Design, Material and Manufacturing Techniques of a Three Stages Compressor TMM025 Turbojet Engine (Hot Section)

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ملخص

الهدف الرئيسي من هذا البحث دراسة شاملة لمحرك توربيني نفاث نوع (TMM025) بمعدل قوة دفع 25daN وسرعة دوران تصل إلى 86500 rpm ، لوضع وثيقة تتضمن التصاميم والمعادن وطرق الإنتاج المختلفة لمحرك توربيني نفاث.
تقنية صناعة المحركات التوربينية النفاثة من التقنيات المتقدمة جدا ،وهذه التقنية غير متوفرة في ليبيا ويرجع دلك لتطلبها شروط ومعايير و مواصفات وسبائك خاصة تتحمل ظروف التشغيل المختلفة من ضغوط ودرجات حرارة عاليه ناهيك عن نقص كبير في العمالة الماهرة والخبرة اللازمة للقيام بهذا العمل المتخصص جدا.
المحرك التوربيني النفاث (TMM025) تم تصميمه وتصنيعه في ليبيا، وقد تطلب دلك قدرا هائلا من الجهد و العمل في العديد من المجالات للإلمام بكافة الجوانب التصميمية والإنتاجية وفق المعايير العالمية،حيث كانت نتائج الاختبارات العملية والمعملية المتحصل عليها تطابقت تماما مع متطلبات التصنيع وبدلك يكون هدا المحرك نواة الجيل الجديد للصناعات الإستراتيجية ، الأمر الذي سيسهم في مساعدة المؤسسات العلمية لفهم التكنولوجيا المستخدمة في مختلف عمليات التصميم والإنتاج للمحركات النفاثة .
كان الهدف الاساسي من هذه الورقة هو التعرف على نظريات التصميم والتصنيع من خلال الدراسة والتحليل والإطلاع على العديد من التقنيات المختلفة والشروط الواجب توفرها عند اختيار المواد وطرق تصنيع كل مكونات المحرك النفاث وما تحتاجه من عملية أتزان ديناميكي للأجزاء الدوارة و معالجة حرارية حسب ظروف التشغيل . اضافة لذلك إيجاد قاعدة علمية واضحة المعالم لعمليات التصنيع والتصميم المستقبلية لصناعة المحركات التوربينية النفاثة حيث وضعت هده الدراسة الخطوط العريضة في هدا المجال.

ABSTRACT

The technology of manufacturing a jet engine is a very advanced technology, due to its complicated components which require very advanced technical methods of manufacture and treatment, It has not been established in Libya due to many difficulties which requires special equipment's and alloys with special specifications and standards to withstand the hard operating conditions, not to mention the necessary skilled and experienced labor required to undertake this specialized work.
Jet engine(TMM025) has been designed and manufactured in Libya. It has required a tremendous amount of work from many sides and areas, despite the lack of technology and skill needed. Jet engine (TMM025) has been balanced and field tested many times for different inputs and outputs and achieved a very good preliminary results. The success of these tests and the results obtained has made this technology the nucleus of new generation of the strategic industry in Libya, which helped the scientific institutions to understand the technology involved in all of the complicated fields and start to build an advanced technology that can research and develop in this field.

The main objective of this research work is to conduct a comprehensive study of a Turbojet engine type (TMM025) with a momentum rate of25daN and rotation speed of 86500rpm, leading to publishing a document that contains restricted and many ways unpublished material in the field of turbojet Engine design and manufacture.
TMM025consists of three stage axial compressor, annular combustion chamber with six injectors, axial turbine. Intake and exhaust nozzle modules may be modified for certain design. Turbo Jet Engine TMM025 it can be used as an expendable turbojet engine, such as in Propulsion of weather forecast vehicles, Propulsion of anti-tank missile, Propulsion of anti-ship missile. Can also be reused multiple times, such as in Propulsion of airplane models, Auxiliary propulsion for gliders, demo engines for education. The main task of this paper are as follows; analysis, check out the many different techniques and conditions that must be met when choosing materials and methods of manufacture of all the components of a jet engine and what you need of dynamic balancing process of

the rotating parts and heat treatment depending on operating conditions. To find a scientific base and a clear-cut manufacturing operations and future design of the jet turbine engine industry.

- **Introduction**

Jet engines move the airplane forward with a great force that is produced by a tremendous thrust and causes the plane to fly very fast.
A jet engine is simply a reaction engine that develops thrust by the rapid discharge of a gas. Jet engines depend on the surrounding atmosphere for oxygen to support combustion and therefore can only operate in regions where an atmosphere exists. [1]

The basic principle of the airplane turbine engine is identical to any and all engines that extract energy from chemical fuel. The basic 4 steps for any internal combustion engine are:

- Intake of air (and possibly fuel).
- Compression of the air (and possibly fuel).
- Combustion, where fuel is injected (if it was not drawn in with the intake air) and burned to convert the stored energy.
- Expansion and exhaust, where the converted energy is put to use.
-

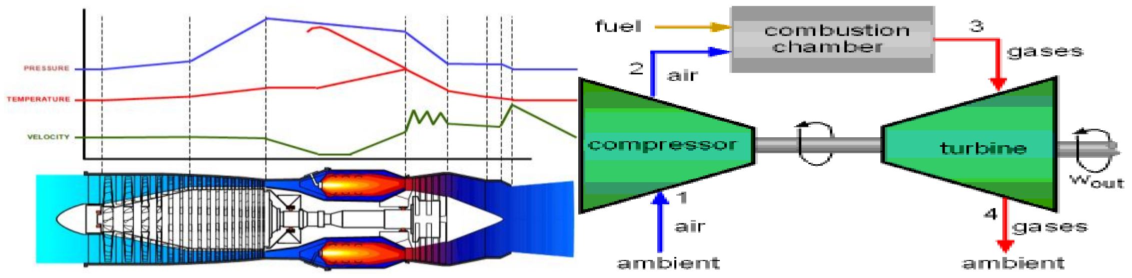


Figure. (1) Flow Diagram of Simple Gas Turbine

- **Advantages and disadvantages of gas turbine engine**

The main advantages of turbine engine can be listed as
Weight reduction of 70%.
Simplicity.
Quicker response time.
Faster Acceleration/deceleration.
Less vibration.
More economical.
Gas turbine engines have a great power-to-weight ratio.
The Gas Turbine Plant is simple in Design and Construction.
In the other hand there are some disadvantages of gas Turbine Engine which includes the following
Many parts under high stress.
High pitched noise.
Needs large quantities of air.
Cannot be repaired in place.
The main disadvantage of gas turbines is that, compared to a reciprocating engine of the same size, they are expensive.

- **Types of Jet Engines**

The types of jet engines can be classified as;

Turbojet {used in military and modern aircraft}.

Turboprop {used in aircraft operated in low altitudes}.

Turbofan {used in passenger aircraft}.

Turboshaft {used in helicopters}.

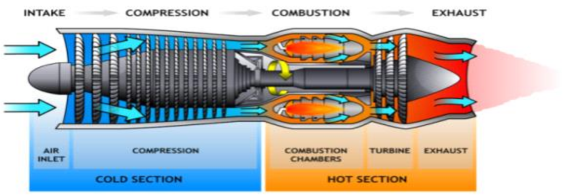


Figure 2 Turbojet Engine

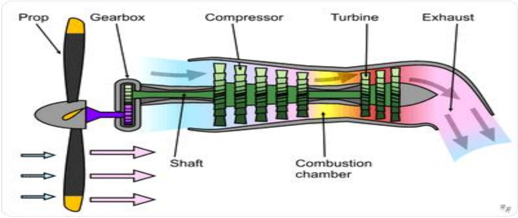


Figure 3 Turboprop Engine

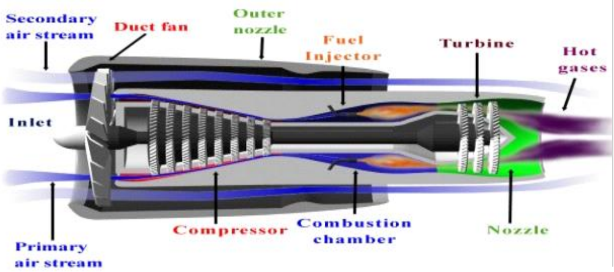


Figure 4 Turbofan Engine

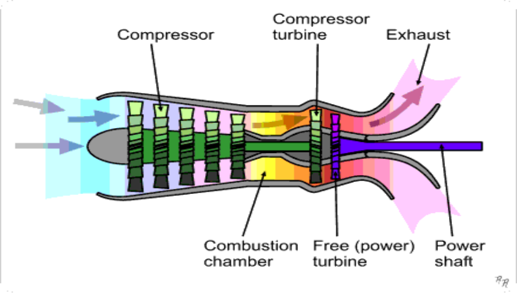


Figure 5 Turbo shaft Engine

Turbojet Engine with afterburner

An afterburner (or reheat) is an additional component added to some jet engines, primarily those on military supersonic aircraft. Its purpose is to provide a temporary increase in thrust**.**

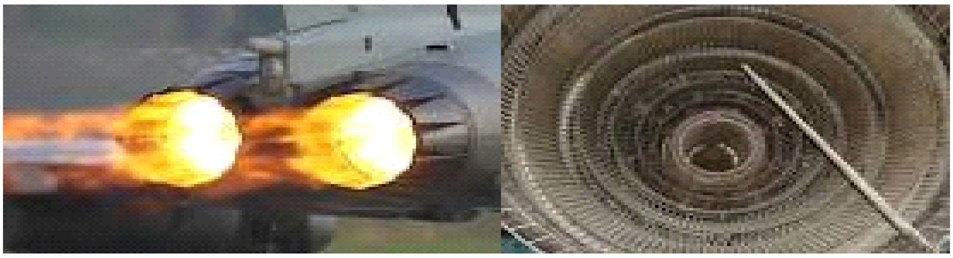
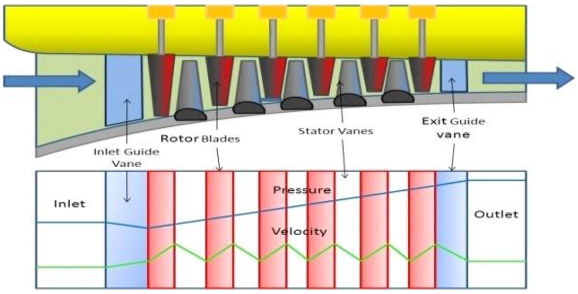


Figure 6 Turbojet Engine with afterburner

- **Major components of gas Turbine Engine**

Air intake (Inlet) All turbine engines have an inlet to bring free stream air into the engine.
Fan The fan is the first component in a turbofan . The large spinning fan sucks in large quantities of air.
Compressor The compressor is the first component in the jet engine core. The compressor is made up of fans with many blades and attached to a shaft. The compressor squeezes the air that enters it into progressively smaller areas, resulting in an increase in the air pressure. This results in an increase in the energy potential of the air. The squashed air is forced into the combustion chamber.
Types of compressors; are Axial flow Compressor, Centrifugal Compressor Combination (Centrifugal-Axial flow) Compressor.



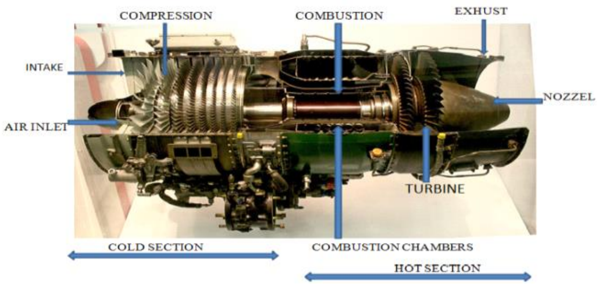


Figure (7) Turbojet Engine Parts   Figure (8) Compressor Operation

Combustion Chamber.

The combustor is where fuel is added to the compressed air and burnt to produce high velocity exhaust gas. Down the middle of the combustor runs the flame tube. The flame tube has a series of holes in it to allow in the compressed air. It is inside .The flame tube that fuel is injected and burnt. There will be one or more igniters that project into the flame tube to start the mixture burning. Air and fuel are continually being added into the combustor once the engine is running.

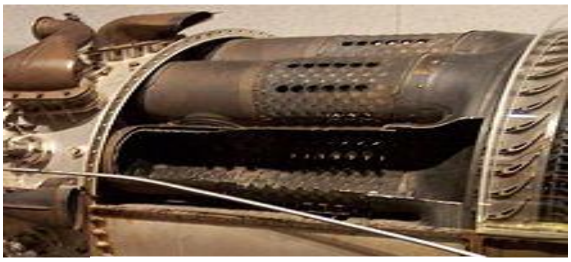


Figure. (9) Combustion Chamber

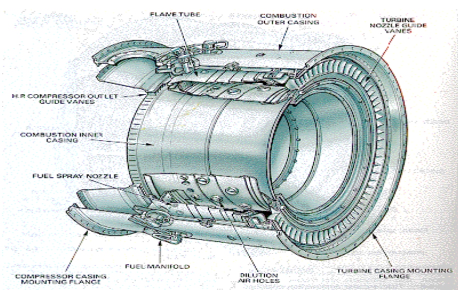
Types of combustion chamber

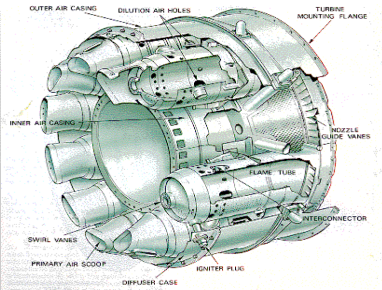
A-Multiple chamber

b-can-annular

c- Annular chamber

Figure.(9) Combustion Chamber





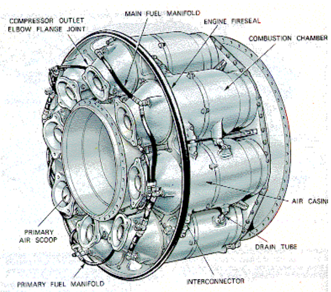
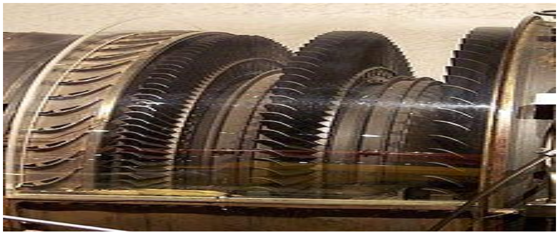


Figure. (10) Multiple chamber   Figure. (11) can-annular   Figure. (12) Annular chamber

Turbine.

The turbine is an assembly of discs with blades that are attached to the turbine shafts,. The turbine extracts energy from the hot gas stream received from the combustor. This power is used to drive a fan, propeller, compressor or generator. [20]



Figure(13) Turbine.

Nozzle.

The exhaust cone attached to the rear of the turbine assembly, is a tapered, cylinder-shaped outlet for the gases. The cone eliminates turbulence in the emerging jet, thereby giving maximum velocity.

Figure(14) Nozzle

Turbojet Engine TMM025

TMM25 a small expendable turbojet engine rated for 25daN of static thrust. It has been design to meet low-cost engine approach, but to keep thrust-to weight and thrust-to-cross section ratio at the challenged level. Also, design goal was that engine can be easily sized to bigger engines, up to 300daN. Engine consists of three stage axial compressor, annular combustion chamber with six injectors, axial turbine. Intake and exhaust nozzle modules may be modified for certain design.

Engine configuration

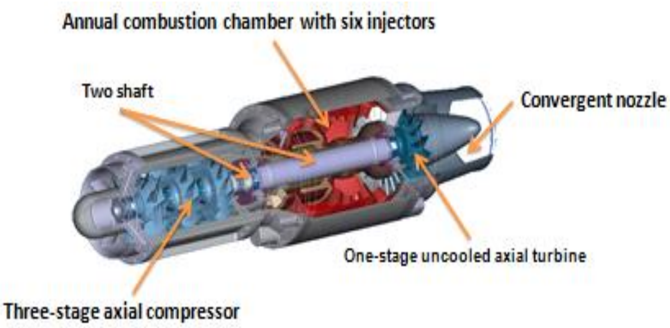


Figure.(15)Turbojet Engine TMM025

The engine design configuration is:

- Two shafts.

- Three-stage axial compressor.
- Annual combustion chamber with six injectors.
- One-stage uncooled axial turbine.
- Convergent Nozzle.

TMM025 Turbojet Engine Uses

Civil application:

- Propulsion of airplane models.
- Auxiliary propulsion for gliders.
- Propulsion of weather modification vehicle.
- Demo engines for education.

Military application:

- Propulsion of anti-tank missile.
- Propulsion of anti-ship missile.
- Propulsion of small Unmanned Air Vehicle.

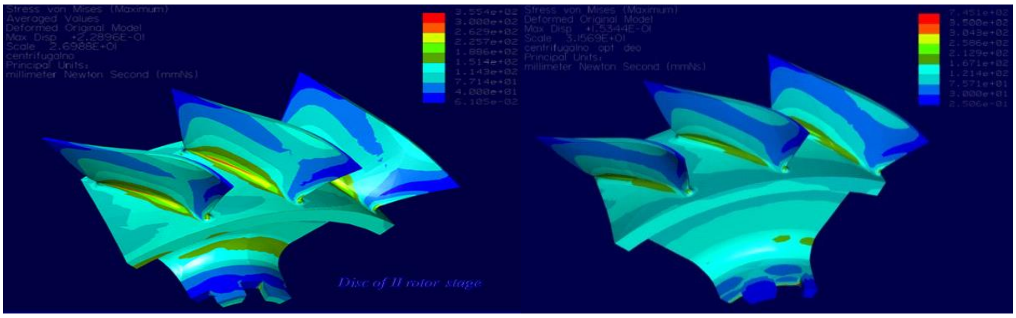
The major components of turbojet engine TMM 025

The major components of turbojet engine TMM 025 are the:

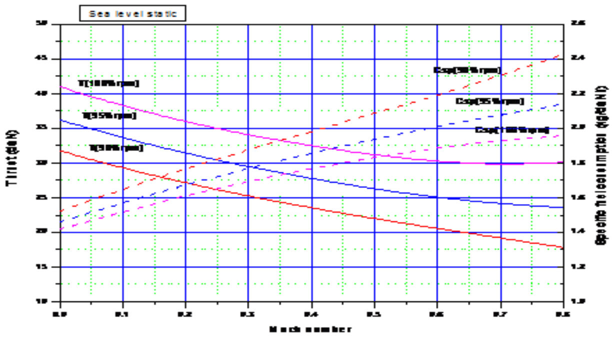
- **Cold Section consists of**: Cup intake, Intake, compressor Rotor- Stator, Compressor Housing, Diffuser.

-Hot Section it consist of:(Combustion chamber, Turbine, Exhaust, Nozzle).

Figure. (16) Hot section Components



Figure(17) Hot section Components



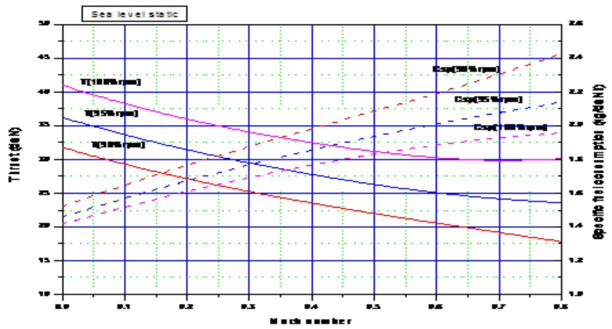


Figure.(18) load distribution stresses blades, Figure.(19) Trust, Mach No. and fuel consumption at sea and 5000m levels

Description of engine design

- All elements designed by Pro-ENGINEER.
- Mechanical calculation done by Pro-MECHANICA.
-Gas dynamic calculation done by Phonics' and by own developed Programs.
-Thermodynamic calculation done by Phonics and by Pro-Mechanical thermal.
-Rotor dynamic done by Sysrotor.

possible engine upgrade:

- By-pass turbojet engine with rear fan.
- Turbojet engine with afterburner.
- Turbo shaft engine with free turbine.
- Turboprop.

Implement technologies:

- Milling on 5axies CNC machines connected with Pro-ENGINEER.
- Investment casting of light alloy.
- Vacuum casting of super alloy.
- Laser beam welding.
- Turning Process.
- Drilling Process.
- Grinding Process.
- Heat treatment Process.

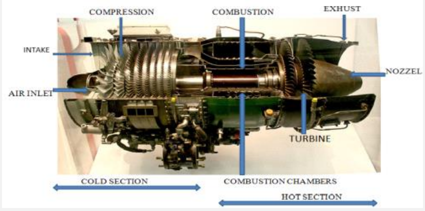
• Features low production costs ,minimal number of parts , small engine dimensions where a length up to (600mm) engine diameter up to (155mm), engine mass (6.5K.g) .

• Possible working condition Air temperature (-30C) to (65C) flight altitude (5000m), a low fuel consumption, up to (1.2Kg/daNh) Compressor ratio (3.4) and rotor rotational velocity (86500rpm).

TMM025 Turbojet Engine

Manufacture Process

Hot Section

Name of part	It consist of	It consist of
• Combustion Chamber	• Chamber cover **1.2** External combustion chamber **1.3** Internal combustion chamber	**1.1.1** cover cone **1.1.2** Cylindrical part of cover
• Turbine Assembly	**2.1** stator assembly **2.2** Rotor Assembly	**2.1.1** Turbine stator pipe **2.1.2** Nozzle guide vane **2.2.1** blades-Disks **2.2.** Shaft
3. Exhaust Nozzle	**3.1** cone **3.2** pipe **3.3** nozzle	

- **Combustion Chamber**

Name of part	It consist of	It consist of
1.Combution Chamber	**1.1** Chamber cover	**1.1.1** Cylindrical part of cover **1.1.2** cover cone



2-Turbine Assembly

Name of part	It consist of	It consist of
2- Turbine Assembly	**2.1** stator assembly **2.2** Rotor Assembly	**2.1.1** Turbine stator pipe **2.1.2** Nozzle guide vane **2.2.1** blades-Disks **2.2.** Shaft


3-Exhugt Nozzle

Name of part	**It consist of**
3. Exhaust Nozzle	**3.1** cone **3.2** pipe **3.3** nozzle

Balancing

Balancing is the process of eliminating or at least reducing the ground forces and/or moments. It is achieved by changing the location of the mass centers of links. Balancing of rotating parts is a well known problem. A rotating body with fixed rotation axis can be fully balanced i.e. all the inertia forces and moments. For mechanism containing links rotating about axis which are not fixed, force balancing is possible, moment balancing by itself may be possible, but both not possible. We generally try to do force balancing. A fully force balance is possible, but any action in force balancing severe the moment balancing. [40]

Types of unbalance

There are three types of unbalance:
1- Static unbalance: is where the mass axis is displaced only parallel to the shaft axis. The unbalance is corrected only in one axial plane.
2- Couple unbalance: is where the mass axis intersects the running axis. For example: a disk that has swash run-out with no static unbalance. The unbalance is usually corrected in two planes.
3- Dynamic unbalance: is where the mass axis is not coincidental with the rotational axis. This unbalance is usually a combination of static and couple unbalance and is corrected in two planes.

Balancing limits

There are balance limits, just like machining limits, where the unbalance is acceptable. International and national standards are quoted for rotors, for example: Car wheels are balanced to a limit of grade 40 and small electrical armatures are balanced to grade 2.5. The grades are converted to unbalance units, depending on the rotational speed of the rotor as per ISO 1940 standards.

Table 1 ISO Quality Grades Balance for various groups (From ISO 1940/1)

Table 4-1 ISO Quality Grades Balance for various groups (From ISO 1940/1)

Balance quality grade G	ew 1] 2] mm/s	Rotor Types - General examples
G 40	40	- Car wheels, wheel rims, wheel sets, drive shafts. - Crankshaft-drives of elastically mounted fast four-cycle engines (gasoline or diesel) with six or more cylinders4). - Crankshaft-drives for engines of cars, trucks and locomotives.
G 16	16	- Drive Shafts (propeller shafts, cardanshafts with special req - Parts of crushing machinery. - Parts of agricultural machinery. - Individual components of engines (gasoline or diesel) for cars, trucks and locomotives. - Crankshaft-drives of engines with six or more cylinders under special requirements.
G 6,3	6,3	- Parts or process plant machines. - Marine main turbine gears (merchant service). - Centrifugal drums. - Fans - Assembled aircraft gas turbine rotors. - Fly wheels. - Pump impellers. - Machine-tool and general machinery parts. - Normal electrical armatures. - Individual components of engines under special requirements.
G 2,5	2,5	- Gas and steam turbines, including marine turbines (merchant service). - Rigid turbo-generator rotors. - Rotors. - Turbo-compressors. - Machine-tool drives. - Medium and large electrical armatures with special requirements. - Small electrical armatures. - Turbine-driven pumps.
G 1	1	- Tape recorder and phonographs (gramophone) drives. - Grinding-machine drives. - Small electrical armatures with special requirements
	0,4	- Spinles, disks and armatures of precision grinders. - Gyroscopes.

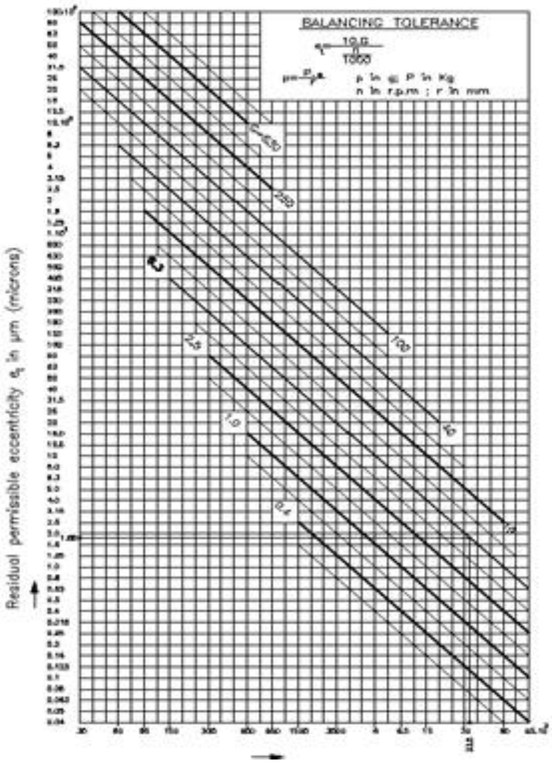


Figure.(20) The Balancing Tolerance Graph

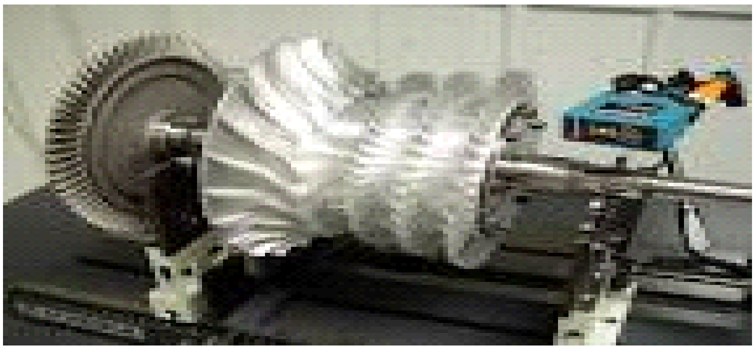


Figure.(21) Universal Balancing Machines

Jet Engine materials

Aircraft jet engines are required to operate within extreme conditions of temperature and pressure. The typical jet engine consists of many different materials depending on the components purpose. Because there is such a huge temperature difference from one end of the engine to the other, designers use the lightest possible materials that are strong enough and have a high enough melting point.

Strong, lightweight, corrosion-resistant, thermally stable components are essential to the viability of any aircraft design, and certain materials have been developed to provide these and other desirable traits. Titanium, first created in sufficiently pure form for commercial use during the 1950s, is utilized in the most critical engine components, it strong when subjected to intense heat. To improve its malleability titanium is often alloyed with other metals such as nickel and aluminum. [42]

Materials Used in Aircraft Engines

1-Aluminum alloys for low pressure compressors and low stress components such as cowlings.

2-Nickel alloys are used for HP compressors and turbines, grown as a single crystal to stop cracking in the extreme heat, in excess of 1000 degrees C.
3-Ceramics are also found in turbine blades and high temperature components.
4-Titanium is used for fan blades and other low temperature components for its high strength and low weight.
5-Carbon fiber is being introduced for use in fan blades and cowling's on General Electric engines.[42]

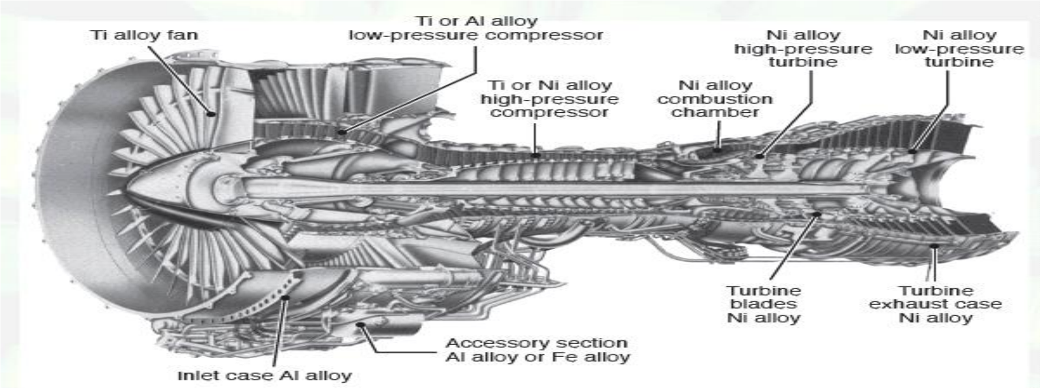


Figure. (22) Jet Engine Materials

Jet engine materials requirements

- High strength,
- High stiffness,
- Low weight.

CONCLUSIONS

Technology of production of aircraft Engines is a modern and complex technology that includes complex design methods and production techniques, as it is one of the first attempts to be under taken to enter the field of aviation industry .

The study includes the design stages, production process and materials used in the manufacture of a turbo-jet engine . The study outlines and presents the
difficulties in undertaking this work as well as the technological benefits achieved .This difficulties and benefits are summarized as follows:

- Difficulties faced the Design, Manufacturing and Materials Selection for Turbojet engine (TMM025)

• The weakness of scientific infrastructure in this field in terms of Scientific References, research and development centers that related to aviation industry.
• Lack of experience in terms of design and production when dealing with the jet propulsion system.
• Lack of knowledge of the various materials composition that are used for the manufacturing of parts of the jet propulsion system.
• Shortage of heat treatment equipment’s and knowledge for the materials that are used in manufacturing process.

- Benefits gain from the Design, Manufacturing and Materials Selection for Turbojet engine (TMM025)

• Knowing the design parameters, manufacturing and selection of the appropriate materials that suit different operating conditions.
• Full knowledge of engineering software’s that are used in the design stages, data analysis, obtaining and collecting the results when the operation of the engine is conducted.
• Identify the materials used in manufacturing of specific parts for each engine system.
• Using the appropriate production process for specific part of the engine taking the correct in account all conditions in manufacturing processes.
-5 acquiring knowledge of the heat treatment process in terms of heat treatment procedure, requirements and application.
- 6 acquiring knowledge of the mechanical balance technique (Balancing) for rotating parts in the system and the whole engine in general.

As a concluding remark, it has been a research work that included the collection of data from many fields, Which are otherwise restricted and not published in any way.
The collection of this data in one document represents a huge leap forward as one of the references that answers questions and supplies solutions to many restricted and unpublished Technologies .

Recommendations

1- The use of advanced software's in the simulation of real time conditions (F.E.A, Pro Mechanical, Pro-Engineer) to obtain parameters of mechanical and thermal loads and vibrations force. These provide data on the optimal operating conditions of pressure and elevated temperatures that would improve the performance of all the components of a jet engine.
2 - Acquiring knowledge of the materials composition used in the jet Propulsion engines and its manufacturing process, production and development.
3 - Acquiring knowledge of the heat treatment process technique and providing the equipments to be used in this technique.
4 - Supports the scientific infrastructure in the aircraft industry field through establish research and development centers for implementation of design, manufacture and production process and with corporation of other various industry sectors and international companies.
5 - Support the researches and studies in the aviation industry sector in order to develop the manufacturing process of all parts of the jet propulsion system.
6 - Preparing, support and develop skills of the national expertise in this field and provide the necessary equipments and laboratories for Aviation industry search centers.

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