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THE ENVIRONMENTAL CONTROL SYSTEM FOR A MODERN HELICOPTER:

A BLEND OF NEW TECHNOLOGIES

by

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1. Introduction

A modern helicopter for civil or military transport has usually a non negligible amount of heat load that shall be efficiently dissipated.
The increase of amount of heat load in the recent projects, compared with the previous ones, is due to the higher number of passengers that can be carried and to the much higher power installed in the avionics compartments.
This plays an important role because it is strictly connected to the flight safety. In fact the operating temperature of the avionics, which are more and more deeply involved in the flight control operations, shall be always kept lower than a critical value which heavily impacts the avionics reliability and the flight safety.
The obvious consequence is that on such helicopters the air conditioning is absolutely a must. The system shall not only generate cooling/heating according to the needs; it shall perform also at very high efficiency level in order to have the minimum penalty impact on the aircraft performance.
The main results of the recent studies of Microtecnica for the design of a modern helicopter are discussed in this paper. The adopted technologies are already well known in the industrial and commercial applications. They have been further developed for the airborne application and their suitability to the helicopter ECS has been demonstrated by test and analysis.

2. System architecture selection and description

The first decision to be taken is about the system philosophy. As usual, the question arises: Which is the most suitable architecture? Is it an air cycle or a vapor cycle?
To this purpose, two systems (air and vapor cycle), both meeting the requested performance, have been preliminarily designed and compared from the point of view of their impact on the helicopter performance.
The requested performance are listed in Table 2-I.
In the system design it has been assumed that no bleed was available for air cycle cooling; therefore, the air cycle ECS shall be equipped with an air compressor mechanically driven by the helicopter gearbox.
The leading characteristics of the air and vapor cycle systems meeting the requested performance are shown in Table 2-II. It is evident the big difference between the power requested for the air compressor driving and the vapor one. On the other end, the vapor cycle system is heavier than the air cycle but, considering the total impact on the helicopter performance, the vapor cycle is surely the most suitable.
The helicopter penalties related to the ECS installation and operations have been evaluated by means of the method shown in Ref. 1 and 2.

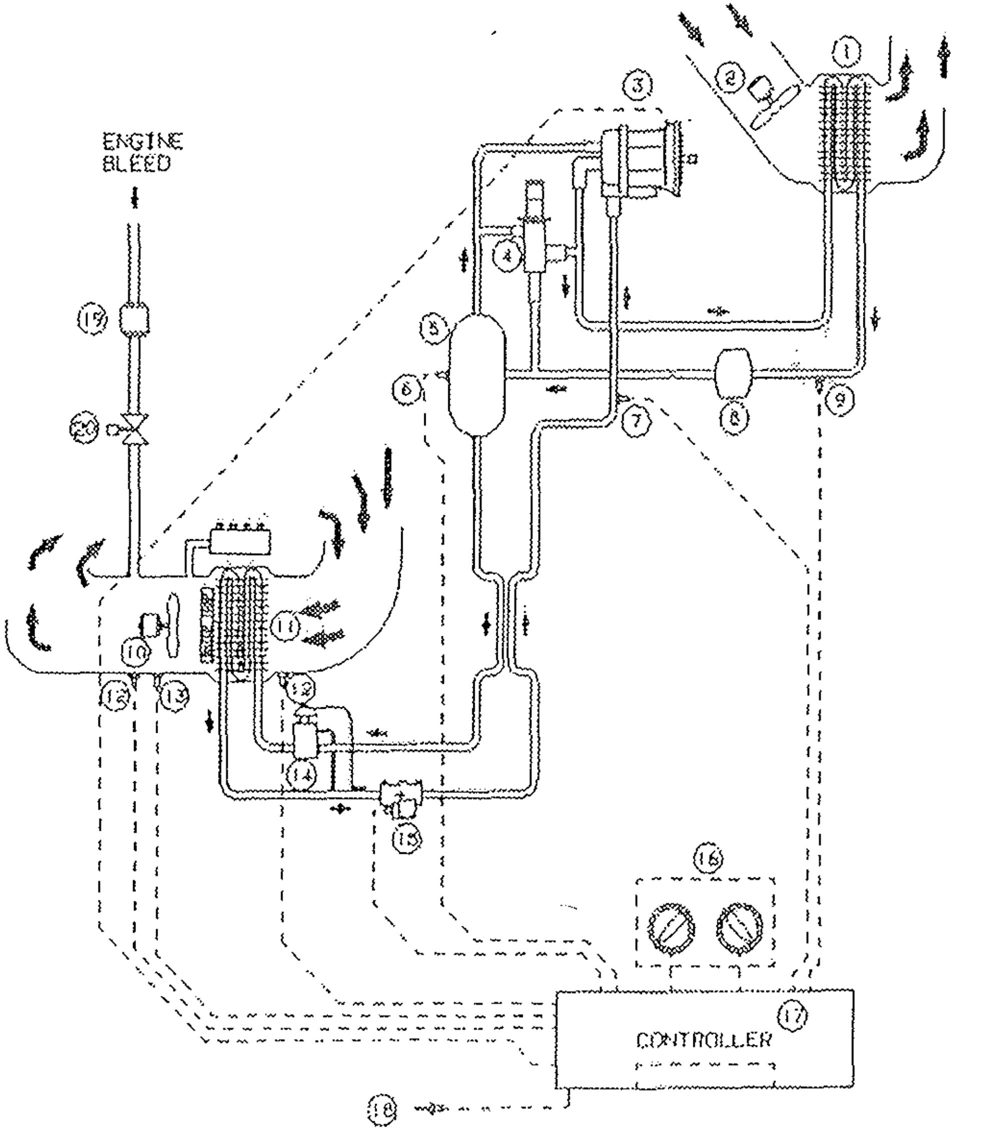
Altitude		s. l.
Ambient Temperature		40°C
Ambient Humidity		19 g/kg
Heat Load	Sensible	11500 w
	Latent	3000 w
Compartment Temperature		27°C
Compartment Humidity		< 50 %

Table 2-I System Design

The results of the penalty evaluation study are shown in Table 2-II.
Several components concur to the helicopter total penalty. They are:

- the weight of the system itself;
- the weight of the fuel spent for the generation of the power needed to the ECS operation;
- the weight of the fuel spent to carry the system and the amount of fuel described in the point above.

The sum of these components is reported in Table 2-II as "Total Penalty" and represents the loss of pay load



LEGEND:

1. CONDENSER
2. FAN, CONDENSER
3. COMPRESSOR
4. VALVE, HOT GAS BY-PASS
5. FLASH TANK
6. SENSOR, LEVEL
7. SENSOR, PRESSURE
8. FILTER
9. SWITCH, PRESSURE
10. FAN, EVAPORATOR
11. EVAPORATOR
12. SENSORS, TEMPERATURE
13. SWITCH, TEMPERATURE
14. VALVE, THERMOSTATIC EXPANSION
15. VALVE, EVAPORATOR PRESSURE REGULATOR
16. TEMPERATURE SELECTOR
17. CONTROLLER
18. SENSOR, AMBIENT TEMPERATURE
19. SHUT-OFF VALVE
20. MOTORIZED VALVE

Fig.3-1 Vapor Cycle System Schematic

which can not be carried due to the installation and operation of the ECS. The results of the study show that, notwithstanding the lower weight of the air cycle system, the pay load is less penalized by the vapor cycle due to its lower power extraction. Therefore, it can be concluded that, in our sample case, a vapor cycle ECS allows to carry an extra pay load of 46 kg respect to an air cycle ECS having the same cooling capacity.

3.- ECS schematic and component selection

The system (Fig 3-1) is vapor cycle based for cooling purpose, while the heating performance is achieved through the engine bleed. The refrigerant fluid is the non-ozone-depleting HFC-134a which replaces the outlawed CFC-12 in any application.

Helicopter and mission data

Spec. fuel consum........0.32 kg/h/kW
Mission duration.................4 hours

	Air		*R-134a*
System Mass	55	kg	65
System Power	50	kW	8
Total Penalty	140	kg	94

Table 2-II ECS penalty evaluations

The refrigerant *Compressor*, which can be electrically, mechanically or hydraulically driven, sends the gas to the *Condenser* which is cooled by an electric *Fan*. At the exhaust from the condenser, the liquid passes through an *Orifice* and enters a *Flash Tank*. Both liquid and vapor phases are present in the Flash Tank. The saturated vapor portion is directed back to the compression process while the saturated liquid portion continues normally to the *Thermostatic Expansion Valve* and *Evaporator*.

The saturated vapor is reintroduced into the compressor at an intermediate stage of the compression. Here it is mixed with the flow being compressed and reduces its temperature. In this way, also the total compression efficiency is increased because it takes benefit from the inter-refrigerated compression process.. The liquid phase goes to the *Evaporator*, passing through the *Thermostatic Expansion Valve*. The refrigerant loop is closed by the gas which exhausts from the evaporator and enter the compressor. On this line, the *Evaporation Pressure Regulator* is installed: this valve is controlled by the *Electronic Regulator* and allows the modulation of the cooling (in partial cooling conditions). The change of the pressure in the flash tank, consequent to the throttling of the evaporation pressure regulator, is avoided by means of the *Hot Gas By-Pass Valve* which is installed between the compressor exhaust and the flash tank.

The heating is achieved by bleeding the air from the engines and introducing it into the distribution ducts through a subsystem consisting of one *Shut-off Valve* and one *Motorized Valve*.

The complete System operations are controlled by a digital *Electronic Regulator*.

The following special features give important advantages on the usual solutions:

- *Economizer technique;*
- *Cooling modulation* by means of evaporation pressure control;

Other special characteristics can be found in the component technology selection which has been done with aim to have the best quality and reliability with the best cost effectiveness. Examples of such approach are:

- *the Scroll Compressor;*
- *the Flat Tube and Fin Condenser.*

The paper deals with these peculiarities, leaving out the detailed description of the more traditional system and component features.

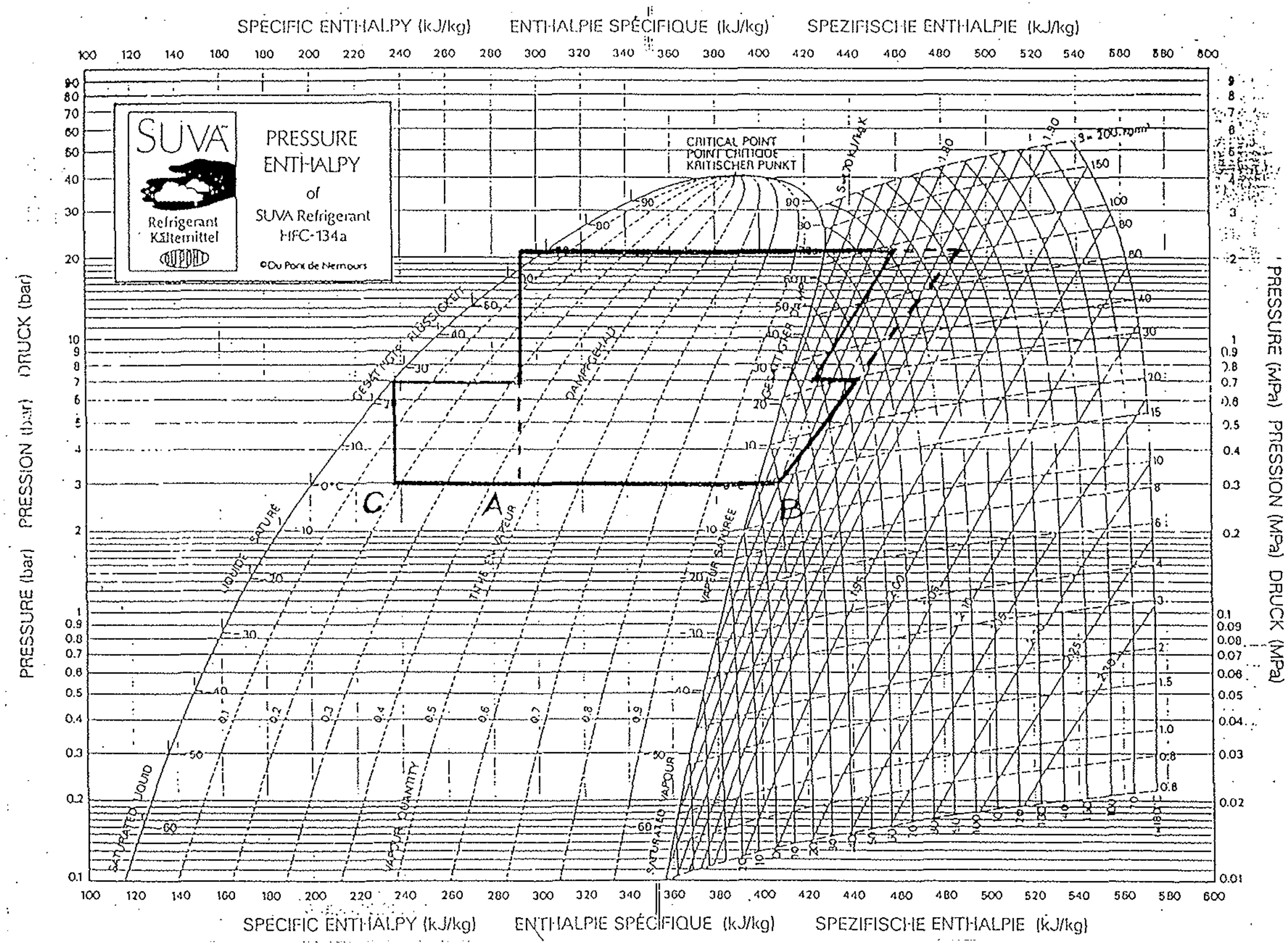


Fig. 4-1 Economized vs. Standard Cycle comparison

4. Economizer

The economized cycle allows an important increase of system performance for a datum compressor size and speed.

In an economized cycle, the liquid refrigerant, exhausted from the condenser, enters a Flash Tank, passing through a calibrated orifice. An alternate solution to the flash tank is a subcooler matched with an expansion valve.

As already described in the previous paragraph, the gas phase is sent back to the compressor, while the liquid portion enters the thermostatic expansion valve and the evaporator.

The economizer technique decreases the vapor/liquid ratio of the refrigerant entering the evaporator, so that it is closer to the saturated liquid line, resulting in a larger cooling capacity of the system.

Fig. 4-1 shows the comparison between an economized cycle and a traditional one, both based on the input data reported in Table 2-I. It is evident the difference between the lengths of the segments A-B and C-B which represent respectively the evaporator enthalpy rises in the non economized and in the economized cycles.

The economized cycle allows a 50% higher cooling capacity; this means that a smaller compressor can be used or, for a datum compressor, it can run at lower speed (about 33% lower than the same compressor in a non economized cycle, for a volumetric compressor) with non negligible advantage in terms of reliability.

As far as the component is concerned, the economized machine, in our sample case, shows a mechanical power which is only 22% higher than te non economized one.

Due to these combined effects (increase of cooling capacity lower than the related compression power), the Coefficient of Performance (COP) of the economized cycle is 23% higher than the traditional cycle.

5.- Cooling modulation by means of evaporation pressure control

A few traditional ways are available for partial cooling control: the most frequent are the "compressor on/off" and the "hot gas by-pass" to the evaporator.

Both the above mentioned methods have some important drawbacks:

- they can not provide a continuous cooling modulation;
- the compressor on/off has a negative impact on the compressor reliability.

The *Evaporator Pressure Regulation* (EPR) technique in partial cooling conditions enhances the system reliability and, in the same time, provides the minimum power extraction.

The EPR is installed downstream of the Evaporator, on the pipe from the Evaporator to the Compressor. It is controlled by the Electronic Regulator and adjusts the heat exchanged in the Evaporator by modifying the refrigerant pressure and temperature in the evaporator itself, when a partial cooling is requested.

Two types of EPR are available on the market for the industrial refrigeration applications. In both designs, the evaporator pressure modulation is provided by throttling the valve which opens or closes a passage in the pipe downstream to the evaporator, according to the need of cooling capacity increase or decrease. The difference between the valves is in the actuator design which can be based on a bimetal or on a fluid capsule. In both cases, an electrical resistance, electronically controlled, heats the actuator element which expands, throttling the valve. While the valve is throttled to close, the evaporation temperature increases and, at the same time, the pressure at the compressor inlet decreases. The EPR throttling to close is automatically stopped when the upstream compressor pressure approaches the ambient pressure; in this way, the ingestion of air and humidity into the refrigerant circuit (which heavily impacts the system reliability) is avoided.

In order to operate in the airborne applications, the EPR shall be matched with a device which stabilizes the pressure upstream to the evaporator, avoiding the refrigerant reverse flow when the EPR is throttled to close. This device has been patented by Microtecnica and consists in a Hot Gas By-Pass Valve to the Flash Tank.

The Evaporation Pressure Regulation technique has several important features and advantages on the other above mentioned methods of compressor cycling and hot gas by-pass to the evaporator. They are:

- No compressor cycling, with positive impact on its life and reliability.
- Lower compressor power due to the lower refrigerant flow and pressure at the compressor inlet in partial cooling conditions; on this aspect, it must be pointed out that the traditional "hot gas by-pass to the evaporator" has no reduction of refrigerant flow through the compressor.
- Low starting power by throttling the EPR to close at the starting phase.
- Anti-icing operations on the evaporator surface.

6.- Flat Tube and Fin Condenser

The Condenser is one of the key components in a vapor cycle system. In fact, it plays a fundamental role not only as far as the performance are concerned, but also in the weight definition.

Performancewise, the Condenser shall be sufficiently efficient to allow a large rejection of heat coming from the evaporator and from the compressor. The needed size is often in conflict with the small room available for installation and the light weight requested.

The solution of this problems is the modern technology of the *Flat Tube and Fin* condenser. This is a mature technology already extensively used in the automotive applications, mainly in the high range cars where the price slightly higher than the traditional condensers is still accepted and largely compensated by the superior inherent features.

The excellent sealing properties and high compactness of this design make it very interesting also for the airborne application where up to now only the Plate and Fin or, more frequently for the Vapor Cycle, the Round Tube and Fin have been used.

Fig. 6-1 shows a schematic of such condenser.

A row of flat tubes, having an external thickness of about 1 mm, is brazed between two cylindrical collectors.

The refrigerant flows inside the collectors and the tubes in a certain number of passages (one or more), according to the number and position of the circular sectors brazed inside the collectors.

A very thin fin is brazed inside the tubes in order to enhance the heat exchanged on the refrigerant side, while an other fin, brazed between the tubes, improves the heat exchange efficiency on the air side. The result is a very large total surface exposed to the fluids which allows an overall efficiency comparable

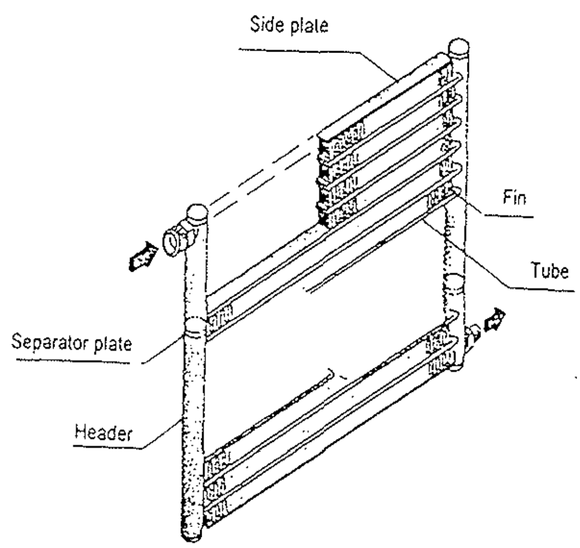


Fig 6-1 - Flat Tube and Fin Condenser Schematic

to the Plate and Fin design.
Moreover, these kinds of condensers are very thin and have air pressure drop much smaller than any other design. This allows, on one hand, a light weight unit, on the other one a much lighter fan that shall have a definitely smaller prevalence than a fan matched with traditional condensers.
Let us compare condensers of different technology (flat tube and fin, round tube and fin, plate and fin, all light alloy material)designed in orser to meet the requirements of the sample case of Table 2-I. All three heat exchangers have been designed for the same heat rejection, same frontal area, same cooling air flow and same related pressure drop. The masses of these condensers are quite different. In terms of percentage, referred to the mass of the "plate and fin" design, they are:

- Plate and fin............................ 100%
- Round tube and fin.....................55%
- Flat tube and fin..........................40%

Viceversa, for a datum condenser volume and mass, the pressure drop relevant to the 'Flat Tube and Fin" design is much lower than the others; therefore the associated fan has the lowest mass and power consumption

7. The scroll compressor

It is obvious to emphasize the importance of the refrigerant compressor in the vapor cycle. If it is true that the system efficiency and reliability depends on the optimum matching and quality of all the system components, it is also well known that the amount of cooling produced by the system almost depends on the compressor. It is a difficult task to have a refrigerant compressor for an airborne application at the same time powerful, efficient, reliable and very cost effective.

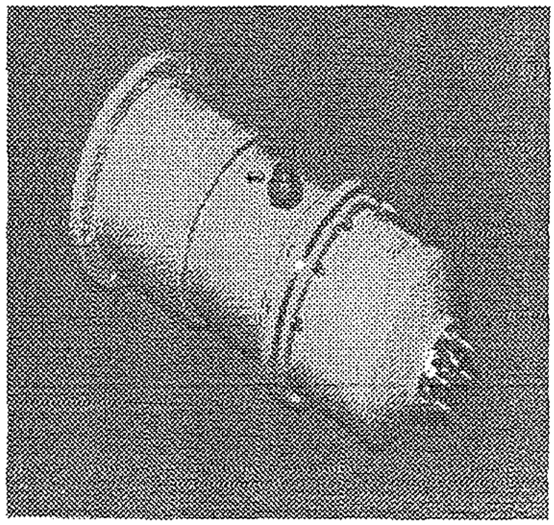


Fig. 7-1 Microtecnica's airborne Scroll Compressor

Several kind of compressors already in use in automotive applications are available on the market. The airborne system manufacturers very often use these machines in their applications when the requested cooling capacity does not exceeds few kilowatts. In these cases, the automotive compressors have demonstrated their reliability with low costs. However, when the cooling capacity request is higher (from about 7 kw on in the typical and severe aeronautical environment) the automotive compressors, like they are available on the market, are no longer suitable. Important modifications are needed in order to adapt such compressors to the requirements of the airborne applications. This heavy redesign can be an expensive and frustrating exercise because the target to derive from a small automotive compressor a bigger machine featuring high performance and reliability is a very difficult one.
The development of a new compressor, specifically designed for the airborne application is of course not less expensive and is anyway a risky exercise: a new basic design shall be found, featuring a very mature technolo-

gy and the highest reliability inits field in order to allow an easy and safe derivation of the machine for the new airborne application.
These features have been found in a very modern family of scroll compressors designed for the industrial and commercial refrigeration and heat pump applications. The tremendous reliability of such compressor (it has been originally designed for 80,000 hours of trouble free operation) was an ideal base for the derivation of the airborne machine which shall operate with more severe. constraints, but for much less hours (Fig. 7-1).
To these purposes, the economizer has been introduced, the material of some parts has been changed, using light alloy to the maximum extent, the original 60 Hz electric motor has been replaced by a 400 Hz 200 V ac motor or by a mechanical drive with a magnetic clutch, according to the different customer specifications.
The core of the compressor , that is the *Pump Assembly* which includes the

Condition	*Hours*
Max load floodback	3500
Max Pressure	3000
Max Pressure Ratio	3000
Blocked Fan	500
Flooded Start	500
Transient Slug	500 (500 Transients)
Stop/Start	350 (200.000 Cycles)
Defrost	1000 (500 Cycles)

Table 7-I Tests performed on the commercial scroll compressor

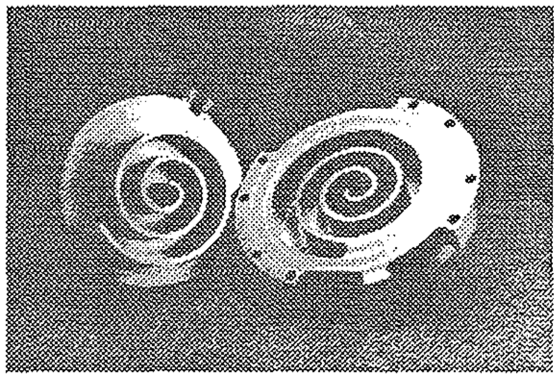


Fig. 7-2 Scroll Wraps

Scroll Wraps (Fig. 7-2) has been kept basically the same of the commercial unit, with the implementation of the economizer holes: this guarantees the highest level of quality at very cheep costs. The material of some parts, whenever possible and convenient, has been changed, using light alloy.
In addition to the very severe qualification tests already passed by the commercial original unit (Table 7-I), other tests have been performed in order to validate the implemented modifications.
A thorough investigation of the performance has been done on a dedicated rig in order to measure the improvement deriving from the modifications and compare them with the original performance of the standard design. The stability of the airborne compressor, its cooling capacity and the absorbed power have been measured at several evaporation and condensation temperatures and for various subcooling values. All the figures already foreseen by the mathematical model of the new economized airborne compressor have been confirmed within a range of +/-3%.
In addition to the performance experimental evaluation, a complete vibration test has been performed in both random and sinusoidal modes. During the vibration, the compressor has been operated in order to check the impact of the vibrations on the performance. Analyzing the behavior of

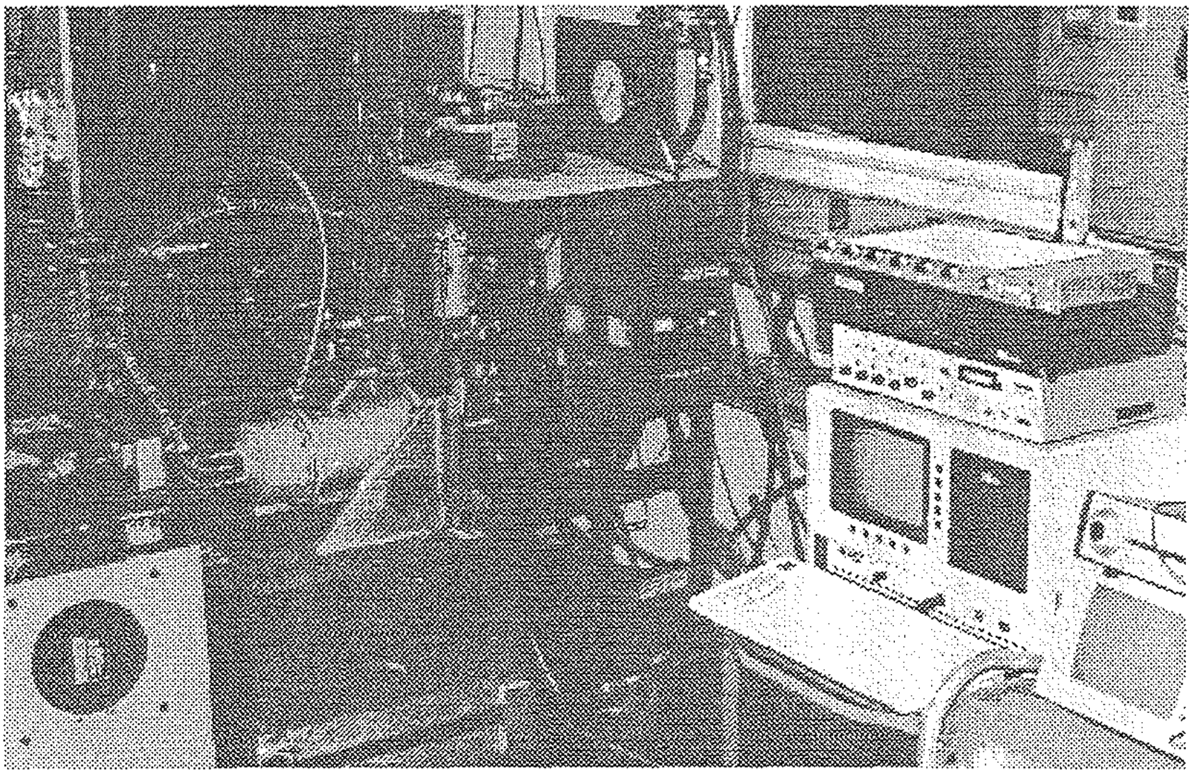


Fig. 7-3 The airborne scroll compressor during the vibration test

the compressor in terms of cooling capacity, absorbed power and refrigerant leakages before, during and after the vibration, it has been concluded that this machine is such robust to withstand without any problem all the constraints typical of the most severe airborne environment.

8. Conclusions

In the present aerospace market situation, any new development must feature high performance at reasonable cost. Therefore, whenever possible, it is worthwhile to explore any synergy with other fully developed applications, even if not airborne.
An example of application of this concept has been discussed in this Paper where some new and efficient technologies, imported from the commercial fields, are described.
This approach allows the use of available advanced solutions with important cost savings and minimum technological risk.

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