CHAPTER 1

GAS TURBINE ENGINE GENERAL

- SYMBOLS
- UNITS
- REVIEW OF A FEW PRINCIPLES
- PRINCIPLES OF PROPULSION
- VARIOUS TYPES OF ENGINES
- THEORY OF OPERATION OF A GAS TURBINE ENGINE
- GAS TURBINE ENGINE COMPONENTS
- PERFORMANCE AND CHARACTERISTICS
- FACTORS AFFECTING THE PERFORMANCE
- VARIOUS FUNCTIONS OF A TURBO - ENGINE
- VARIOUS TYPES OF GAS TURBINE ENGINE
- TURBOMECA SURVEY
- ENGINE DRAWINGS
- MISCELLANEOUS APPLICATIONS

UNITS

	C.G.S.	M.T.S.	M.K.p.S.	M.K.F.S. ou SI
Length	Centimètre - cm	Mètre - m	Mètre - m	Mètre - m
Mass	Gramme - g	Tonne - t	Unité masse (Kg)	Kilogramme-masse kgm
Time	Seconde - s	Seconde - s	Seconde - s	Seconde - s
Force	Dyne - dy	Sthène - sn	Kilogramme - Kg	Newton - N
Work	Erg	Kilojoule - kj	Kilogrammètre kg.m	Joule - J
Power	Erg/s	Kilowatt - kW	Kilogrammètre-seconde kg.m/s	Watt - W
Pressure	Barye - b	Pièze - pz	Kilogram/cm2 kg/cm2	Pascal - P

CONVERSION FACTORS

Mass :

1 kgp . . . . 9,81 kgf
1 kgf. . . . . .0,102 kgp

Force :

1kg . . . . .9,81 N
1N . . . . 0,102 kg. . . . $.10^5$ dynes
1sn . . . . .102 kg

Work :

1 kg/m . . . . 9,81 joules

Power :

1 kg/m/s . . . . 9,81 W
1 Cv. . . . . 0,736 kW. . . . . .75 kg.m/s
1kW . . . . 1,36 ch . . . . . . .102 kg.m/s

Pressure :

1 kg/cm^2 . . . . .98,1 pz

1 Atmos = 1013 mb = 1,033 kg/cm^2 = 760 mm.Hg = 101,3 pz = 29,92 inch.Hg

CONVERSION TABLE FOR UNITS OF PRESSURE

UNITS OF PRESSURE	Pa	mb	pz	mm H20	g/cm2	mm Hg	p.s.i.	inch .of Hg
Pascal Newton/m2	1	0,01	0,001	0,101972	0,010197	0,007500	0,000145	0,000295
Hectopascal mb	100	1	0,1	10,1972	1,01972	0,75006	0,014503	0,02953
Kilopascal Pieze	1 000	10	1	101,972	10,1972	7,5006	0,145037	0,2953
mm H20 Kg/m2	9,80665	0,098066	0,0098066	1	0,1	0,073556	0,001422	0,002896
g/cm2	98,0665	0,980665	0,0980665	10	1	0,73556	0,014223	0,02896
mm Hg	133,322	1,33322	0,133322	13,5951	1,35951	1	0,01934	0,03937
Pound per square inch.	6894,8	68,948	6,8948	703,08	70,308	51,71	1	2,036
inch of Hg	3386,4	33,864	3,3864	345,3	34,53	25,4	0,4912	1

A FEW ANGLO-SAXON UNITS

1 inch (pouce) .... 25,4 mm

1 foot (pied) .... 0,33 m

1 horse power (cheval vapeur brit) .... 0,745 kW

1 gallon imperial .... 4,54 l

1 gallon US .... 3,78 l

1 PSI (pound square inch) .... 68,948 mb

1 mile (terrestre) .... 1609 m

1 mile (marin) .... 1852 m

SYMBOLS

Cte	Constant
C	Consumption
CH	Fuel consumption (in kg/h)
Cs	Fuel specific consumption
ch ou cv	Horse power
d	Distance
F	Force or thrust
G	Air flow (in kg/s)
Hpz	Hectopiez
K	Coefficient
°K	Kelvin degree
kW	Kilowatt
L	Litre
m	Mass
mb	Millibar
N	Rotation speed
N	Newton
da N	Deca Newton
P	Pressure
Px	x : reference indicating station eg : P2 : pressure at station n° 2
Ph	Oil pressure
Pr	Residual thrust

BP	Low pressure
HP	High pressure
Q	Flow in l/h
R ou Reg	Control unit
T	Absolute temperature (in K° degree)
t	Relative temperature (in C° degree)
Tx	x : reference indicating station
th	Oil temperature
t	Time in seconds
v	Velocity
vi	Aircraft velocity
V	Volume
W	Power
Z	Altitude
α (alpha)	Angle
β (bèta)	Angle
γ (gamma)	Acceleration
η (êta)	Efficiency
ρ (rhô)	Density
Ω (oméga)	Ohm
ω (oméga)	Angular Velocity
Δ (delta)	Difference
ΔP	Difference of pressure
ΔT	Difference of temperature

REVIEW OF A FEW PRINCIPLES

PRINCIPLE OF ACTION AND REACTION

When a body A exerts a force F on a body A', the body A' exerts a force F' on the body A equal and opposite to F.

It is said that the action is equal to the reaction.

FUNDAMENTAL LAW OF DYNAMICS

The force which creates the movement is proportional to the acceleration:

$$F = m\gamma$$

GRAVITY

When the force represents the weight of the body, the acceleration which characterizes the fall of the body, is called the acceleration of gravity.

$$P = mg \qquad (g = 9{,}81\ m/s/s \text{ in Paris})$$

QUANTITY OF MOVEMENT

This is the product of the mass by the velocity

$$Q = m \times V$$

FORCE - TORQUE

The moment of a force is the product of the force times its distance from the point of application

$$M = Fd$$

The torque is the combination of two equal forces parallel and in opposite directions.

The moment of a torque is equal to :

$$C = Fd$$

WORK

This is the product of the force by its displacement

$$T = Fd$$

POWER

Work done by unit of time

$$W = \frac{T}{t} = \frac{Fd}{t}$$

When the displacement is angular : $W = C \times \omega$

$$C \text{ (Torque)} = Fd \qquad \omega = \frac{2\pi N}{60}$$

$$W = \frac{2\pi N \times F \times d}{60}$$

ENERGY

Potential

Energy stored in a body and which can be released as required

Kinetic

Energy of a body in movement

$$Ec = \frac{1}{2} m v^2$$

BERNOUILLI' S THEOREM

In a flow of fluid, the sum of the energies is constant.

$$Ps + \frac{1}{2} \rho v^2 = Cte$$

Ps = Static pressure

$\frac{1}{2} \rho v^2$ = Dynamic pressure

ρ = Density

v = Velocity

The Bernouilli' s theorem is only applicable at subsonic velocity.

In supersonic velocity, the St Venant' law must be applied.

$$Cp \times T + \frac{1}{2} \rho v^2 = Cte$$

Cp = Specific heat at constant pressure

T = Absolute temperature

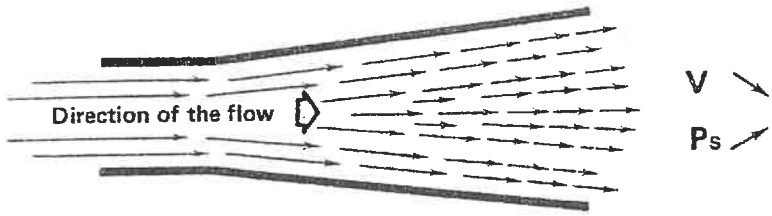
Note : the absolute temperature is equal to the relative temperature in Celsius degree + 273°.

It is expressed in Kelvin degree.

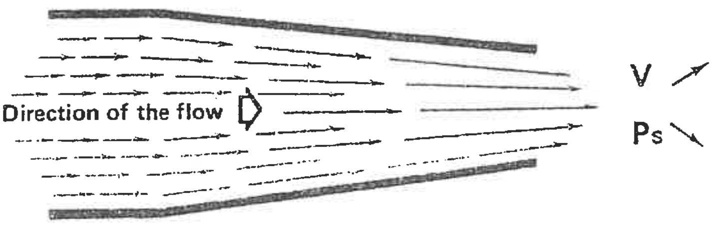
$$T = t + 273°$$

Application of Bernouilli's theorem

Flow through a divergent passage

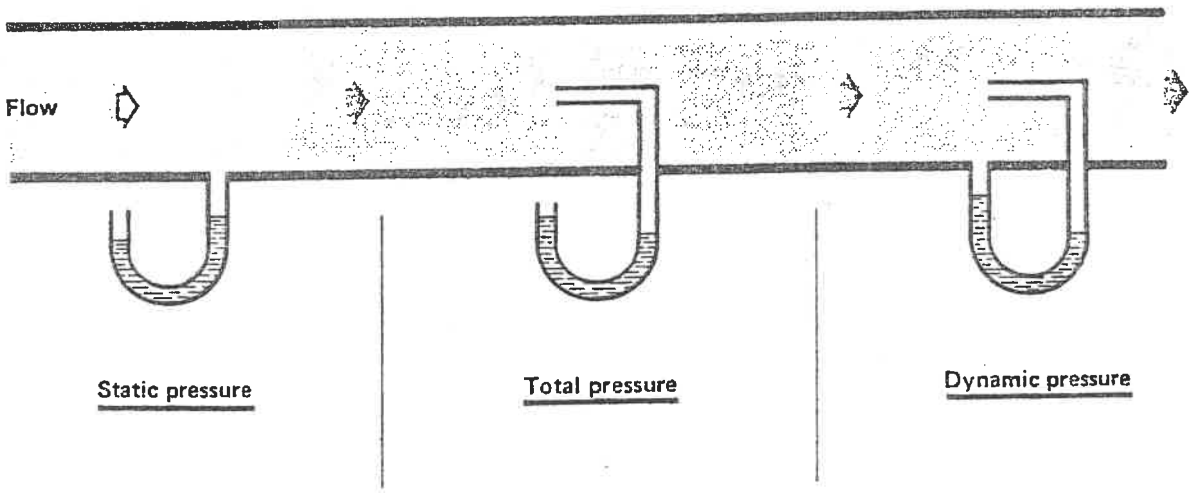


Flow through a convergent passage



Measurement of pressures

$$P_s + \frac{1}{2}\rho v^2 = P_t \qquad \frac{1}{2}\rho v^2 = P_t - P_s$$



REVIEW OF THERMODYNAMICS

Perfect gas equation

$$PV = KT$$

T : Temperature
P : Pressure
V : Volume
K : Coefficient (about 287 for air)

Two of the above parameters are sufficient to determine the state of a gas.

Specific heat

At constant volume

$$Q = mC_v (T_2 - T_1)$$

Q : Quantity of heat
Cv : Specific heat
T2 - T1 : Temperature difference

At constant pressure

$$Q = mC_p (T_2 - T_1)$$

Cp: Specific heat

$$C_p > C_v \qquad \frac{C_p}{C_v} = 1{,}4 \text{ for cold air}$$

First law of thermodynamics

$$W + JQ = 0$$

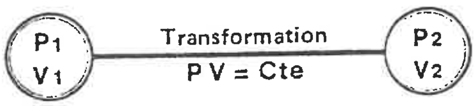
W : Work (in joule)
Q : Calory
J : Mechanical equivalent of calory (4,186)

State transformation

Adiabatic	without exchange of heat with the atmosphere
Isothermic	at constant temperature
Isobaric	at constant pressure

Example of a reversible adiabatic transformation

V : Volume



$$P_1 V_1 = P_2 V_2$$
$$P_1 V_1 = R T_1$$
$$P_2 V_2 = R T_2$$

$$\frac{C_p}{C_v} = \gamma$$

$$\frac{T_2}{T_1} = \frac{P_2}{P_1}^{\frac{\gamma - 1}{\gamma}}$$

FLUID MECHANICS

$$C_p \times T + \frac{1}{2} \rho v^2 = Cte$$

Cp : Specific heat at constant pressure
T : Absolute temperature

Calculation of impact temperature

$$C_p \times T_1 = C_p \times T_o + \frac{1}{2} \rho v^2$$

$$T_1 = T_o + \frac{\rho v^2}{2 C_p}$$

With the Mach number : $M = \dfrac{v_i}{\text{Velocity of sound}} = \dfrac{v_i}{20{,}1 \times \sqrt{T_o}}$

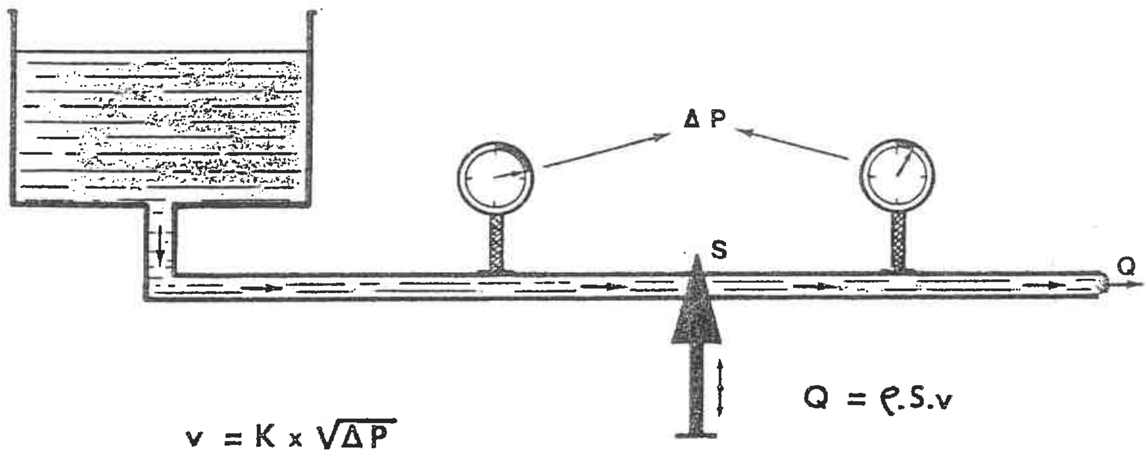
$$T_1 = T_o \left(1 + 0{,}2 M^2 \right)$$

Calculation of total pressure

$$\frac{T_1}{T_o} = \left(\frac{P_1}{P_o} \right)^{\frac{\gamma - 1}{\gamma}} \qquad \frac{P_1}{P_o} = \left(\frac{T_1}{T_o} \right)^{\frac{\gamma}{\gamma - 1}}$$

FLOW OF FLUIDS

The «stream» is characterized by : the amount of fluid Q,the density ρ, the passage S, and the velocity V.



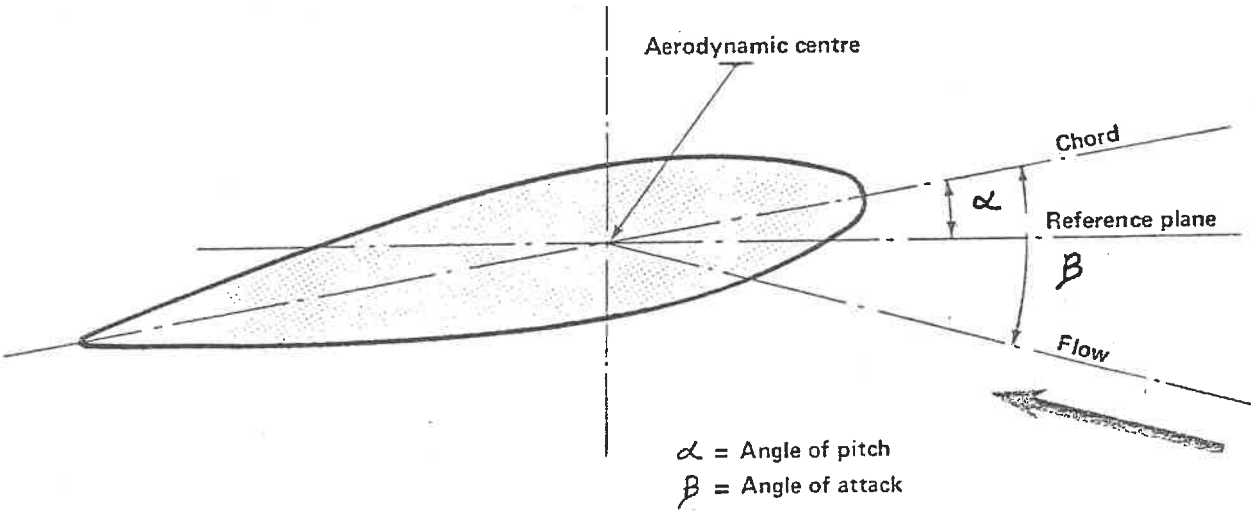
$$Q = \rho . S . v$$

$$v = K \times \sqrt{\Delta P}$$

K = Coefficient
ΔP = Upstream pressure – Downstream pressure

AERODYNAMICS

Review of definitions

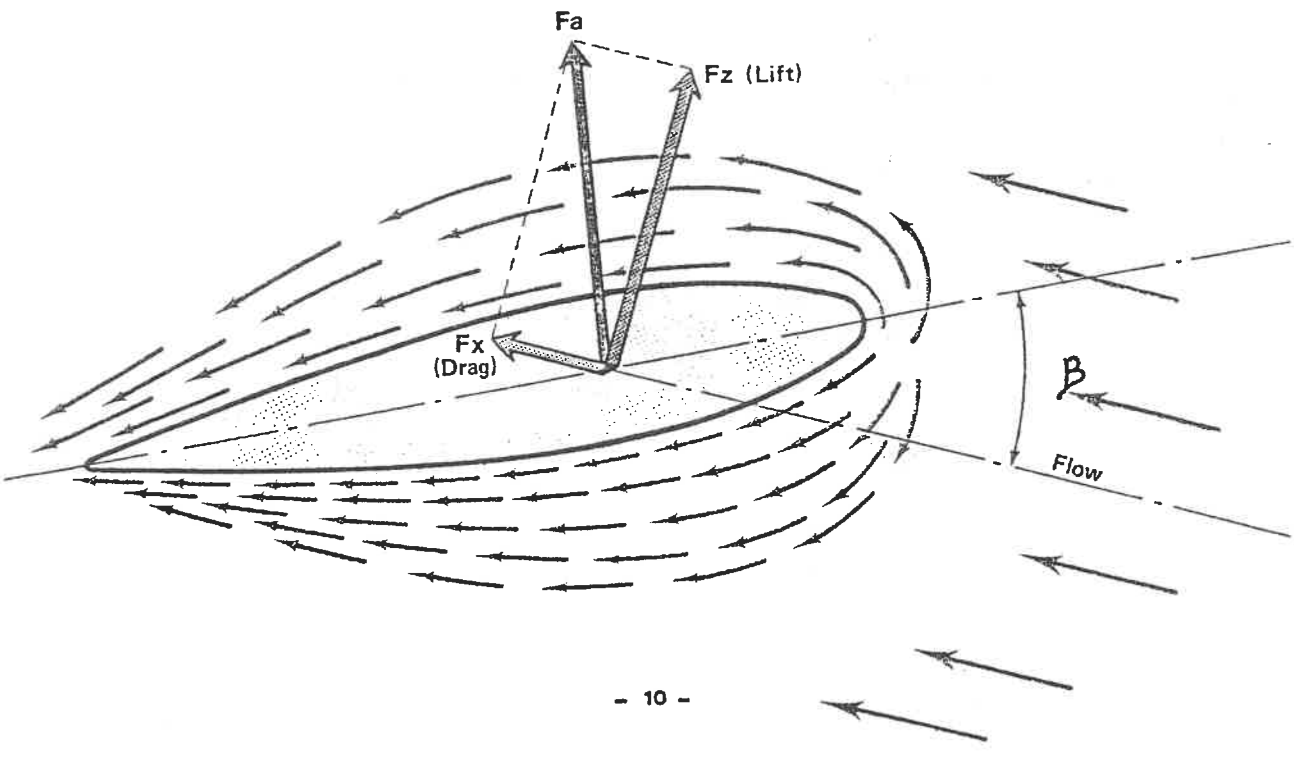


Aerodynamics forces

The laminar flow on an airfoil section induces forces which are depending upon : the velocity of flow V, the frontal surface S, the type of airfoil section Cz or Cx and the air density ρ .

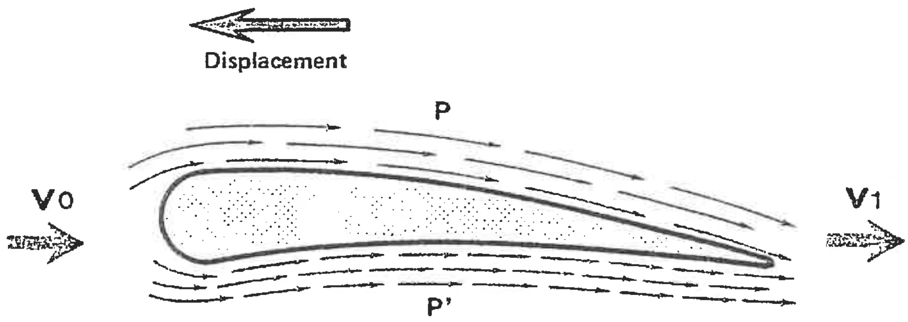
Lift : $Fz = \frac{1}{2} \rho v^2 S Cz$

Drag : $Fx = \frac{1}{2} \rho v^2 S Cx$



PRINCIPLES OF PROPULSION

PROPULSION BY ACTION



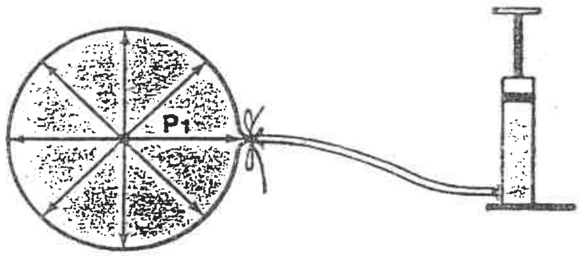
Low difference of velocity

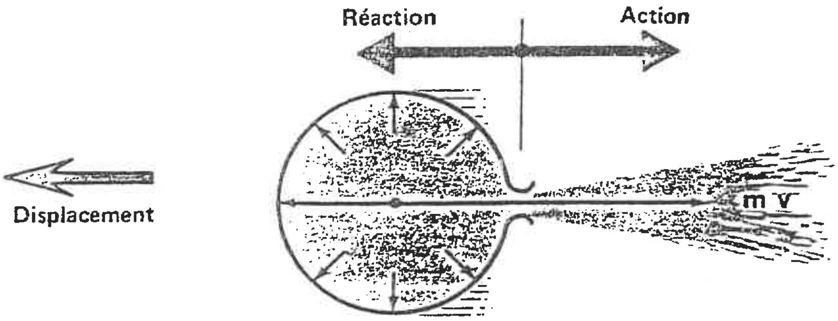
High difference of pressure $P' > P$

PROPULSION BY REACTION

$P_1 > P_0$

$F = 0$





The propulsive force is the resultant of internal pressure forces.

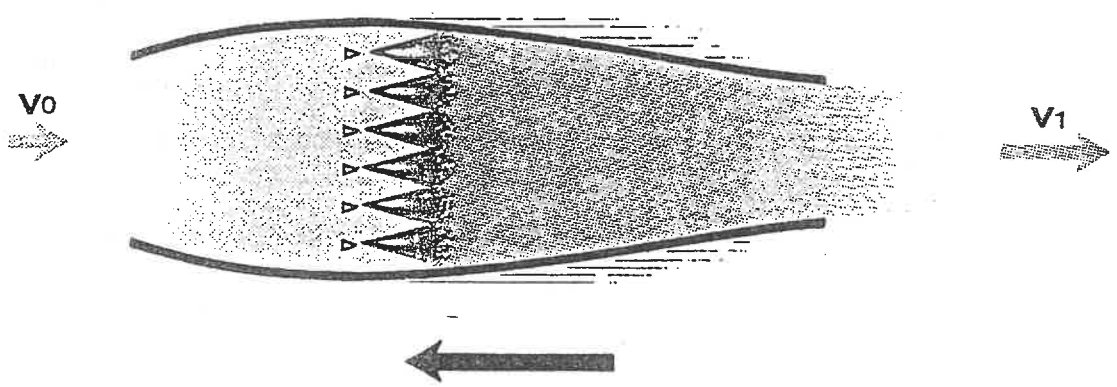
If we recall the fundamental law of dynamics : $F = m\gamma$

In this case : $F = m\,v$

m : Mass of gas expelled

v : Velocity of gas expelled

REACTION PROPULSION SYSTEM



$$F = m\,(v_1 - v_0)$$

A mass of air « m » enters the device with a velocity « vo ».

By some means (for example : combustion), the «device» gives an acceleration to this mass of air which is expelled rearwards at a velocity « v1 ».

A forward force is then produced which is called thrust.

$$F = m\gamma$$

$$F = m\,(v_1 - v_0)$$

It can then be seen, that the propulsive force depends upon the mass of air and the exhaust gas velocity.

It is not necessary, to take into account the quantity of fuel injected to obtain acceleration when computing the thrust.

VARIOUS TYPES OF ENGINES

INTRODUCTION

Aero-engines are machines used to transform the potential energy contained in combustible and comburent.

- either into kinetical energy (direct reaction)
- either into mechanical energy (indirect reaction)

Most of the propulsion systems use the air as comburent, and makes it undergo series of transformations which are usually divided into three phases :

- compression
- combustion
- expansion

A propulsion system therefore consists of :

- a compression stage (static, rotative or alternative)
- a combustion chamber
- an expansion stage (static, rotative or alternative)

CLASSIFICATION OF PROPULSION SYSTEMS

Propulsion systems may be classified in two main categories :

- those which do not use ambient air
- those which use ambient air

It is also possible to consider :

- direct reaction systems (kinetical energy)
- indirect reaction systems (mechanical energy)

NOTES

The rocket is in fact the only propulsion system which does not use ambient air.

DIRECT REACTION DEVICES

(Devices delivering kinetical energy)

Rocket

The « rocket » is a system using the combustion of a comburent and of a combustible to ensure propulsion by reaction.

A rocket engine essentially consists of :

- a supply system (comburent and combustible)
- a gas generator (combustion chamber)
- a propulsive jet pipe

The process of combustion is obtained :

- either by combustion of powders
- either by combustion of liquids.

Ram - jet

The ram - jet is a propulsion system using the air as a comburent and which has no mechanical part in movement.

The compression obtained in the air intake is due to the shape of the air intake and to the ram effect at high speed.

The fuel is injected and burnt in the stream of air, and the gases resulting from this combustion are expelled through a propulsive jet pipe.

The operation of such a system is only possible at relatively high speed and its efficiency is rather low.

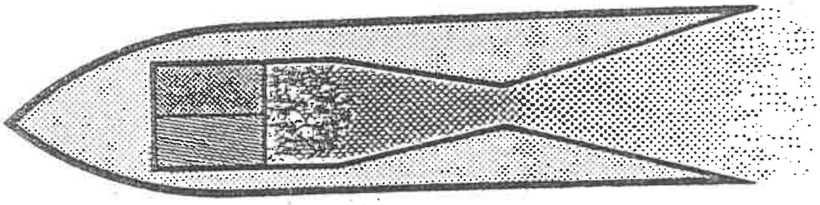
Pulso - jet

The pulso-jet is an engine using the principle of «pulsed combustion» to ensure propulsion.

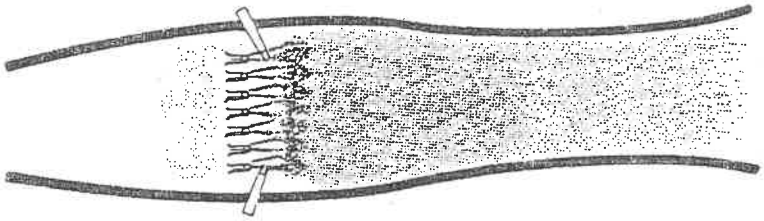
The pulsed operation is obtained by a periodic supply of the combustion chamber.

An air intake system allows the pulsed admission of air. The system can be mechanical or aerodynamical.

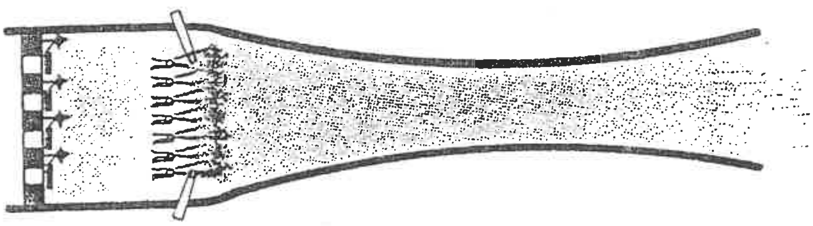
ROCKET



RAM - JET ENGINE



PULSO - JET ENGINE



Turbo-jet

The ambient air is admitted, compressed and delivered to the combustion chamber by an air intake channel and a compressor.

The air under pressure is mixed with the fuel injected into the combustion chamber and burnt under a continuous burning process.

The gases resulting from the combustion are then expanded rearwards through a turbine and an exhaust system.

Part of the energy from the gases is used by the turbine to drive the compressor and the accessories required for the operation of the engine.

By-pass turbo-jet

It is a turbo-jet engine in which more air than required by the gas generator is admitted. The air entering the engine is divided into two flows :

- a «warm» flow for the gas generator,
- a «cold» flow passing around the generator.

This arrangement allows an increase in propulsive efficiency and a better fuel specific consumption.

Twin spool turbo-jet

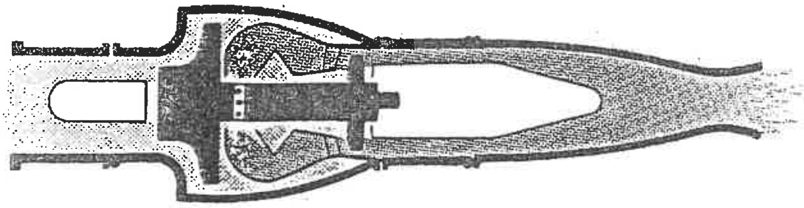
It is a turbo-jet engine with two rotating assemblies mechanically independent one from the other.

- a low pressure assembly (compressor and turbine)
- a high pressure assembly (compressor and turbine)

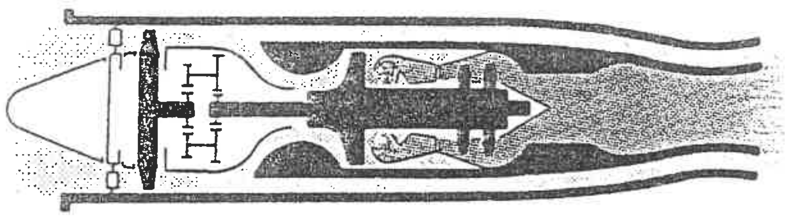
The transmission shaft of the low pressure assembly is located coaxially inside the shaft of the high pressure assembly.

This arrangement allows a good adaptation of compressors and turbines, a better efficiency and an appreciable reduction of weight and dimension of the engine.

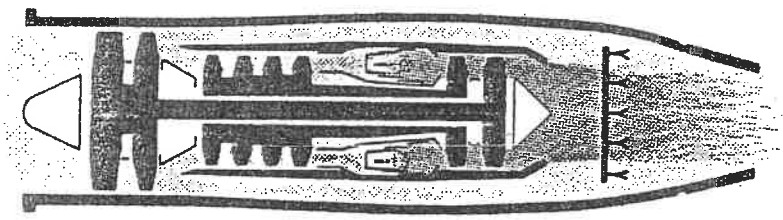
TURBO - JET



BY-PASS TURBO - JET



TWIN SPOOL TURBO - JET



INDIRECT REACTION DEVICES

(Devices delivering mechanical energy)

Reciprocating engine

Piston engine used to drive a propeller. In the case of a «turbo-compound», there is in addition one rotative compression stage (supercharger) and one rotative expansion stage (turbine).

Turbo-propeller

Gas turbine engine driving a propeller. The turbines of the gas generator extracts the maximum of energy from the gases so as to drive the compressor, the accessories and the propeller.

Turbo-shaft

Gas turbine engine for various applications. For example :

- driving of an helicopter rotor,
- driving of an electric generator,
- driving of an hydraulic pump, etc...

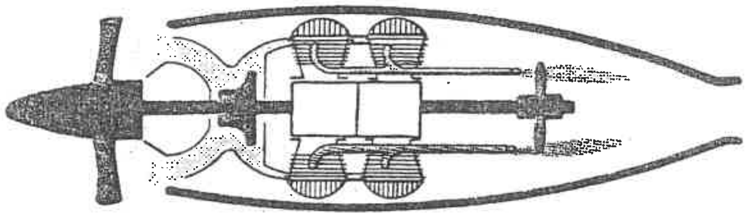
Free turbine

A conventional gas generator (same components as in a turbo-jet engine) supplies power in the form of kinetic energy to a turbine which is called «free turbine». This free turbine transforms this kinetic energy into mechanical energy so as to drive the shaft of a «receiver». A free turbine can be used as turbo-propeller power plant or turbo-shaft power plant.

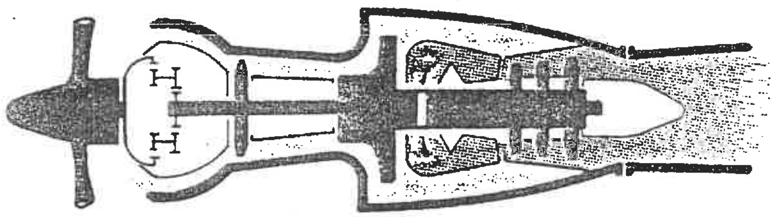
Turbo-air generator

It can be considered as a special case in our classification, because it does not exactly deliver neither kinetic energy nor mechanical energy. The compressor of such an engine is oversized so as to use the air under pressure at the outlet of it for any application.

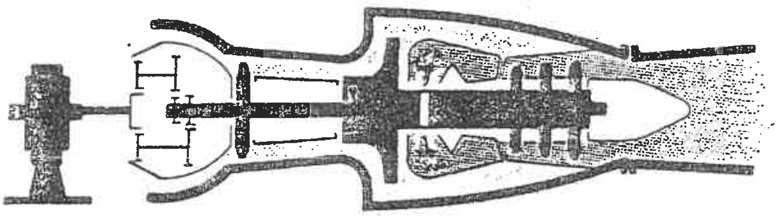
RECIPROCATING ENGINE
TURBO-COMPOUND



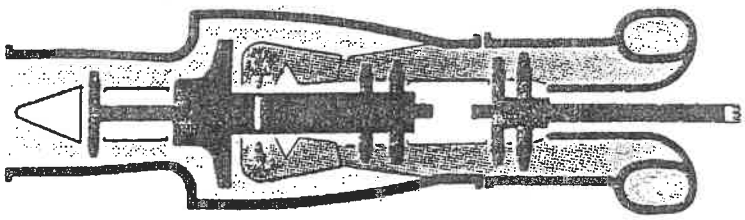
TURBO - PROPELLER



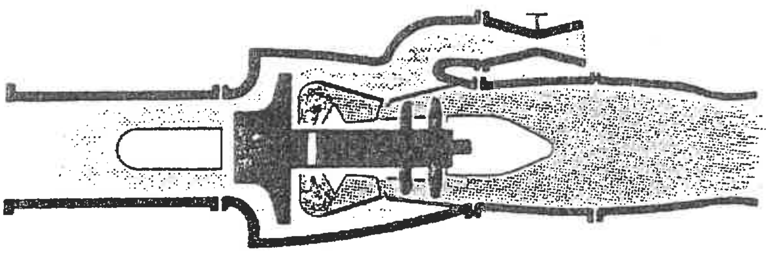
TURBO - SHAFT



TURBO - SHAFT
FREE ENGINE



TURBO - AIR GENERATOR



GAS TURBINE

The term «gas turbine» indicates a type of engine producing energy with the following components : air intake, compressor, combustion chamber and turbine.

GAS GENERATOR

The gas generator is the part of the power plant in which is actually produced the energy. When the generator mainly delivers mechanical energy on a shaft it is also called «power generator».

TURBO-POWER PLANT

The turbo-power plant is a gas turbine engine for a particular application. It usually consists of a gas generator section and of accessories components :

- Turbo-jet power plant, gas turbine engine producing kinetic energy to ensure propulsion by direct reaction.

- Turbo-propeller power plant, gas turbine engine producing mechanical energy to drive an aircraft propeller.

- Turbo-shaft power plant, gas turbine engine producing mechanical energy for various applications.

- Turbo-air generator, gas turbine engine producing energy under the form of compressed air.

THEORY OF OPERATION OF A GAS TURBINE ENGINE

PHASES OF OPERATION

Whatever the type of propulsion, the following phases of operation are always present :

- compression
- combustion
- expansion

GAS TURBINE ENGINE MAIN COMPONENTS

A gas turbine engine usually comprises the following sections :

– air intake – compressor	→ compression
– combustion chamber	→ combustion
– turbine – exhaust pipe	→ expansion

The arrangement of the various components can change according to the type of engine but the basic sections are always present.

Various accessories are required to allow the operation of the gas turbine and to form a power plant adapted to a particular utilization.

The thermodynamic operation as well as definition of performance, powers, efficiencies are dealt with in the following pages.

PRINCIPLE OF OPERATION

The air is admitted at a certain speed in the air intake channel. It is subjected to a first transformation due to the shape of the air intake and to the forward velocity.

It is then compressed in the compressor section and delivered to the combustion chamber.

In the combustion chamber, it is divided in two flows :

- a primary air flow (mixed with the fuel and burnt under constant pressure)
- a secondary air flow (for the cooling of burnt gases)

The burnt gases are at first expanded in the turbine which extracts from them a certain amount of energy. This energy is used to drive the compressor, the accessories and in some cases a receiver. This expansion is then achieved in an exhaust system.

ENGINE REFERENCE STATIONS

The various «stations» of a gas turbine engine are usually numbered so as to allow the reference of the flow.

Thus, for a given type of engine the following stations can be considered :

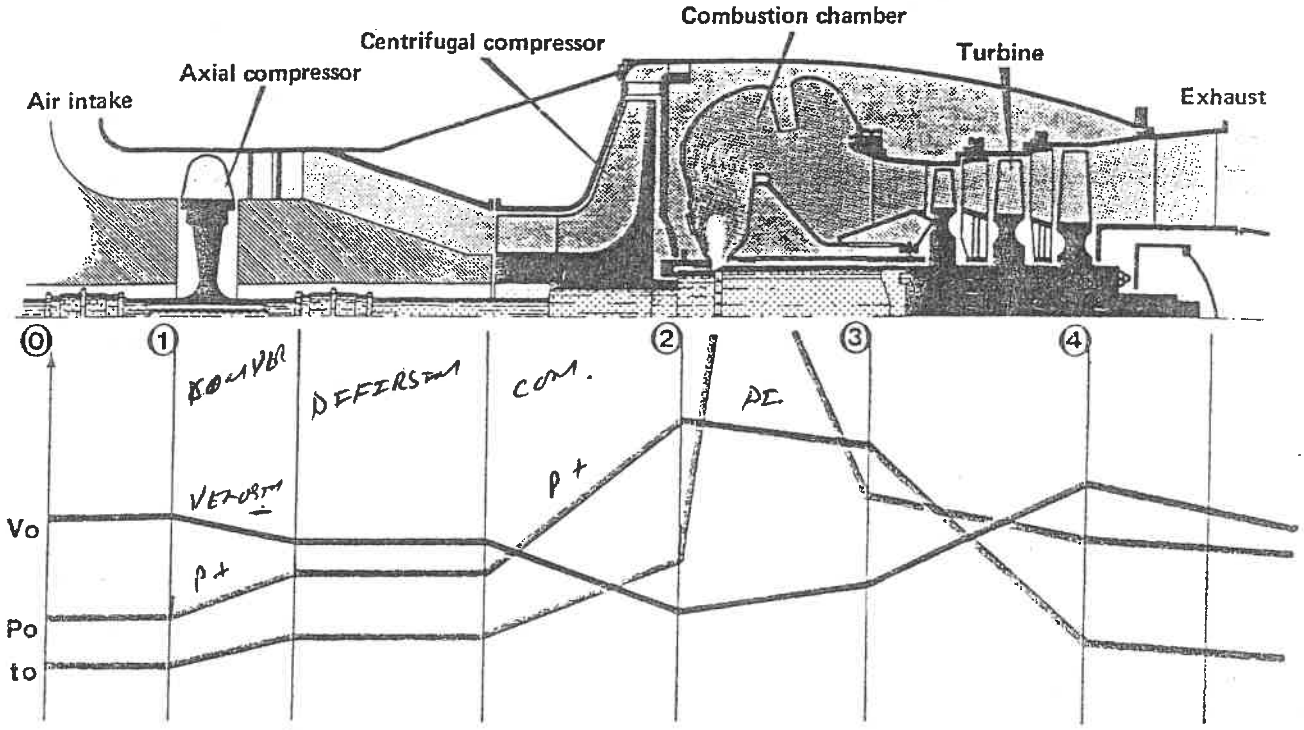
O — Upstream

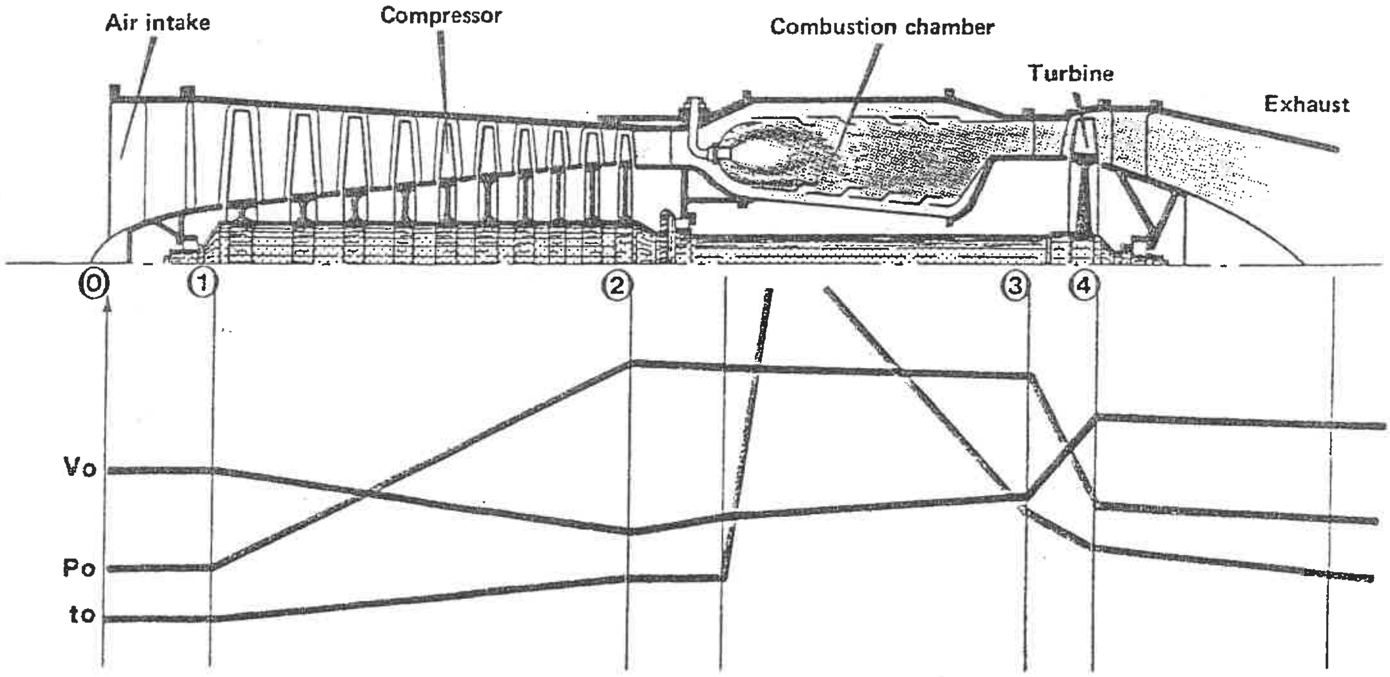
1 — Air intake

2 — Compressor outlet

3 — Turbine inlet

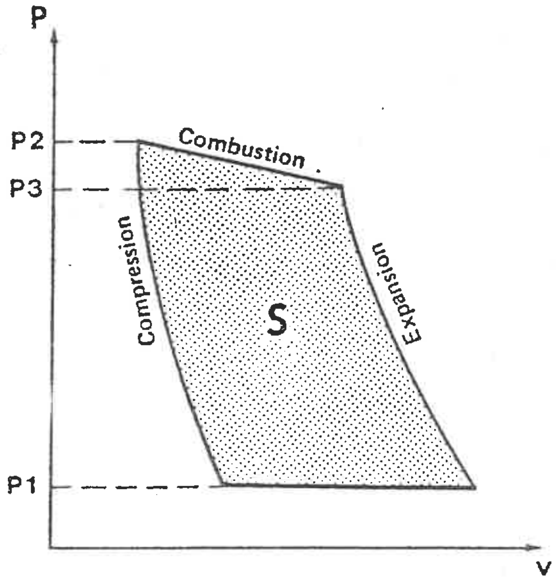
4 — Turbine outlet



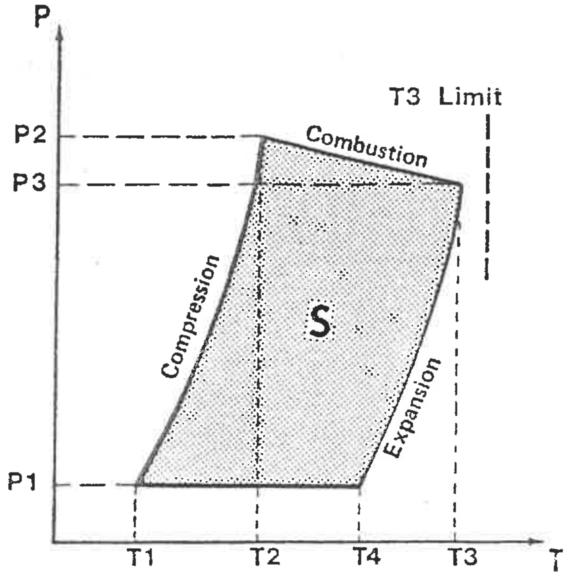


GAS FLOW DIAGRAMMES

THEORETICAL DIAGRAMMES



Pressure-Volume



Pressure-Temperature

Compression

Adiabatic $\frac{T1}{T0} = \frac{P2}{P0}^{\frac{\gamma - 1}{\gamma}}$

Power required $m \times Cp\ (T2 - T1)$

m : air mass flow
Cp : Coefficient
(specific heat at constant pressure)

Combustion

Isobaric T2 ↗ T3 P2 > P3

Expansion

Adiabatic $\frac{T3}{T4} = \frac{P3}{P4}^{\frac{\gamma - 1}{\gamma}}$

Conclusion

To increase the surface of the diagramme, i.e. the useful output it is necessary :

- to increase the compression ratio P2/P1
- to increase the turbine inlet temperature T3

POWERS AND EFFICIENCIES

Thermodynamic power (WT)

It is the power which could be obtained from the fuel if the engine was perfect :

$$WT = Wc \times \eta t$$

Wc : Power supplied by the fuel
ηt : Theoretical efficiency of the cycle

Thermic power (Wth)

It is the power transmitted to the mass of gas during its passage through the engine.

$$Wth = \frac{1}{2} m \left(v1^2 - vo^2 \right)$$

Propulsive power (Wp)

It is the power used for the flight.

$$Wp = F \times vo$$

F : Thrust

$$Wp = m \left(v1 - vo \right) \times vo$$

Dissipated power (Wd)

It is the difference between the thermic power and the propulsive power.

$$Wd = Wth - Wp$$

Jet power (Wj)

It is the energy of the mass of gas at the outlet of the jet.

$$Wj = \frac{1}{2} m v^2$$

Note : on ground run $Wth = Wd = Wj$

Thermodynamic efficiency (ηT)

It is the ratio of the thermodynamic power WT and of the energy supplied by the fuel

$$\eta T = \frac{WT}{Wc} = \frac{\gamma - 1}{\gamma}$$

γ characterizing the compression ratio, it can be seen that the higher γ is, the greater is the efficiency.

Thermic efficiency (ηth)

It is the ratio of the thermic power and of the fuel calorific power.

$$\eta th = \frac{Wth}{Wc}$$

It is of about 25 to 30 %

Internal efficiency (ηi)

It is the ratio of the thermic power and of the thermodynamic power.

$$\eta i = \frac{Wth}{WT}$$

It is of about 80 %

Propulsive efficiency (ηp)

It is the ratio of the propulsive power and of the thermic power.

$$\eta p = \frac{Wp}{Wth} = \frac{m\,(v1 - vo) \times vo}{\frac{1}{2}\,m\,(v1^2 - vo^2)} = \frac{2\,vo}{v1 + vo}$$

It is of about 60 %

Overall efficiency (ηg)

It is the ratio of the energy developped by the engine and of the energy released by the fuel. It is equal to the product of thermodynamic, internal and propulsive efficiencies ; or to the product of thermic and propulsive efficiencies.

$$\eta g = \eta th \times \eta p$$

It is of about 20 %

GAS TURBINE ENGINE COMPONENTS

AIR INTAKE

It is a duct designed to admit the air and to guide it in the best possible conditions to the compressor.

Its shape is studied in order to obtain the smallest possible drag and an even flow of air in all operating conditions.

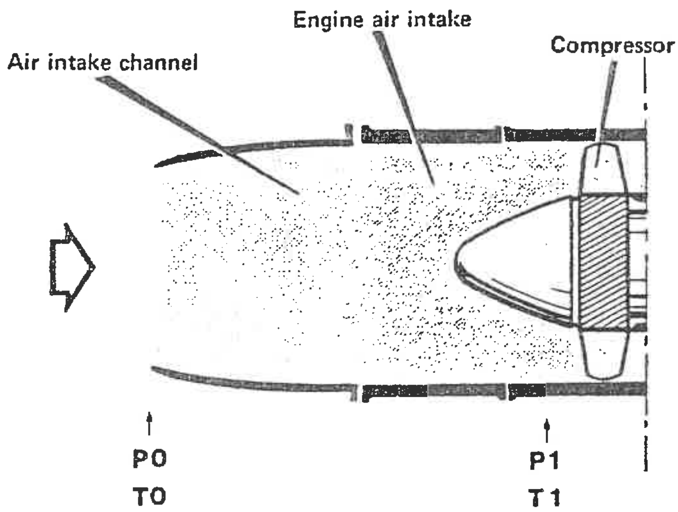
Air intake can be :

- with convergent passage
- with divergent passage
- with variable passage.

The pressure ratio in the air intake is P1/P0, taking :

- P0 : inlet pressure
- P1 : pressure at outlet of air intake.

This pressure ratio, as well as the air flow, varies with atmospheric and flight conditions.



COMPRESSOR

The combustion (particularly the achievement of a high combustion efficiency) requires a supply of a certain flow of air under pressure. The purpose of a compressor is to ensure this supply of air under pressure.

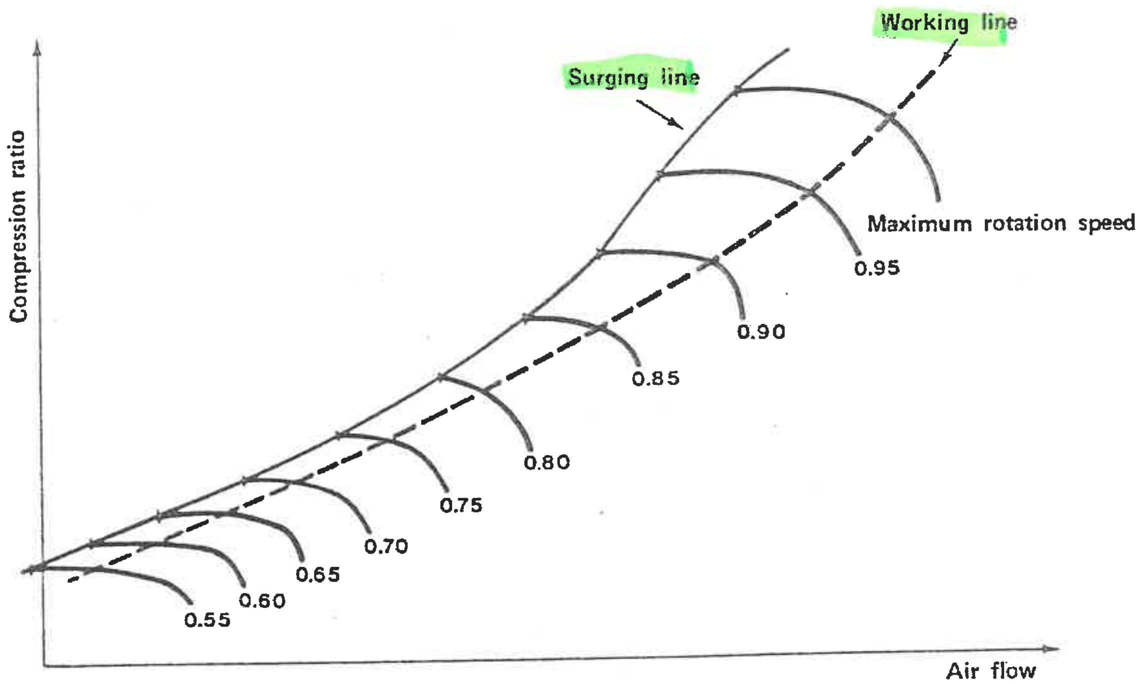
A compressor mainly consists of :

- a rotor which induces a movement to a mass of air and subjects it to a first compression.
- a stator which transforms the velocity of air into pressure.

A compressor is characterized by the following parameters :

- compression ratio $= \dfrac{\text{Outlet pressure}}{\text{Inlet pressure}}$
- air flow G expressed in kg/s
- efficiency $\eta = \dfrac{\text{Total variation of energy}}{\text{Energy supplied by the turbine shaft}}$

  It is about 0,8

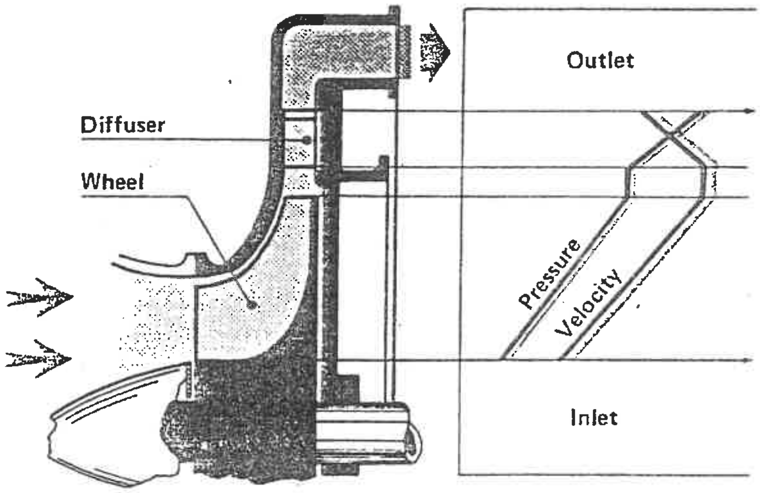


COMPRESSOR CHARACTERISTICS

CENTRIFUGAL COMPRESSOR

It mainly consists of :

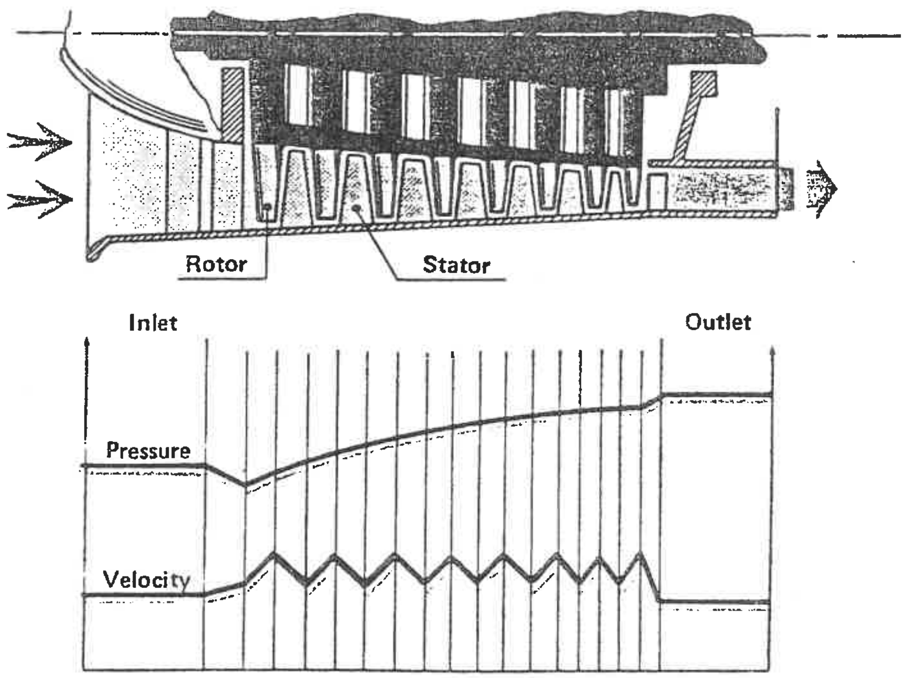
- a rotor with an admission wheel
- a stator or diffuser



AXIAL COMPRESSOR

It is made of several stages ; each stage consists of :

- moving blades (rotor)
- stator vanes (stator)



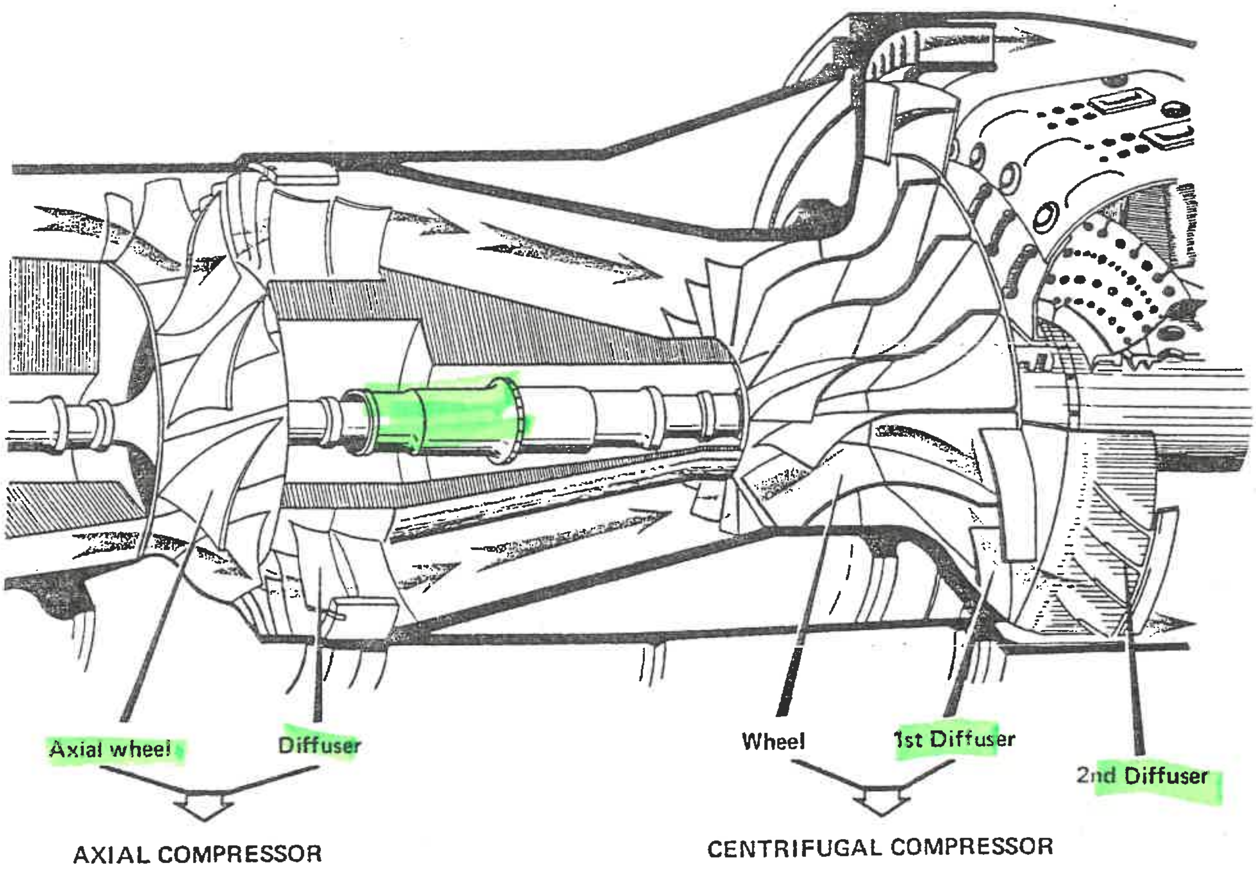
AXIAL AND CENTRIFUGAL COMPRESSOR

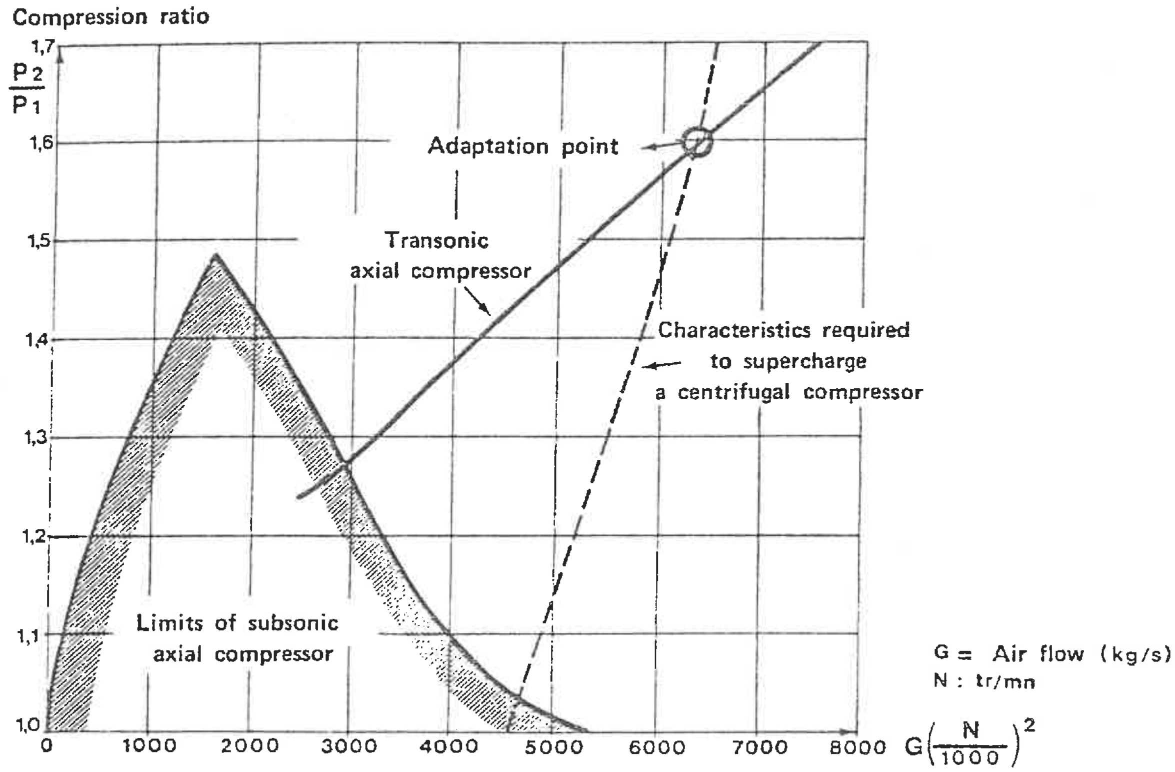
In some engines the compression phase is ensured by means of an axial type compressor followed by a centrifugal type compressor.

This solution allows to keep all the advantages of a centrifugal type compressor and to obtain an appreciable increase in compression ratio.

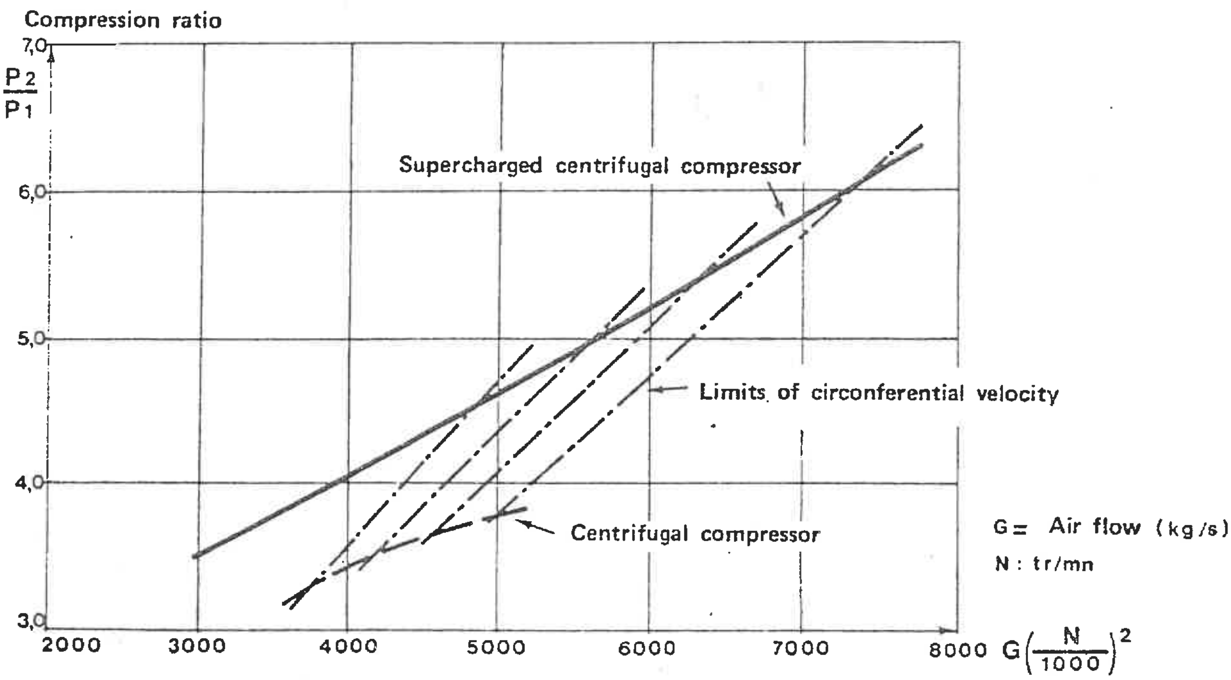
A transonic axial compressor is used to supercharge the centrifugal compressor in order to obtain, for the same rotation speed, the increase in compression ratio.

In that way, from a compression of about 4/1 with a single centrifugal compression a ratio of about 6/1 is obtained with a one stage axial compressor and up to 8/1 with a two stages axial compressor.





CHARACTERISTICS OF «SUPERCHARGING» BY AXIAL COMPRESSOR



GAINS OBTAINED BY SUPERCHARGING

SURGING

Surging is a phenomenon of engine unstable operation.

Description of the phenomenon

The compressor delivers air under pressure into a «capacity» formed by the combustion chamber, the turbine and the exhaust system (downstream circuit).

If the pressure of this downstream circuit P3 overcomes the compressor delivery pressure P2, the compressor air flow becomes void and the expansion of gases is accomplished towards the upstream circuit as well as towards the downstream circuit. In this condition, upstream pressure P3 falls down, the compressor flow is recovered until its pressure is again overcome. Then, this phenomenon is taking place at a frequency of about 120 cycles per second. It is obvious that such a condition disturbs the engine operation and may have serious consequences.

Causes of surging

Surging occurs when P3 pressure overcomes P2 pressure. It is therefore due, either to an abnormal decrease of P2 pressure (upstream circuit) or to an abnormal increase of P3 pressure (downstream pressure).

Thus, it is possible to consider the surging due to upstream circuit and the surging due to the downstream circuit.

- Upstream circuit :

When the flow of air is disturbed there is an aerodynamic stalling on the compressor blades and a drop of P2 pressure leading to surging condition. Any damage or defect of air intake and compressor may cause surging. Surging may also occur when the air velocity is too high in one part of the compressor.

- Downstream circuit :

When upstream pressure is too high or increases too rapidly surging may also occur. The following causes can be mentionned : too quick a change in engine rating, defect or damage of the combustion chamber, turbine, exhaust system...

Consequences of surging

- Rise in turbine inlet temperature which could damage the turbine blades.
- High vibrations which could lead to damage of rotating assembly and bearings.
- Abnormal noises.
- Smokes and flames.

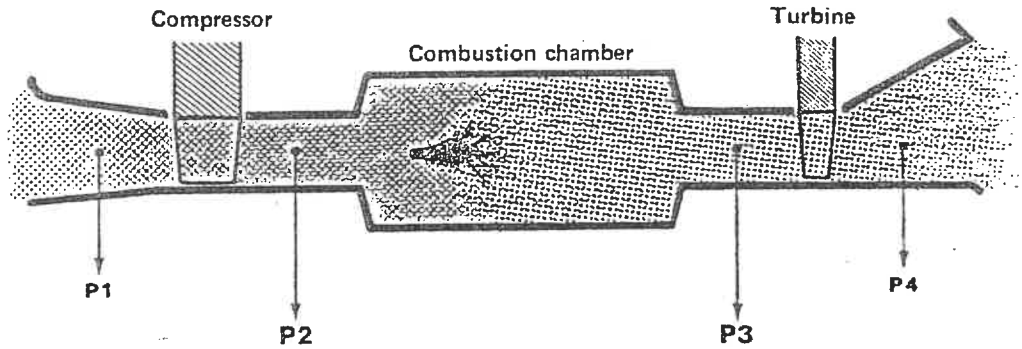
Procedures and remedies in case of surging

When surging is encountered on a turbo-jet engine, it is usually recommended to reduce fuel flow.

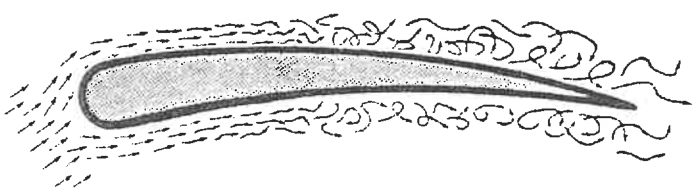
On a turbo-propeller or turbo-shaft engine it is necessary to reduce the load applied to the output shaft.

Engine inspection is usually required after a surging operating condition.

It is sometimes necessary to use a system maintaining a safety margin in operation, devices such as : compressor bleed valve, air intake guide vanes, acceleration control unit ...



P3>P2 → Surging



Stalling on an airfoil section

COMBUSTION CHAMBER

The purpose of the combustion chamber is to burn a mixture of fuel and air, and to release the resulting gases to the turbine in the best possible condition.

The fuel-air ratio to obtain an efficient combustion is of about 1/15. However, this ideal ratio cannot be admitted because the resulting temperature would be too high for the turbines.

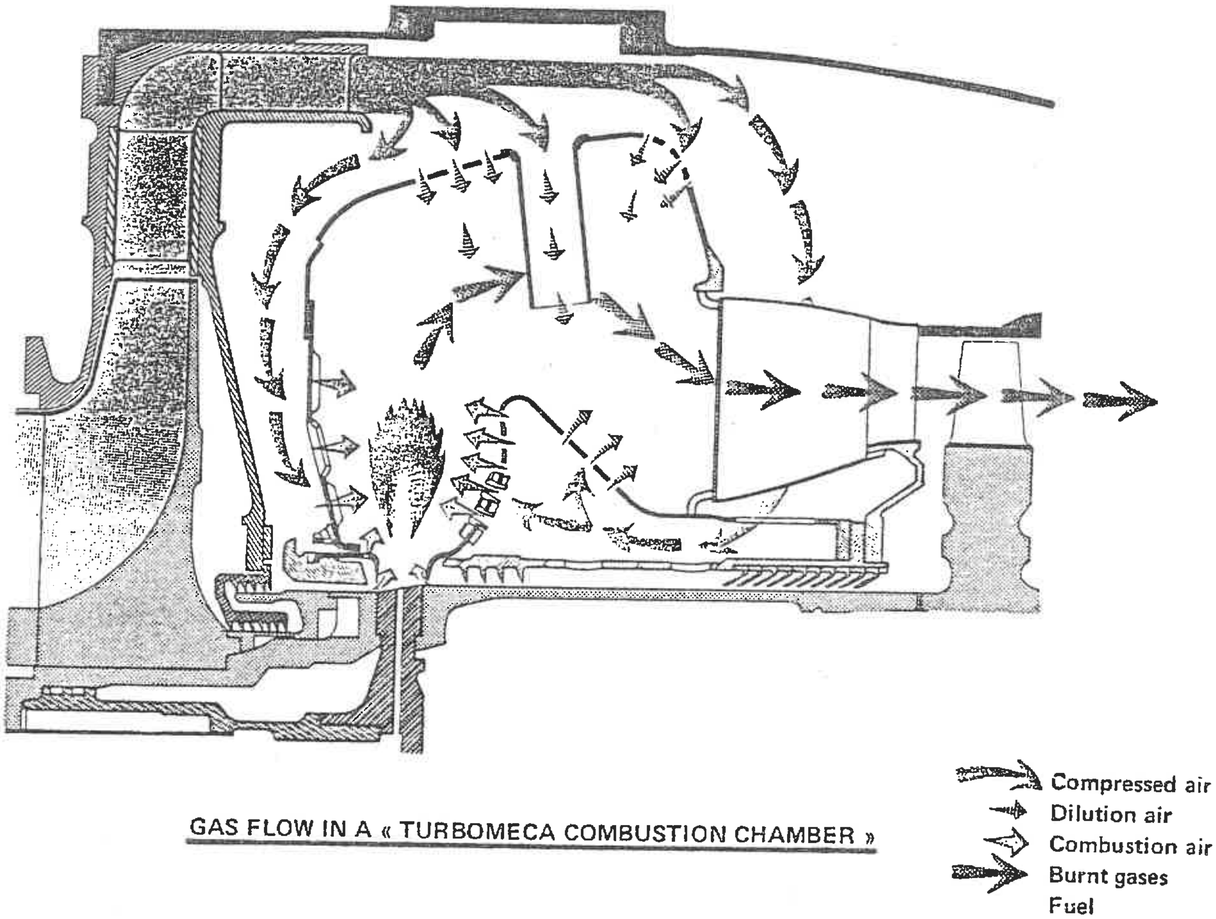
Therefore, the combustion chamber admits a ratio of about 1/50, but only 1/15 is used for combustion and the remaining air for dilution of burnt gases.

The efficiency of a combustion chamber is about 95 %. Moreover, the combustion chamber must ensure : the stability of the flame, the operation over a wide range of fuel flow and rotation speed, ignition during starting and relighting in flight, operation in altitude ...

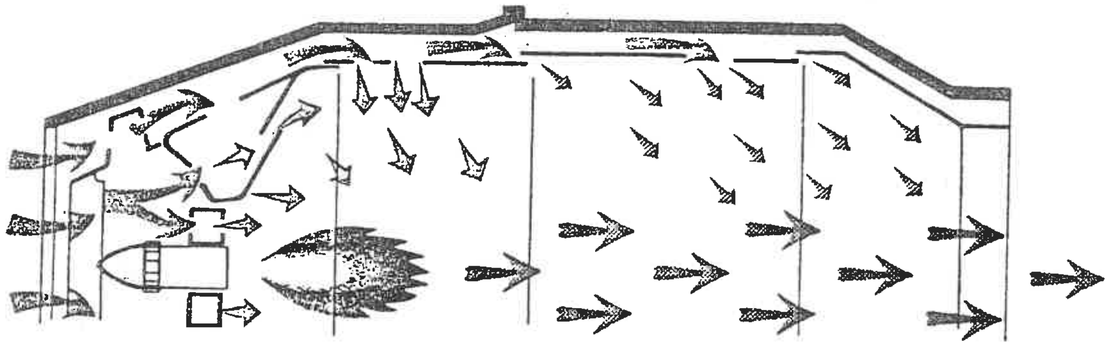
Types of combustion chamber

There are three main types of combustion chamber :

- multiple combustion chamber
- annular combustion chamber
- «can-annular» combustion chamber



GAS FLOW IN A « TURBOMECA COMBUSTION CHAMBER »



A TYPICAL COMBUSTION CHAMBER FLOW

Fuel injection

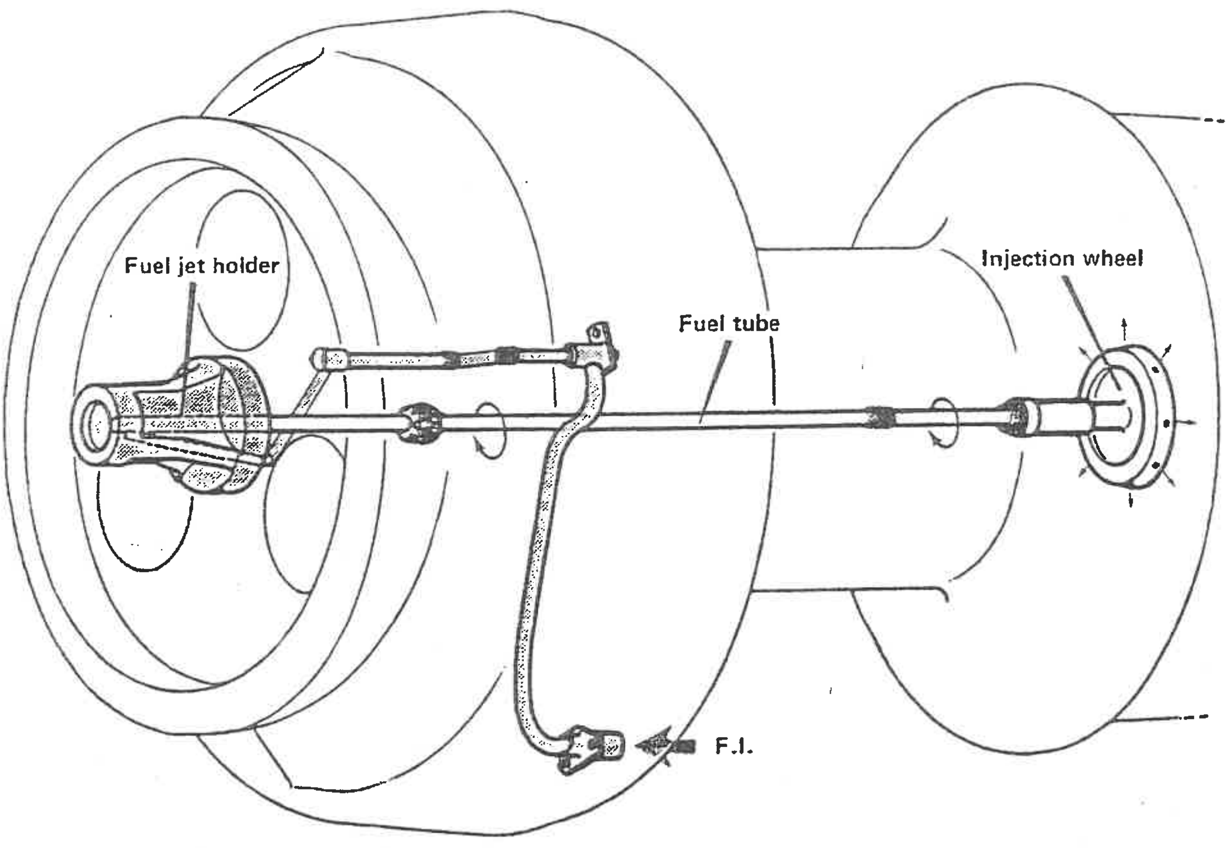
Several distinct principles of fuel supply are in use :

- injection with pre-vaporization
- spraying injection (direct or indirect) by means of burners
- centrifugal injection (Turbomeca type)

The centrifugal fuel injection has the following advantages :

- no need for a high pressure fuel system
- spraying quality practically independent of fuel flow
- less risk of clogging due to the fact that the diameter of the jets is greater than those of an ordinary burner.

However, the sealing between the fuel tube rotating at high speed and the fuel static supply sets a delicate problem.



TURBOMECA TYPE INJECTION SYSTEM

TURBINE

The purpose of the turbine is to transform the kinetic energy of the gases resulting from combustion into mechanical energy, in order to drive the compressor, the accessories, and also in some engines to provide shaft power.

In a turbo-jet engine, the turbine extracts part of the energy to drive the compressor and accessories, whereas in a turbo-shaft engine the turbine extracts the maximum of energy to drive in addition a propeller or any « receiver ».

A stage of turbine comprises stationary part (row of guide vanes) and a moving part (turbine wheel). To produce the driving torque the turbine may consist of several stages.

The efficiency of a turbine is of about 92 %. In a turbo-shaft engine, about 2/3 of the total power extracted by the turbine is used to drive the compressor.

Principle of operation

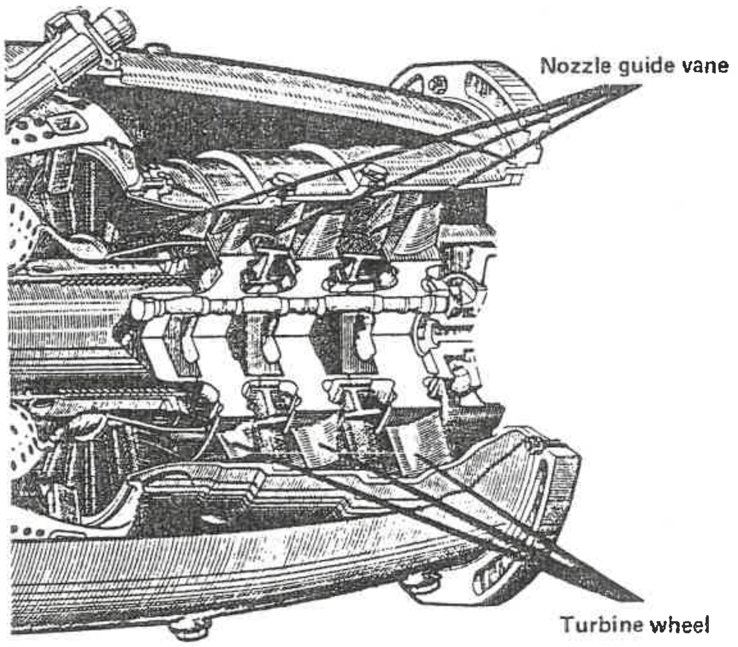
The gases resulting from combustion flow at first through the row of stationary nozzle guide vane. The convergent passage increases the velocity of the gases and give them a whirling movement in the direction of rotation.

The gases then flow through the turbine blades causing by impulse and reaction the turbine to rotate and so provide the power for driving the turbine shaft and compressor.

The torque applied depends mainly upon the gas flow and the variation of energy in the turbine wheel.

The pitch of turbine blades, as well as the pitch of the nozzle guide vanes, vary from the root to the tip of the blade so as to equalize the work achieved by the mass of gas.

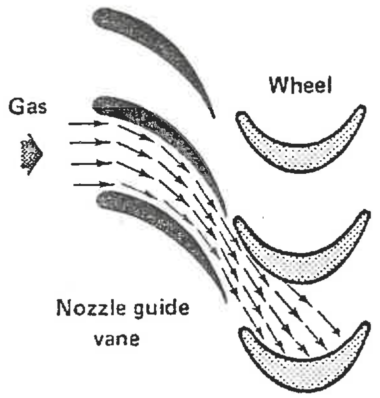
3 STAGES TURBINE



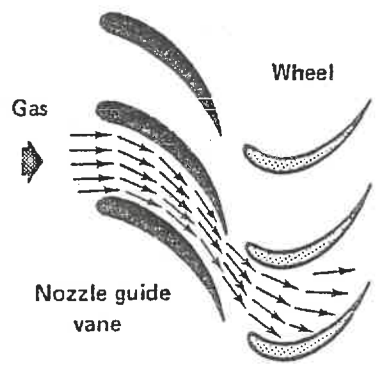
Types of turbines

Three types of turbines can be considered :

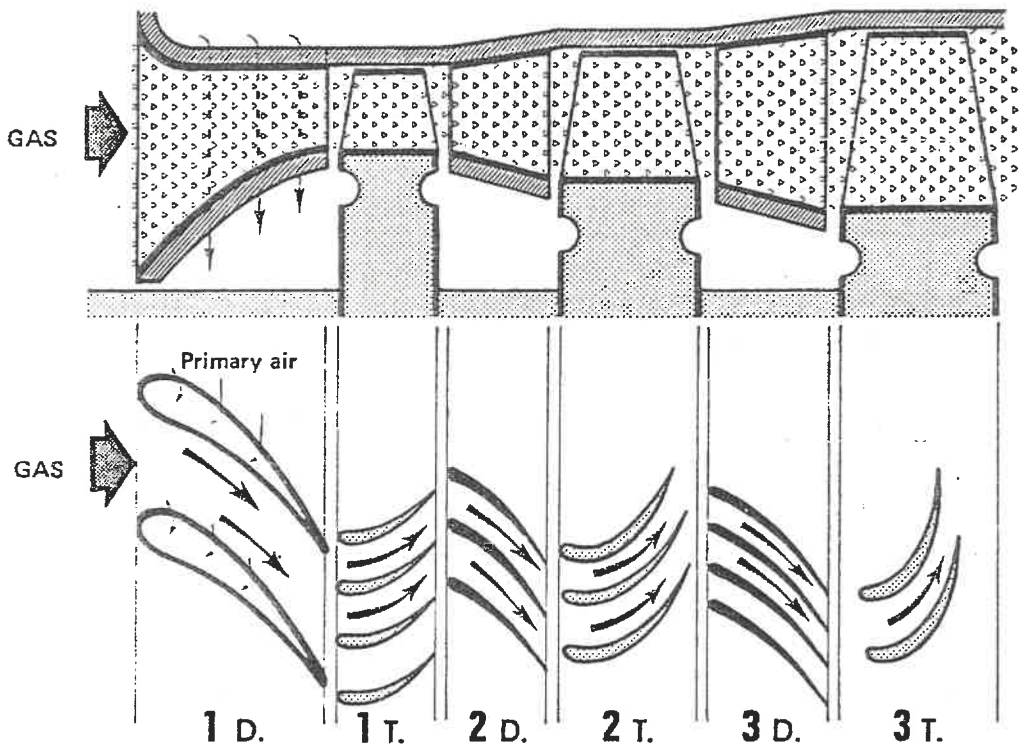
- impulse type turbine
- reaction type turbine
- impulse reaction type turbine



IMPULSE TYPE TURBINE



REACTION TYPE TURBINE



EXAMPLE OF A TURBOMECA 3 STAGES TURBINE

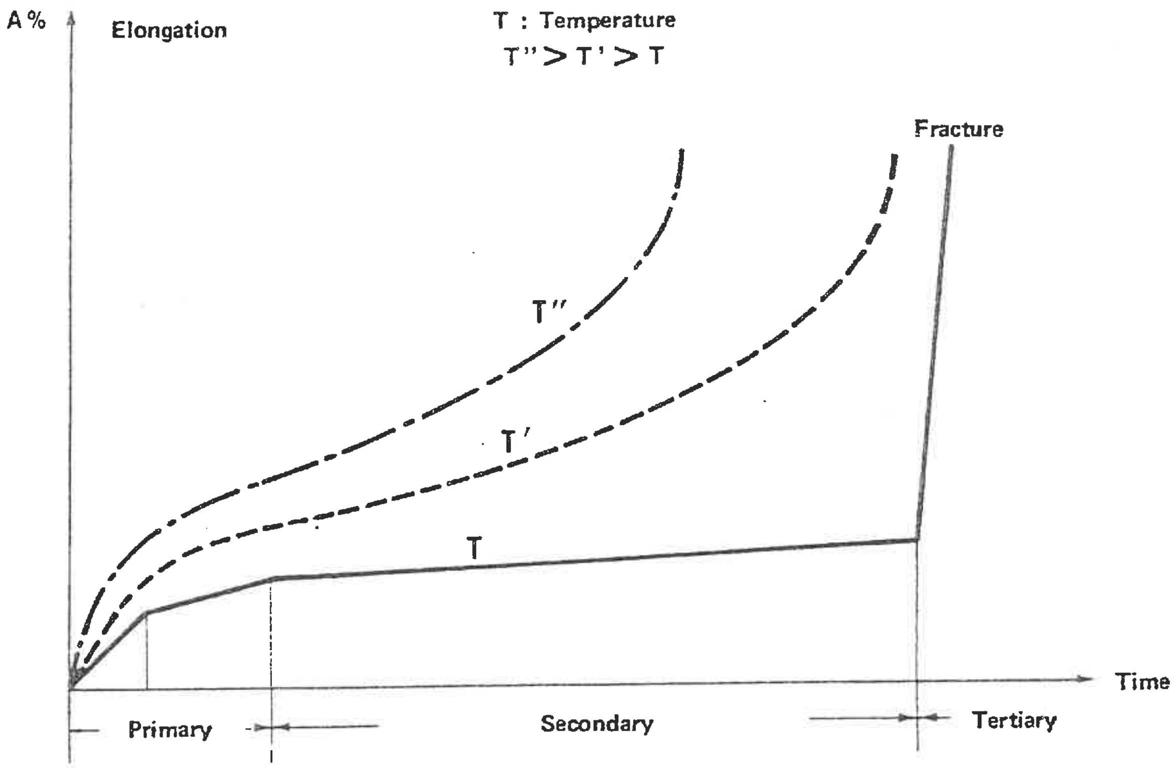
Turbine stress

The turbine blades are subjected at the same time to heavy mechanical loads (centrifugal force) and very high temperatures.

It is essential to limit these stresses so as to avoid the deterioration of the blades.

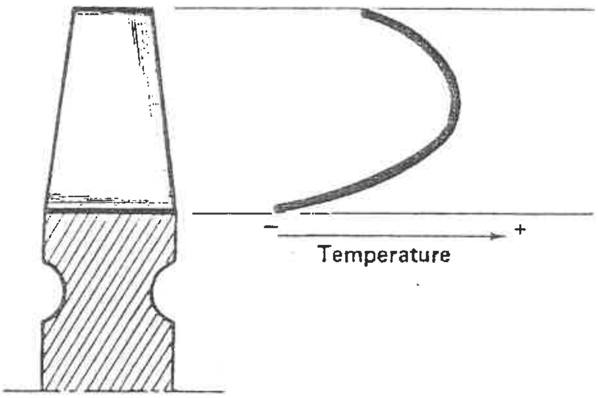
In fact, if the stresses to which the turbine blades are subjected are too high, the molecules constituting the metal slide against each other and there is an elongation of the blade.This phenomenon is called «creeping» and it is very important to know the resistance to creep of the turbine, in order to ensure operation within well defined limits. NB

This resistance to creep is determined by measuring the elongation of a specimen bar of metal subjected to mechanical and thermal stress during a given time. A curve is then obtained which represents the characteristics of the metal, regarding creeping strain.

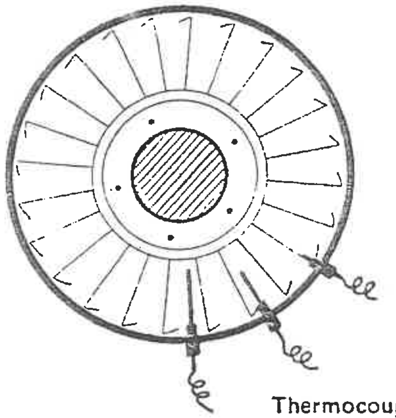


CREEPING CURVE

To avoid «creeping» it is particularly necessary to limit the temperature but also to ensure a good distribution of temperature on the turbine. The proper distribution on a blade would be to have the highest temperature in the middle section and the lowest temperature on the tip and on the root of the blade. Usually, the distribution is made so as to protect as far as possible the root of the blades.

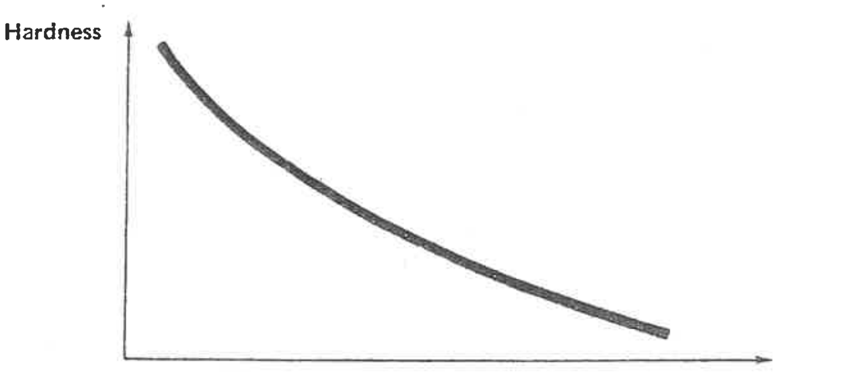


BLADE T° DISTRIBUTION



T° DISTRIBUTION CHECK

There is a relation between the temperature and the hardness of the metal; this allows to check the turbine condition by measuring the hardness.



HARDNESS - TEMPERATURE CURVE

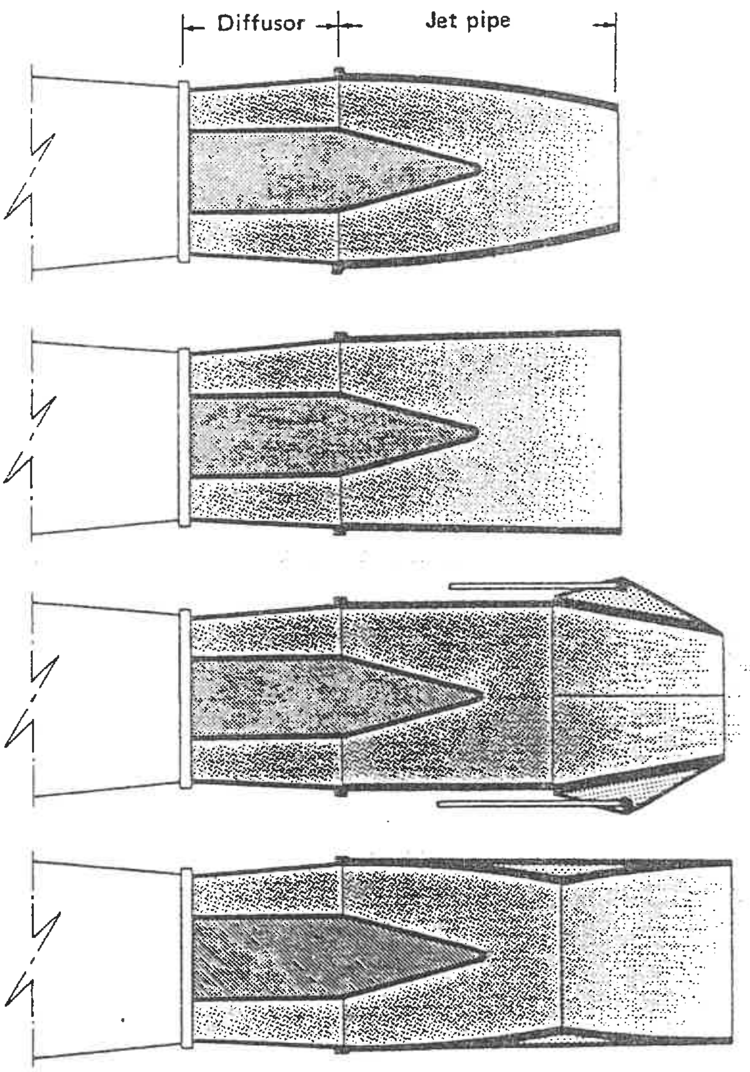
EXHAUST SYSTEM

The purpose of the exhaust system is to ensure expansion in order to obtain the optimum output.

This expansion takes place in a jet pipe forming a convergent passage.

In a turbo-shaft engine, the expansion takes place mainly in the turbine and as the increase in thrust being not requested, the pipe forms a divergent passage.

Some engines are provided with variable outlet jet pipe allowing a control of expansion (particularly turbo-jet engine with afterburning).



CONVERGENT EXHAUST

DIVERGENT EXHAUST

VARIABLE EXHAUST

SUPERSONIC EXHAUST

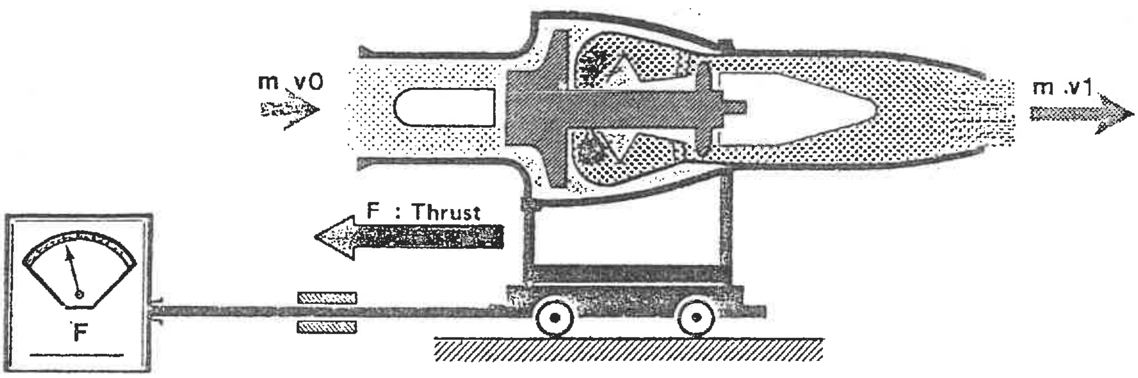
PERFORMANCE AND CHARACTERISTICS

THRUST OF A TURBO-JET

The thrust can be calculated by means of the formula :

$$F : \dot{m}\,(v1 - v0)$$

It can also be measured on a test bench
Thrust is expressed in kilogramme or in newton.

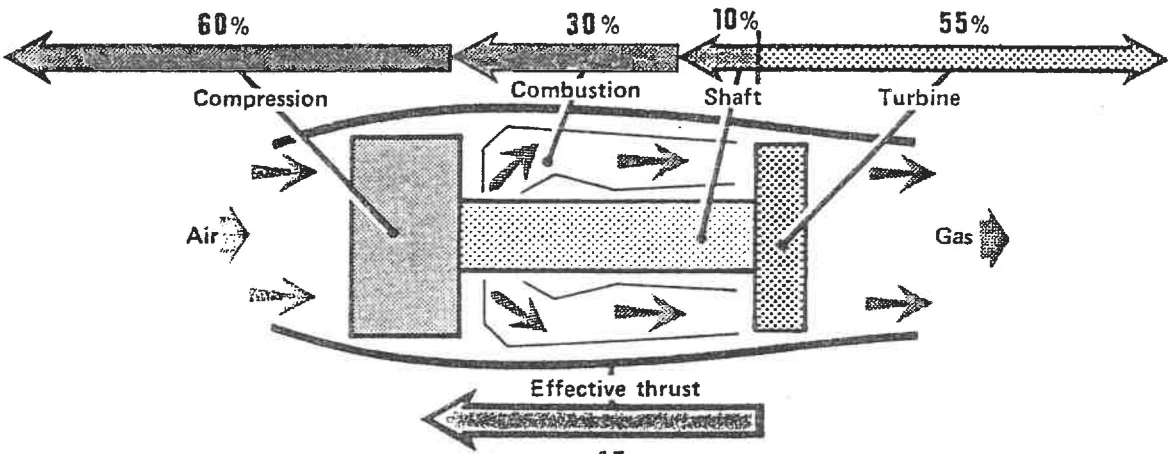


Thrust distribution

It is quite difficult to define exactly the points on which the thrust is felt. It is however possible to give the following order of importance :

- 60% forwards resulting from compressor reaction force
- 30% forwards from the combustion chamber
- 10% forwards on the shaft
- 55% rearwards resulting from turbine

The actual thrust is a force equal to :
(60+30+10)–55 = 45%



THRUST OF A TURBO-PROPELLER

The total thrust is equal to the sum of the propeller thrust and of the gas generator thrust.

Propeller thrust : M (v1 - v0)

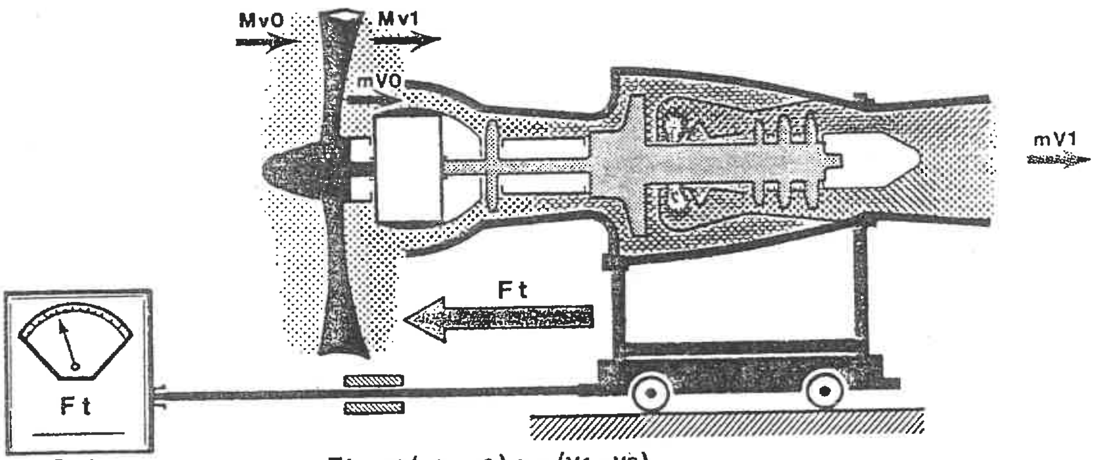
- high mass of air M, small difference of velocity v1 - v0

Residual thrust : M (V1 - V0)

- small mass of air m, high difference of velocity V1 - V0

Total thrust : M (v1 - v0) + m (V1 - V0)

This thrust may also be measured on a «test bench».

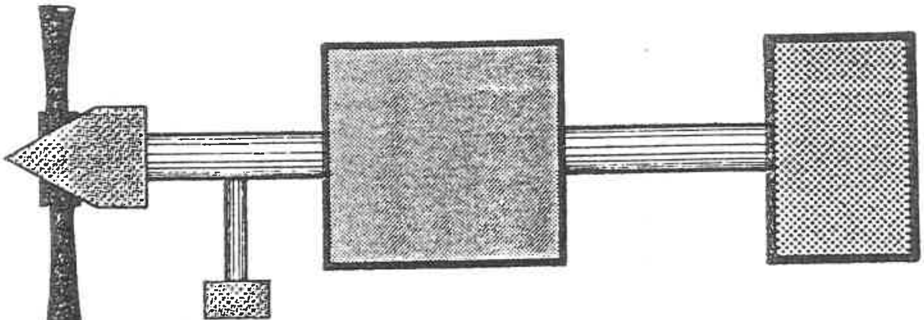


Ft = M (v1 - v0) + m (V1 - V0)

Power distribution (W) :

$$\frac{1}{3} + \frac{2}{3} = \frac{3}{3}$$

W shaft — W compressor — W extracted by turbine



POWER

Let us recall the formula of the power :

$$W = C \times \omega$$

C = torque = force x distance (F x d)

ω = angular velocity = $\frac{2\pi N}{60}$

$$W = \frac{2\pi N \times F \times d}{60}$$

Measurement of power

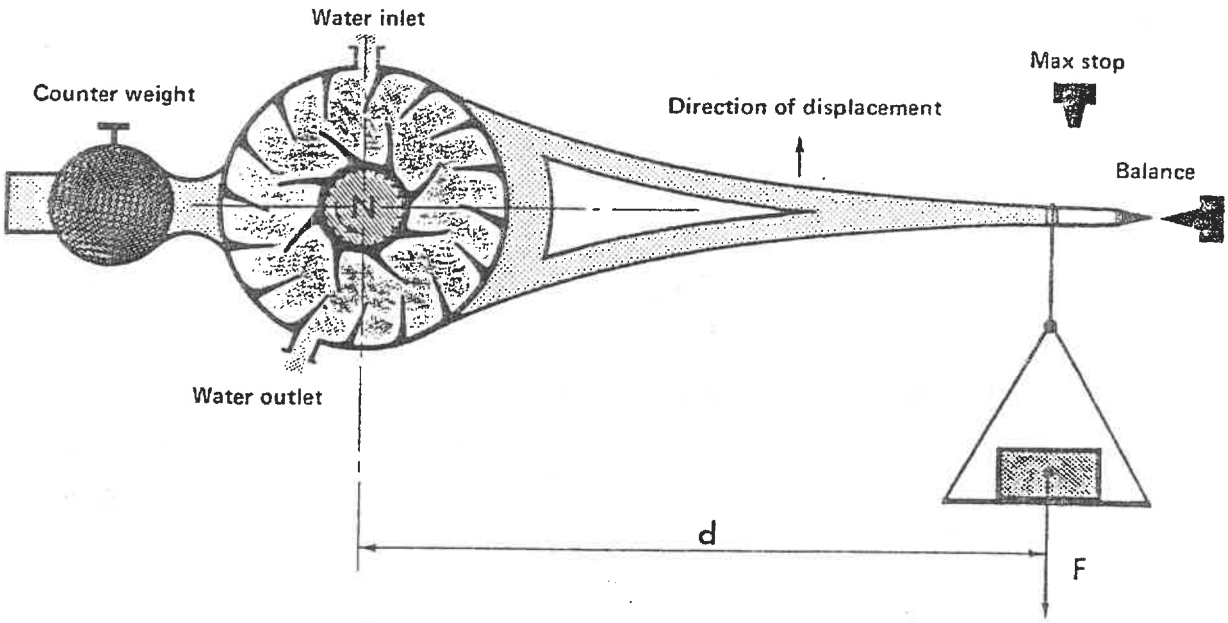
A torque is applied on the engine output shaft. Knowing the value of the torque and the rotation speed, the power can be easily determined. To measure the shaft power a test bench of water brake type (Froud water brake) is generally used.

Equivalent power

The « equivalent power » is the power on the shaft plus the power of the residual thrust.

Power units

kg/m/s ⟶	75 kg/m/s = 1cv
cheval vapeur ⟶	1cv = 0,736 kW
kilowatt ⟶	1kW = 1,36 cv



SCHEMATIC DIAGRAMME OF A WATER BRAKE

FUEL CONSUMPTION

$$CH = Q \times \rho$$

CH : hourly fuel consumption in kg/h
Q : fuel flow in l/h
ρ : fuel density

SPECIFIC CONSUMPTION

It is the amount of fuel required to produce a unit of power (or thrust) in a unit of time.

In other words : $CS = \frac{CH}{W \text{ or } F}$

In the case of a turbo-shaft engine, Cs is expressed in g/kW/h
In the case of a turbo-jet engine, Cs is expressed in kg/daN/h

FUEL - AIR RATIO $= \frac{\text{Actual fuel flow in g/s}}{\text{Actual air flow in g/s}}$

COMPRESSION RATIO $= \frac{\text{Compressor delivery pressure}}{\text{Compressor inlet pressure}}$

POWER - WEIGHT RATIO $= \frac{\text{Engine weight}}{\text{Power}}$

ROTATION SPEED

Rotation speed of the compressor-turbine assembly. The rotation speed is usually expressed in R.P.M. However the rotation is sometimes expressed in percentage of maximum rotation speed.

TURBINE INLET TEMPERATURE

Temperature in front of the turbine first stage nozzle guide vane. It is the «reference» temperature which is important to limit and to control.

TURBINE OUTLET TEMPERATURE

Temperature which is usually measured as it is difficult to measure the turbine inlet temperature:

ENGINE OPERATING RATINGS

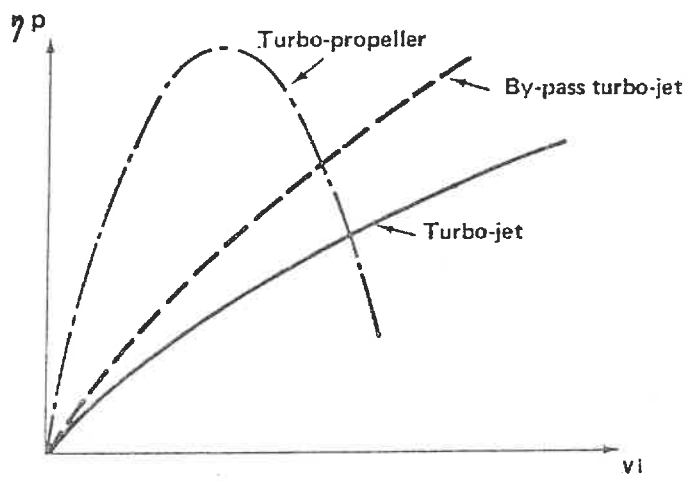
- Take-off — Rating corresponding to max power or max thrust
- Max continuous — Maximum rating without limitation of time
- Cruising — Rating corresponding to the aircraft cruise condition
- Intermediate — According to aircraft
- Flight idle — Minimum rating in flight, corresponding usually to aircraft descent condition.
- Ground idle — Rating on ground.
- Starting

FACTORS AFFECTING THE PERFORMANCE

EFFECTS OF AIRCRAFT SPEED (vi)

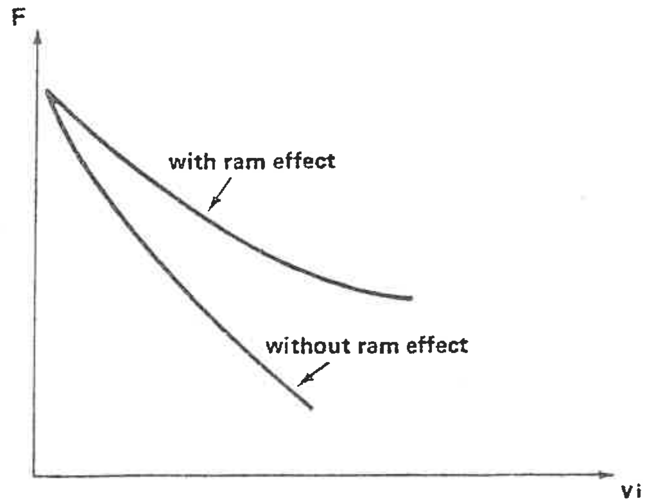
On the propulsive efficiency

The curve illustrates the operating ranges of turbo-propeller, turbo-jet and by-pass turbo-jet engine.



- On the thrust

The thrust depends upon the air flow and the difference of velocity. It appears that, when the aircraft speed increases, the thrust decreases. However, this decrease in thrust is compensated by the «ram effect» causing an increase in air flow above a certain aircraft speed.



- On the thrust of a turbo-jet

The thrust tends to decrease when the aircraft velocity increases.

- On the fuel consumptior. of a turbo-jet

The increase in air flow with aircraft velocity implies an increase in fuel flow. Therefore, the fuel consumption increases with the aircraft velocity.

- On the power of a turbo-propeller

The increase in speed Vi causes an increase in air pressure, air temperature and air flow.

The increase in temperature tends to cause a decrease in power but the effect of the pressure is stronger. Therefore, there is an increase in power with the aircraft speed.

- On the fuel consumption of a turbo-propeller

The fuel consumption increases with the aircraft speed, but at a lower rate than in a turbo-jet. Therefore, the fuel specific consumption decreases with the aircraft speed.

EFFECTS OF ALTITUDE

Let us recall that, when the altitude increases : the atmospheric pressure decreases, the temperature decreases and the density of air decreases.

- On the thrust

The decrease in pressure causes a decrease in thrust.

The decrease in temperature tends to cause an increase in thrust.

However, the effect of the pressure is stronger than the effect of the temperature and the thrust decreases when the altitude increases.

- On the fuel consumption of a turbo-jet

Being given that the airflow decreases with altitude, there is an automatic reduction of fuel flow (fuel control to keep engine reference parameters within limits) Therefore, the fuel consumption decreases with altitude as well as the specific consumption (specific consumption is improved due to the effect of temperature).

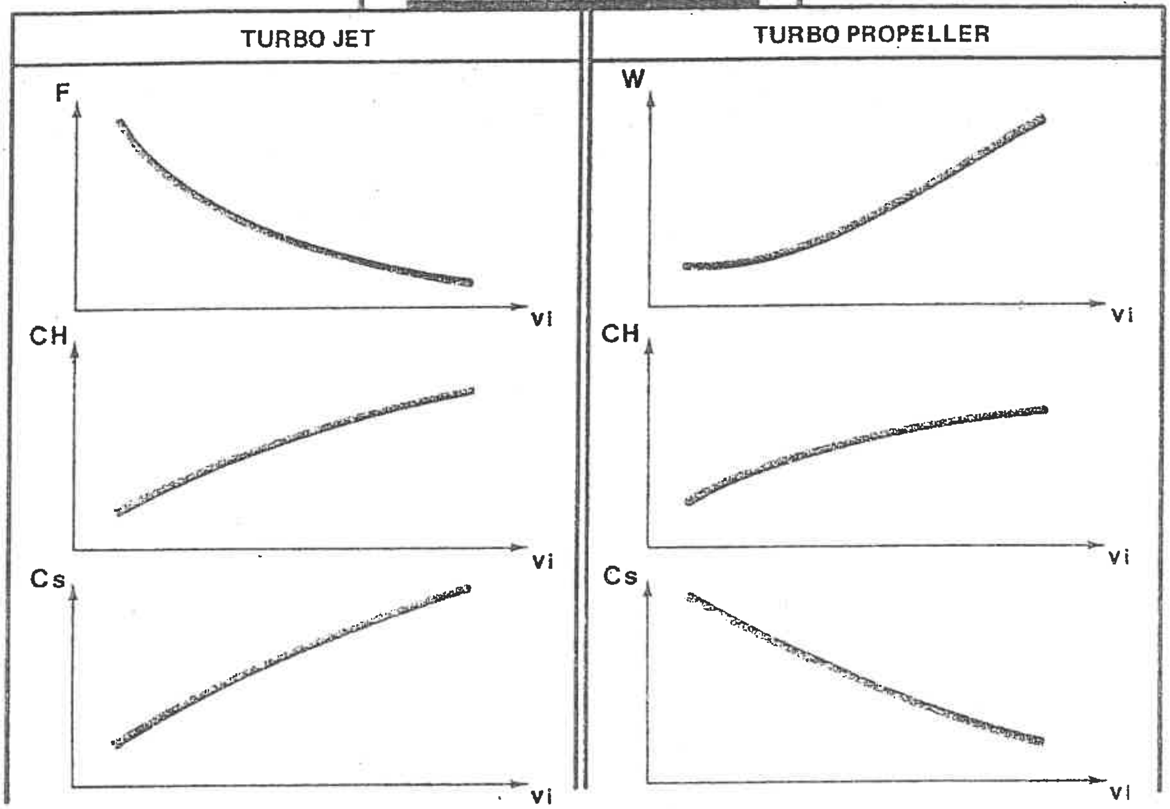
- On the power of a turbo-propeller

The power decreases for the same reasons as the thrust.

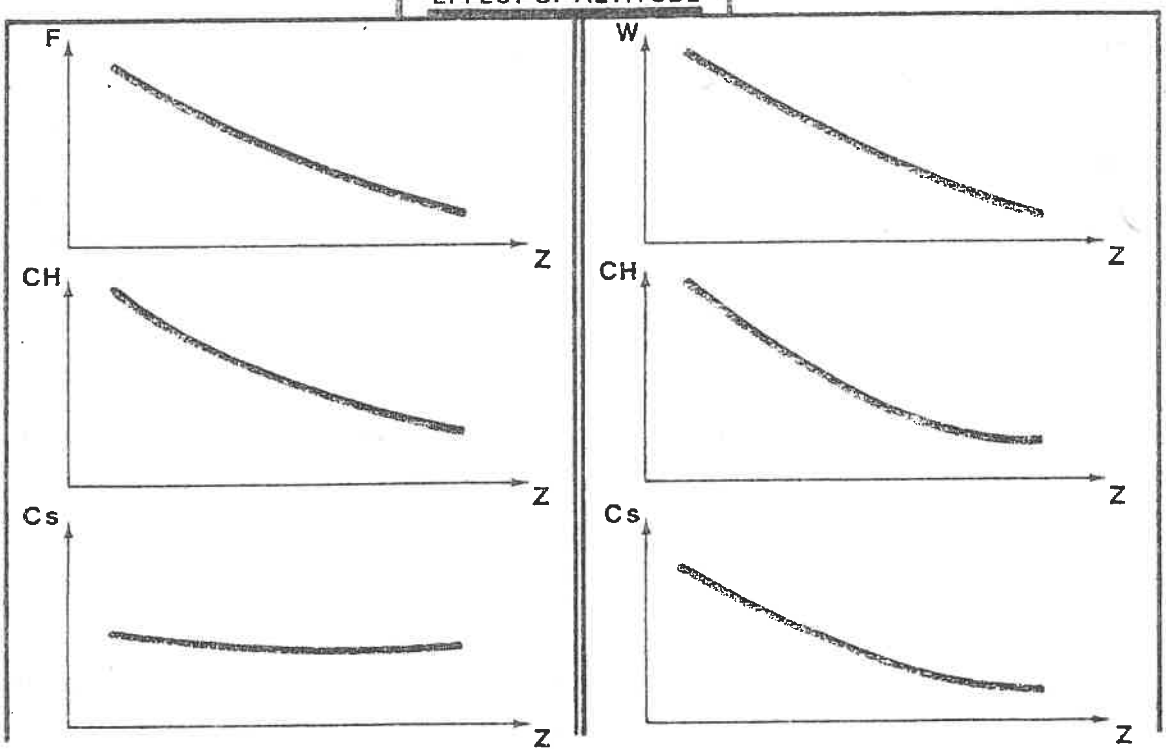
- On the fuel consumption of a turbo-propeller

In the same way, the fuel consumption decreases when the altitude increases. However, the fuel consumption decreasing more rapidly than the power, the specific consumption is improved with altitude. Nevertheless, there is a limitation which is particular to the type of engine.

EFFECT OF AIRCRAFT SPEED



EFFECT OF ALTITUDE



CORRECTION OF PARAMETERS AND CHARACTERISTICS

In order to compare the characteristics of engines tested under different atmospheric conditions , it is necessary to correct to standard atmosphere the results observed during the tests.

Let us recall the meaning of international standard atmosphere :

— Pressure Po = 1013 mb or 760 mmHg

— Temperature to = 15° C or 273°+15° = 288° K

The characteristics are corrected by means of the following formula :

Rotation speed $N = N1 \times \sqrt{\frac{288}{To}}$

N : corrected speed
N1 : observed speed
To : absolute temperature during testing

Thrust $F = F1 \times \frac{1013}{Po}$

Power $W = W1 \times \frac{1013}{Po} \times \sqrt{\frac{288}{To}}$

Consumption $CH = CH1 \times \frac{1013}{Po} \times \sqrt{\frac{288}{To}} \times \sqrt[4]{\frac{288}{To}}$

Temperature $T = T1 \times \frac{288}{To}$

VARIOUS FUNCTIONS OF A TURBO - ENGINE

COOLING

This function must ensure the «thermic balance» of the engine.

Cooling of the various engine components and accessories may be carried out :

- by circulation of air
- by lubricating oil
- by circulation of a «fluid»

LUBRICATION

It is necessary to ensure the lubrication and also the cooling for : the bearings supporting the gas generator, the reduction gear, the accessory drive.

The oils used must have certain properties required to obtain a correct lubrication. There are two main categories of oils in use : mineral oils, synthetic oils.

The oil system is usually of dry sump type. Lubrication is ensured by spray of oil on the components to be lubricated. A system consists usually of the following components : an oil tank, a pack of oil pumps, safety valves, filter unit, oil cooler and accessories to indicate pressure and temperature.

FUEL SUPPLY AND FUEL FLOW CONTROL

It is the function to ensure fuel supply and fuel metering in all operating conditions of the engine.

The fuel is usually of «kerosene» type TRO, TR4.

A typical fuel system consists essentially of : a fuel supply pump, a fuel flow control unit, filters, safety devices and an injection system in the combustion chamber.

STARTING

The starting of the engine includes three main functions :

- Cranking of the rotating assembly. Usually ensured by an electric motor.
- Supply of fuel under pressure. Usually ensured by the main fuel pump or sometimes by an auxiliary fuel pump.
- Ignition of the fuel-air mixture. Usually achieved by igniter plugs producing sparks. The high voltage current required is supplied by a «high voltage ignition coil» or by a «high energy ignition coil».

The starting cycle is usually automatic. An electric control box monitors the sequences of automatic operation.

VENTILATION

It is sometimes required to crank the engine rotating assembly without fuel injection and ignition. This function is called «ventilation». The ventilation is used in the following cases :

- draining of fuel from the combustion chamber (after a «wet start» for example)
- cooling of the residual temperature
- tests, inspections.

RELIGHT IN FLIGHT

The process of relight in flight is almost identical to the starting on ground. However, in the case of a turbo-jet or of a turbo-propeller, the rotating assembly windmilling caused by the stream of air, avoids the use of the starter. The operation of the starter is then cancelled by means of a special device (for example : ground flight switch manually operated).

ENGINE CONTROL

The control of the engine is usually ensured by means of a single lever, allowing the selection of the rating requested.

The main positions of the control correspond to :

- take-off
- maximum continuous power
- cruising
- flight idle
- start and stop positions

ENGINE INSTRUMENTATION

The following indications are usually provided to check the operation of the engine :

- rotation speed
- gas temperature
- oil pressure and temperature

Some engines are also provided with other miscellaneous indications such as :

- thrust indication
- torque indication
- fuel flow
- vibrations.

WATER AND WATER-METHANOL INJECTION

The purpose of water (or water-methanol) injection is to increase the engine output in certain operating conditions.

The method consists in injecting water (or a mixture of water and methanol) in the flow of air of the engine.

The injection has the following effects : decrease in temperature due to the spraying, increase in compression ratio and increase in air flow. It is then possible to increase fuel flow or to use the combustion of methanol. In both cases a consequent increase in power is obtained (for example : utilization for take-off with a high atmospheric temperature).

There are various methods of water injection : injection in the air-intake, injection in the compressor and injection in the combustion chamber.

AFTER BURNING

After burning is a method used to increase the thrust of a turbo-jet engine. The method consists in ensuring a second combustion in the exhaust system.

This second combustion is possible because there is a high proportion of air in the burnt gases. On the other side, a high temperature can be admitted due to the fact that there are no mechanical parts in movement.

The increase in thrust which is obtained depends on the velocity of the gases expelled. The velocity of the gases increases in relation with the square of the increase in temperature. Thus the increase in thrust may reach 50 %.

However, the operation of after burning is quite expensive regarding the fuel consumption.

The operation of after-burning implies a system to meter the amount of fuel injected.

It is also necessary to operate after-burning without disturbing the operation of the gas generator section ; this usually implies a control of the jet pipe variable outlet.

It is worth mentionning that after-burning is particularly advantageous in the case of a by-pass turbo-jet.

FUEL HEATING

The function of fuel heating usually consists in transferring the calorific energy of lubricating oil or engine gases to the fuel.

This heating of the fuel permits :

- to improve the flow
- to obtain a better spraying
- to avoid icing of the water contained in the fuel
- to re-introduce in the cycle an energy which would be lost otherwise.

DE-ICING

It is important to distinguish between :

- anti-icing systems the purpose of which are to prevent the formation of ice.
- de-icing systems the purpose of which are to remove the ice.

The main component to be protected in a gas turbine engine is the air intake. The protection of this part can be made by warm air (for example taken at the outlet of the compressor) or by an electric heating system.

FIRE PROTECTION

The power plant is usually provided with a fire detection system (for example : thermic detector and warning light) and a fire extinguish system (for example : extinguish bottles and spraying ramp).

THRUST REVERSION

A reverse thrust to slow down the aircraft speed may be obtained by inverting the flow of the burnt gases in the turbo-jet engine.

In the case of a turbo-propeller a braking effect may be obtained by reversing the pitch of the propeller.

NUISANCES

Engines are now designed so as to reduce as far as possible the nuisances and particularly the noise level.

The design of combustion chamber and the use of noise suppressor in the jet pipe permits a consequent reduction of noise

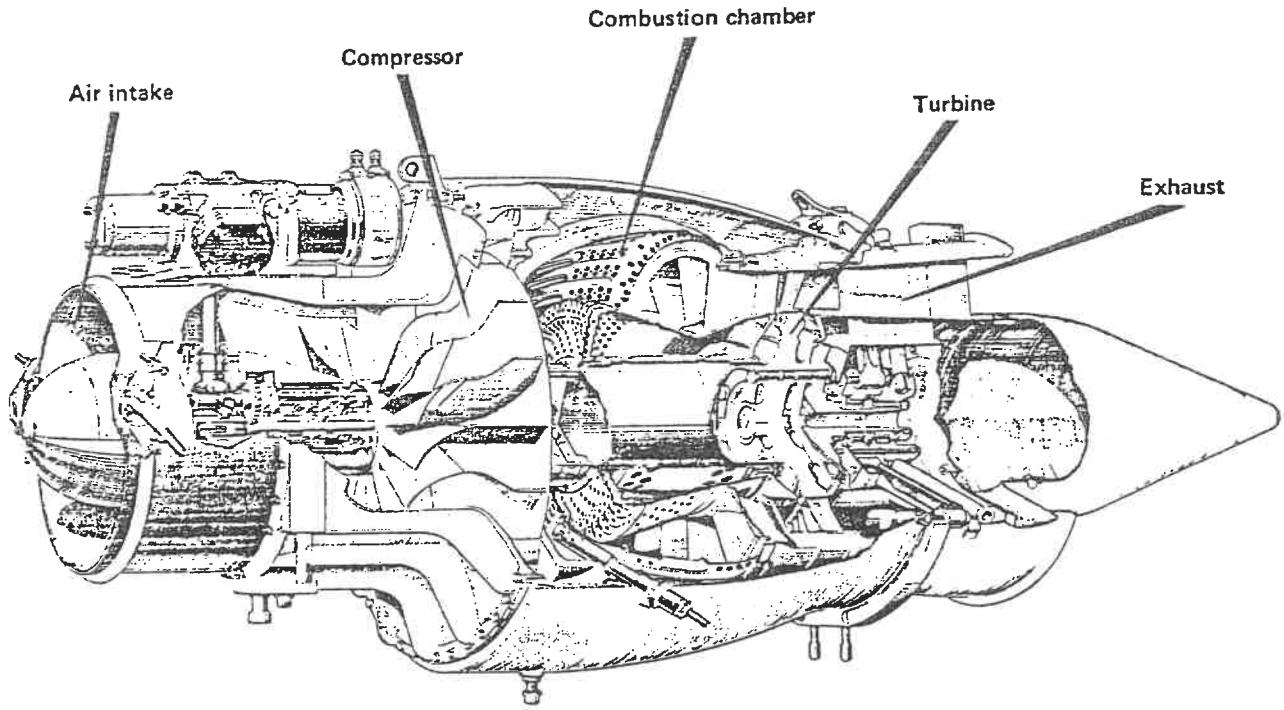
VARIOUS TYPES OF GAS TURBINE-ENGINE

TURBO-JET ENGINE

It is a one flow turbo-jet (i.e. all the air flow is passing through the gas generator) and single spool (i.e. there is only one compressor-turbine rotating assembly).

The thrust produced by the components of the gas turbine depends upon the mass of air entering the engine and the acceleration given to this mass of air.

The operating point is mainly characterized by the rotation speed, the turbine inlet temperature and the thrust.



Example of a turbo-jet engine : MARBORE

BY-PASS TURBO-JET

Propulsive efficiency

It is the ratio of the power required for the flight (propulsive power) and of the thermic power.

$$\eta p = \frac{Wp}{Wth} = \frac{m(v1 - vo) \times vo}{\frac{1}{2} m (v1^2 - vo^2)} = \frac{2\,vo}{v1 + vo}$$

Increase of the efficiency

If v1 is replaced by its value taken out from the thrust formula, we obtain :

$$\eta p = \frac{2\,vo}{\frac{F}{m} + vo + vo} = \frac{2}{\frac{F}{mvO} + 2}$$

Thus, it appears that ηp is higher when $\frac{F}{mvO}$ is small. Therefore, for a given thrust the efficiency is high when the air flow «m» is important. And if vO is relatively low, «m» must be high to obtain a good efficiency.

The solution which consists in increasing the air flow «m» without increasing the fuel flow to lower exhaust velocity v1 does not give full satisfaction because the thermic efficiency is then reduced.

By-pass turbo-jet

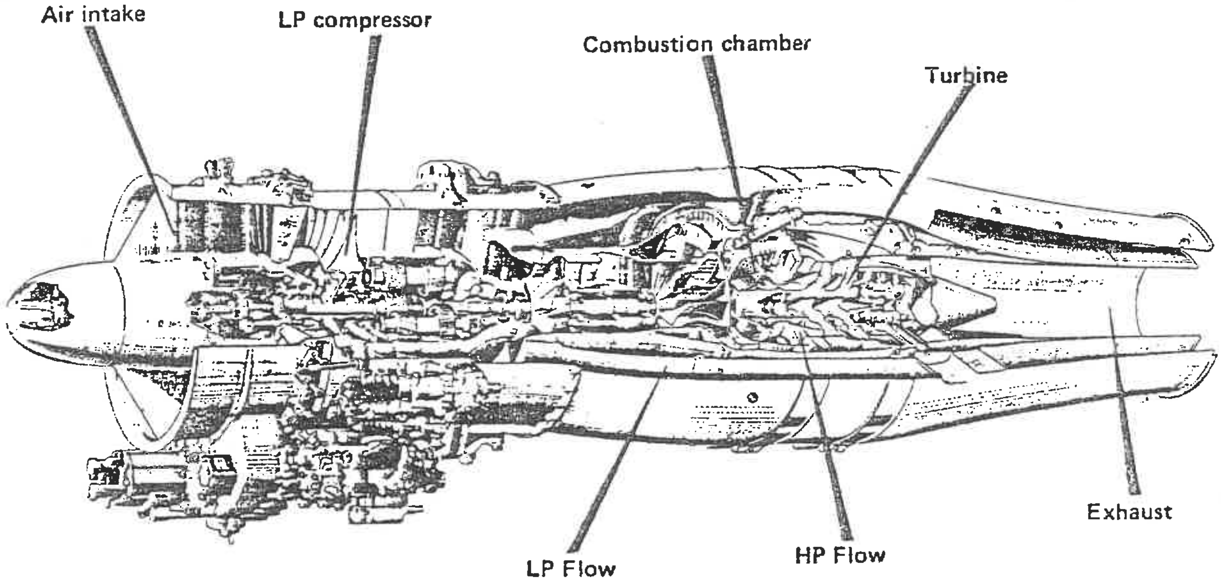
Thus, to increase «m» and decrease «v1» without reducing the thermic efficiency, one solution appears ; to divide the total air stream into two flows :

- a high pressure flow for the gas generator with a fuel flow determined so as to keep a good thermic efficiency.

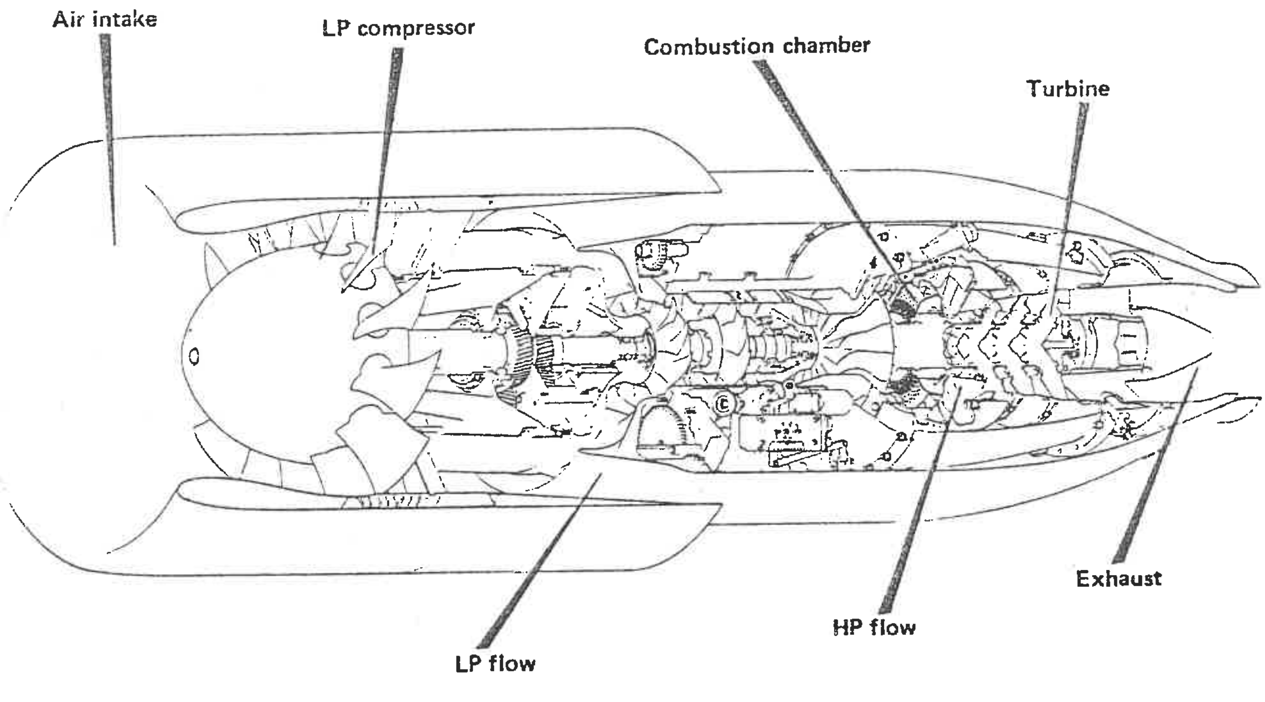
- a low pressure flow in by-pass mixed with the low pressure flow either in the atmosphere or on the jet pipe.

In that way, a compromise is obtained between the turbo-jet and the turbo-propeller. The operating range is therefore comprised between the turbo-propeller which is limited by the drop of efficiency at high speed and the simple turbo-jet the efficiency of which becomes acceptable only at high speed.

Compared to the simple turbo-jet, the following advantages are obtained : a better propulsive efficiency, a lower fuel consumption, a lower level of noise. On the other side, after-burning can be more efficient.



Example of a by-pass turbo-jet : AUBISQUE



Example of a by-pass turbo-jet : ASTAFAN

TWIN SPOOL TURBO-JET

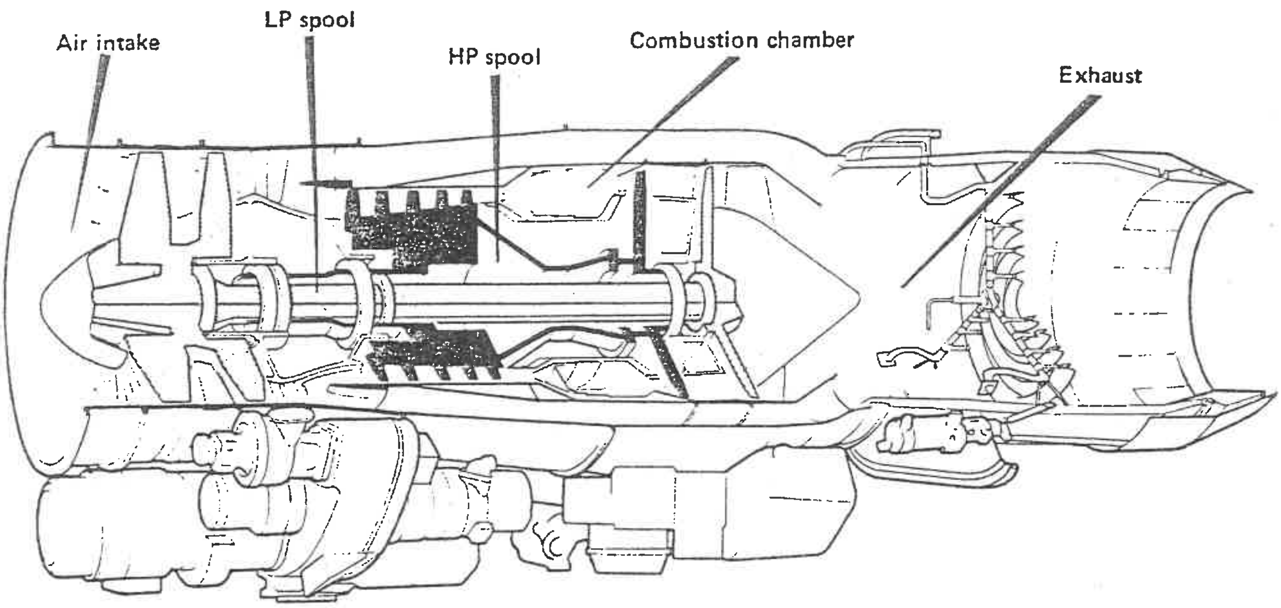
The turbo-jet engine has two rotating assemblies mechanically independents : a low pressure compressor turbine assembly and a high pressure compressor turbine assembly.

The transmission shaft of the low pressure assembly is located coaxially inside the high pressure shaft.

In regard to the operation of such an engine, the following points can be noted :

- the rotation speeds of the two rotors are more or less proportional,
- each compressor has its own diagramme on which the adaptation curves can be plotted,
- the diagrammes show less risk of surging in altitude, but more risk of surging of LP compressor at low rotation speed,
- same compression ratios as in single spool can be obtained with less stages of compressor and the LP compressor is driven at the rotation speed required without a reduction gear,
- the first turbine (HP turbine) rotating at a faster rotation speed, the safety margin in relation to creep limitation is larger. Therefore, it is possible to obtain higher expansion ratios and to reduce the number of turbine stages (or to improve efficiency).

For all the reasons above mentioned, an appreciable reduction in weight and dimensions of the engine is obtained. Moreover, the power required to start the engine is lower (drive of the HP assembly only). However, the technology of the engine is more complex.



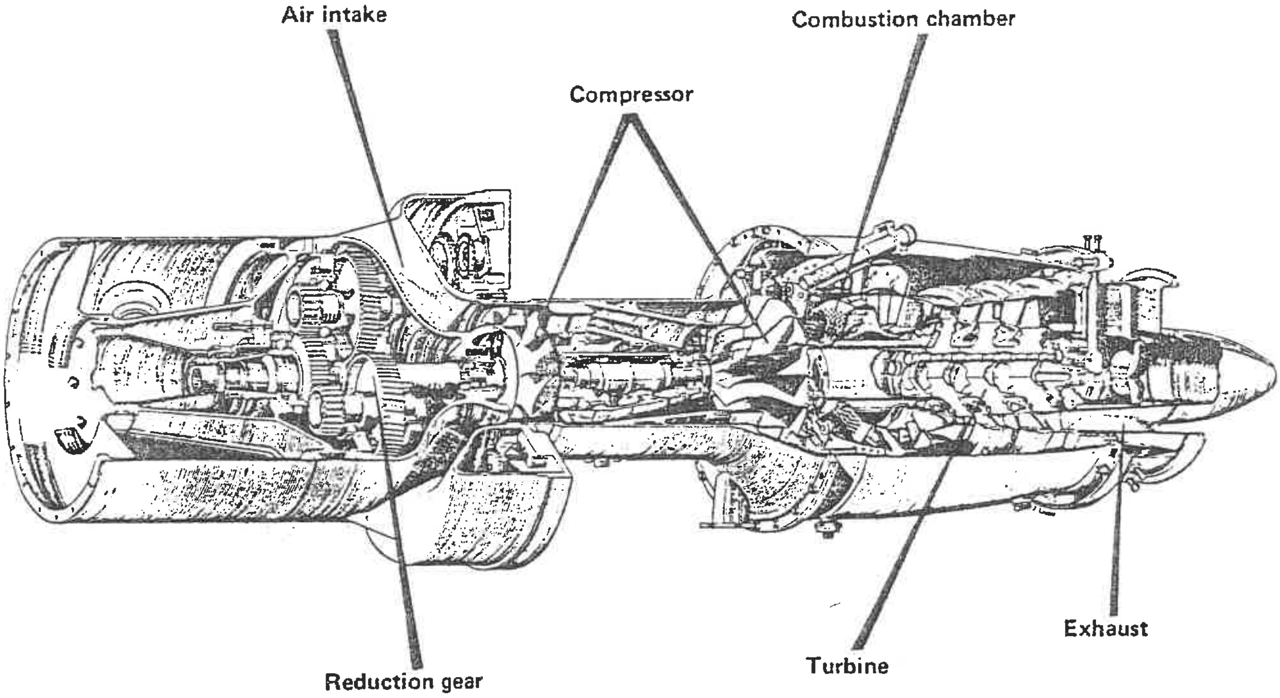
Example of a twin-spool turbo-jet : ADOUR

FIXED TURBINE TURBO-SHAFT ENGINE

The gas turbine engine supplies mechanical power on a shaft to drive a «receiver».

A single shaft connects the turbine, the compressor and the output shaft.

This type of engine usually implies an operation at constant rotation speed. The adaptation of engine torque and resisting torque is then ensured.



Example of a «fixed» turbine turbo-shaft : ASTAZOU III

FREE TURBINE TURBO-SHAFT

Introduction

.There are two rotating assemblies. The first one is a gas generator, the operation of which is quite similar to a turbo-jet engine. The second (free turbine) drives the power shaft. Both assemblies are rotating at different speeds. The gas generator operation is practically independent from the free turbine and mainly function of fuel flow. The free turbine operation is determined by the balance between the energy received from the gas generator and the energy taken by the receiver.

Characteristics

They are usually represented by a diagramme showing free turbine rotation speed and the power. On this diagramme are plotted the curves corresponding to the speed of the gas generator. As the gas generator operation is considered independent from the free turbine, the fuel consumption is also independent and the iso-speed curves of the generator are also iso-consumption curves.

The power does not vary much within a wide range of free rotation speed ; ie. the free turbine efficiency is not affected by its rotation speed. The best conditions to achieve maximum power are present when the free turbine rotation speed is as low as the gas generator.

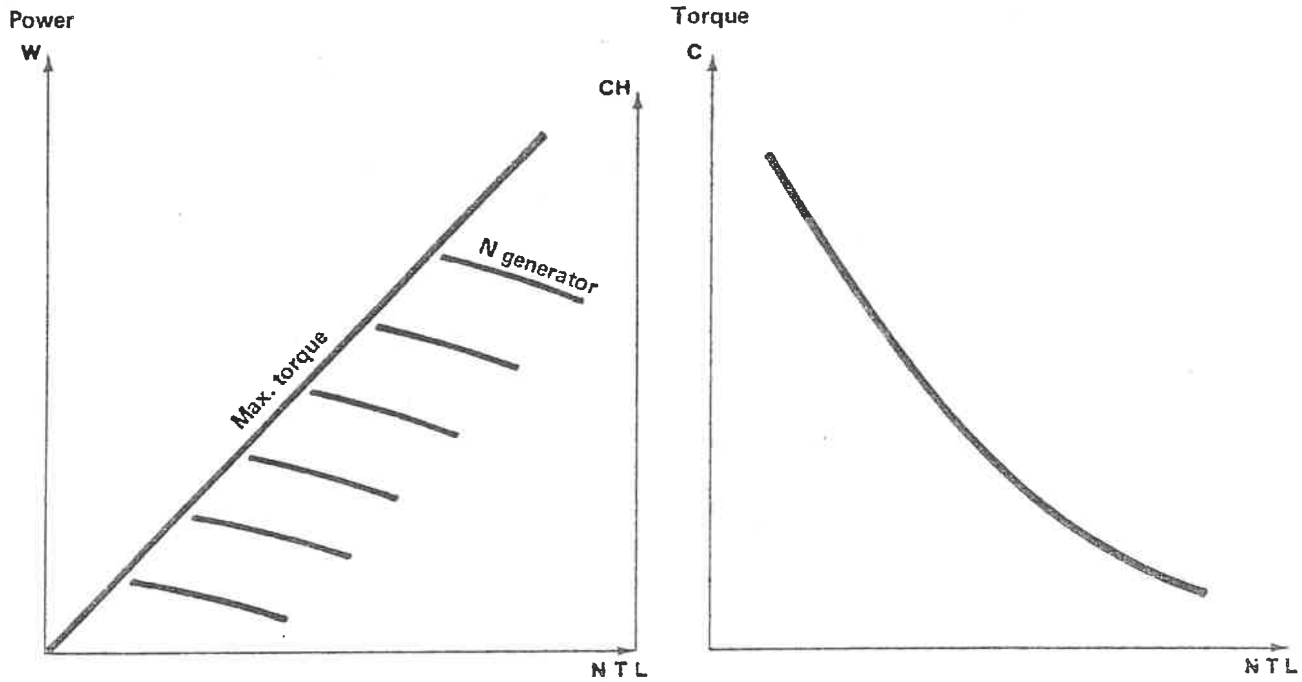
The torque on the output shaft varies inversely with the free turbine rotation speed. It reaches its maximum when the free turbine rotation speed is zero.

Advantages of the free turbine

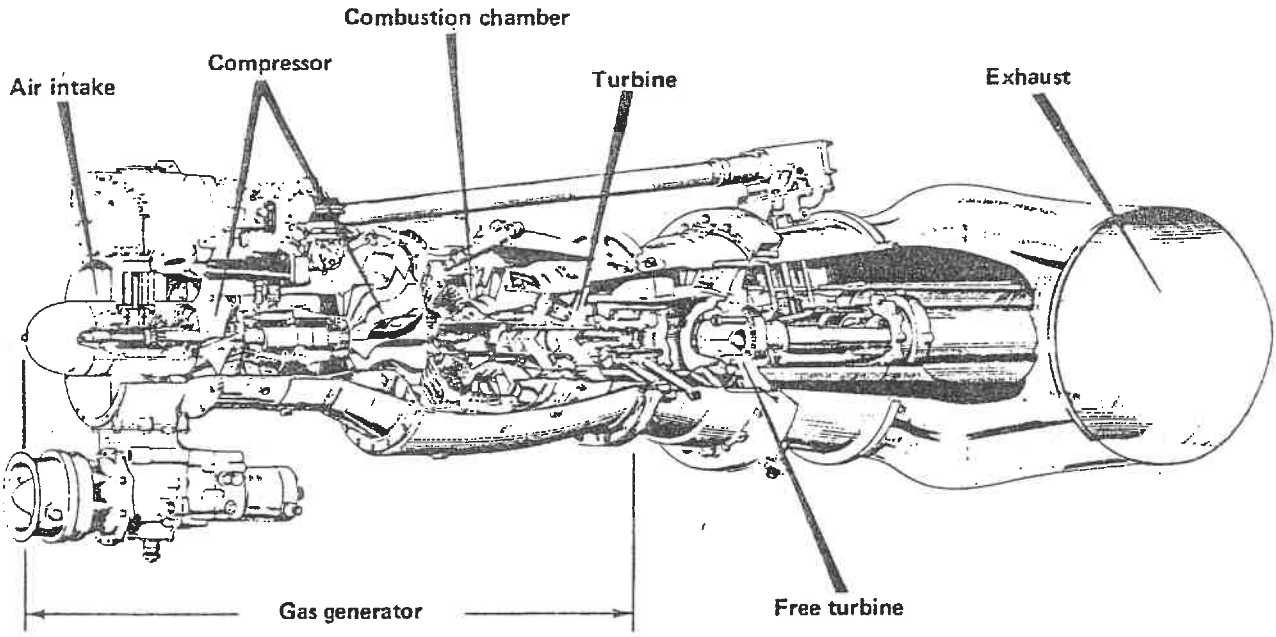
Compared to the fixed turbine, the free turbine engine has the following advantages :

- better adaptation of operation since the gas generator operates independently,
- easier starting
- possibility to accumulate energy
- no need for a clutch on an helicopter installation

However, the output shaft being at the rear of the engine the operation as a turbo-propeller requires : either an external transmission shaft quite heavy, or a free turbine shaft coaxial within the gas generator shaft of difficult mechanical design.



FREE TURBINE ENGINE CURVES



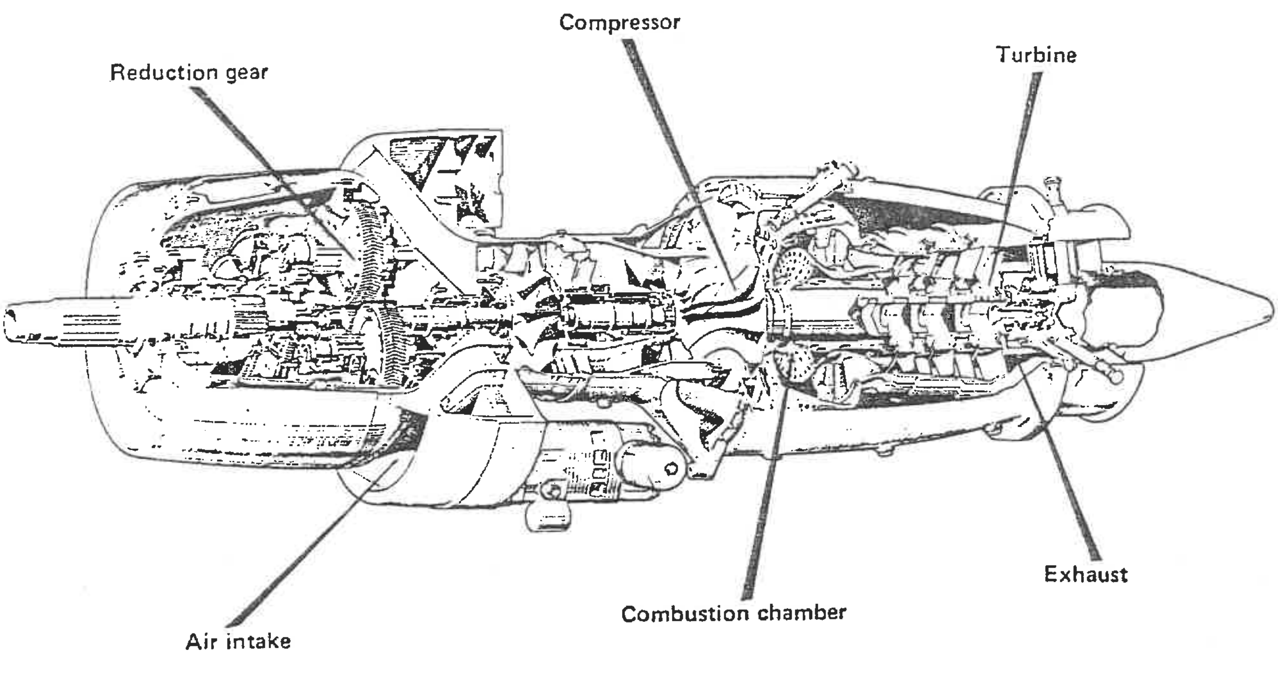
Example of a free turbine turbo-shaft : TURMO IIIC4

TURBO-PROPELLER

The gas turbine engine supplies mechanical power on a shaft to drive an aircraft propeller.

The turbo-propeller can be of fixed type turbine or of free type turbine.

The control of the power plant is ensured by acting on the receiver (propeller) or on the engine. Two different types of control can be considered : conventional turbo-propeller in which the control lever determines a power which is kept constant, and non-conventional turbo-propeller in which the power is automatically variable.



Example of a turbo-propeller : BASTAN VI

TURBOMECA SURVEY

Foundation in 1938 by Mr. SZYDLOWSKI

Situation in 1972 : Three factories, BORDES (main factory), TARNOS, MEZIERES

- Covered surface : 124 000 m^2
- Number of employees : 4 217
- Output in 1972 : 354 millions of francs ; 211 millions of which for exportation in 88 different countries
- Number of engines produced : (situation in December 1972) : 12 500 in France, 10 000 abroad.
- Countries with TURBOMECA licences : Spain, U.K., U.S.A., Yougoslavia, India, Israel.

TURBOMECA ENGINES

BASIC COMPONENTS

— Centrifugal compressor

— Annular combustion chamber with centrifugal fuel injection

— Turbine.

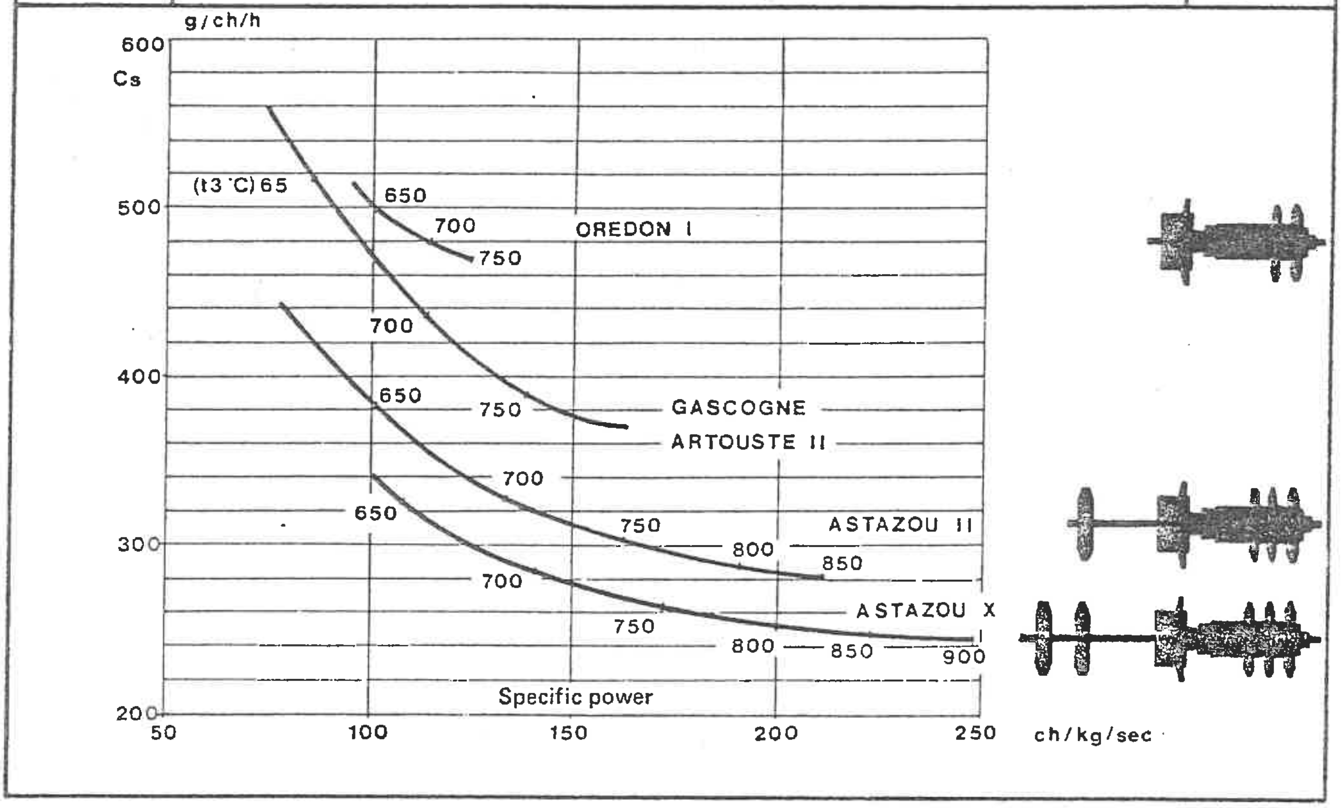
DIFFERENT GENERATIONS

First generation : one stage centrifugal compressor (MARBORE, ARTOUSTE II)

Second generation : one stage axial compressor and a centrifugal compressor (ARTOUSTE III, ASTAZOU II, AUBISQUE, BASTAN, TURMO)

Third generation : two stage axial compressor and a centrifugal compressor (ASTAZOU XII, ASTAZOU XIV)

DEVELOPMENT OF PERFORMANCES BETWEEN THE THREE GENERATIONS OF TURBOMECA GAS TURBINE ENGINES



SURVEY ON TURBOMECA PRODUCTION

NAMES OF ENGINES

Turbo-jet .... name of pyrenean mountain

By-pass turbo-jet .... name of pass

Turbo-jet (RR) .... name of river

Turbo-shaft .... name of lake

Turbo-propeller .... name of valley

Turbo air-generator .... name of wind

Example of designation

ASTAZOU XIV C01

ASTAZOU	:	Name
XIV	:	Type
C	:	Variant (aircraft adaptation)
01	:	Version

FIRST MODELS

Piméné : Turbo-jet - designed in 1947 - 80 kg of thrust

Orédon I : Turbo-shaft - designed in 1948 - 160 ch of power

Aspin : By-pass turbo-jet - designed in 1949 - 360 kg of thrust

Palas : Turbo-jet - designed in 1950 - 160 kg of thrust

Gourdon : Turbo-jet - designed in 1953 - 380 kg of thrust

Gabizo : Turbo-jet - designed in 1955 - 1100 kg of thrust

ENGINES IN PRODUCTION

TURBO - JETS

NAME	Type	Year	N (tr/mn)	F (Kg)	Cs kg/daN/h	P2/P1	G (Kg/sc)	T3 °C	P (Kg)
MARBORE II	TR	1950	22 600	400	1,15	3,9	8	770°	159
MARBORE VI	TR	1959	21 500	480	1,11	3,8	9,6	770°	165
AUBISQUE	TR.d.F.	1962	32 500	740	0,61	6,92	22,2	850°	285
ADOUR	TR.d.F. RR	1968	HP:15 500	2 000 sans PC	0,68	9,6	41,7	1100°	570
LARZAC	TR.d.F. SNECMA	1970	HP 22 700	1045	0,605	9	26	1000°	260
ASTAFAN II	TR.d.F.	1970	43 000	800	0,4	8	24	1000°	200

TURBO-SHAFTS

NAME	Type	Year	N tr/mn	W ch	Cs gr/ch/h	P2/P1	G	T3 °C	P kg
ARTOUSTE II C	TM	1953	34 000	406	400	3,4	3,25	750°	143
ARTOUSTE III	TM	1957	33 500	550	340	5,3	4,5	700°	182
ASTAZOU II A	TM	1959	43 500	530	290	5,9	2,5	860°	122
TURMO III C3	TM-TL	1958	33 500	1 500	270	5,85	6,1	900°	250
TURMO III C4	TM-TL	1967	33 500	1 300	279	5,8	4,5	870°	225
OREDON III	TM	1967	59 000	380	259	7,5	1,9	880°	93
ASTAZOU XIV	TM	1967	43 000	600	280	7,6	3,3	970°	160
ASTAZOU III N	TM	1969	43 500	600	260	6	2,6	900°	140
TURMASTAZOU	TM-TL	1970	43 000	900	233	8	3,3	900°	160
ARRIEL	TM-TL	1974		650					
ASTAZOU XVIII	TM	1974		1000					

TURBO-PROPELLERS

NAME	Type	Year	N tr/mn	W ch	Cs g/ch/h	P2/P1	G	t3 °C	P kg
BASTAN VI	TP	1960	33 500	1 000	270	5,8	4,5	870°	252
TURMO III D3	TP. TL	1960	33 500	1 500	276	5,8	6,1	850°	365
ASTAZOU II	TP	1958	43 000	550	280	5,97	2,56	860°	123
ASTAZOU XII	TP	1964	43 000	700	254	7,8	2,9	900°	156
ASTAZOU XIV	TP	1967	43 000	800	240	8	3,3	900°	188
ASTAZOU XVI		1969	43 000	950	238	8,15	3,3	950°	190
ASTAZOU XX	TP	1971	43 000	1000	210	8,9	3,6	1000°	220

TURBO AIR-GENERATORS

NAME	Type	Year	N tr/mn	G Bled-off gr/s	CH kg/h	P2/P1	G	t3	P
PALOUSTE IV	Tg Air	1954	34 000	1 140	120	3,8	3,3	725°	83
ALIZE	Tg Air	1969	43 000	900	117	9,2	3,3	800°	171

INDUSTRIAL ENGINES

NAME	Type	Year	N tr/mn	W kW	CH Cs	P2/P1	G	t3	P
BASTANGAZ	Turbo-Génér.	1968	33 500	550 kW	289 m^3 gaz	5,6	4,5	760°	310
ASTAGAZ XII	Turbo-Génér.	1968	43 000	400 kW	185 m3 gaz	7,3	2,87	800°	200
TURMO III F	Turbo-Rail	1969	32 000	820 kW	340 kg 415g/kW/h	5	6	820°	350
TURMO III N	Naviplane	1969	33 500	760 kW	425g/kW/h	6,1	6,2	900°	390
TI 255		1970	42 000	170 kW	537g/kW/h	6,2	3,2	800°	160

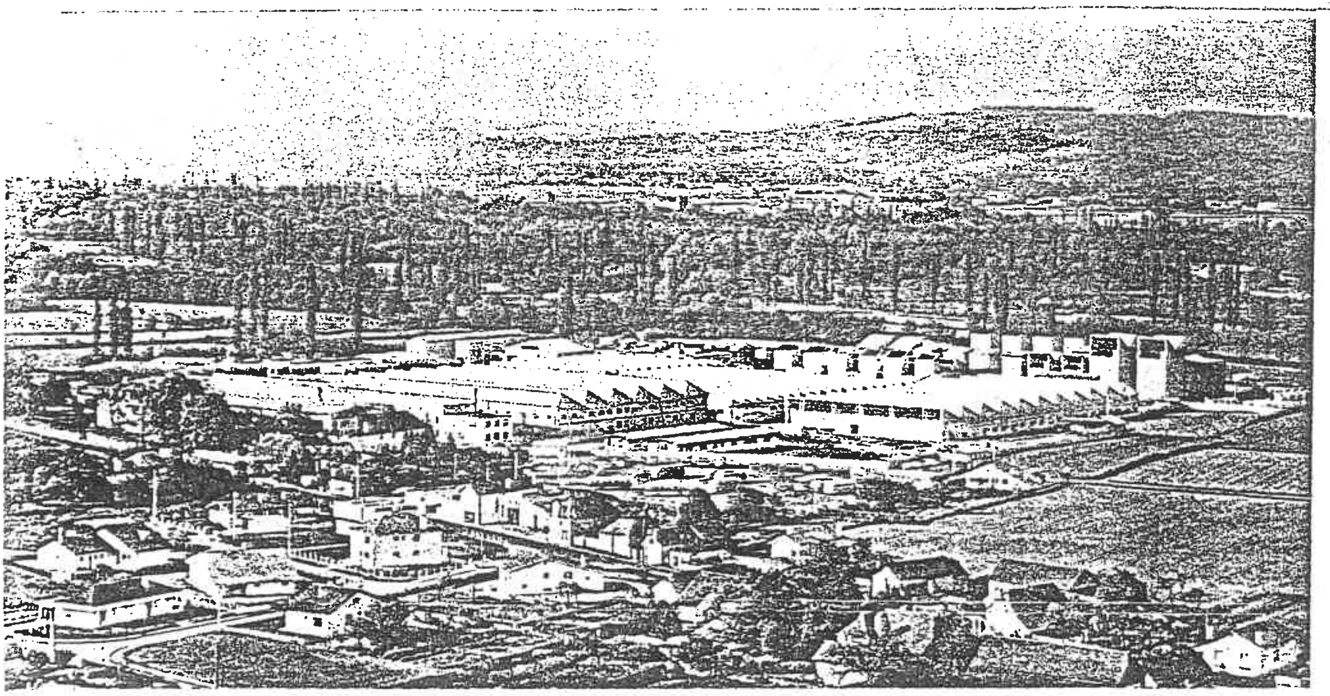
MANUFACTURING PROCESS

The production of a gas turbine engine calls for a very wide range of manufacturing processes.

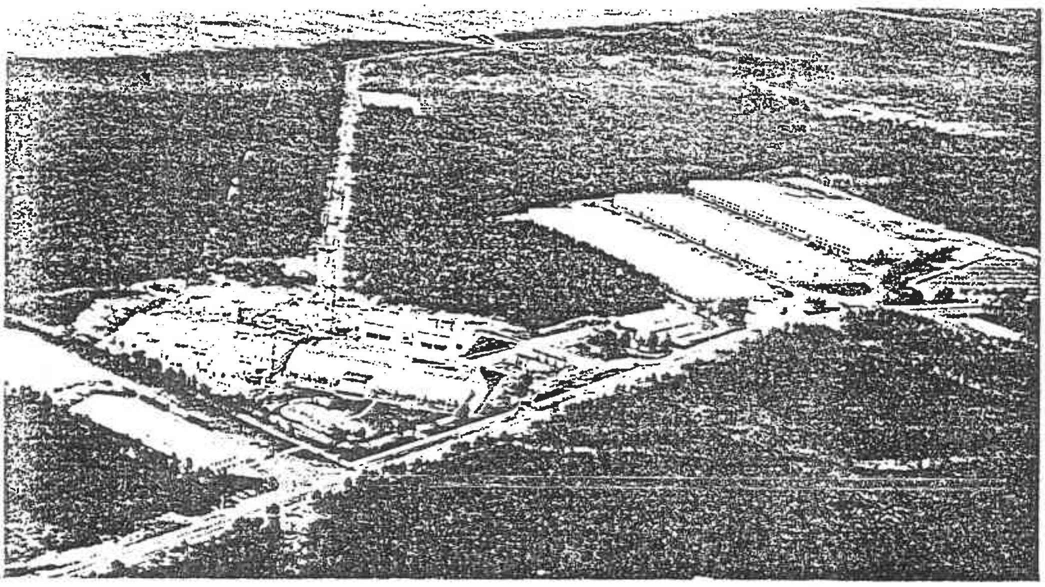
In the case of Turbomeca-engines, the diversity of models do not permit the use of special machine tools adapted to each part. However, since the components of the various engines are similar, it is possible to apply similar manufacturing process for different parts.

We shall simply list here some of the manufacturing process among the most outstanding :

- Casting of light alloy for the manufacture of various casings and accessories (eg. air intake casing, reduction gear casing, fuel control unit housing...)
- Drilling with automatic drilling machine tools
- Gear cutting
- Electro-erosion - Method which consists in attacking the metal by electric discharges. The discharges are obtained by sparks taking place between two electrodes ; one being the part to be manufactured, the other the tool (eg. turbine nozzle guide vane, turbine blade, airfoil sections, holes ...)
- Hydrospinning - Manufacturing process by cold buckling applied to parts of cylindrical or conical shape (eg: turbine casing, turbine ring, jet pipes .....)
- Welding and brazing process (argon welding, high temperature brazing, vacuum welding, electro-beam welding).
- Mass cutting of turbine blades. Cutting of turbine blades is carried out by means of a special machine tool designed in TURBOMECA.
- Casting of turbine wheels and turbine blades.
- The whole range of heat treatments
- Tests, checks, inspections and metallurgic research.

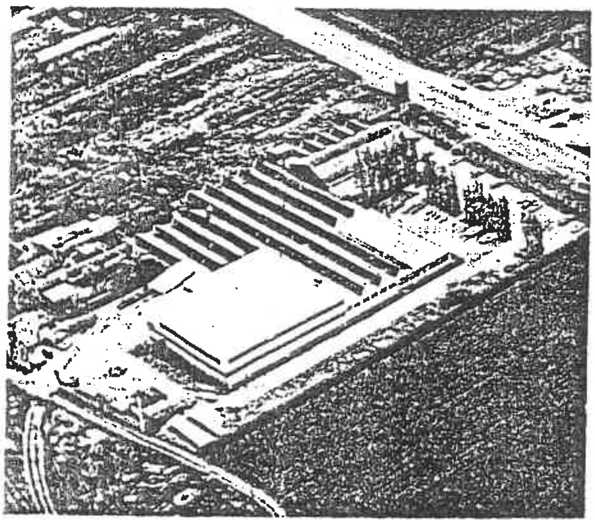


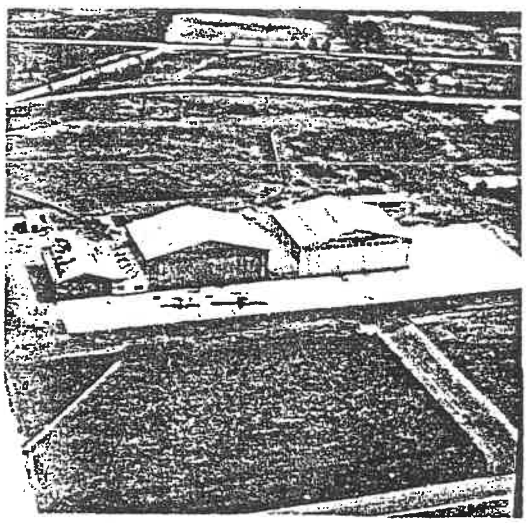
BORDES



TARNOS

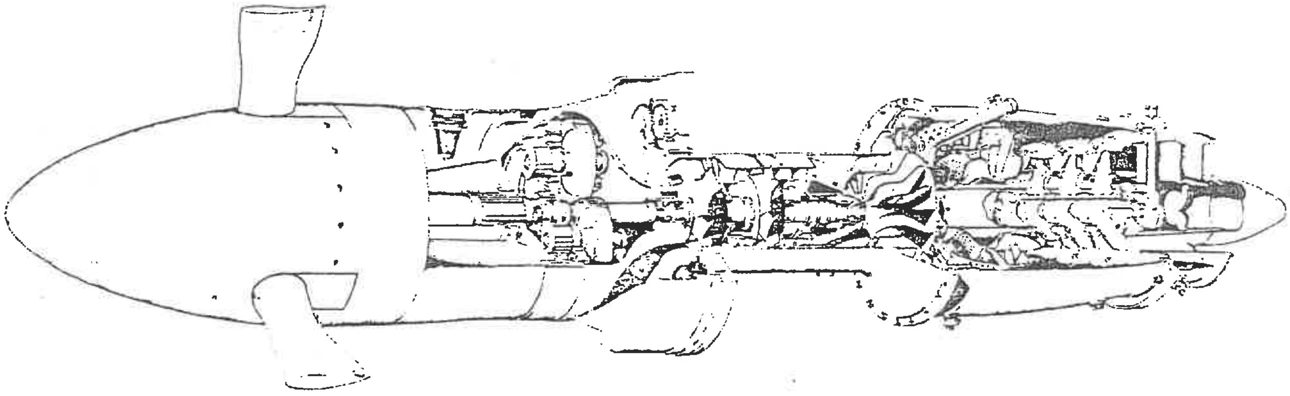
MEZIERES-sur-SEINE



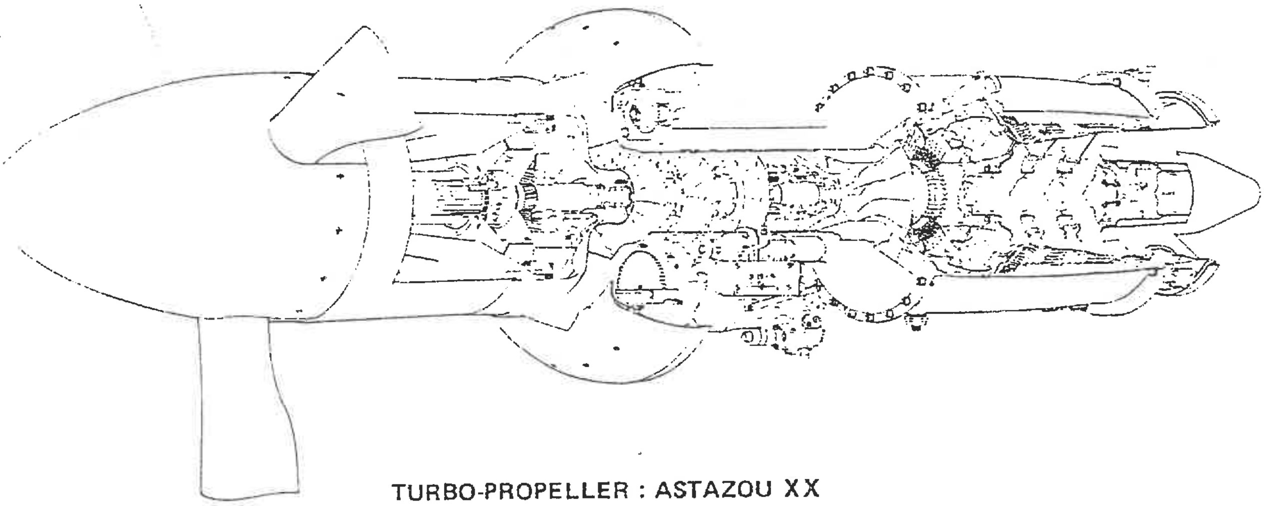


UZEIN

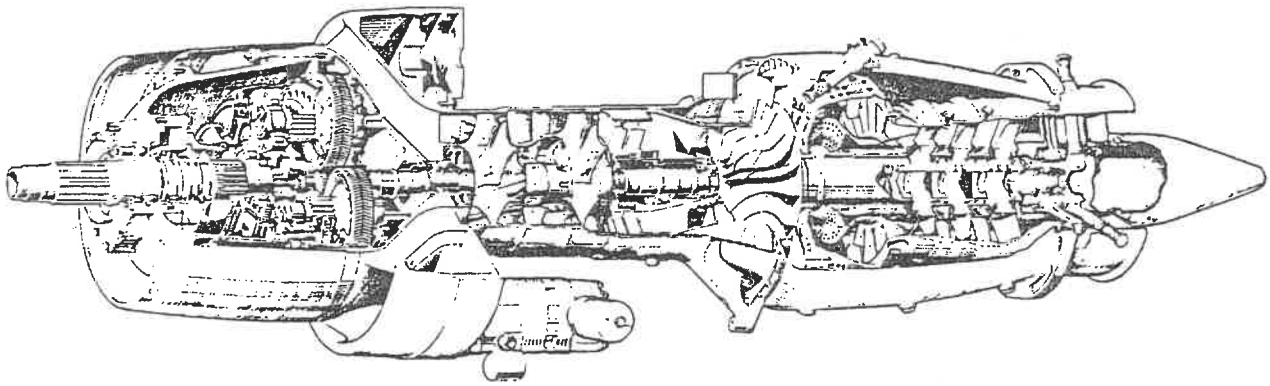
ENGINE DRAWINGS



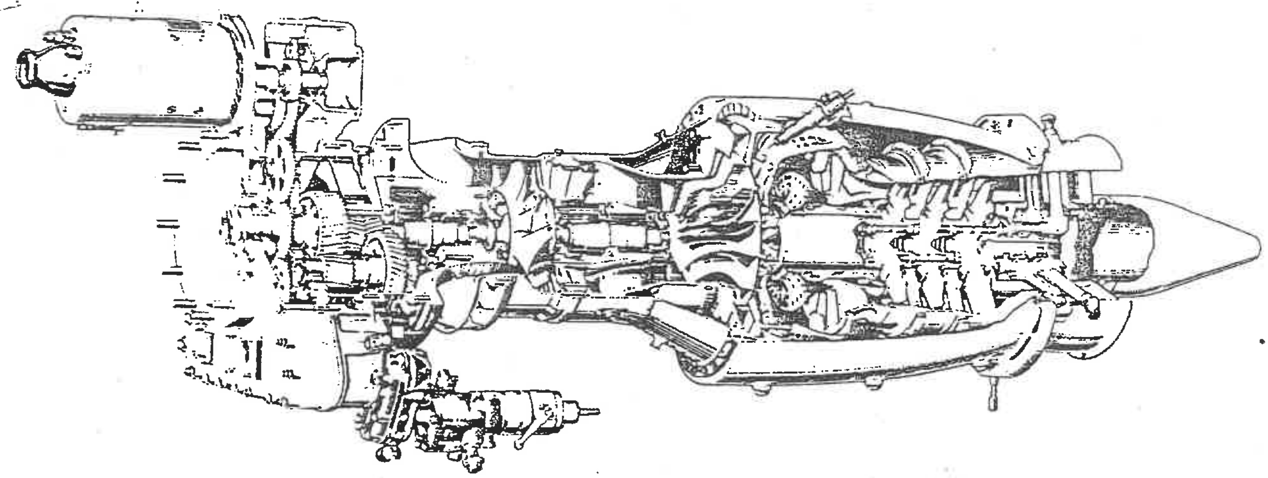
TURBO-PROPELLER : ASTAZOU XVI



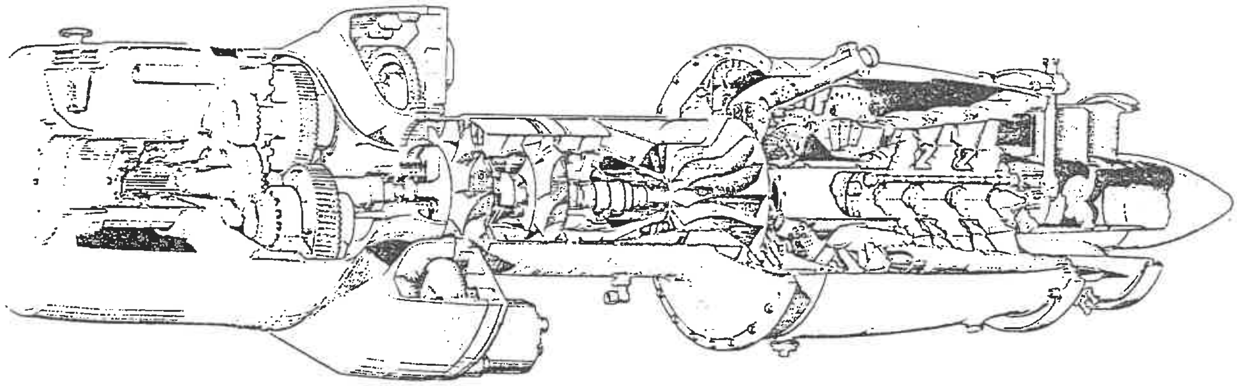
TURBO-PROPELLER : ASTAZOU XX



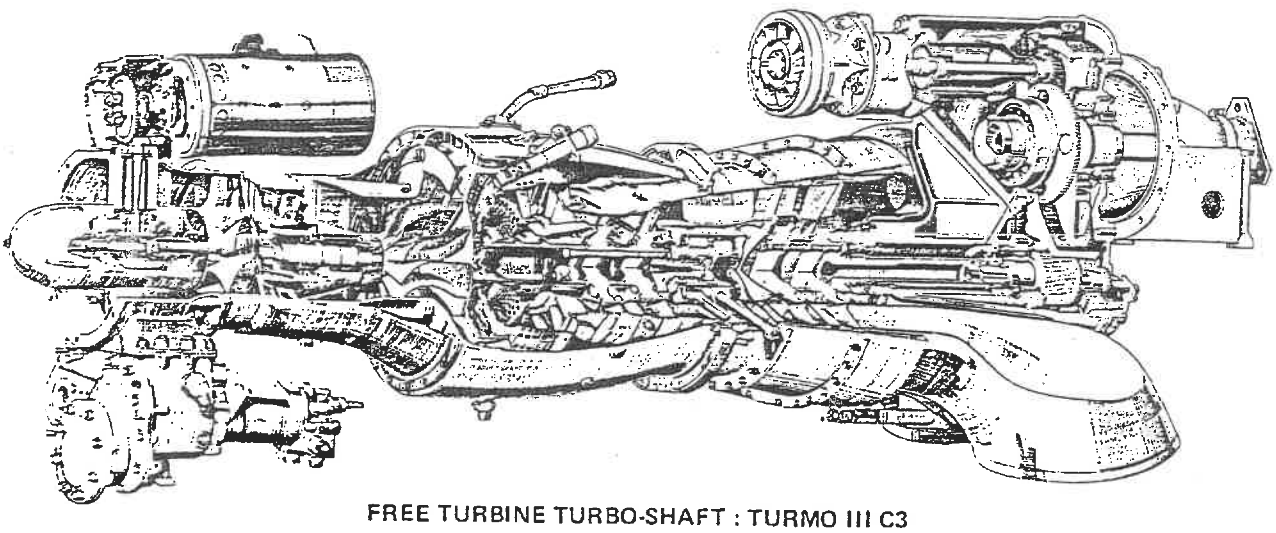
TURBO-PROPELLER : BASTAN VII



TURBO-SHAFT : ARTOUSTE III

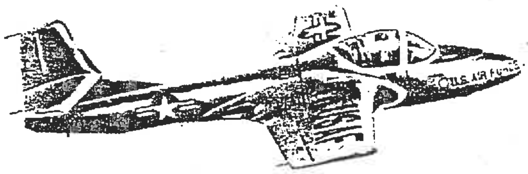


TURBO-SHAFT : ASTAZOU XIV

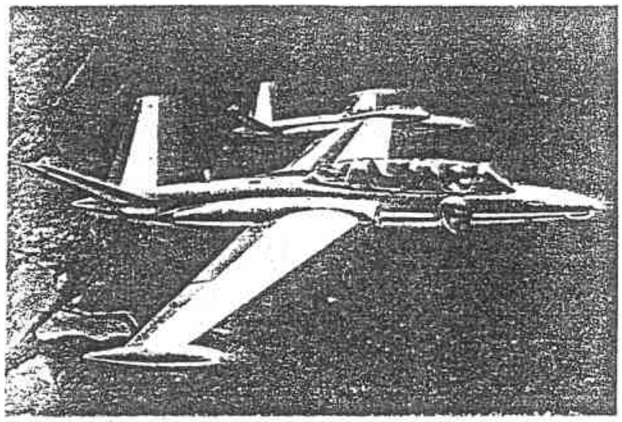


FREE TURBINE TURBO-SHAFT : TURMO III C3

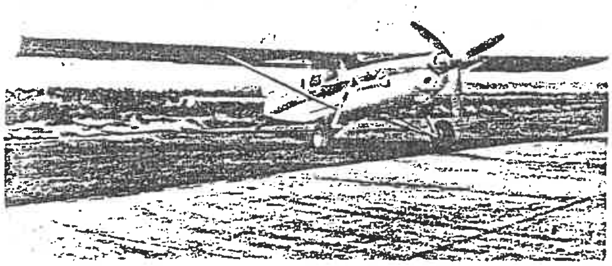
MISCELLANEOUS APPLICATIONS



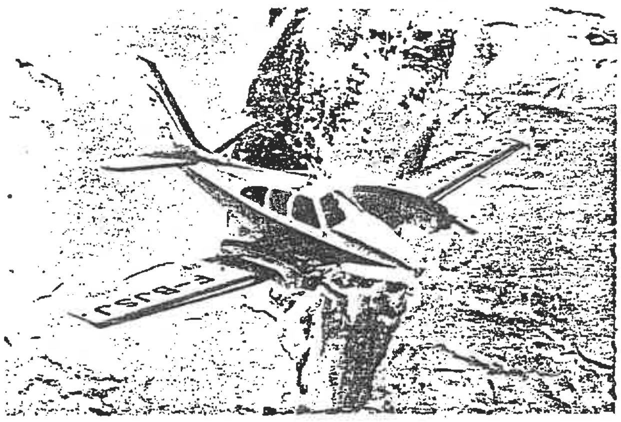
CESSNA T-37



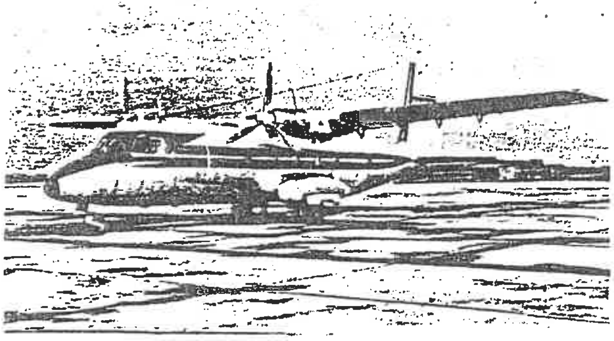
CM 170 MAGISTER



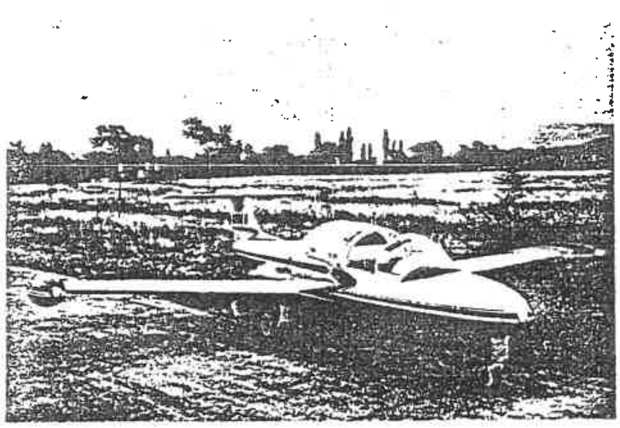
PILATUS PORTER



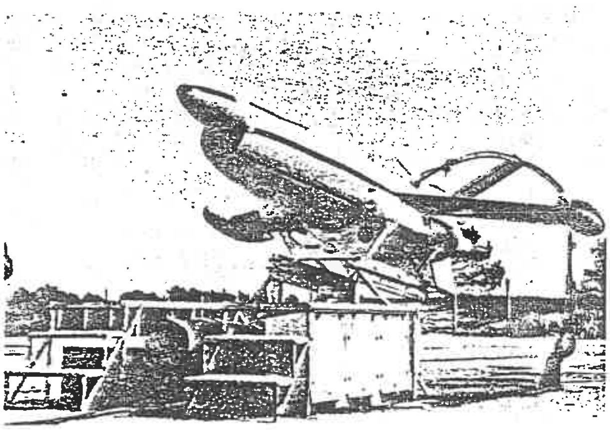
BEECHCRAFT "MARQUIS"



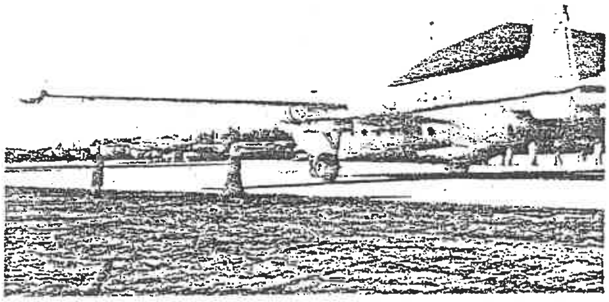
NORD 262



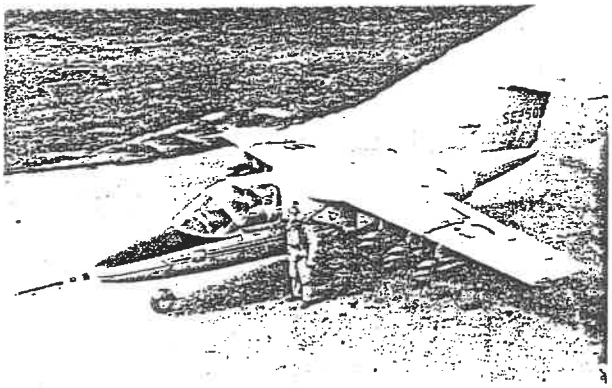
MORANE "PARIS"



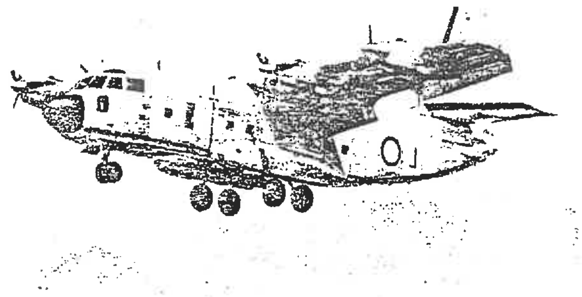
CT 20



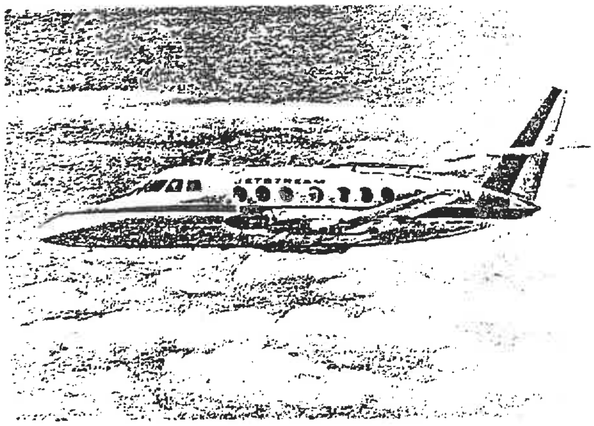
NORD 2506



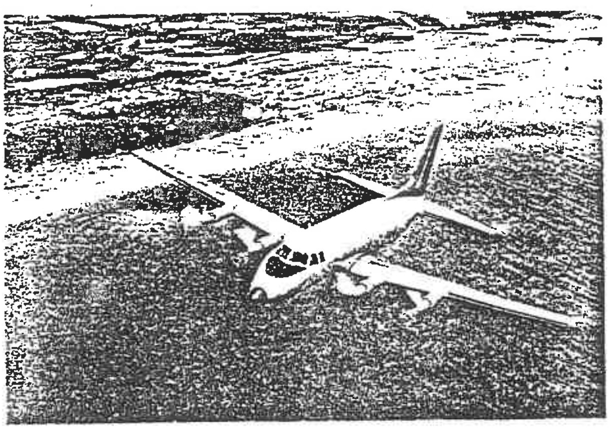
SAAB 105



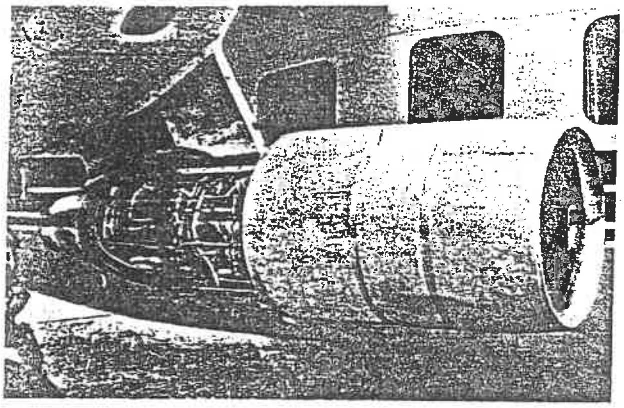
BREGUET 941

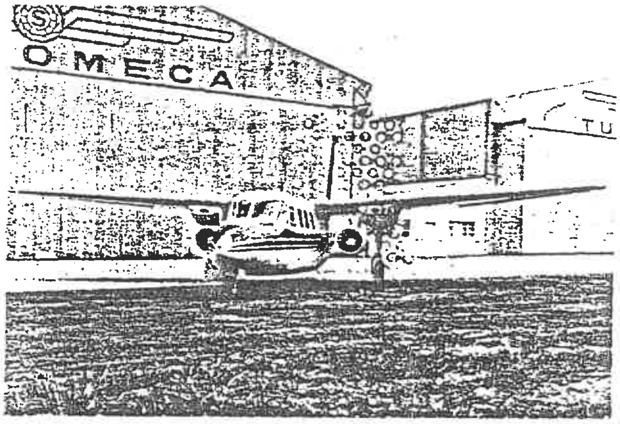


HP 137 JETSTREAM

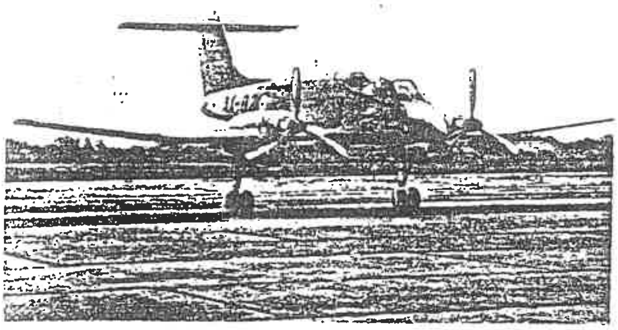


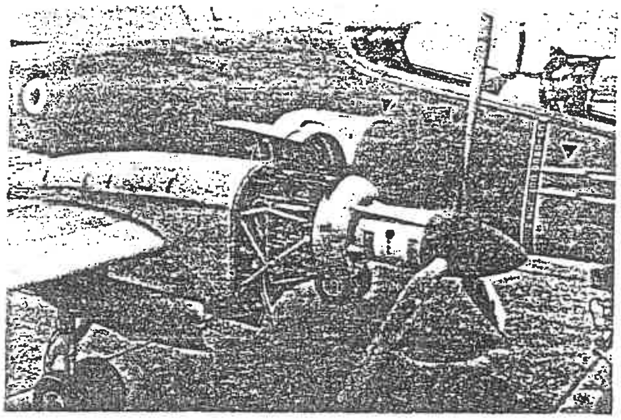
POTEZ 840





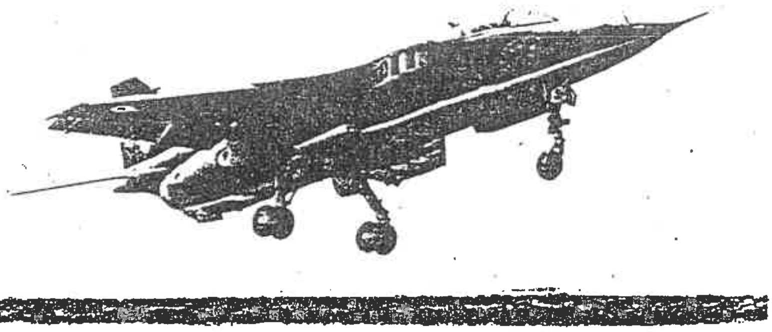
ASTAFAN COMMANDER

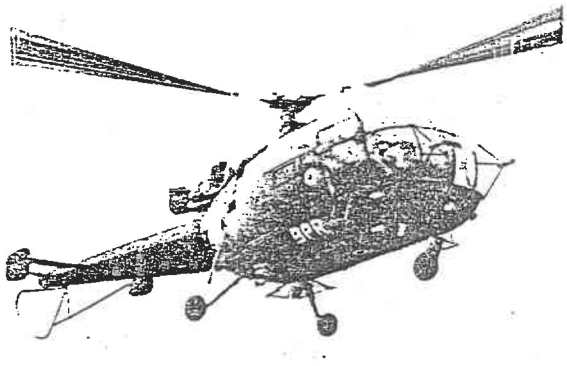




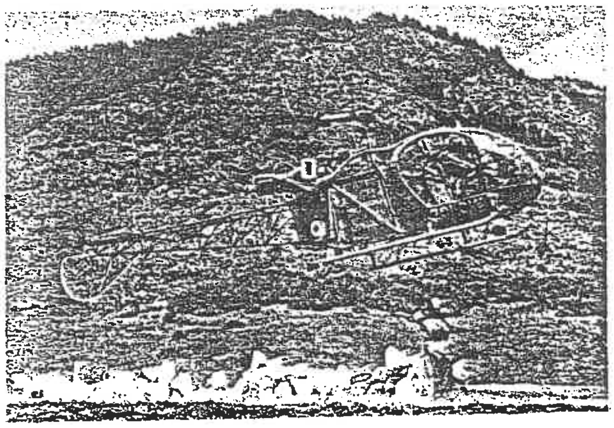
PUCARA

JAGUAR

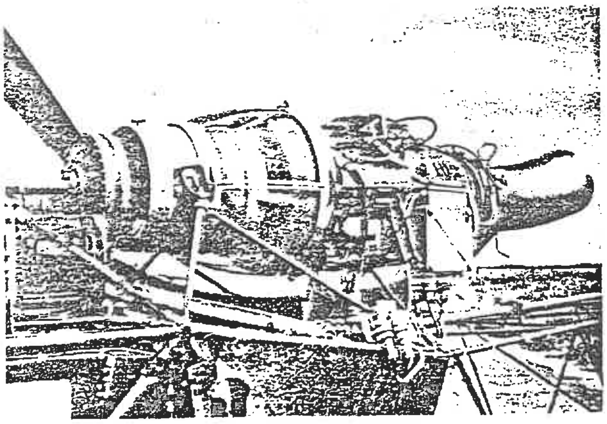




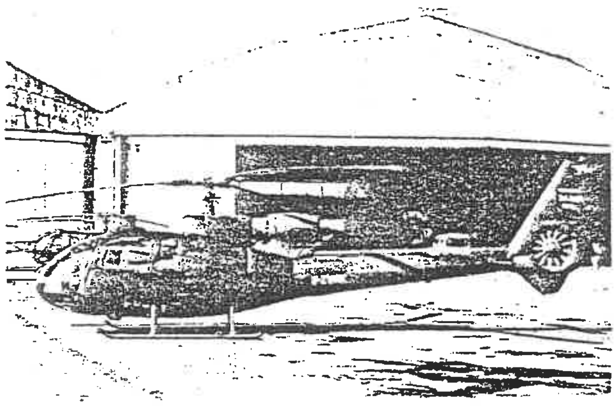
SE 3160 ALOUETTE III



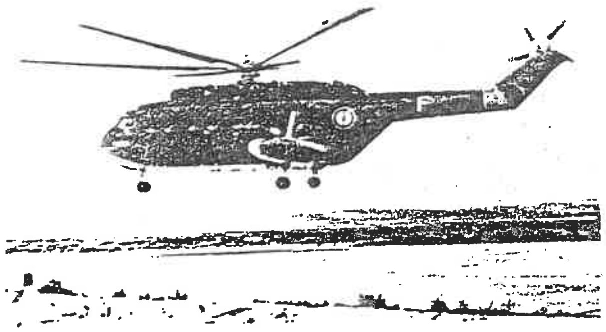
SE 3130 ALOUETTE II



ASTAZOU II ON SA 3180 ALOUETTE

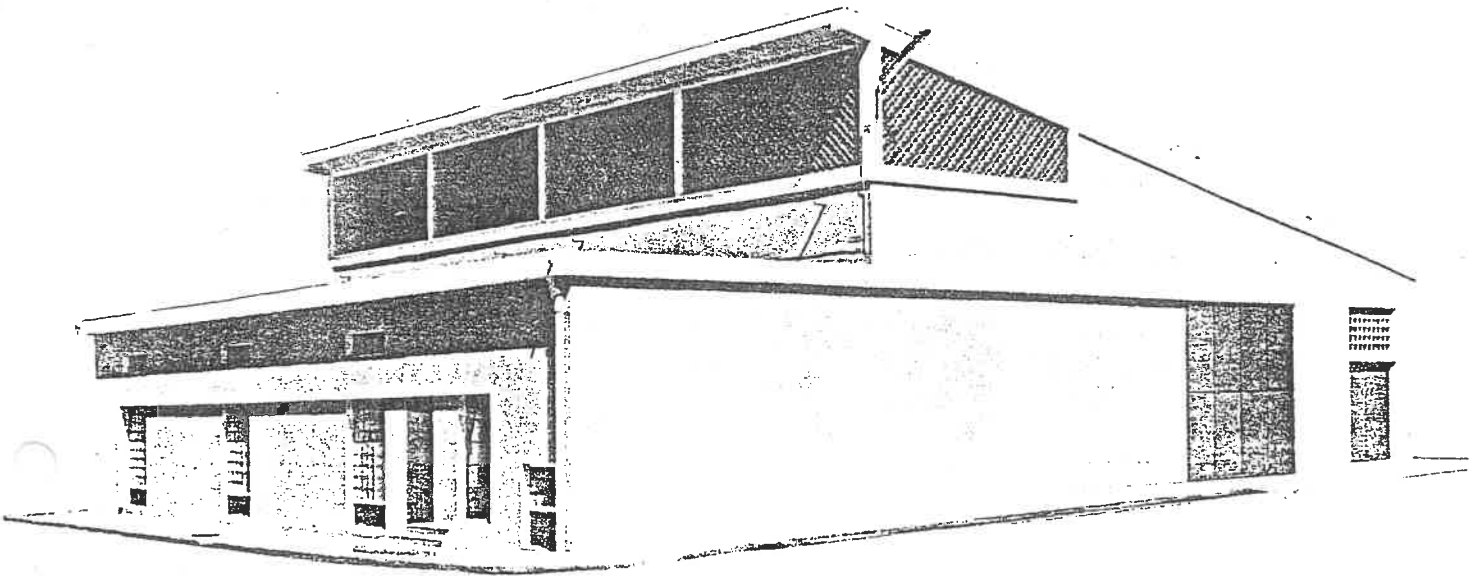


SA 341 GAZELLE

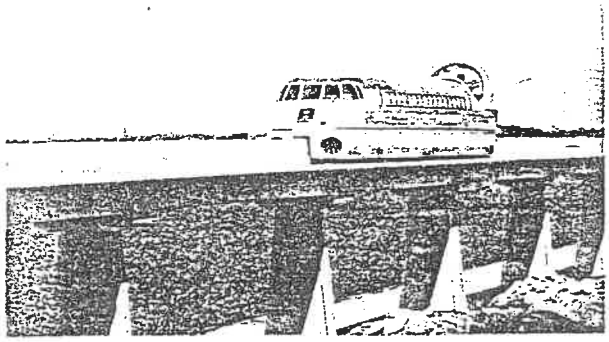


SA 321 SUPER FRELON

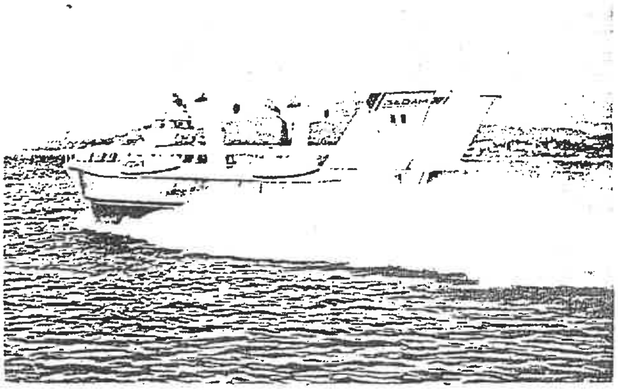
SA 330 PUMA



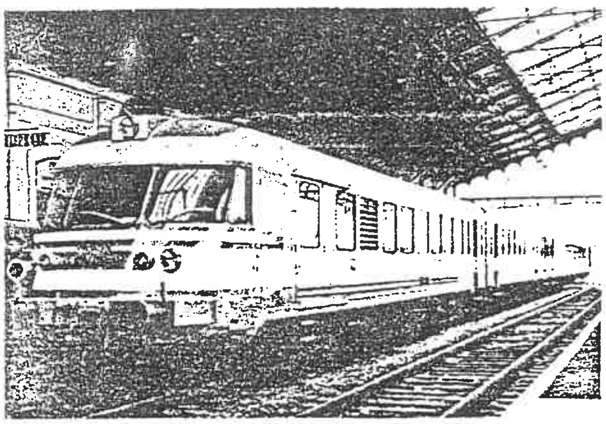
BASTANGAZ POWER STATION
OF THE BORDES FACTORY



AEROTRAIN



HOVERCRAFT



TURBOTRAIN