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Hybrid Environmental Control System for Military Aircraft

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Abstract - Environmental Control system (ECS) or Air management system plays a vital role in aircraft performance. Almost all military aircrafts are equipped with conventional - bleed air based ECS. For a single engine military aircraft, such a system results in an enormous ~1.2 MW of thermal power penalty over the engine. Electrical ECS (EECS) is revolutionary, rather evolutionary, since it affects many other systems. A lot of research has been carried out to incorporate EECS in civil airliners. But little has been done as yet in case of military aircrafts. There could be many reasons for the same like availability of electrical power on board, availability of eco-friendly refrigerants, high Avionics and Radar heat load, appropriate medium for condenser cooling etc. As electrical technology has gone through a lot of power density upgrades in recent decade specially, compared to pneumatic systems, it calls for a need to seriously work over electric ECS. However electric system has not yet achieved its mature stage and has its own limitation. If Electric ECS is used in military aircraft it would be the largest consumer of the Electric power. Presently, a combination of Conventional and Electric ECS called Hybrid ECS could be the best decision based on the available technology and as an intermediate step towards realisation of electric ECS for future aircrafts. This paper covers a brief description of conventional, electric and Hybrid ECS systems and compares them for military aircraft application. A special emphasis is given over the selection of refrigerant based on available cooling medium and electrical power on board for the electric ECS. Even after the Electric ECS simplicity, high performance and Low aircraft signature a lot challenges need to be addressed to make it feasible for combat high agility high speed military aircraft.

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HYBRID ENVIRONMENTAL CONTROL SYSTEM FOR MILITARY AIRCRAFT

Hybrid Environmental Control System for Military Aircraft

Rahul Agrawal [α] & Sankaraiah Mada [σ]

Abstract - Environmental Control system (ECS) or Air management system plays a vital role in aircraft performance. Almost all military aircrafts are equipped with conventional - bleed air based ECS. For a single engine military aircraft, such a system results in an enormous ~1.2 MW of thermal power penalty over the engine. Electrical ECS (EECS) is revolutionary, rather evolutionary, since it affects many other systems. A lot of research has been carried out to incorporate EECS in civil airliners. But little has been done as yet in case of military aircrafts. There could be many reasons for the same like availability of electrical power on board, availability of eco-friendly refrigerants, high Avionics and Radar heat load, appropriate medium for condenser cooling etc. As electrical technology has gone through a lot of power density upgrades in recent decade specially, compared to pneumatic systems, it calls for a need to seriously work over electric ECS. However electric system has not yet achieved its mature stage and has its own limitation. If Electric ECS is used in military aircraft it would be the largest consumer of the Electric power. Presently, a combination of Conventional and Electric ECS called Hybrid ECS could be the best decision based on the available technology and as an intermediate step towards realisation of electric ECS for future aircrafts. This paper covers a brief description of conventional, electric and Hybrid ECS systems and compares them for military aircraft application. A special emphasis is given over the selection of refrigerant based on available cooling medium and electrical power on board for the electric ECS. Even after the Electric ECS simplicity, high performance and Low aircraft signature a lot challenges need to be addressed to make it feasible for combat high agility high speed military aircraft.

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I. Introduction

As ECS has interface with many other systems, ECS efficiency widely depends upon the technological improvements of these systems. In a military aircraft, Environmental Control System (ECS) caters the need of Avionics, Radar and Cabin Cooling, Cabin pressurisation, Cabin Ventilation, Wind Screen De-misting, Cabin Sealing System, Radar air supply to Fuel Tanks Pressurisation. However these cooling and pneumatic services may vary aircraft to aircraft. In conventional ECS to meet these services air is tapped from engine which upsets the engine flow pattern and increases the turbine inlet temperature. Bleeding the air from the engine is not cost effective way since the bleed air is at high pressure and temperature which has to be brought down to condition level. In case of Electric ECS (Vapour Cycle based), outside ambient air would be tapped and compressed to required pressure and cooled through refrigeration cycle. Hybrid ECS is the blend of both Electrical and Conventional ECS, to meet cooling requirements of various services in the complete envelope of aircraft.

II. Brief Description

a) *Conventional ECS*

It works on boot strap cycle where Compressed air is tapped from the compressor of engine through a combined PRV/SOV. This air fed to the heat exchangers where heat is taken by outside ram air. In case of low Mach flight, jet pumps are used to increase the efficiency of heat exchanger. This jet pumps further use engine bleed air for primary flow. The outlet of heat exchanger goes into CAU (compressor coupled with turbine) unit where ECS air is compressed, cooled and then expanded. This expended air goes to condenser where it is brought down to final conditional level for ECS requirements. High pressure water separator is used after CAU compressor for dehumidification. Present technology of high pressure water separator has eliminated the service problem of low pressure water separator. A typical conventional ECS schematic is shown below as fig-1

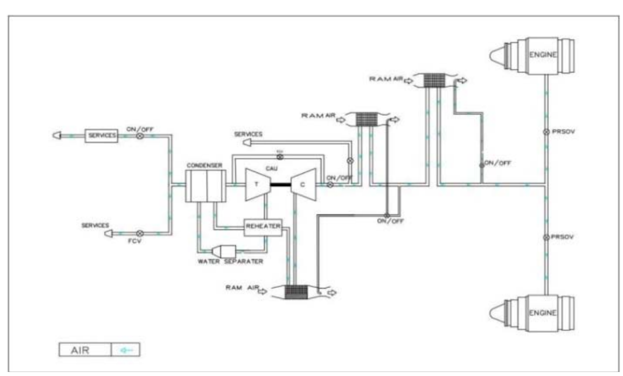

Figure 1 : Conventional Environmental Control System

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b) Electric ECS

It works on the principle of Vapour Compression Cycle System. It is the fact that Vapour cycle is more efficient than air cycle regarding the function of cooling. The great strides made in recent times with microprocessors and integrated circuit are well known. This added a big heat load in the name of Avionics and Radar heat load which has to be removed by ECS. As shown in fig-2, All electrics ECS schematic is divided into two circuit, one is exclusively for radar and second is for other ECS services. For other services, the required quantity of ram air is tapped by an electric motor driven variable speed compression ratio air Compressor. After compression it is forwarded to ram air heat exchanger where ram air cools it. Then it moves to Evaporator where it is again cooled by Refrigerant to a predefined temperature level. At the Evaporator outlet condensed moisture is removed by water separator and sent to the required services for instance cabin cooling, Avionics cooling, OBOGS etc. In Radar circuit Coolanol fluid removes the heat load directly which in turn cooled by refrigerant. Coolanol has High and Low-Temperature Stability and can easily withstand the high- and low-temperature extremes encountered by airborne electronic equipment. These fluids are designed to meet the special needs of sensitive electronic components for aircraft, missiles and spacecraft.

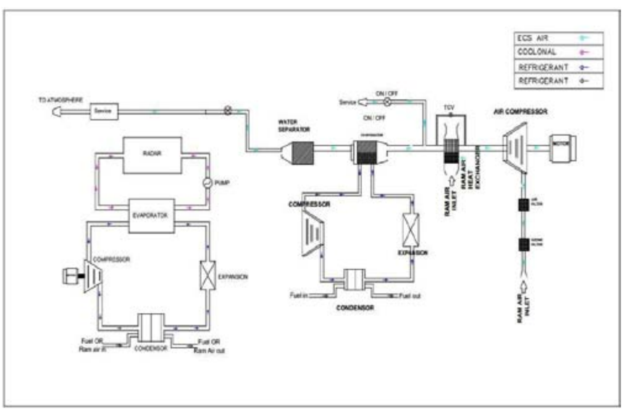

Figure 2 : Electric ECS

c) Hybrid ECS

It is the blend of both conventional and Electric ECS,. In hybrid ECS, Radar heat load is removed through the refrigerant in same as explained earlier and other services are met through conventional ECS.

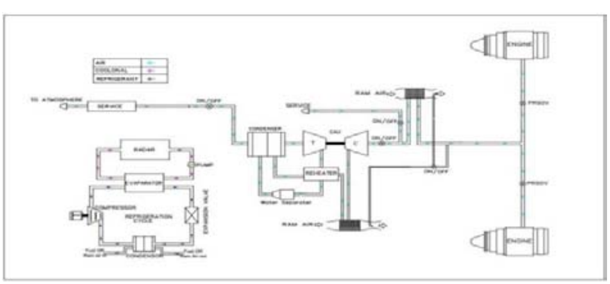

Figure 3 : Hybrid ECS

III. Analysis Study

A comparative study for twin engine military aircraft is made among Conventional, Electrics and hybrid ECS. The aim of this study to highlight pros and cons of these three ECS configuration and find the best feasible solution based on available technical capability. Following heat loads/Mass flow rates, as shown in Table: I, considered to various ECS requirements for ECS configuration study.

Table I : ECS requirements for Study

Sl. No	ECS requirement	Heal Load/Mass flow rate
1.	Cabin	11 kw.
2	Radar	15 kw
2.	Avionics	05 kw
4.	On Board Oxygen Generation System (OBOGS)	1.3 kg/min

Based on study over above requirements for different ECS configuration and past experience with conventional ECS, the following observations are made.

a) Conventional ECS

i. *Cons*

i) Total bleed of 100 kg/min(50 kg/min/engine) is required to meet ECS services which causes1.5Mw(for 100kg/min bleed) thermal load penalty over engine performance at low Mach cases.
ii) Comparatively complex, inefficient and bulky.
iii) Use of many heat exchangers with ram air cooling increases the aircraft signature. Since Heat exchanger performance also varies with Mach no and altitude. So some aircraft require fan for electronic cooling at Ground/low Mach flight.
iv) High Pressure Drop.
v) High cockpit Noise.
vi) System experience unsteady state whenever engine rating is changed.
vii) Leakage problem at high pressure and temperature.
viii) In single Engine Navy aircraft, conventional ECS bleed need to be cut off to facilitate high thrust requirement for Ski-Jump Take off.
ix) Complex system ducting and layout.

ii. *Pros*

i) No critical sealing requirement compare to electric ECS.
ii) Established maintenance base.
iii) Established technology base.

b) Electric ECS (VCS)

After ban of chlorinated refrigerant due to their ozone depletion potential only few refrigerants are left for use. For Electric ECS, R134a, R236fa and R245fa, are considered for study. These refrigerants are free from chlorine and hence do not causes ozone depletion and are globally accepted. The critical properties of these refrigerants are tabled below as Table II.

Table II : Refrigerant Properties

Sl No	Properties	R134a	R245fa	R236fa
1	Critical Temperature	101°C	154°C	125°C
2	Critical Pressure	4.06MPa	3.64MPa	3.2MPa

i. *With Refrigerant R134a*

i) Total electrical power requirement, for both Radar and
other services, is found minimum in case of R134a. It is around 45Kw.

ii) Outside Ram air cannot be used for R134a condenser
cooling. Since its critical temperature is near to ram air temperature, at low altitude and high Mach flight.

iii) High specific heat, high density and low temperature aircraft fuel could be considered for R134a condenser cooling. Fuel is also considered as energy conserving heat sink. However, it may require additional Heat Exchanger to cool the fuel prior to delivery to main fuel tank.

iv) Total Fuel flow requirement is around 200lpm which require additional electrical power over 45Kw for circulation.

ii. *With Refrigerant R245fa*

Total electrical power and fuel flow requirement is quite high. It is not feasible for aircraft applications.

iii. *With Refrigerant R236fa*

i) It can be considered other option where fuel is not available all the time for condenser cooling. Since its critical temperature is high compare to R134a, Ram air can be considered as a cooling medium. However Heat exchanger size requirement would be high which will affect stealth of aircraft.

ii) Total electrical power requirement is more than R134a. It is around 60 kw

iii) In case of fuel, flow requirement is 240lpm.

iv) In case of Ram Air, flow requirement is 120kg/min which demand huge condenser size

a. *General Observation over electric ECS*

i) If All Electric ECS is used. It would be the largest consumer of aircraft electrical power.

ii) To drive the fuel/ram air as the case may be, require additional pump/fan which will add additional electrical
power.

iii) If high flow rate of fuel flow is to be avoided then combination of R236fa and R134a can be considered. R236fa for RADAR condenser which can be cooled through Ram air and R134a for other services (Cabin and Avionics) condenser which can be cooled through fuel flow. In this configuration total power requirement will increase a little.

iv) Less aircraft signature, less cockpit noise.

v) Small Components and simple Ducting layout.

vi) Critical sealing requirement

vii) Possibility of forming corrosive fluid

viii) No maintenance technology base.

ix) Little technology base- Some company like Fairchild Controls and Liebherr Aerospace Toulous are working towards it. However main attention is given towards commercial aircraft.

c) *Hybrid ECS*

i) Electrical power required is 14kw with R134a and engine bleed is 50 kg/min (25kg/min/engine).

ii) Thermal penalty over engine is 7.5(for 50 kg/min bleed) Mw.

iii) Less Electrical power & low fuel flow requirement are easy to configure in their system architecture.

Hybrid ECS is trade off between Conventional and electric ECS. Present technological base of companies like Honeywell, Libherr Aerospace, Fairchid Controle are capable to develope Hybrids ECS for commercial aircraft.

IV. Conclusion

Despite the technological challenges of VCS, Increase in its reliability, life span and temperature stability of Avionics and flight control systems demand pollution and humidity free ECS air which can be met effectively by refrigerant based dedicated cooling system. Today Hamilton- Sundstrand VCS, using high efficiency Nonazeotropic refrigerant mixture are found in NH NATO helicopter, Sirorsky S-92 Civil helicopter and USAF F-16 &F-22, Hybrid system is becoming quite popular. Fairchild Controls, USA has developed the refrigerant compressors specifically designed for Military and Commercial Airborne application. These compressors have low suction and discharge pulsations for better control, extremely close tolerance to achieve high volumetric efficiency and low weight with advance oil management. Liebherr Aerospace Toulouse has established technical capability towards realisation of Electric ECS for Commercial Aircraft. Electrical VCS needs more innovation and technological upgrades to bring it into the market. At one hand, demand for High stealth, high agility, high Mach and high performance military aircraft made Conventional ECS outdated, on other hand high electrical power consumption made Electric ECS very expensive/nonviable to use. With present technology, Hybrid ECS with R134a refrigerant, with fuel is available as cooling medium, could be best start towards realisation of Electric ECS.

V. Abreevation

PRV - Pressure Regulating Valve

SOV - Shut Off Valve
TCV - Temperature Control Valve
VCS - Vapour Cycle System
CAU - Cold Air Unit
NATO - North Atlantic Treaty Organisation
ECS - Environmental Control System
EESOV - Electric Environmental Control System

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