheduled depot maintenance. Costs of major aircraft subsystems that have different overhaul cycles (i.e., airframe, engine, avionics, armament, support equipment) should be identified separately within this element.

**4.2 Other.** Include in this element any significant depot maintenance activities not otherwise accounted for. For example, this could include component repair costs for reparable not managed by the DBOF, second-destination transportation costs for weapons systems or subsystems requiring major overhaul or rework, or contracted unit-level support.

## **5.0 CONTRACTOR SUPPORT**

Contractor support includes the cost of contractor labor, materials, and overhead incurred in providing all or part of the logistics support required by an aircraft system, subsystem, or associated support equipment. Contract maintenance is performed by commercial organizations using contractor personnel, material, equipment, and facilities or government-furnished material, equipment, and facilities. Contractor support may be dedicated to one or multiple levels of maintenance and may take the form of interim contractor support (ICS) if the services are provided on a temporary basis or contractor logistics support (CLS) if the support extends over the operational life of a system. Other contractor support may be purchased for engineering and technical services.

**5.1 Interim contractor support.** Interim contractor support (ICS) includes the burdened cost of contract labor, material, and assets used in providing temporary logistics support to a weapon system, subsystem, and associated support equipment. The purpose of ICS is to provide total or partial logistics support until a government maintenance capability is developed.

**5.2 Contractor logistics support.** Contractor logistics support (CLS) includes the burdened cost of contract labor, material, and assets used in providing support to an aircraft system, subsystem, and associated support equipment. CLS funding covers depot maintenance and, as negotiated with the operating command, necessary organizational and intermediate maintenance activities. If CLS is selected as the primary means of support, all functional areas included in the CLS cost should be identified.

**5.3 Other.** Include in this element any contractor support costs not otherwise accounted for. For example, if significant, the burdened cost of contract labor for contractor engineering and technical services should be reported here.

Note: Contractor support during the pre-operational phase of a system is typically funded as a system development or investment cost. However, post-operational contractor support is an O&S cost and should be addressed in this element.

After the ICS period, the government assumes responsibility for supporting a weapon system. However, contractor support may still be employed in specific functional areas, such as sustaining engineering, software maintenance, simulator operations, and selected depot maintenance functions. Applicable contractor costs should be reported against these elements in the CES. To avoid double counting, the contractor support element should be annotated to identify any contractor costs that are reported in other elements.

## **6.0 SUSTAINING SUPPORT**

Sustaining support includes the cost of replacement support equipment, modification kits, sustaining engineering, software maintenance support, and simulator operations provided for an aircraft system. War readiness material is specifically excluded.

**6.1 SUPPORT EQUIPMENT REPLACEMENT.** The costs incurred to replace equipment that is needed to operate or support an aircraft, aircraft subsystems, training systems, and other associated support equipment. The support equipment being replaced (e.g., tools and test sets) may be unique to the aircraft or it may be common to a number of aircraft systems, in which case the costs must be allocated among the respective systems.

**6.2 Modification kit procurement/installation.** The costs of procuring and installing modification kits and modification kit initial spares (after production and deployment) required for an aircraft and associated support and training equipment. Includes only those modification kits needed to achieve acceptable safety levels, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excludes modifications undertaken to provide additional operational capability not called for in the original design or performance specifications.

**6.3 Other recurring investment.** Include in this element any significant recurring investment costs not otherwise accounted for.

**6.4 Sustaining engineering support.** The labor, material, and overhead costs incurred in providing continued systems engineering and program management oversight to determine the integrity of a system, to maintain operational reliability, to approve design changes, and to ensure system conformance with established specifications and standards. Costs in this category may include (but are not limited to) government and/or contract

engineering services, technical advice, and training for component or system installation, operation, maintenance, and support.

**6.5 Software maintenance support.** The labor, material, and overhead costs incurred after deployment by depot-level maintenance activities, government software centers, laboratories, or contractors for supporting the update, maintenance and modification, integration, and configuration management of software. Includes operational, maintenance, and diagnostic software programs for the primary system, support equipment, and training equipment. The respective costs of operating and maintaining the associated computer and peripheral equipment in the software maintenance activity should also be included. Not included are the costs of major redesigns, new development of large interfacing software, and modifications that change functionality.

**6.6 Simulator operations.** The costs incurred to provide, operate, and maintain on-site or centralized simulator training devices for an aircraft system, subsystem, or related equipment. This may include the labor, material, and overhead costs of simulator operations by military and/or civilian personnel, or by private contractors.

Note: On-site simulator operations and maintenance that are an integral part of unit manning and unit consumption should be reported as unit-level mission costs for the system in question. However, the costs of all contract-funded simulator operations and all centralized government simulator operations should be reported in this element.

**6.7 Other.** Include in this element any significant sustaining support costs not otherwise accounted for. Examples might include the costs of follow-on operational tests and evaluation, such as range costs, test support, data reduction, and test reporting.



## 7.0 INDIRECT SUPPORT

Indirect support includes the costs of personnel support for specialty training, permanent changes of station, and medical care. Indirect support also includes the costs of relevant host installation services, such as base operating support and real property maintenance.

**7.1 Personnel support.** Personnel support includes the cost of system-specific and related specialty training for military personnel who are replacing lost through attrition. Also included in this element are permanent change of station costs, and the cost of medical care. Each of these elements should be addressed separately. Descriptions are provided below:

- Specialty Training. The cost of system-specific training (non-investment funded) and specialty training for military personnel who are replacing individuals lost through attrition. For example, specialty training costs may include undergraduate pilot training, non-pilot aircrew training, non-aircrew officer training, and enlisted specialty training. Replacement specialty training costs should be calculated for those personnel associated with the system being investigated. Training costs should include government non-pay-related training costs (course support costs, materials, per diem, travel, etc.) as well as the cost of pay and allowances for trainees, instructors, and training support personnel. Excluded are recruiting, accession, basic military training, and separation costs.
- Permanent Change of Station (PCS). The cost of moving replacement personnel to and from overseas theaters and within the continental United States.
- Medical Support. The cost of personnel pay and allowances and material needed to provide medical support to system-specific mission and related military support personnel.

**7.2. Installation support.** Consists of personnel normally assigned to the host installation who are required for the unit to perform its mission in peacetime. Include only those personnel and costs that are directly affected by a change in the number of aircraft and associated mission personnel. Functions performed by installation support personnel include:

- Base Operating Support. The cost of personnel pay and allowances and material necessary to provide support to system-specific mission-related personnel. Base operating support activities may include functions such as communications, supply operations, personnel services, installation security, base transportation, etc.
- Real Property Maintenance. The cost of personnel pay and allowances, material, and utilities needed for the maintenance and operation of system-specific mission-related real property and for civil engineering support and services.

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## APPENDIX B. O&S COST MODELS

In order to estimate the O&S costs, many analysts use computer-based models to help them with their prediction. Different agencies use different types of models and common experience is that they prefer certain set of models, which best fit, their environment.

Three O&S cost models widely used in the USA are the Cost Analysis Strategy Assessment (CASA) model, the Air Force's Cost Oriented Resources Estimating (CORE) model, and Automated Cost Estimating-Integrated Tools (ACE-IT) [Ref. 27].

### A. CASA

The CASA model is basically a management decision-aid tool for LCC. CASA is a set of analysis tools formulated into one functioning unit. It contains a number of programs and submodels that, along with LCC comparisons and summations, allow the user to generate program data files, perform life-cycle costing, perform sensitivity analysis, and perform LCC risk analysis. CASA offers a wide variety of pre-programmed output report formats designed to support the analysis process. United States Army Materiel Command LOGSA is responsible for further development of CASA.

CASA covers the entire life of the system, from its initial research costs to those associated with yearly maintenance. It also covers spares, training costs, and other expenses once the system is delivered. The model calculates and projects the O&S costs over the 20 to 30 years of system operation. The CASA model employs some 82 algorithms with 190 variables. Only a small number of inputs are mandatory. Most of the inputs are optional and are subject to tailoring to the needs of the analysis.

CASA works by taking the data entered, calculating the project costs and determining the probabilities of meeting, exceeding, or falling short of any LCC target value. CASA offers a variety of strategy options and allows for alteration of original parameters to observe the effects of such changes on strategy options.

## **B. CORE**

The CORE model is documented in Air Force Instruction (AFI) 65-503. It is designed to provide a cost-estimating model that may be used to develop aircraft squadron annual operating and support cost estimates. The CORE model follows the cost element structure guidelines set forth in the Office of Secretary of Defence Cost Analysis Improvement Guide (described above). It can be used for either programming exercises or LCC studies. Input information can be taken either from AFI 65-503 or developed independently.

## **C. ACE-IT**

Originally conceived by the Air Force, ACE-IT development has been jointly managed and adapted by the Air Force and the Army. It was developed by a private consulting firm Telecote Research, Inc. The Navy has recently adopted ACE-IT as a recommended tool for their cost analysis. The early use of Integrated Product team principles brought the user community into the development phase. The resulting product incorporates commercial off the shelf software, a user-friendly interface to a familiar spreadsheet like tool, structured around the cost estimating process. ACE-IT is used to develop LCC estimates within standard guidelines. It can be used to conduct sensitivity and risk analysis.

Generally, useful model should be comprehensive, sensitive, flexible, simple, and easily modified.

Key aircraft design features affecting O&S costs are:

- Reliability
- Maintainability
- Fuel consumption
- Engine durability

## APPENDIX C. SAMPLE CALCULATIONS

### A. LCC CALCULATIONS FOR THE F-16 AIRCRAFT

#### 1. Procurement cost

Procurement cost for the F-16 aircraft was derived from recent sales, contracts under consideration, and data published in expert magazines or news releases. The following table is an example of how such data were handled to derive procurement costs for each aircraft.

Country	Total contract	Number of aircraft	Price per aircraft
Israel	\$ 4.5 billion	110	\$ 40.9 million
Greece	\$ 2 billion	50	\$ 40 million
Bahrain	\$ 303 million	10	\$ 30.3 million
Egypt	\$ 950 million	24	\$ 39.58 million

Table 14. Recent Sales of the F-16 Aircraft.

#### Sources:

- Jane's weekly
- Code one magazine
- [www.newstime.com](http://www.newstime.com)
- [www.lmaeronautics.com](http://www.lmaeronautics.com)
- [www.flug-revue.rotor.com](http://www.flug-revue.rotor.com)

As a result, the procurement cost of the F-16 was predicted for \$ 40 million per aircraft.

## 2. Operation and Support costs

It is very difficult to estimate O&S costs for a specific aircraft in a specific country. Available O&S cost models rely on extensive databases derived from experience in specific countries. First order estimates are provided in order to illustrate the methodology in Chapter V. As more data become available, more precise estimates are possible. This study focused on Cost Per Flying Hour (CPFH) as the most important driver of the O&S cost. The author expects the Czech Air Force will authorize two pilots per aircraft, each flying 150 hours per year, for a total of 300 hours per year per aircraft. The CPFH includes consumables, depot level reparable, fuel, and depot maintenance. According to U.S. AFI 65-503, the CPFH of the F-16 is \$ 3,775. Detailed description of the CPFH calculation is provided in Table 15.

	F/A-16C	F/A-18E	Mirage 2000-5	JAS-39	Eurofighter	MiG-29 SMT
Consumables	332	498	460	450	580	249
DLR	2,472	3,622	3,380	3,080	4,021	1,780
DLM	54	140	60	70	160	128
Aviation fuel	917	1,600	900	700	1,500	1,400
Total	3,775	5,860	4,800	4,300	6,261	3,557

Table 15. CPFH Calculation.

### Notes:

- 1) Consumables are the costs of material consumed in the operation, maintenance, and support of an aircraft.
- 2) Depot Level Repairables (DLR) represent spare parts replenishment and it is expressed as percentage of flyaway cost. The multiplicative coefficient is equal to  $8.82857E-5$ .
- 3) Depot Level Maintenance (DLM) are costs associated with repair effort during engine overhaul.
- 4) Aviation fuel includes petroleum, oil, and lubricants.

Consumables. This part of the CPFH estimation is based on similar expenditures incurred by the Czech Air Force while operating the L-39 jet trainer (benchmark) and the amount published for the F-16 (AFI 65-503).

DLR are based on a specific aircraft flyaway cost multiplied by a coefficient equal to  $8.82857E-5$ . This part of the CPFH is concerned mostly with spare parts

replenishment; therefore, using flyway cost is appropriate. Here again, the author compared what is such ratio for the L-39 and the F-16. The flyaway cost was established as 70% of the procurement cost.

	F/A-16	F/A-18	Mirage 2000-5	Jas-39	Eurofighter	MiG-29 SMT
Flyaway cost (in millions USD)	28	42	38.5	38	49	21
DLR	2,472	3,622	3,380	3,080	4,021	1,780

Table 16. Flyaway cost and DLR estimates.

DLM is basically a fund for financing engine overhaul. This approach is based mostly on how many engines a specific aircraft has.

Aviation fuel includes petroleum, oil, and lubricants. The biggest portion of this amount is petroleum, which can be established based on specific consumption of each aircraft. Cost per one ton of petroleum is assumed to be \$ 400 (in 2000 Dollars).

	F/A-16	F/A-18	Mirage 2000-5	Jas-39	Eurofighter	MiG-29 SMT
Consumption	2.1	3.7	2	1.6	3.5	3.2
Petroleum cost	840	1,480	800	640	1,400	1,280
Oil & lubricants	77	120	100	60	100	120
Total	917	1,600	900	700	1,500	1,400

Table 17. Aviation fuel estimates.

A simplified LCC equation is:

$$LCC = PC + \text{SUM } AC/(1+r)^1 + AC/(1+r)^2 + \dots + AC/(1+r)^{20}$$

where

PC = procurement cost

AC = annual O&S cost

r = nominal discount rate (5%)

inflation rate = 4%



This equation does not include RDT&E and disposal costs for the reasons mentioned in Chapter V.

The annual O&S cost will be first inflated and then discounted. The *nominal* discount rate is 5% for government projects in the Czech Republic [Ref. 31].

$$\begin{aligned} \text{LCC (NPV)} = & 40,000,000 + (1,777,800/1.05 + 1,224,912/1.1025 + 1,273,908/1.157 + \\ & 1,324,864/1.215 + 1,377,859/1.276 + 1,432,973/1.340 + 1,490,292/1.407 + \\ & 1,549,904/1.477 + 1,611,900/1.551 + 1,676,376/1.629 + 1,743,431/1.710 + \\ & 1,813,169/1.796 + 1,885,695/1.885 + 1,961,123/1.98 + 2,039,568/2.079 + \\ & 2,121,151/2.183 + 2,205,997/2.292 + 2,294,237/2.406 + 2,386,006/2.527 + \\ & 2,481,446/2.653) = \underline{\underline{60,518,530}} \end{aligned}$$

## B. AIRCRAFT EFFECTIVENESS SCORES CALCULATIONS

This is a sample calculation of a fighter mission score for the MiG-29 SMT. The specifications for this aircraft can be found in Table 6 and all necessary weighting factors are available in Table 7.

$$WSPrt = ((F_{PL_r} \times PL_r \times PU_{rt}) + (F_{Rr} \times (R + BF + 2MR) \times NAV_r + (F_{Mr} \times M_r) + (F_{Vr} \times V_r)) \times S_r$$

Where:

$F_{PL_r}$  = Payload weighting factor

$PL_r$  = Payload, expressed in number of air-to-air ordnance stations, including one for an internal gun, divided by 8

$PU_{rt}$  = Payload utility factor

$F_{Rr}$  = Range weighting factor

$R + BF + 2MR$  = Maximum range for a clean aircraft, using internal fuel only to fly a high-low-high mission profile; plus basing factor; plus two times missile range; the sum divided by 1800 km

$NAV_r$  = Navigation capability factor

$F_{Mr}$  = Maneuverability weighting factor

$M_r$  = Maneuverability, expressed as maximum excess power at the altitude of 4.5 km

$F_{Vr}$  = Useful airspeed weighting factor

$V_r$  = Useful airspeed expressed as best Mach, divided by 2.2

$S_r$  = Survivability factor

$$PU_{rt} = (TF_{gmr} \times TA_{gmr} \times GME_{rt} \times CM_{gmr} \times WE_{gmt}) + (TF_{ngmr} \times TA_{ngmr} \times NGME_{rt})$$

where

$TF_{xrt}$  = Target fraction for guided or non-guided munitions in role r

$Ta_{xrt}$  = Target acquisition capability factor for guided or non-guided munitions in role r in year t

$GME_{rt}$  = Guided munitions engagement capability factor in role r in year t

$CM_{rt}$  = Countermeasure susceptibility factor in role r in year t

$WE_{gmt}$  = Guided weapon enhancement factor for air-to-air weapons in year t

N	Characteristics		Index.	Weighting Factor	
				Fighter	Interceptor
1	Payload		Fpl	3	4
2	Range		Fr	2	3
3	Maneuverability		Fm	3	1
4	Useful Air Speed		Fv	2	2
5	Target Fraction	Guided Weapon	TFgmr	0.8	0.9
		Non-guided Weapon	TFngmr	0.2	0.1
6	Target Acquisition Capability	Clear Day	TAXxxrt	1.0	1.0
		Clear Night		1.0	1.2
		Limited All Weather		1.2	1.6
		Good All Weather		2.0	2.0
7	Guided Munition Engagement Factor	Within Visual Range	GMert	Semi-active	0.8
				Active homing	1.0
				Multi-target	1.2
				Off-bore Site	1.4
		Beyond Visual Range		Semi-active	0.8
				Active homing	1.2
Multi-target	1.6				
Long-rangeMT	---	3.0			
8	Countermeasure Susceptibility Factor	Very high	CMrt	0.7	0.7
		High		0.8	0.8
		Average		0.9	0.9
		Low		1.0	1.0
		Very low		1.1	1.1
9	Guided Weapon Enhancement Factor	US	WEtgm	1.2	1.2
		NATO/WP		1.2	1.2
10	Navigation Capability	Poor	NAVr	0.8	0.8
		Fair		1.0	1.0
		Good		1.0	1.0
11	Useful Lifetime		ULr	15	25
12	Basing Factor	V/STOL	BF	200	
		STOL		450	
		CTOL		750	

Table 18. TASCFORM-AIR Methodology Factors for Air Combat Roles.

$NGME_r =$  Non-guided munitions capability factor in role  $r$  in year  $t$

$$TF_{gmr} + TF_{ngmr} = 1$$

Target Fraction	Fighter	Interceptor
$TF_{gmr}$	.8	.9
$TF_{ngmr}$	.2	.1

Table 19. Target Fraction ( $TF_{xxr}$ ) Values for Air Combat Roles.

Target acquisition capability factor values for air combat roles are available from the following table.

Capacity	Fighter	Interceptor
Clear day	1	1
Clear night	1	1.2
Limited all-weather	1.2	1.6
Good all-weather	2.0	2.0

Table 20.  $TA_{xxr}$  Values.

A guided munitions engagement factor ( $GME_r$ ) is developed as an index of each aircraft's weapon delivery capability, as shown in Table 19.

Guidance		Fighter	Interceptor
Within	Semi-active	.8	.8
Visual	Active homing	1	1
	Multi-target	1.2	1.2
Beyond	Semi-active	.8	.8
Visual	Active homing	1.2	1.6
	Multi-target	1.6	2

Table 21.  $GME_r$  Values.

The  $GME_r$  factor is further modified by a factor that reflects countermeasure susceptibility ( $CM_r$ ). This term is intended to degrade or enhance the relative value of guided weapons based upon the ease or difficulty with which they can be countered through various means.

Susceptibility	Fighter	Interceptor
Very high	.7	.7
High	.8	.8
Average	.9	.9
Low	1	1
Very low	1.1	1.1

Table 22.  $CM_r$  Values.

Each aircraft usually carries more than one type of air-to-air missiles simultaneously; therefore, it is necessary to calculate a weighted average munitions engagement factor. The author considered a standard armament of the MiG-29 SMT, which usually consists of four R-73 Archer short-range and four R-77 Adder medium-range air-to-air missiles.

$$(GME_r)_{Av} = \text{Sum } (N_{AAM}) \times (TA_{gmri}) \times (GME_{ri}) \times (CM_{ri}) \times (TF_{gmr}) / N_{AAM}$$

$N_{AAM}$  = Quantity of each type of missile

then

$$(GME_r)_{Av} = (4 \times 2 \times 1 \times 1 \times .8) + (4 \times 2 \times 1.2 \times 1 \times .8) / 8 = \underline{1.7}$$

Country/Alliance	1960	1965	1970	1975	1980	1985	1990	1995	2000
U.S.	1	1	1	1	1.1	1.1	1.1	1.1	1.2
Non-U.S. NATO/ Warsaw Pact	1	1	1	1	1	1.1	1.1	1.1	1.2

Table 23.  $WE_{gmt}$  Values.

The non-guided munitions engagement term ( $NGME_r$ ) for air combat roles is based on whether or not the aircraft carries an internal gun.

$$PU_r = (.8 \times 2 \times 1.7 \times 1 \times 1.2) + (.2 \times 2 \times 1) = \underline{3.664}$$

In the  $WSP_r$  calculation, there is a modification applied to the range term based on an assessment of whether the internal navigation capability of the aircraft is poor, fair, or good. The values for this navigation capability factor ( $NAV_r$ ) are shown in Table 22.

Capability	Fighter	Interceptor
Poor	.8	.8
Fair	1	1
Good	1	1

Table 24.  $NAV_r$  Values.

The last factor necessary for a Weapon System Performance calculation is the survivability factor ( $S_r$ ). After the raw survivability factor (Raw Sum) is determined for an aircraft using the scoring system shown in Table 25, the value is normalized to a range between .8 and 1.2, using Table 26.

Scoring categories			Fighter			Interceptor		
			Hi	Av	Lo	Hi	Av	Lo
Suscep- tibility	Agility	Maneuverability	35	25	15	10	5	0
		Velocity	25	20	10	20	15	10
	Signature	Size	20	15	10	25	20	10
		Smoke	10	0	0	10	5	0
	Countermeasures	Active CM	0	0	0	10	5	5
		Passive	5	5	0	10	5	0
	Weapon delivery flexibility	Fire and forget	10	10	5	15	15	10
		Standoff capability	10	10	5	20	15	15
Vulner- ability		Hardening	15	10	10	10	5	5
		Redundancy	10	5	5	10	10	5
		Raw Sum	140	100	60	140	100	60

Table 25. Survivability Factor Calculation.

Raw Sum	S <sub>r</sub>	Raw Sum	S <sub>r</sub>
60	.80	105	1.03
65	.83	110	1.05
70	.85	115	1.08
75	.88	120	1.10
80	.90	125	1.13
85	.93	130	1.15
90	.95	135	1.18
95	.98	140	1.20
100	1.00		

Table 26. Survivability Factor Normalizing Schedule.

$$WSP_{\pi} = ((3 \times 1 \times 3.664) + (2 \times (1.70) \times 1) + (3 \times 1.64) + (2 \times 1)) \times 1.1 = \underline{23.44}$$

Mission	F/A-16C	F/A-18E	Mirage 2000-5	JAS-39	Eurofighter	Mig-29 SMT
Fighter	22.89	25.9	23	19.3	29	23.44
Interceptor	25.73	29.7	26.10	21.4	32.9	26.5
CAS	22.54	31.9	24.95	19.2	28.62	21.53
Interdiction	21.70	29.38	23.76	18.95	26.93	21.10
Composite score	23.48	28.34	24.27	19.83	29.76	23.70

Table 27. Author's Aircraft Effectiveness Scores using TASCFORM methodology.

Mission	F/A-16C	F/A-18E	Mirage 2000-5	JAS-39	Eurofighter	Mig-29 M
Fighter	19.4	NA	19.8	15.5	26.4	19.4
Interceptor	19.8	NA	25.7		32.6	21.4
CAS	NA	NA	NA	NA	NA	NA
Interdiction	24	NA	14.2	7.7	NA	17.7

Table 28. TASC Effectiveness Scores.



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Note on sources: This thesis by its nature necessarily relies extensively on Czech language and internet sources. The bulk of the good material on the the history and current situation of the Czech Air Force is, not surprisingly, written in Czech (the author's first language). This thesis project also required an extensive search for aircraft technical and cost data. In many cases, the most current sources (and sometimes the only sources) are found on internet sites -- especially official web pages such as [www.osd.mil](http://www.osd.mil), subject journal sites such as [www.flug-revue.rotor.com](http://www.flug-revue.rotor.com), [www.janesweekly.com](http://www.janesweekly.com) and corporate sites such as [www.dasault-aviation.fr](http://www.dasault-aviation.fr). Also, the most current information on the Czech Republic and its armed forces is often found at internet sites such as [www.army.cz](http://www.army.cz) and [www.letadla.cz](http://www.letadla.cz).

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