tainers into a concourse where passengers can take their baggage from the proper color-coded containers (Fig. 12).

Safety in Handling People

This concludes our analysis of passenger handling under normal conditions. A word about safety is appropriate here. The 747 has been carefully designed for easy and rapid passenger evacuation during emergency situations. In a typical passenger section holding 90 passengers, four double-size doors are available for exit; and no passengers are further than approximately 20 ft from a door. Practical tests have demonstrated the capability of deplaning a full passenger load in 90 sec. This fully meets Federal Aviation Administration requirements for emergency evacuation. Automatically inflatable slides are stowed in each door. A manual backup is provided for actuation by cabin attendants. The width of each slide allows two passengers to deplane simultaneously and permits an uninterrupted flow from all doors until evacuation is complete (Fig. 13).

Conclusion

Ever-increasing numbers of air travelers are crowding terminals. Passenger handling problems are rapidly growing more serious, and require not only the attention of airport and airline operators but also the best efforts of airplane designers and manufacturers. Designers of the 747 analyzed problems relating to passenger flow and found major bottlenecks involving baggage handling, passenger flow into and within the airplane, customs inspection, deplaning, and recovering baggage. As a result, the Model 747 airplane is designed to receive and discharge passengers with unparalleled speed and ease. The Boeing 747 demonstrates how an airplane manufacturer can make a significant contribution to better passenger handling through improved airplane design.

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A Logistics-Independent Oxygen System for Military Aircraft

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The requirement to provide a reliable source of breathing oxygen for aviators flying at high altitudes has traditionally been met by providing a sufficient amount of oxygen for each flight prior to takeoff. Storage and maintenance of quantities of high-pressure or cryogenic oxygen on board aircraft pose significant logistics and safety problems. Provision for the production, storage, and transportation of aircraft oxygen at combat air bases poses additional safety hazards and levies a significant cost in training and surveillance. TRW has developed a technique that extracts oxygen from atmospheric air at the time and place it is needed. This technique seems well-suited to aviation application in that the source of oxygen could be cabin air and the storage and transport of quantities of pressurized gas or cryogenic liquid would be avoided. The approach conceived at TRW is simple: only sources of air and electrical power are required to separate pure oxygen from the inert gases and impurities found in the air. The concept is based upon electrochemical technology and utilizes an electrochemical cell design that is lightweight, compact, and includes all the features necessary for operation independent of orientation or gravitational forces.

Introduction

The requirement to provide a reliable source of breathing oxygen for aviators flying at high altitudes or under adverse conditions has traditionally been met by providing a sufficient amount of oxygen for each flight prior to takeoff. The oxygen is stored on board as either a high-pressure gas or a cryogenic liquid. Of these two methods the cryogenic or LOX system has gained the widest acceptance, because it requires a lower weight and volume per unit quantity of stored oxygen.

Of the many reasons that have been cited for developing a new oxygen system, the major ones are 1) to eliminate the ground support facilities for generating, storing, and transporting the liquid oxygen†; 2) to eliminate between-flight servicing and the costs associated with training personnel to carry out such servicing; and 3) to provide for increased safety and comfort to the pilot and increased safety and versatility for the aircraft.‡

In summary, the reasons for developing a "next generation" oxygen system for aviators can be expressed as follows: to

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* Program Manager, Aviator Oxygen System Development.

† It takes more than ten men to operate a LOX generating plant on a 24-hr-a-day basis. Each man requires almost a year of special training at a cost to the Government of over $5000. The modern, transportable LOX generating plant costs over $300,000 with one plant needed per squadron. A critical problem that occurs in a Vietnam-type conflict is that one carefully placed bullet can completely put this ground support equipment out of business. The result is that an entire squadron of aircraft loses its source of aviator's breathing oxygen.

‡ As an illustration of the need for increased aircraft versatility, one can cite the recent challenge Hon. H. Brown gave to industry to help make our present and future-generation aircraft more versatile by working on those characteristics and equipment that will result in "...aircraft (that are) more reliable, economical, and effective."[2]

eliminate logistics and cost, and to provide increased safety, reliability, aircraft versatility, and pilot comfort.

Onboard O_2 Generation Eliminates Dependence on Ground Support

In 1963, as part of its corporate research activities, TRW developed an oxygen-generating technique that extracts oxygen directly from atmospheric air at the time and place it is needed. As a result of discussions with Air Force personnel,[1] it was determined that this technique might be well suited to the aviation application in that the source of oxygen could be cabin air and the storage and transport of quantities of pressurized gas or cryogenic liquid oxygen would be avoided.

The concept is based upon electrochemical technology and utilizes a unique TRW electrochemical cell design that is inherently lightweight, compact, and possesses the features necessary for operation aboard an aircraft, including operation that is independent of orientation or gravitational forces.

The approach is simple in that only a source of air and electrical power are required to obtain pure oxygen, separated from the inert gases and impurities found in air. The method by which pure oxygen is withdrawn can be illustrated with the aid of the simplified cell diagram shown in Fig. 1. The basic cell consists of two porous metal electrodes separated by an electrolyte solution of aqueous potassium hydroxide. The electrolyte is held in an absorbent porous matrix designed to prevent the solution from leaking through the porous electrodes and to serve as a gas-impermeable barrier between the air and the pure oxygen that is generated.

Air is passed into the gas compartment over one of the porous electrodes, called the cathode. When a d.c. power source is connected to the cell electrodes, electrons are caused to flow through the cathode. The oxygen molecules in the air react with these electrons and with water molecules from the electrolyte to form hydroxyl ions. The reaction that occurs at the cathode is given by

$$O_2\,(\text{Air}) + 2H_2O + 4e^- = 4OH^-$$

The hydroxyl ions migrate under the electromotive force provided by the power supply to the other porous electrode, termed the anode. At this electrode, the ions are discharged to again form the oxygen, water, and electrons, according to the reaction

$$4OH^- = O_2 + 2H_2O + 4e^-$$

The oxygen in the anode compartment is now separated from the other gases found in the air. These gases, in turn, pass out of the cell through an exhaust manifold. The water released at the anode returns to the electrolyte and the electrons travel through the external circuit back to the cathode, where they react with more oxygen. The process continues as long as air and power are provided to the electrochemical cell.

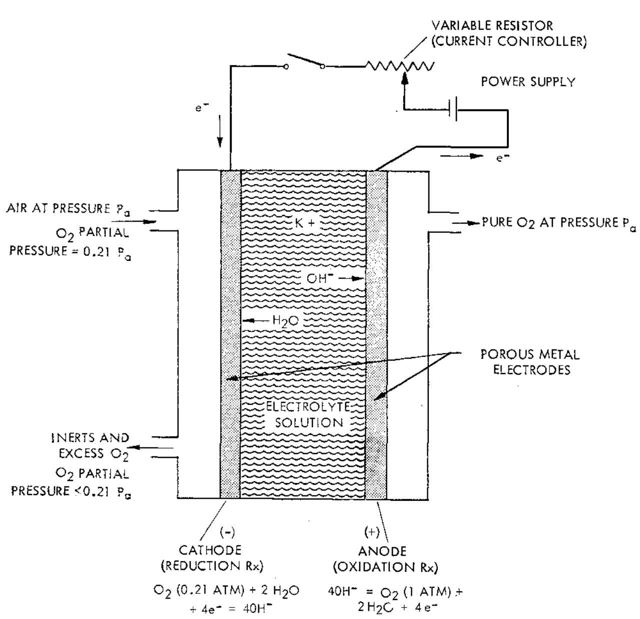

Fig. 1 Cell reactions and schematic of the TRW oxygen generator.

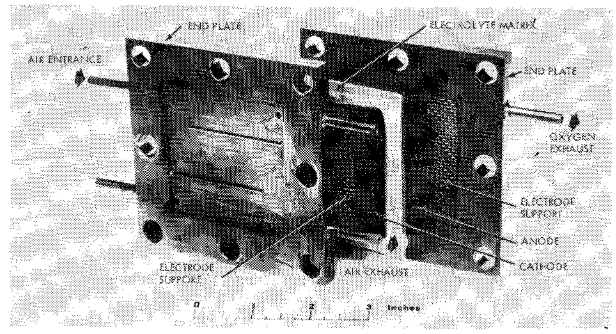

Fig. 2 Experimental single cell.

Air Force Participates with TRW to Develop Concept

TRW was sponsored by the Air Force Flight Dynamics Laboratory (AFFDL) director's discretionary fund to design, fabricate, test, and deliver an experimental model of this oxygen-generating technique.§ Prior to initiation of this program, TRW had operated a variety of experimental cells to demonstrate concept feasibility and had characterized cell performance. Figure 2 is a photograph of one such experimental cell. Under Air Force sponsorship, the concept was scaled into a 26-cell unit capable of generating 0.6 lb/hr of pure oxygen.[3] This capacity is sufficient to supply at least two men with 100% oxygen, if combined with a rebreather to remove CO_2 and H_2O from the exhaled gases. A photograph of the actual unit delivered is shown in Fig. 3.[4]

Onboard Generator and Rebreather Constitute a Complete System

Prior to describing the next-generation oxygen system, it is necessary to review certain aspects of the application, since

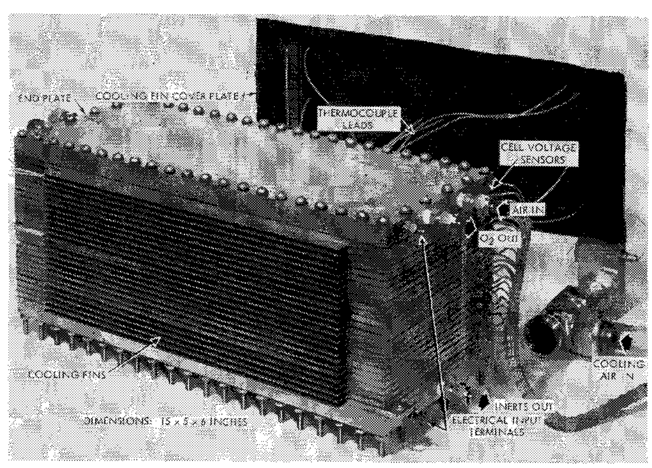

Fig. 3 26-cell oxygen generator.

§ Funding was obtained from the Director's Discretionary Funds, Flight Dynamics Laboratory, Col. G. Buck, Laboratory Director.

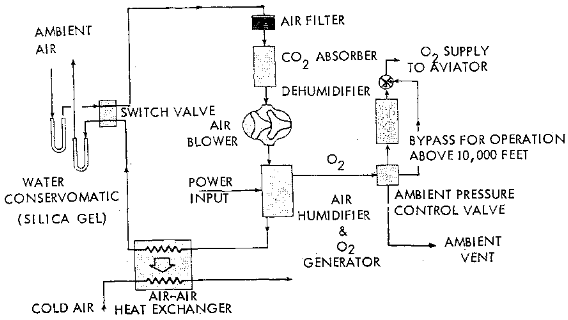

Fig. 4 Oxygen generator schematic.

designing an onboard oxygen system having the appropriate capacity involves tradeoffs different from those of the LOX system. Table 1 summarizes those aspects of the application upon which the capacity is dependent. Table 2 defines when oxygen is required and the type of equipment which must be used in terms of flight altitude.[5] Finally, these requirements must be expressed in terms of rate of oxygen supply or capacity.¶ The rate at which oxygen must be supplied per man under a variety of conditions is summarized in Table 3.

Typically, an aviator flying at or above 35,000 ft using a mask set to deliver 100% oxygen, requires slightly more than two normal liters of oxygen/min (NLPM) or about 5 normal ft³/hr (NCFH).[6] Using the onboard oxygen generator to provide this quantity of oxygen when the plane is flying at altitude, would require about 400 w of power without considering the power required by the system accessories. The largest rate required by the aviator, however, is when he is denitrogenating while at sea level. In this case, he has a requirement for an oxygen flow rate of 22 NLPM or 47 NCFH. This would require about 3.6 kw of power.

It is possible to decrease this power during sea-level operation by using a rebreather to conserve the oxygen generated. This modification to the system would decrease the oxygen requirements to those shown in the last column in Fig. 4. In

Table 1 Oxygen supply requirements

I) Number of crew members
II) Flight plan
    A) Type of aircraft
        1) Fighter
        2) Bombardment
        3) Transport
    B) Range of aircraft including
        1) Mid-air refueling
        2) Range extension by added fuel supply
    C) Percentage of mission for which maximum O_2 must be supplied
    D) Altitude profile
III) Ground operating time on 100% O_2
    A) 30 min: bombardment and jet transports
    B) 15 min: fighters
IV) Type of O_2 equipment specified
    A) Mask
    B) Flow regulator
    C) Pressure suit

¶ The term "capacity" applied to onboard oxygen system refers to oxygen-generation rate per unit time. The term "capacity" applied to the existing LOX or high-pressure system refers to the total inventory that must be put aboard prior to takeoff. This must be sufficient for the complete flight plus contingencies. With the onboard generating system, the capacity, if expressed as total quantity, is virtually infinite since oxygen continues to be generated as long as the aircraft flies or generates power. This means that flight plans can be made and changed without having to consider the quantity of oxygen that can be put aboard initially or the unused quantity that remains during an in-flight schedule change.

Table 2 Oxygen supply conditions[5]

Condition	Routine flight	Emergency for few minutes
Without O_2	10,000 ft	18,000 ft
With demand O_2	35,000 ft	43,000 ft
With pressure demand O_2	42,000 ft	50,000 ft
With pressure demand O_2 and pressure suit	50,000 ft indicated altitude or above	50,000 ft indicated altitude or above

this case, the generator only needs to generate sufficient oxygen to replace that which man consumes and that which is lost due to leakage from the system.

TRW's Complete Aircraft Oxygen Supply System

TRW has done extensive analysis to determine the system characteristics best suited to the design of a complete oxygen supply system. The general performance specifications are listed in Table 4, whereas the emergency conditions that were considered are shown in Table 5. The particular components that make up the onboard oxygen generating system, together

Table 3 Supply entire O_2 demands

	"100%" oxygen[6]		Pressure[6] suit	With rebreather
Cabin altitude, ft	≥35K	Sea level	Sea level	...
Mask, % O_2	100%	100%	100%	Make-up
Flow rate, 70°F, dry				
liter/min	2.3	13.1	22.2	0.57
ft³/hr	4.9	27.8	47.0	1.21
lb/hr	0.4	2.3	3.9	0.10
Power, kw				
Generator	0.4	2.1	3.6	0.1

with their functions, are summarized in Table 6. Figures 4 and 5 show the complete breathing-oxygen supply system that is obtained by combining the O_2-generator loop and the rebreather circuit. Figure 6 shows one of the O_2-generator models that has been designed to illustrate how the unit would be packaged for integration into an aircraft.

Comparison of Onboard Generating System with LOX System

Table 7 presents a comparison of the TRW-designed system with the conventional LOX system on the basis of features available in the systems. The new or next-generation system is preferred from all points considered, except one. However, when the complex ground support equipment necessary with the LOX system is included as part of the total LOX system, the onboard approach is again preferable.

Table 4 General specifications

Flight times: over 24 hr
Acceleration: to 12 *g* for 90 sec
Warm-up time: less than 1 min
Orientation: all degrees of rotation
Storage temperature: −65° to 165°F
Turn-around time: none required
Variable O_2 demands: automatic response to demands
Dry O_2: below 10,000 ft
Moist O_2: above 10,000 ft
Denitrogenate: ground level, automatic
O_2 delivery pressure: 70 psig

Table 5 Emergency conditions considered

Loss of air:	revert to electrolysis cell
Loss of power:	3-min storage capacity
Overload capacity:	3 times normal
Remote field landing:	no servicing

The present LOX system weighs 50 lb, including the 5 lb of heat exchanger tubing required to warm the liquid oxygen to the temperature necessary for human consumption and has a total capacity rating of 10 man-hr. It occupies an envelope of 1.3 ft^3 and provides oxygen having a purity of 99.5%. The TRW-designed unit based on existing technology and including the rebreather will, upon development, weight 45 lb, occupy less volume, and provide for an oxygen purity equal to, or better than, that available with the LOX system. The cryogenic system tends to condense impurities from the surrounding ambient into the liquid oxygen container.[7,8]

Questions Asked in the Process of Designing the System

In addition to many discussions with Air Force personnel, including those with aviation medicine backgrounds, TRW

Table 6 TRW aircraft O_2 system components

O_2 generator:	make-up O_2
Power conditioning:	28-v d.c. or 400-cycle a.c. into const current
Air humidifier:	condition feed air inside generator
Air blower (compressor):	feed air at pressure
Air filter:	remove solids
Air-air heat exchanger:	remove H_2O from exhaust "air"
CO_2 absorbent cartridge:	remove trace CO_2 ambient
Water conservomatic:	remove last trace H_2O exhaust air → feed air
Ambient pressure controlled O_2 dehumidifier:	dry or moisturized O_2

engineers have held technical meetings with oxygen system and aircraft environmental control system engineers of three different prime aircraft manufacturers. These discussions proved to be of considerable value in designing an onboard oxygen-generating approach that is practical from a field-hardware viewpoint. Aircraft such as the F-4, A-6, and F-111 were considered in defining the specifications necessary for an oxygen system that could be standardized for multiple aircraft.

During these meetings with Air Force and industrial personnel, several questions were invariably asked. These questions and answers are listed below.

1) What happens to the source of oxygen if the aircraft loses its electrical power? The concentrator design contains a reserve capacity of oxygen sufficient to supply the aviator with oxygen at the maximum rate (e.g., 0.4 lb/hr) for five

Table 7 Basis of comparison

Feature	TRW system	LOX
No ground support equipment required	X	
Generating		
Storage		
Transporting		
Safety	X	
In-flight explosion hazards		
Servicing hazards		
Crashworthiness		
Flight plan completion	X	
Time between servicing	X	
Pilot comfort	X	
Complexity		X
Highest-purity oxygen	X	

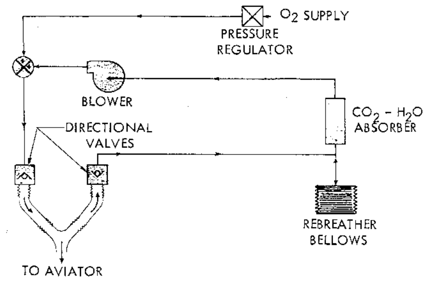

Fig. 5 Rebreather circuit.

times the length of time the pilot can remain in the aircraft after it has lost electrical power.

2) What happens if the aircraft loses its supply of cabin air? In this case, the unit reverts to a secondary or water electrolysis mode of operation and continues to deliver the oxygen.

3) What is the source of air to be used? Two sources of air have been proposed: ram air using a specially designed TRW Root's Compressor** to increase the air pressure to above 5 psia or engine-bleed air presently used to supply air to the pressure suits. The quantity of air required is less than 1 lb/min.

4) How do you prevent the valves from freezing if the oxygen contains water vapor? The system includes an accessory called the "ambient pressure controlled dehumidifier" that removes all the moisture from the oxygen being fed to the pilot during the time the aircraft is flying below 10,000 ft. This eliminates the water from the gas feed lines to prevent valves freezing shut during low-temperature storage conditions. Above 10,000 ft, the aviator is provided with moisturized oxygen to prevent throat and nose desiccation.

5) Will the system be able to withstand storage and startup under the temperature extremes of −65° to +165°F? The unit was designed to use an electrolyte that does not freeze at −65°F†† and has the capability of immediate

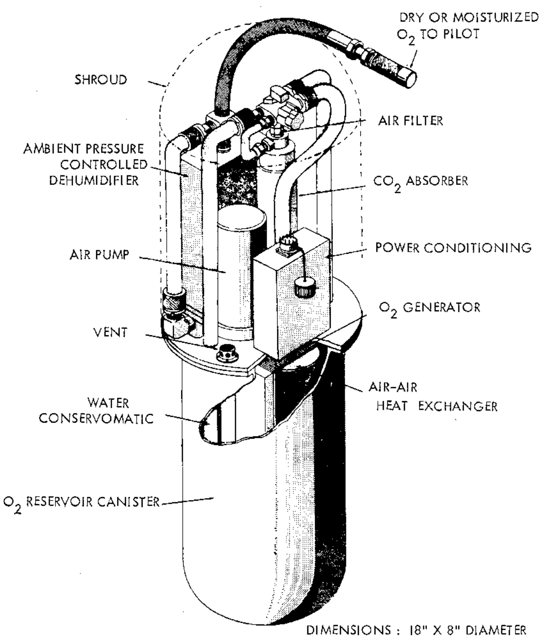

Fig. 6 Oxygen generator model.

** The particular TRW-Root's Compressor was specially designed to fit the present application by P. Cooper and R. Zoratti of the TRW Aircraft Accessories Division.

†† A private communication with D. Geiger, Project Engineer, Flight Dynamics Laboratory has verified that under actual test conditions the electrolyte does not freeze at −65°F.

Table 8 TRW corporate research objectives

Extend the technology
Reduce complexity, power, volume, and weight
Evaluate O_2 system-aircraft interface
Alternate applications: decrease development costs
Incorporate technology available in literature

startup at these low temperatures. The higher the operating temperature, the lower the power required to generate the oxygen.

6) At what temperature will the oxygen be delivered to the pilot? The oxygen will be delivered to the pilot within the comfort region and typically will fall within the range of 65° to 75°F.

7) What type of servicing will be required with the unit? Initially, the "first generation" design calls for the use of a nonregenerative rebreather that will have to be replaced after each flight. Then, when a regenerative rebreather is incorporated, no servicing will be required for over 1000 hr of flight time, and ultimately, no servicing for over 5000 hr.

What Action is Recommended?

The results to date have provided a clear indication of the merits in this method of onboard generation of oxygen. Although TRW's internal research program has carried the majority of the development efforts completed on the design and the concept, much additional work remains to be done to translate the prototype design into a piece of hardware that can undergo engineering evaluation and flight test. Major efforts include: 1) integrate the onboard oxygen generator and the rebreather into a complete package, 2) optimize the design to best match the oxygen system-aircraft interface as it exists in military aircraft, 3) design system accessories that are tailor-made for the application, and 4) continue the experimental efforts toward decreasing system complexity and increasing generator performance. This will result in further reduction in power, weight, and volume.

TRW Efforts Devoted to this "Next Generation" Oxygen System

TRW Equipment Laboratories has been responsible for the technology in four distinct areas: basic concept, system controls, system accessories, and the selection of optimum cell operating parameters. Work is continuing on the concept in the areas of basic studies, performance evaluations, and system analyses to eventually meet the objectives listed in Table 8. These efforts reflect themselves in the existing onboard oxygen-generating design, which is more than competitive with the existing systems. These efforts have allowed for a decrease in system weight, power, volume, and complexity until the point has been reached that prototype hardware can be built.

Conclusion

The presently used oxygen system for supplying aviators with breathing oxygen is costly to the government from both manpower and ground support equipment standpoints. A new approach to meeting the requirement for supplying oxygen to aviators has been conceived, tested, and designed to the point where flight hardware can be built. The cost savings possible in manpower and ground support equipment warrant translating the present designs to flight-qualified hardware.

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