Alcor – A High Altitude Pressurized Sailplane

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I. General Comments and Summary

Alcor is a Research sailplane which has utilized unusual design concepts and manufacturing techniques to enable comfortable and safe flying at high altitude.

The design philosophy has placed emphasis on practicability and cost control without seriously compromising safety and performance. This new sailplane has a 20-meter wing span with an aspect ratio of 28. The performance capability has placed emphasis on a low sink rate. For this reason, weight saving has been an important guideline in both design and fabrication. The requirement for low weight with flutter resistance has required the use of new materials and lay-up techniques. All critical assemblies are of the sandwich type assembly with the cross sectional dimension adjusted to give, where necessary, an improvement in the structural stiffness.

Physiological problems, presented in the high altitude environment, are solved in part through cabin temperature and pressure control. The oxygen system and pilot mask are nonconventional in both design and operation. The system permits a high level of oxygen partial pressure at altitude and allows direct breathing from the cabin environment, with all exhaled gases going directly to the cabin pressure regulator and discharged overboard.

The initial flight testing of Alcor is about complete and at present, with Boeing staff assistance, a comprehensive flutter analysis utilizing computer technology is being finalized. Only preliminary checks of the cabin sealing system have been completed. During 1974 it is hoped that all qualitative flight tests will be completed and some high altitude flying will be accomplished.

II. Purpose

The design development of the Alcor sailplane was not directed to the making of new records but to examine and utilize new materials and fabricating techniques allowing the use of special methods for cabin temperature and altitude control. It is hoped that this type of sailplane will allow a higher level of safety and comfort while investigating high altitude lift phenomena.

III. Design Concepts and Philosophy

With new material technology growing rapidly throughout the entire world, it is possible, with no limits on cost, to design and build a reliable aircraft structure at a weight of less than 50% of conventional designs. The philosophy applied in the design and building of Alcor has been to keep the utilization of these new materials within practical limits on cost and fabricating techniques. For this reason emphasis has been placed upon the utilization of «S» glass fibres where truly beneficial. In certain cases, resin sized Sitka spruce veneers in sandwich layups have been used because of gains in compression strength and stiffness.

There are three basic design objectives which have been pursued diligently throughout the development of the sailplane. They are as follows:

1. The use of new materials and, when needed, an adjusted sandwich cross section to optimize structural capability.
2. The utilization of a new oxygen management system which, with safety, will allow high dry oxygen concentrations in the cabin environment with a simple and reliable pressure regulating system.
3. The provision of a simple and reliable means of cabin temperature control at all flight levels.

Figure 1 shows some recent advances in specific strength capability with various fibrous materials. This chart is projecting specific tensile strength and tensile modulus of certain fibres and more conventional materials.

A great deal of pro and con on the relative benefits of new versus old material has been plaguing engineers involved in general aviation and sailplane design activities. There is no question but that aluminium, as an isotropic material, has certain benefits. The physical characteristics are well known; the fabricating techniques are well understood and have proven a high level of reliability at low cost. However, considering the rather spectacular performance capability of new materials, as shown in the comparative chart in Figure 1, and considering the simple control technique for changing the sectional characteristics through sandwich thickness and/or material orientation, in many application the new materials will undoubtedly prove superior. Much remains to be done, however, before this will be a proven fact. Physical characteristics in the composite case need further investigation and documentation. This is a rather difficult task in that there is an almost infinite variety of material and matrix combinations. Fabricating techniques need to be further developed and this will require innovation, much like heat treating techniques were developed in the use of aluminium alloys. Likewise, with composites, fabricating techniques will allow specific improvements in physical characteristics.

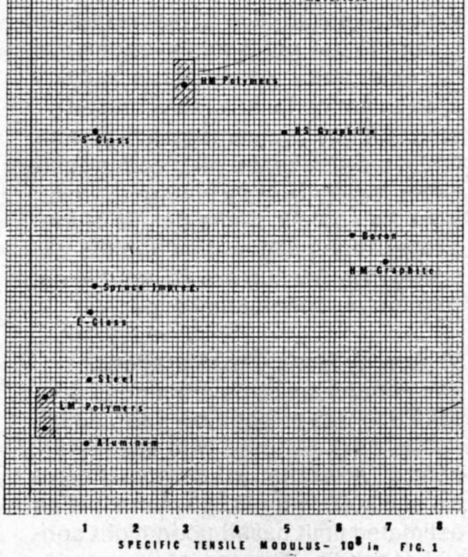


Fig. 1

In the design development and fabrication of Alcor, one rather interesting example stands out where the design problem has benefitted by the utilization of fibre sandwich materials. This had to do with the utilization of «S» glass fibres with varying foam sandwich cores so as to give further improvements in compression and torsional stiffness. The result being as shown in Figure 2. The wing has a high ratio of wing torsional stiffness to wing bending which should provide gust loading relief in turbulent air and extend the critical flutter speed.

IV. High Altitude Problems Reviewed

Before and during World War II, I was involved in special assignments with the Boeing Airplane Company connected with flight testing aircraft at high altitude. Most of the early flying was unpressurized. Little was known about the high altitude environmental effect on the human body, on aerodynamic performance and control, on the airframe structure, or power plant operation. In fact, very little was known about atmospheric conditions above 8,000 metres. Since that time a tremendous file of information has been gained and made available for the design and safe operation of aircraft to extremely high altitudes. OSTIV has made a tremendous contribution in this area and this knowledge is being shared throughout the world. This knowledge has enabled certain design concepts to be applied in the development of Alcor with a fair

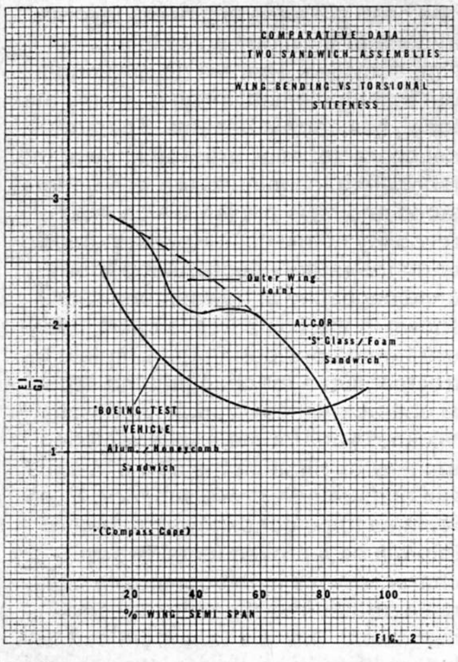


Fig. 2

degree of confidence. To provide a sailplane that would operate safely to altitudes of 60,000 feet (18,500 metres) the following considerations have been carefully analyzed and tentatively solved in the development. While safety is a broad overrunning design consideration, the specific problems related thereto are:

1. Physiological.
2. Aerodynamic.
3. Structural capability.
4. System reliability.

The physiological problem, while concerned primarily with the oxygen supply, also includes a requirement for cabin heat control, elimination of canopy frosting, safety against fire hazards, and an emergency bailout procedure.

Aerodynamic considerations, while placing a heavy weighting on minimum sink performance at altitude, also is concerned with critical mach number influences and control response in normal and abnormal manoeuvres.

In the structural case, emphasis has been placed on providing a practical V-n envelope within the confines of which the pilot can safely operate. The effect of temperature on materials and the structural reliability and proper sealing of the pressure pod have been carefully considered.

The system reliability has been concerned with basic flight controls, cabin pressurization control, and oxygen level while at altitude.

The following material details the design solution and where applicable the operating procedure followed when meeting these various high altitude problems.

V. Physiological Considerations

We all know that oxygen is used at high altitude or low ambient pressures to maintain a minimum level of oxygen pressure within the lungs. This alveolar pressure is quite different than the partial pressure of the oxygen contained in the oxygen mask or in the cabin environment. The system, as proposed in Alcor, is to maintain a minimum alveolar partial pressure of oxygen throughout the full flight regime and to provide additional partial pressure over the minimum at extreme high altitudes (above 12,000 metres). Figure 3 shows the general proportions of partial oxygen pressure with altitude in the ambient and the pressurized conditions. Likewise, it also shows the alveolar partial pressure of oxygen in the lungs with altitude in the pressurized condition.

Humidity control is in some respects a more difficult problem. While no difficulty is experienced in developing a relatively dry cabin environment because of the dry oxygen source flowing continously into the cabin area, there is a physiological problem relating to the effects of a dry air environment. For long flights, in excess of six hours, body dehydration becomes an important consideration. A small aluminum honeycomb screen is attached to the inner surface of the mask, covering both inlets and the outlet. This condensing unit is cooled on inhalation and collects by condensation a portion of the water vapor during exhalation. Some of the moisture is then returned to the dry oxygen on inhalation.

Figure 4 projects the normal lapse rate in the standard atmosphere and adds to it the estimated benefit of the solar heating unit. Also shown is the estimated benefit of the body heat retention due to the fuselage insulation. The negating influence of heat from radiation and slipstream effects is also shown. These curves are approximate in the quantative measure but certainly indicate interesting possibilities. Most important is the fact that the cabin environment can be made more comfortable with minimum complications.

To protect against very serious physiological exposure due to inadvertent exposure to low pressure environments, i.e., emergency bailout and/or cabin pressurization loss, a conventional constant flow type emergency bailout bottle is worn by the pilot and triggered either manually or by emergency exit from the cockpit. Some details of the oxygen regulating system and the emergency backup are covered in subsequent portions of this paper.

VI. Aerodynamic Considerations

The aerodynamic requirement in this sailplane was to optimize a low sink rate at peak altitudes with adequate control. A mach number restriction of 0.5 at 60,000 feet (18,500 metres) is an estimated limit based upon flight control capability. The operating speeds

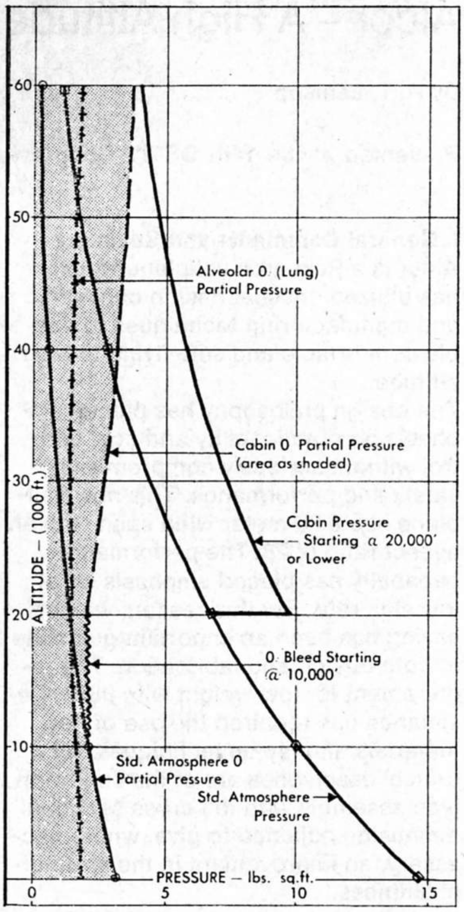


Fig. 3

that maximum altitude, will range between 45 mph indicated and 100 mph indicated. This is acceptable but stability and control in the environment is critical. For this reason conventional control surface configurations have been incorporated and trailing edge flaps deleted.

For the emergency condition, to effect rapid deceleration and/or descent, conventional wing spoilers are installed and a tail mounted drag chute will be installed in the near future.

VII. Structural Design

Sandwich type construction has been utilized quite extensively in the building of Alcor. As I have already stated, this has been done to improve the stiffness characteristics in the critical areas. The fuselage section in basically a one-piece Sitka spruce glass sandwich assembled from thin veneers previously resin sized and moulded in such a way as to give high torsional rigidity in the tail section and internal pressure resistance capability in the nose section. The sandwich materials used in the wing are «S» and «E» glass unidirectional fibre and fabric materials sandwiched with epoxy resins to a polyvinyl chloride foam core. The PVC foam used in this assembly varies from 4 to 6 lb. per cubic foot in density and, to ensure high shear capability, a vacuum forming system was used to bond the inner skin to the wing spar D section. There are a number of reasons

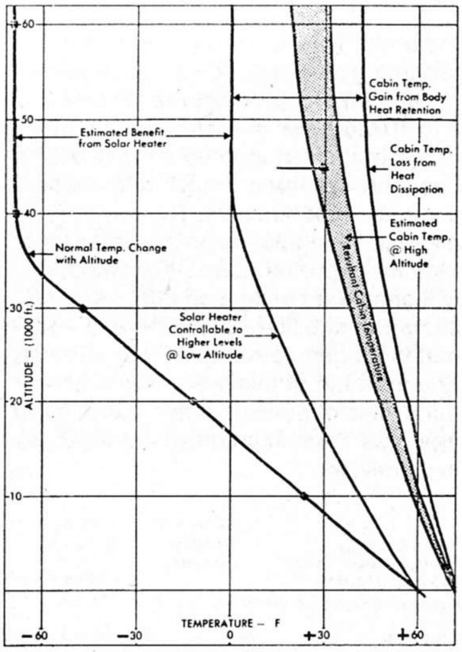


Fig. 4

for the selection of the epoxy, glass, and sandwich materials.

1. The high specific strength of «S» glass, while spectacular in the tension loading, is also good in compression when utilizing certain epoxy formulations and can be further benefitted by careful selection of the sandwich lay-up geometry.
2. Ability to form and/or mould to compound curvatures.
3. Ability to form in simple moulds with low pressure requirements.
4. Wood fiber/epoxy/glass sandwich has shown very interesting test results giving high torsional stiffness. This material application was utilized in building the tail section.
5. The spruce/epoxy/glass sandwich utilized in the nose section is laid up in such a way as to give a practical measure of thermal compatibility with acrylic canopy material, part of which is bonded directly to the nose section. The spruce sandwich method of construction of the nose section, together with the circular cross section and additional reinforcements for pressurization, provide a high measure of protection against nose-impact type accidents.
6. The ability, in fibre resin sandwich assembly, to control and improve the basic physical characteristics of a given fibrous material to a specific loading case, i.e., wing torsional resistance.

The canopy utilized in this design is of the faired type; however, to handle pressurization loads the cross section in the canopy area has a slight figure 8 configuration and considerable care has been applied in developing adequate beam supporting structure on the two longerons in this canopy cut-out area. The canopy is free moulded utilizing a special technique which allowed the incorporation of a double plexiglass canopy in the cockpit area and facilitates a rather simple installation of a tubular type silicone seal to retain cabin pressure. Unfortunately, acrylic materials have a relatively high thermal coefficient and a relatively low modulus, of elasticity. While the former has been counteracted to some extent by the selection of nose fuselage material, the low modulus, under pressurization loads, will effect certain distortions and could be a problem. The 3 p.s.i. cabin pressure differential committed in this design is primarily a direct result of this consideration. If the problem proves to be serious, the conventional solution, as committed to fighter aircraft canopies using this type of material, will necessitate increasing wall thickness of the plex material to handle the loads adequately.

VIII. Oxygen and Pressure Regulating System and Operation

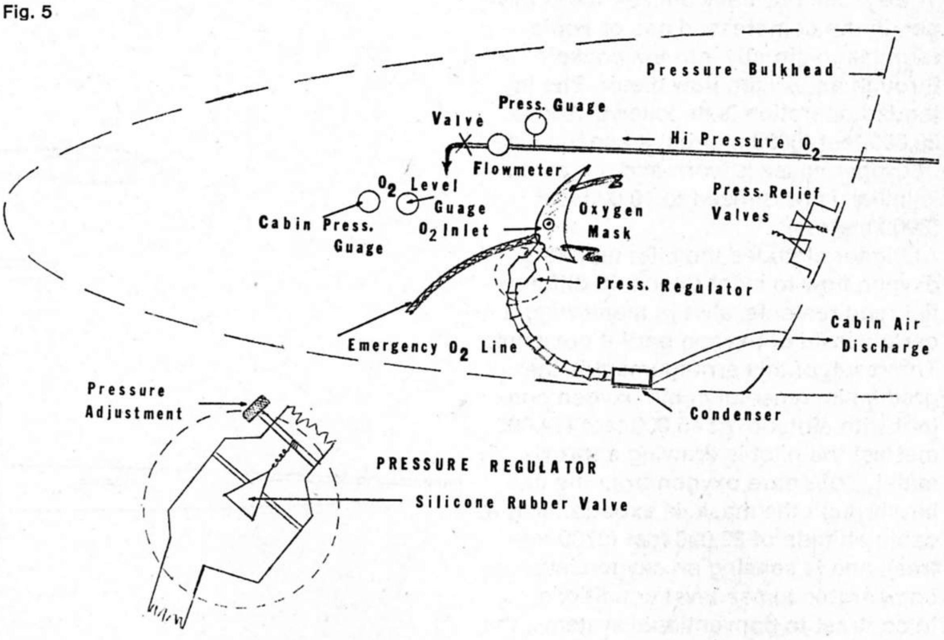
The oxygen management and cabin pressurization concept being applied in the Alcor development is a research effort.

Much has been written about the physiological aspects of high altitude flight. Many accidents have occurred as the result of conventional oxygen system failures or misuse. A number of years ago Vic Saudek of the SSA presented a very interesting proposal to the OSTIV Congress, proposing two pressurized sailplane concepts. Unfortunately, the lack of supporting funds precluded the actual flight testing of his proposals.

One might ask as to whether or not cabin pressure investigations in sailplanes are really worthwhile. I would think they are because there are other benefits, apart from cabin pressurization and safety improvements in high altitude flight operation. These benefits relate to cabin heat control, a reduction of cabin moisture levels, and the elimination of canopy fogging. In Alcor, because of the simplicity of the system, the oxygen level can be better matched to human needs, reducing fatigue and giving additional safety benefits. It might be stated that the broad objective in this design is to enable long middle-to-high altitude flights in a safe and comfortable cabin environment with clear vision at all times.

The pressurization concept, as applied in the Alcor design, iş basically quite simple. The sailplane, in effect, is a space capsule sealed to zero leakage of cabin air, and provided with a pressure oxygen system to maintain a predetermined cabin altitude. This is monitored by a simple cabin regulating valve, manually set by the pilot to a desired cabin pressure differential setting. Figure 5 shows a schematic diagram of the oxygen and cabin pressurization system. It should be noted that high pressure oxygen is brought into the cockpit area with a reference gauge for existing tank pressure and with a manual valve allowing manual control of oxygen flowing through a flow meter. Two instruments are carried on the instrument panel, one giving cabin pressure differential and a second showing cabin oxygen level readout. There is no connection between the oxygen outlet and the oxygen mask. The oxygen mask includes the cabin pressurization regulator in the outlet tube. This silicone valve is present but manually adjustable, and is located close to the pilot's face to allow the benefit of warm exhaled air to prevent freezing. This valve works at all times whether the mask is worn or not. A condensation plenum is located in the outflow line from the oxygen mask and pressure regulator to prevent excessive

Fig. 5



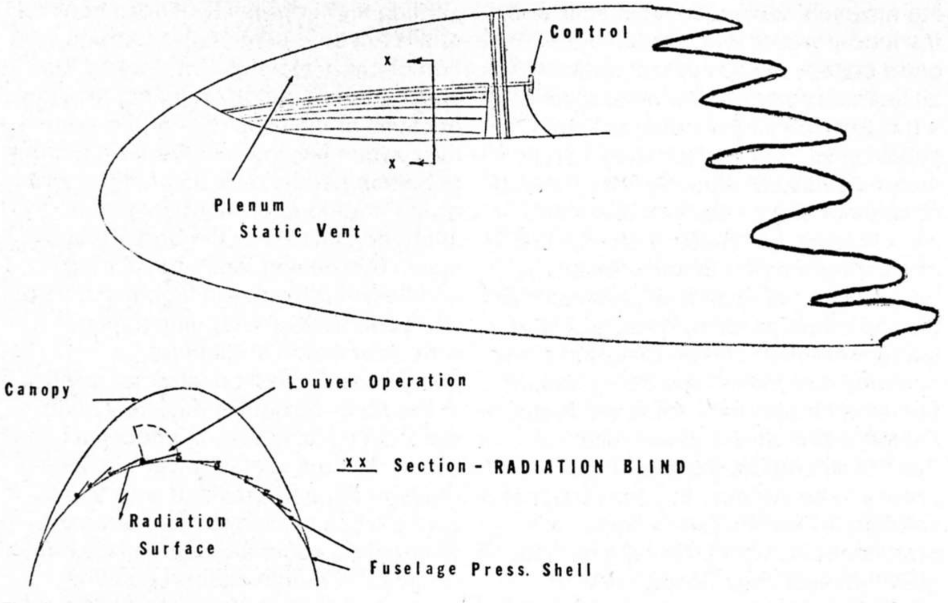


Fig. 6

frost buildup in the outflow line. It should be noted in the attached schematic diagram, separate from the mask outflow system is a small unit containing two relief valves. One protects overpressurization of the pilot compartment and the other eliminates any negative pressurization which might result from high rates of descent.

The cabin pressurization has been given a preliminary check. Within 12 months it is hoped that a full system evaluation can be persued.

As designed, the Alcor pressuration system meets three basic requirements. These are:

1. Zero cabin leakage.
2. Cabin structure capability to a cabin differential to 10 lb. per square inch at ambient temperatures to –70°F (3 lb. per square inch – operating pressure).
3. A cabin oxygen level readout instrument allowing pilot monitoring of oxygen levels at all times.

The system basically utilizes 100% oxygen in the compressed gas or liquid form taken directly into the cockpit through an oxygen flow meter. The intended operation is as follows. Above 20,000 feet (6000 metres) a special type of oxygen mask is worn and the cabin is initially pressurized to 10,000 feet (3000 metres).

At higher altitudes the pilot monitors oxygen flow to meet the cabin differential requirements, always monitoring a certain level of oxygen partial pressure. The result of this arrangement is the gradual increase of cabin oxygen content with altitude. At 45,000 feet (14,000 metres) the pilot is drawing approximately 90% pure oxygen from the cabin through the mask, is experiencing a cabin altitude of 22,000 feet (6700 metres), and is sensing an oxygen level comparable to sea level conditions.

In contrast to conventional systems, the oxygen mask is worn for two important reasons:

1. The mask provides the means to gather and discharge overboard, through the cabin pressure regulator, exhaled portions of carbon dioxide and water vapour. The mask, in this case, is not connected to the oxygen source but is attached to the cabin pressure regulator which is connected to the outlet tube.
2. The second reason for wearing this mask is for the emergency case, at which time the mask will function as with the conventional system with 100% oxygen coming from a separate emergency bailout bottle.

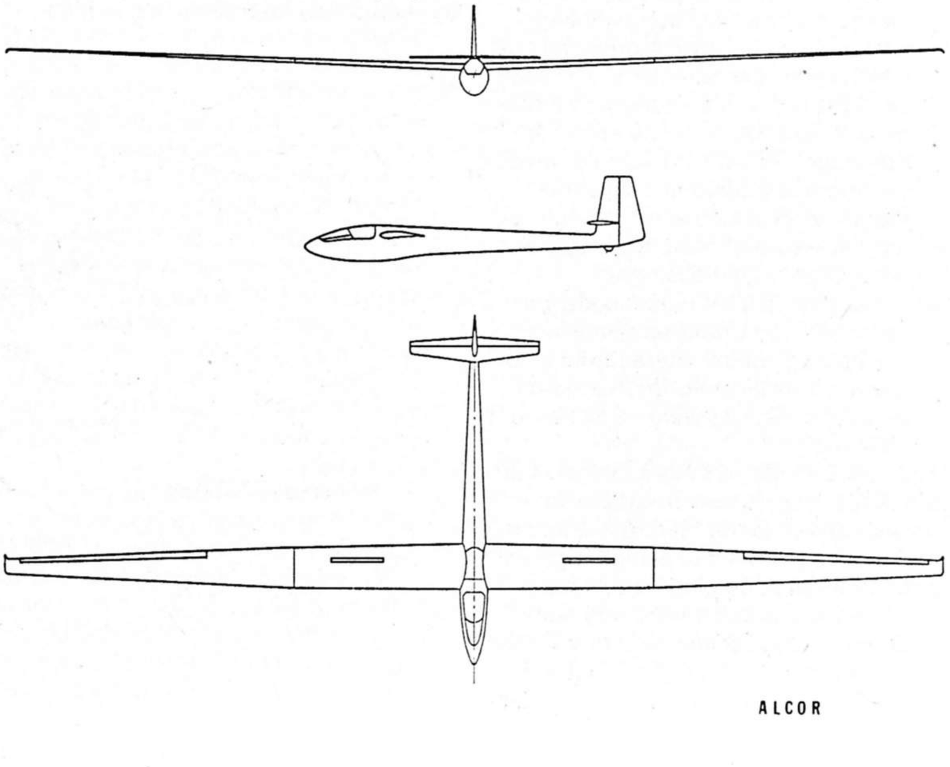
The average healthy pilot requires about 250–300 c.c. per minute of oxygen in the sea level environment. This is the amount of oxygen consumed by the body. This, however, requires a breathing rate of 10 to 12 cycles per minute with lung volume requirement of 8 to 10 liters per minute. This is a normal average requirement at rest and can increase three or four-fold under unusual flight stresses. The oxygen mask used in this instance serves as a plenum or partial rebreather bag and will enable an estimated pilot consumption of 8 liters per minute in normal flight manoeuvers while at altitude. The duration of this system with two full cycles of pressurization, zero leakage, and breathing equivalent leakage, is as follows:

	a Sea level	*a* 3 p.s.i.
Bottle Capacity	60 cu ft	300 cu ft
Cabin Pressure Cycles (*a* 12 cu ft/cycle)	2 cycles	–24 cu ft
Available oxygen for Breathing		276 cu ft

Breathing Consumption	Leak Consumption	System Duration
0.35 c.f.m. (8 l.p.m.)	0	$\frac{276}{0.35}=13.1$ h
0.35 c.f.m. (8 l.p.m.)	0.35 c.f.m.	$\frac{276}{0.70}=6.55$ h

The foregoing description of the cabin pressurization and oxygen system can be detailed more precisely only after certain flight tests have been accomplished. These results will be reported later.

Figure 3 gives a general quantitative measure of cabin partial oxygen versus altitude. This measure will vary from flight to flight because of time factors required to purge the cabin of the original nitrogen gas present at takeoff. In addition, body moisture and body gases, other than those exhaled, while minute, will be included in the mix of cabin air when at altitude. During the



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flight test of this system it is intended to investigate this subject quite thoroughly through repeated cabin air sampling so as to determine not only the mean condition but the extremes that might possibly occur under unusual flight conditions.

IX. Cockpit Heat Control

The solar heater, as intended for installation in Alcor, is a device built into the canopy plenum area, forward of the removable canopy section, an area that is unpressurized and vented to the tail section of the airplane. This area includes movable surfaces in a venetian-blind-like layout. This blind has a heat reflective material on one face and a heat absorbent material on the other. The pilot can manually adjust both surfaces to control the amount of direct radiation into the cockpit enclosure. The top inner surface of the nose fuselage structural section under the canopy plenum area is covered with a thin aluminum film as a radiant surface to direct heat into the cockpit area. Figure 6 shows a schematic of the solar heating system. It is intended that the low altitude, high temperature condition will be regulated by the conventional ventilation duct which of course will have to be closed before pressurization is committed at the higher levels.

X. Conclusion

The flight test program for this sailplane is in the initial stage. The sailplane is showing good performance and the handling characteristics are quite satisfactory. The flutter analysis is about complete. The cabin pressurization still has to be tested functionally followed by flight checkout. With only minor changes it is expected that this sailplane will soon be ready for extensive investigations in both low and high altitude flight regimes.