



REGULATED EMERGENCY OXYGEN SYSTEM

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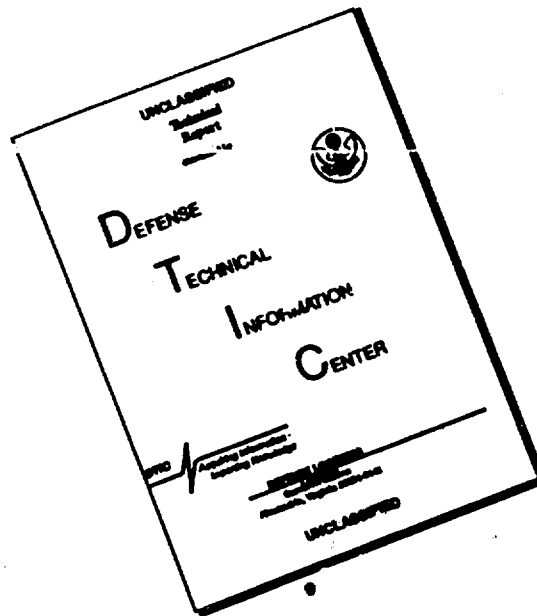


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This report has been reviewed and is approved for publication.



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13. ABSTRACT (Maximum 200 words) This paper describes the accomplishments of the Regulated Emergency Oxygen System (REOS) task. A true emergency secondary oxygen system is nonexistent in current aircraft. The current system is inadequate in regulating pressure, is ineffective at altitudes below 10,000 ft, and provides no option except to activate the emergency oxygen bottle if a malfunction of the primary regulator occurs. The REOS concept alleviates these inadequacies by providing an option to select a secondary regulated oxygen source, rather than the emergency bottle, if there is a malfunction of the primary regulator. Also of significance is that altitude protection has been incorporated into the REOS. The contents of this paper provide greater details as to the background, development, and testing of the REOS.				
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REGULATED EMERGENCY OXYGEN SYSTEM

A. INTRODUCTION

A study by Major Steven N. Ulosevich (Chief Life Support Division, Hickam AFB, HI) and Colonel John B. Bomar, Jr. (USAF School of Aerospace Medicine, Brooks AFB, TX) illustrated the need for an improved emergency oxygen system for USAF tactical aircraft. They found that "the current oxygen systems in U.S. tactical aircraft do not have sufficient flexibility to deal adequately with all high altitude emergencies, nor are they capable of providing true emergency oxygen supply at low altitudes when accompanied by malfunction of the main, aircraft-mounted oxygen regulator" (1). Based on these findings, they proposed a new Regulated Emergency Oxygen System (REOS) for USAF tactical aircraft which would provide the following: "a true mission completion, backup oxygen regulator for the existing regulator; good protection against hypoxia and smoke and fumes at all altitudes; compatibility with APPB (Assisted Positive Pressure Breathing) for G and high altitude protection; and compatibility with tactical aircrew chemical defense systems" (1).

The Crew Technology Division of Armstrong Laboratory (AL/CFT) (formerly part of the USAF School of Aerospace Medicine), Brooks AFB, TX, initiated Task Order No. 0003 of Contract No. F33615-89-C-0603, requiring KRUG Life Sciences to deliver a prototype Regulated Emergency Oxygen System (REOS) based on general design description and figures as conceived by Ulosevich and Bomar (1). This report gives details of the objectives, design, development, and testing accomplished in accordance with the Task Order.

B. TASK ORDER OBJECTIVES

The contractor shall deliver a prototype REOS based on the furnished general design description and figures. The contractor shall support all testing and evaluation of this system and make further modifications as defined during testing.

C. TASK ORDER DESCRIPTION OF WORK

1. The contractor shall develop the REOS based on the furnished general design proposal.

a. Use the existing Government Furnished Equipment (GFE) listed:

1. High Pressure Oxygen Cylinder
2. Reducer Control Valve
3. Modified CRU-79 breathing regulator
4. Quick Disconnect 0.75 in. low pressure
5. CSU-13B/P Anti-G Suit
6. CSU-17/P COMBAT EDGE Pressure Vest
7. Tactical Aircrew Eye/Respiratory System (TAERS) respirator
8. Miscellaneous low-pressure oxygen hoses
9. CRU-94/P Integrated terminal block
10. HGU-55/P Modified Helmet
11. MBU-20/P Mask

b. Purchase from a commercial vendor or design, fabricate, and/or modify the following equipment according to the furnished design proposal:

1. Integrated connector similar to the CRU-60/P
2. T-fitting in oxygen supply to CRU-73A
3. Emergency oxygen initiation mechanism
(valve between Reducer Control Valve and CRU-79)
4. Miscellaneous hoses, tubing sections, connectors
5. Modified CSU-13B/P Anti-G Suit
6. Modified chest counterpressure jerkin
7. Modified TAERS respirator

c. Integrate the equipment listed in a and b into a functional REOS according to the furnished design proposal.

2. The contractor shall construct the REOS suitable for laboratory test and evaluation, and deliver to the USAF. The REOS shall be delivered 12 months after ordering.
3. The contractor shall prepare detailed specifications of the REOS components as required to produce additional systems for flight test and include this with the final report.

D. TASK ORDER DESIGN DESCRIPTION

Figure 1 shows the REOS concept. The major difference between the current system and that shown in Figure 1 is that the emergency oxygen is supplied via a demand breathing regulator (CRU-79) mounted on the seat (1). There is a "T" in the main oxygen supply which creates a parallel oxygen supply via a self-sealing pull-off connector to the CRU-79 (2). This emergency oxygen regulator can be supplied from the main supply or the emergency oxygen cylinder. In the event of failure of the main diluter-demand regulator, the CRU-79 can serve as a backup regulator. If ejection from the aircraft were necessary, 100% oxygen at a properly regulated pressure would be supplied from the seat-mounted high-pressure cylinder. Since this system would supply all the breathing demand of the crew member, a larger high-pressure oxygen cylinder (50 cubic inch), already in the inventory, is proposed (3).

The outlet of the CRU-79 feeds a connector similar to the CRU-60/P, except the emergency oxygen inlet assembly will have a larger diameter bore (4). The connector also provides a port for connecting a chest counterpressure garment to be compatible with ensembles for assisted positive pressure breathing (APPB) (5). The detailed design specifications and drawings of the connector will be furnished by the government.

The emergency oxygen regulator cannot supply positive pressure breathing (PPB) as a function of G; however, it will provide high-altitude bailout protection to enable PPB with G garments to be worn to 60,000 ft (6). To provide 60,000-ft protection, the anti-G suit will contain a separate set of low-pressure, oxygen-compatible bladders (7). An interconnection between the jerkin and the low-pressure bladder system will be required so that when the jerkin inflates, the pressure is transmitted to the anti-G suit (if the high-pressure bladders are not inflated). Thus, the anti-G suit will be inflated to the same pressure as that in the jerkin bladders whenever there is no pressure from the anti-G valve, providing a one-to-one jerkin to anti-G suit pressure ratio during high-altitude pressure breathing (8).

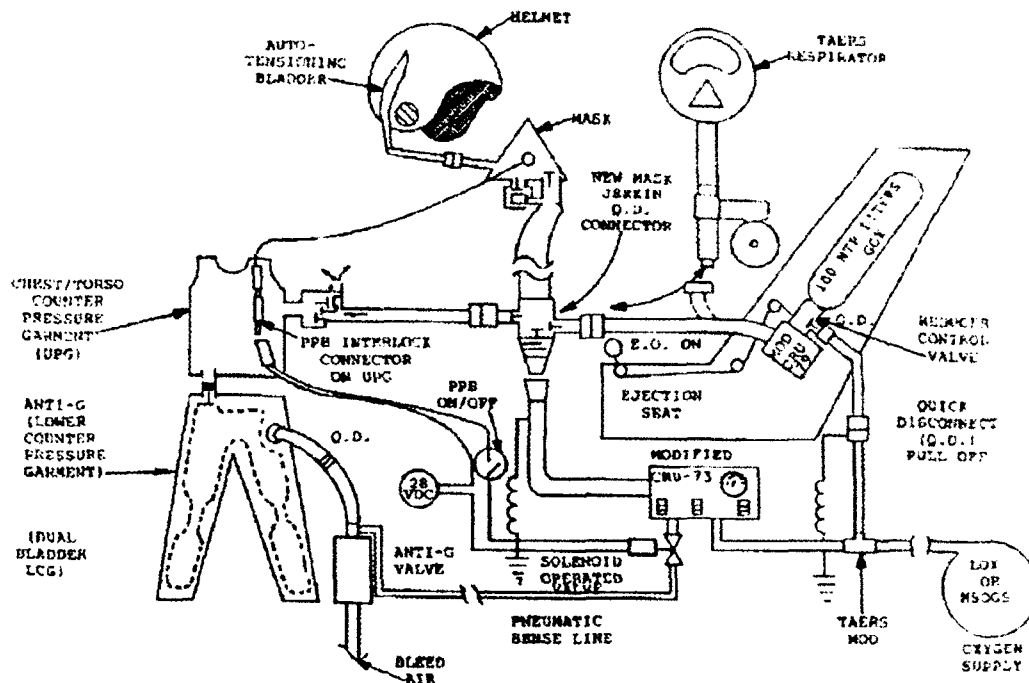


Figure 1. REOS Design as Conceived by Ulosevich and Bomar (1).

REOS will be compatible with the Tactical Aircrew Eye/Respiratory System (TAERS) with just a slight modification of simply removing the CRU-79 from the TAERS and placing it on the seat of the aircraft. A dressing filter/connector will be required to prevent contamination of the breathing gas when the TAERS is connected to the 100% supply (9).

Some material and equipment involved in this modification are as follows:

1. High-pressure Oxygen Cylinder, 50 cubic inch. (Integrate GFE cylinder into REOS design and manufacture brackets for seat mounting.)
2. Reducer Control Valve. (Integrate GFE valve into REOS.)
3. Modified CRU-79. (Integrate GFE regulator into REOS.)
4. T-fitting for CRU-73 supply tubing. (Design and fabricate.)
5. Modified CRU-60/P or replacement design. (Modify existing design, fabricate and integrate into REOS.)
6. Valve between CRU-79 and reducer control valve. (Design, fabricate, and integrate into REOS.)
7. Quick disconnect connectors. (Purchase commercially available connectors and integrate into REOS.)

8. Miscellaneous flexible hoses and hard tubing. (Purchase commercially available materials, fabricate, and integrate into REOS.)
9. Emergency Oxygen ON/OFF control. (Design, fabricate, and integrate into REOS.)
10. Modified CSU-13B/P anti-G suit. (Design modification and modify GFE anti-G suit.)
11. Modified chest counterpressure jerkin. (Design modification and modify GFE jerkin.)
12. Modified Tactical Aircrew Eye/Respiratory System (TAERS) respirator. (Design modification and modify GFE TAERS respirator.)

E. TASK ORDER PROGRAM SUMMARY

Before addressing the components of a new system, a description is required of the current emergency oxygen system and some of its inadequacies (Fig. 2). The emergency oxygen supply cylinder is a 22.5 cubic inch bottle which provides approximately 44 liters of 99.5% aviator's breathing oxygen (ABO) at 1800 psig. The cylinder is mounted on the left side of the ejection seat and can be manually activated by pulling a lanyard attached to a green ball or ring called a green apple. This activation mechanism shears the nipple in the bottle outlet which produces a continuous flow of oxygen which lasts for approximately 10-12 minutes. The oxygen flows through high-pressure oxygen tubing, to the emergency oxygen elbow on the CRU-60/P connector, then to the mask. The current emergency oxygen system inadequately regulates the pressure and flow of oxygen throughout its use. Because this is characteristic of the current emergency oxygen system, activation of the system produces an initial burst of continuous pressure. As time progresses, breathing becomes easier as the bottle is depleted. Although effective for one time use at or below 40,000 ft, this system wastes potentially available oxygen by

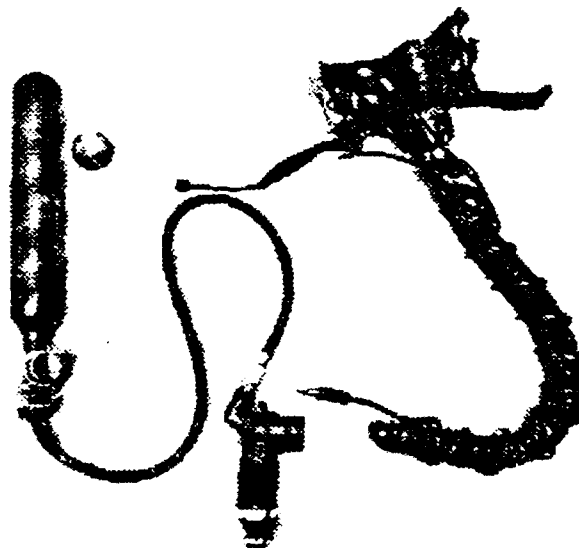


Figure 2. Emergency Oxygen Bail-Out System

flowing continuously throughout expiration. In addition, cockpit air is drawn in through the inward relief valve on the CRU-60/P once the user's breathing demand exceeds the flow from the bottle (2) (Fig. 3). Below 10,000 ft, as seen in Figure 3, the user's demand always exceeds the flow from the bottle. Therefore, the aviator's breathing oxygen is diluted with cockpit air at altitudes below 10,000 ft which compromises the performance of the system.

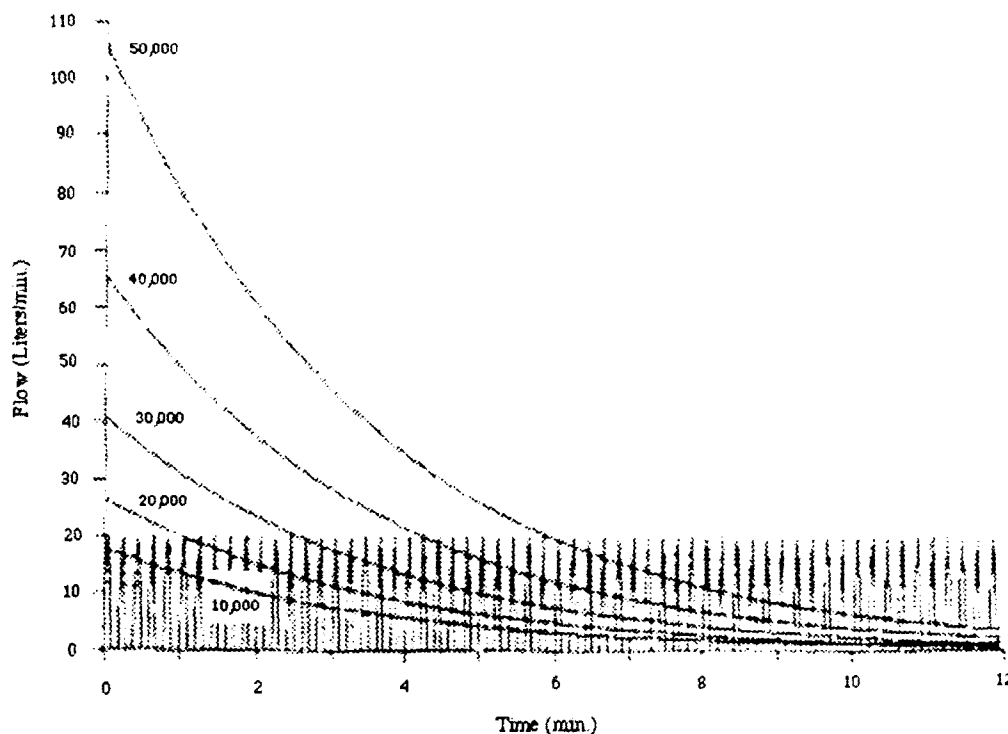


Figure 3. Volume Flow of Gas from a 22.5 Cubic Inch Bottle at Various Altitudes as a Function of Time. (Note the cyclic trace depicting the breathing demand.)

These and other inadequacies were addressed by Ulosevich and Bomar in their assessment of the current system: "although our present Emergency Bail-out Oxygen System is elegant in its simplicity and it functions adequately to meet its primary function during ejection or bail-out, it is not a true emergency oxygen system, nor does it provide a backup to the primary aircraft oxygen regulator. Moreover, its function and use are sometimes misunderstood by crew members" (1). Therefore, U.S. military aircraft and crews could benefit from a REOS which provides better altitude protection and an improved secondary oxygen flow as a function of altitude.

Based on the desire for greater protection at minimal expense, REOS was conceived as a system that features relative ease of modification and use of existing hardware, or hardware already under development, thus minimizing cost and complexity of retrofit (1). REOS was designed as a modular system that consists of four distinct stages. The initial stage provides the basis for a regulated emergency oxygen system. Additional stages provide enhanced protection by combining more components with broader capabilities. The modular design thus allows tactical aircraft to be fitted with only the appropriate components required for its mission. The expense of retrofitting aircraft will be limited to

the mission-essential components of a particular stage, rather than the expense of implementing the entire system into all aircraft.

F. TASK ORDER PROGRAM DETAILS

The following section describes the four REOS stages and their various components. A complete listing of part numbers and vendors is available in the Appendix.

I. Stage I

The first stage provides a larger, regulated emergency oxygen supply in place of the present continuous flow system. The components of Stage I are as follows: (Fig. 4)

- a. 50 cubic inch oxygen cylinder
- b. Cylinder mounting bracket
- c. ARO reducer control valve - PN 226-1760-1
- d. 1/2 inch low pressure oxygen hose with quick disconnect
- e. Modified ARO CRU-79 pressure demand regulator
- f. Modified CRU-60/P connector

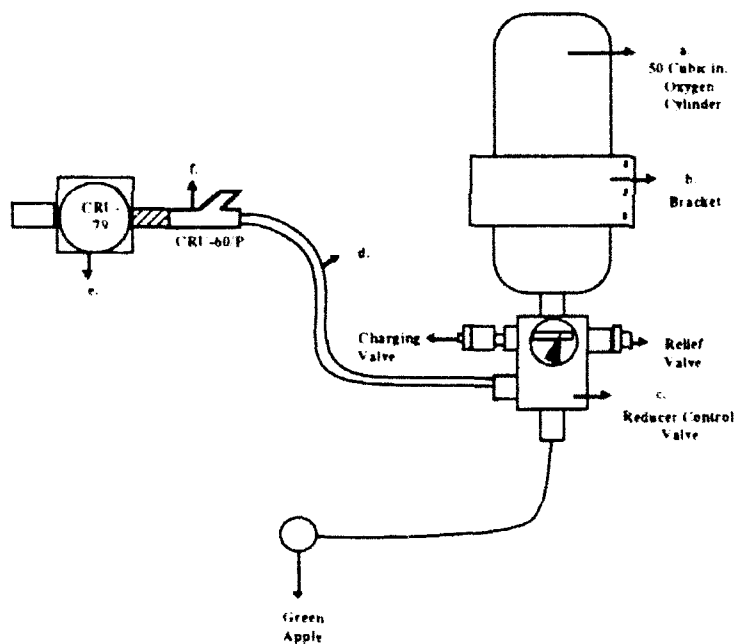


Figure 4. Components of Stage I

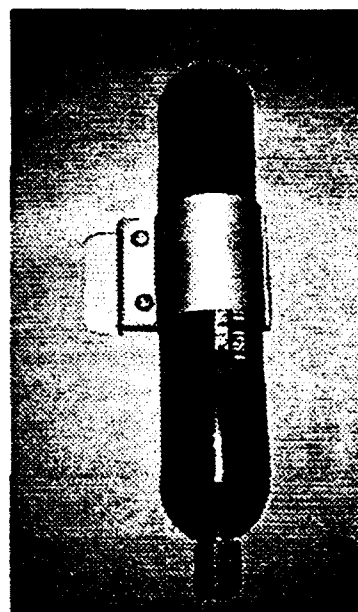


Figure 5. Cylinder Mounting Bracket

Pressurized to 1800 psig and if measured at sea level, the 50 cubic inch cylinder would contain 106 liters of oxygen as opposed to the 47 liters available from the 22.5 cubic inch cylinder currently in use. Thus, the available volume at sea level is increased by 125% when the larger cylinder is used. The larger cylinder would be mounted on the left side of the ejection seat, consistent with the current system except with a larger mounting bracket (Fig. 5). The increased capacity of this bottle alone provides the user with a greater amount of get-me-down protection than currently available. The next component is an ARO reducer control valve mounted on the cylinder outlet. The reducer houses the activation mechanism, a

cable lanyard connected to a green apple. When the cable is pulled, either by the green apple or automatically on ejection, it releases a piston which allows the contents of the bottle to flow. The ARO valve reduces the cylinder pressure from 1800 psig to approximately 70 +/- 10 psig. Once activated, the bottle will flow until emptied. To recharge the system, the cylinder and the reducer must both be removed from the aircraft. The reducer must have the piston mechanically reset, and the cylinder must be filled with 100% oxygen. The 70 +/- 10 psi outlet pressure from the reducer then flows through a 1/2-inch diameter low-pressure oxygen hose which travels along the back of the seat pad on the ejection seat (same hose, path, and quick disconnect as the current system) to the CRU-79. Made by the ARO Corporation, the CRU-79 is a pressure demand regulator for use up to 60,000 ft. The pressure schedule shown in Table 1 shows the outlet pressure provided by the CRU-79 at corresponding altitudes.

Table 1. CRU-79 Outlet Pressure Schedule

CRU-79 DATA

(Test conditions being chamber temperature = 77 +/- 2 degrees,
flow @ 100 LPM with inlet pressure at 80 psig)

ALTITUDE (x 1000 ft)	OUTLET PRESSURE (mm Hg)	
	Regulator 001	Regulator 002
0	3	2
10	2	2
34	2	2
35	2	2
40	4	6
45	32	36
50	60	60
55	70	71
60	70	71

Engineer: Budd
Technician: Washington
Date: 2/19/88

The CRU-79 only delivers oxygen on demand (when the user takes a breath), rather than supplying a wasteful continuous flow. The CRU-79 outlet is coupled with a female quick disconnect via a short segment of oxygen hose. This quick disconnect attaches to the modified emergency oxygen assembly on the CRU-60/P (Fig. 6).

Due to a significant impedance to flow (data available in the Results section), the emergency oxygen elbow assembly was removed and the housing of the CRU-60/P was machined for a snug fit to a RHIMCO three-prong connector. Hysol two compound, a fast setting epoxy, was used to bond the three-prong connector to the CRU-60/P. A Sierra CRU-8/P was attached to the three-prong bayonet connector. To minimize the restriction in movement of the right arm, caused by the modified CRU-60/P, the dovetail assembly used in mounting the CRU-60/P to the pilot's harness was replaced with the dovetail assembly of the CRU-8/P. Figure 7 shows the modified CRU-60/P with the CRU-8/P attached. The male quick disconnect end of the CRU-8/P is the new emergency oxygen port, which has a significantly increased

inner diameter to allow for greater flow. Flow data of the modified emergency oxygen port are available in the Results section. The CRU-8/P male disconnect then couples with the female disconnect on the CRU-79 (Fig. 8). The CRU-60/P, CRU-79 configuration is a man-mounted regulator, rather than seat mounted. A man-mounted CRU-79 allows ease of mounting and maintenance versus a permanent bracket attachment and ejection seat modification. This combination of Stage I components, consisting of a larger capacity bottle, a reducer control valve, a pressure demand regulator, and a modified CRU-60/P connector provides a larger, lower breathing resistance, altitude regulated emergency oxygen system.

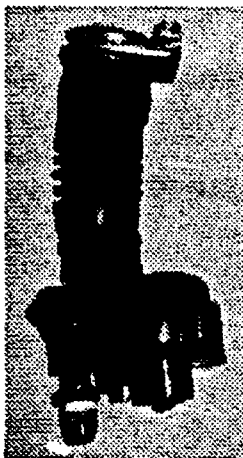


Figure 6. CRU-79 Quick Disconnect Modification



Figure 7. CRU-60/P Modified with CRU-8/P and Three-Prong Bayonet Connector

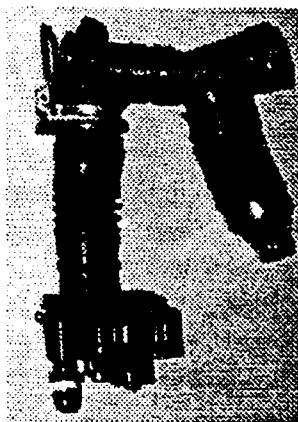


Figure 8. CRU-79 Connected to CRU-60/P

2. Stage II

The components of Stage II are as follows: (Fig. 9)

- a. MBU-20/P COMBAT EDGE Mask
- b. HGU-55/P Modified COMBAT EDGE Helmet (not shown)

- c. Modified CRU-94/P Integrated Terminal Block
- d. Modified CSU-13B/P Modified Dual Bladder G-suit
- e. Modified CSU-17/P COMBAT EDGE Pressure Vest
- f. Vest to G-suit quick disconnect interconnection

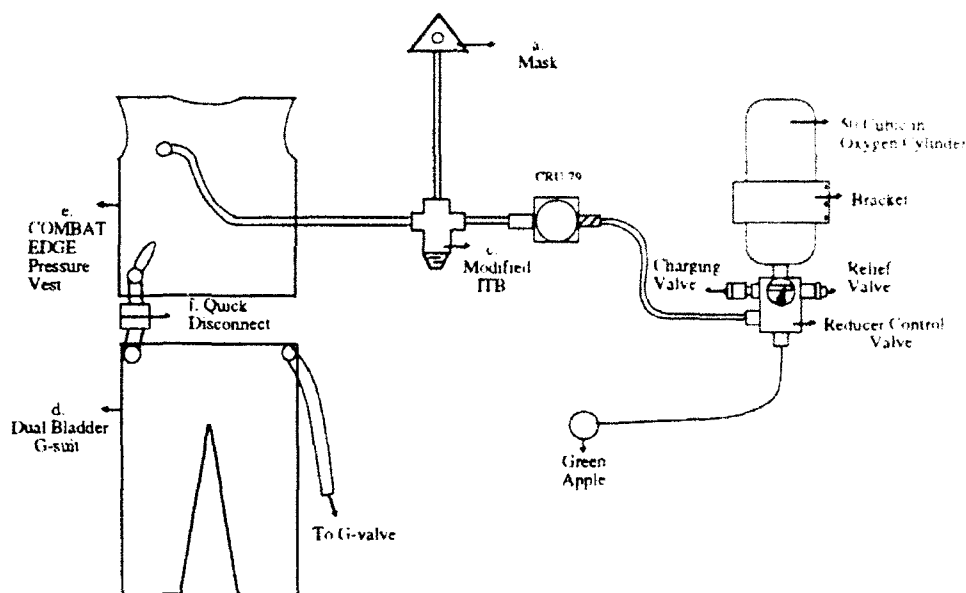


Figure 9. Components of Stage II

Stage II, when combined with Stage I, will extend bailout protection from 47,000 ft to 60,000 ft with use of the Combined Advanced Technology Enhanced Design "G" Ensemble (COMBAT EDGE) pressure vest assembly, a dual-bladder G-suit, and a COMBAT EDGE mask and helmet.

A new connector, the CRU-94/P, must be used in place of the CRU-60/P since it has an additional port for the COMBAT EDGE vest to plug into (Fig. 10). The same CRU-60/P modification of the emergency oxygen elbow assembly was done to the CRU-94/P. The elbow assembly was removed, the port hole machined, then fitted with a three-prong connector, bonded with epoxy, and connected to a CRU-8/P. The CRU-94/P dovetail assembly was also removed to prevent restriction of the right arm.



Figure 10. CRU-94/P Modified with CRU-8/P and Three-Prong Bayonet Connector

The COMBAT EDGE pressure vest was modified to be connected to the G-suit by implanting a rubber spout into the lower right portion of the bladder, sealing it with adhesive, and then coupling it with a female quick disconnect. The modification is shown in Figure 11. A standard medium CSU-13B/P G-suit was also modified as a compatible counterpressure garment. A second set of standard G-suit bladders was added underneath the original G-bladders. The second set is low-pressure, oxygen-compatible, and will be referred to as altitude bladders. The altitude bladders are one size smaller than the G-suit bladders to avoid excess bulk. When the G-suit is donned, the G-bladders are the closest to the skin, and the altitude bladders are on the outside. In this configuration, the altitude bladders will not serve as excess material between the subject and G bladders. A rubber spout was added to the lower right portion of the altitude abdominal bladder, sealed with adhesive, then coupled with the male portion of a quick disconnect (Fig. 12).

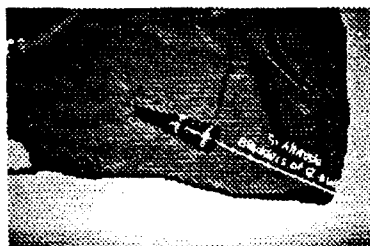


Figure 11. Modified Vest with Quick Disconnect

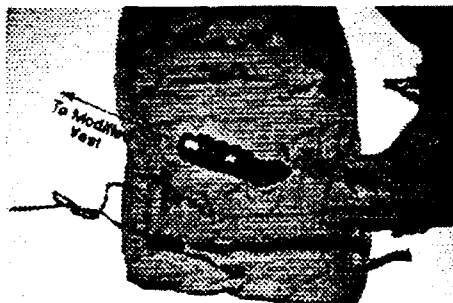


Figure 12. Modified G-suit with Quick Disconnect

The interconnection of the vest and altitude G-suit bladders allows the pressure in the vest to be transmitted to the G-suit, producing a one-to-one vest to G-suit pressure ratio during high-altitude pressure breathing. The two garments are shown connected in Figure 13. (Note: A similar spout and quick disconnect were added to the lower left calf altitude bladder for testing purposes only.)

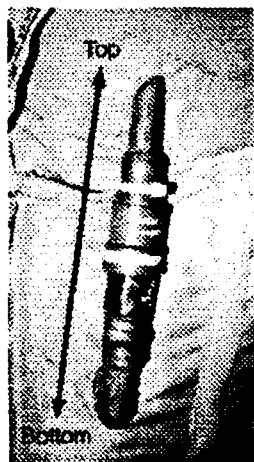


Figure 13. Modified Vest to Modified G-suit Interconnection

Although the CRU-79 regulator cannot supply positive pressure breathing for G (PBG), it will provide positive pressure breathing for altitude (PBA) such that altitude protective garments may be utilized to 60,000 ft. Due to the high breathing pressures required for PBA at 60,000 ft, the COMBAT EDGE mask and helmet will also be used as protective equipment. The auto tensioning nape bladder in the helmet has a feed tube from the mask hose which provides pressure to keep a tight mask seal while breathing at high pressures. Due to the improved seal interface between the mask and face, oxygen loss is minimized thus prolonging the time that the pilot can remain at altitude, which could be advantageous for mission completion. Therefore, in the event of rapid decompression at 60,000 ft and the failure of the primary aircraft regulator, the pilot can select from either the onboard oxygen supply or the emergency bottle sources to provide for breathing and altitude protection via the vest, leg, and nape bladders.

To determine if a 50 cubic inch bottle, pressurized to 1800 psig, adequately provides for protection during emergency descent and/or bailout from 60,000 ft, the findings of a RAF IAM report was used as a baseline from which claims are made (Table 2).

Table 2. Quantity of Oxygen Required to Inflate Pressure Waistcoat and G-Trousers at 60,000 ft and to Meet Pulmonary Ventilation and Mask Leak During 1 minute at 60,000 ft and Subsequent Descent to 40,000 ft at 10,000 ft/min (RAF IAM Aircrew Equipment Report No. 541)

	ITEM	ASSUMPTION	QUANTITY GAS OXYGEN (L)
1.	Inflate pressure waistcoat at 60,000 ft	Inflated to 70 mm Hg gauge Capacity of garment = 15 Liter at 70 mm Hg	2.5
2.	Inflate G trousers at 60,000 ft	Inflated to 335 mm Hg gauge Capacity of G trousers = 10 liter at 260 mm Hg gauge	4.5
3.	Respiratory demand	40 liter (BTPS) /min for 1 minute at 60,000 ft and for descent to 40,000 ft at 10,000 ft/min	12.6
4.	Mask leakage	15 liter/min (at a mean pressure of 136 mm Hg abs) for 3 min	8.1
5.	Total		27.7

The European system uses 27.7 liters of 100% oxygen to inflate the pressure waistcoat and G-trousers at 60,000 ft, to meet pulmonary ventilation and mask leak during 1 minute at 60,000 ft, and subsequent descent to 40,000 ft at 10,000 ft/min (5). Assuming the values for the respiratory demand and mask leakage would be the same for the REOS evaluation, the capacities of the jerkin, nape, and altitude bladders were addressed. The capacities of the jerkin and altitude bladders were calculated at ground

level and were found to be 8 and 8.1 liters at 100 mmHg gauge respectively. Note that the capacities of the REOS jerkin and altitude bladders are smaller than their European counterparts. It is justifiable then to state that the REOS system of bladders requires less gas in order to maintain the desired pressurization. Furthermore, note that the British G trousers are inflated to almost five times the pressure in the altitude bladders of the REOS G-suit (335 mmHg vs. 70 mmHg). If an isochoric and isothermal process is assumed, an increase in pressure yields an increase in the density of a gas. Noting this relationship and the fact that the British G trousers are pressurized at nearly five times above that of the smaller REOS altitude bladders, the British G trousers require a larger quantity of gas. The additional oxygen required by the British ensemble to descend from 40,000 ft is shown in Table 3.

Table 3. Quantity of Gaseous Oxygen Required for Descent to 10,000 ft
(RAF IAM Aircrew Equipment Report No. 541)

Aircraft Descent Rate Below 40,000 ft (ft/min)	Quantity Oxygen Required For Descent to 10,000 ft (L)
3,000	111
5,000	66
10,000	33

The European system requires an additional 33 liters of oxygen to descend from 40,000 ft to 10,000 ft at a rate of 10,000 ft/min. A more cautious and realistic emergency descent rate of 5,000 ft/min requires 66 liters (5). Descent with the European system requires a total of 93.7 liters of emergency oxygen to provide adequate protection from 60,000 ft to 10,000 ft. at a descent rate of 5,000 ft/min below 40,000 ft. If using REOS, the requirement would be less than 93.7 liters, thus proving the 106 liter capacity of the 50 cubic inch oxygen cylinder would be adequate to protect the user on emergency descent from 60,000 ft to 10,000 ft at a similar rate of 5,000 ft/min below 40,000 ft. Assuming that the same garments are used in the descent and ejection studies, the quantity of oxygen consumed on ejection is given in Table 4.

Table 4. Quantity of Oxygen Consumed on Ejection at 55,000 ft and Subsequent Descent in the
Seat to 10,000 ft (RAF IAM Aircrew Equipment Report No. 541)

Phase	Quantity of Oxygen (L)
Inflation of pressure waistcoat and G trousers	6.9
Respiratory demand and mask leak while descending to 40,000 ft	7.0
Respiratory demand during descent from 40,000 ft to 10,000 ft:	
40,000 ft to 20,000 ft	15.3
20,000 ft to 10,000 ft	19.9
Total	49.1

The European system requires 49.1 liters of 100% emergency oxygen for ejection at 55,000 ft and subsequent descent (5). Note that although the study is for ejection at 55,000 ft instead of 60,000 ft, the required amount is 44% of the volume obtainable at ground level (112 liters). It can then be inferred that the additional 5,000 ft is still well within the quantity that can be provided by the 50 cubic inch bottle.

According to the chapter on Oxygen Equipment and Pressure Clothing by Dr. Richard M. Harding in Aviation Medicine, "if the absolute pressure within the lungs is maintained at 141 mmHg, the mask/partial pressure jerkin/G-trouser combination will provide adequate protection to a maximum altitude of 54,000 ft" (4). However, he also acknowledges that a certain amount of hypoxia is acceptable, and advocates a breathing pressure of 68-72 mmHg at 60,000 ft, thus providing an absolute lung pressure of 122-126 mmHg. The output pressure of the CRU-79 will be addressed in the Results section. In addition, Dr. Harding prescribes a descent at a rate of at least 10,000 ft/min to 40,000 ft within 60 seconds of having decompression at 60,000 ft for protection against hypoxia. Since USAF equipment does not yet provide the more extensive altitude protection, a 30-second time limit to initiate immediate descent is more the norm.

The basis of Stage II is the use of protective garments to extend bailout protection from 47,000 ft to 60,000 ft. This is accomplished by combining the modified COMBAT EDGE mask, helmet and vest with the modified CRU-94/P connector and the modified dual bladder G-suit. Stages I and II together provide the fundamentals of the REOS program. The following stages increase system capabilities and add an additional oxygen pathway.

3. Stage III

The only additional component in Stage III is:

- a. Reducer Control Valve with On/Off Toggle (Fig. 14).

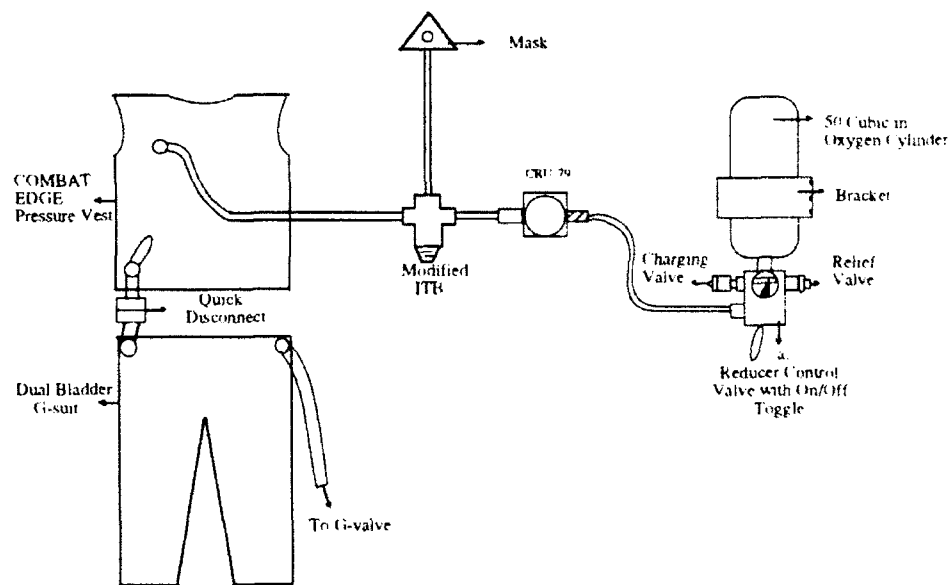


Figure 14. Components of Stage III

The third stage involves the replacement of the ARO reducer control valve with a reducer made by ESSEX Industries that has an On/Off capability. With this capability, two benefits are readily recognized. The first being that the emergency oxygen cylinder becomes reselectable in flight, thus increasing the possibility for mission completion (e.g., the cause for switching to emergency oxygen may have been remedied); and secondly, the on-off feature allows the bottle to be charged within the confines of the aircraft thus reducing the servicing time. The bottle is activated by selecting the toggle during any emergency situation such as an oxygen system failure or smoke and fumes in the cockpit. When the situation is remedied, the toggle may be turned off to preserve the remaining oxygen. However, once the bottle is activated/selected, the mission should be scrubbed because the pilot has already tapped into his guaranteed backup supply. The On/Off selector also allows the bottle to be recharged in the aircraft. A gauge on the reducer displays the amount of oxygen contained in the cylinder. The maintenance turnaround time for cylinder recharging is significantly reduced by not having to remove the cylinder to recharge, reseal a nipple, or reset a piston. The reducer outlet pressure is 65 +/- 10 psig for a flow rate of 125 LPM. The automatic activation on ejection is accomplished with a lanyard from the reducer to the aircraft floor. As the seat begins to leave the aircraft, the lanyard is pulled taut and automatically activates flow from the bottle.

ESSEX Industries has provided two options for combining an On/Off toggle switch with a reducer control valve. Option 1 consists of a small On/Off valve attached to the reducer control valve (1531180100-1) by a mounting bracket (Fig. 15). The toggle switch is a locking lever which will remain in position, resisting shock and vibration. The On/Off valve would best be incorporated on the left side of the reducer so that the toggle and flow outlet are closer to the pilot. The On/Off selector is connected by a lanyard with a disconnect assembly, to the aircraft bulkhead to enable automatic activation of the valve upon ejection. Option 2 includes the same reducer with a larger On/Off valve with a pin-type toggle. It is also mounted to the reducer by a bracket (Fig. 16). The larger size and overall dimensions

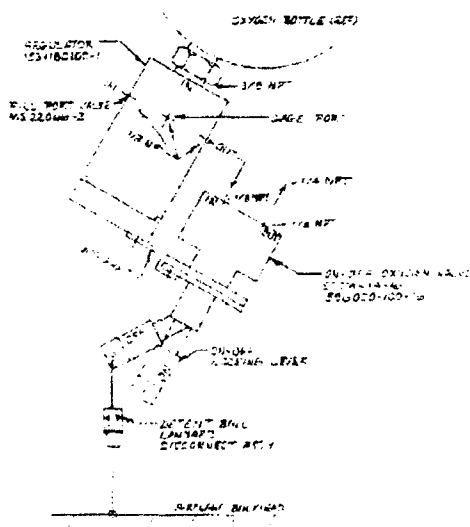


Figure 15. Essex Reducer Control Valve
(Option 1)

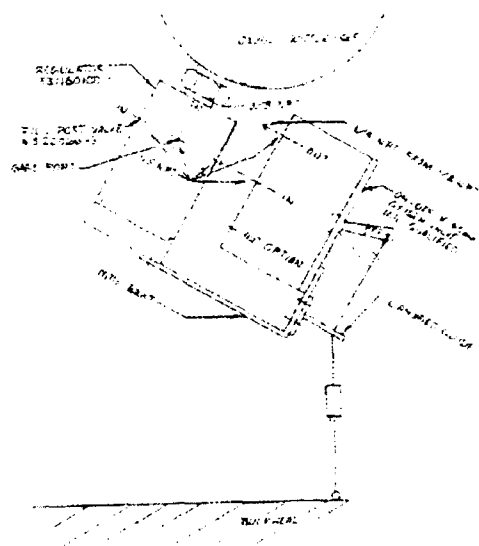


Figure 16. Essex Reducer Control Valve
(Option 2)

of Option 2 are less desirable, but no less functional. The On/Off valve should be switched to the left side of the reducer for easier access, although the small size of the toggle switch may be difficult to

activate in an emergency situation. Option 2 hardware has been provided based on its immediate availability. The lanyard with disconnect assembly is also available on Option 2. Both of these options are rough engineering models only. The delivered lanyard is much heavier than desired, but provided for visual aid. All of the valves included in the drawings are military listed items. Although both options perform fairly equally, Option 1 is preferred due to the size, shape and location of the On/Off valve and toggle. The hardware for Option 1 was not immediately available to meet the contractual deadline, but is the desirable combination. Ultimately, the two portions of either option would be combined into a single piece for production. (Time constraints prohibited this from being an option during the contract.)

An additional asset of the On/Off reducer would be a significant decrease in maintenance turnaround time for cylinder recharging. The On/Off capability could have been included in Stage I, rather than standing alone in Stage III; however, the intention of a modular system is to keep each phase as cost effective and simple to retrofit as possible. Therefore, Stage I can operate effectively without the On/Off selector, but could be significantly enhanced with its addition.

4. Stage IV

The components of Stage IV are as follows: (Fig. 17)

- a. Collins Systems 3 position, 3-way selector valve
- b. 1/4 inch T-fitting
- c. Swagelok quick disconnect
- d. Tactical Aircrew Eye/Respiratory System (TAERS)
- e. Aluminum alloy tubing

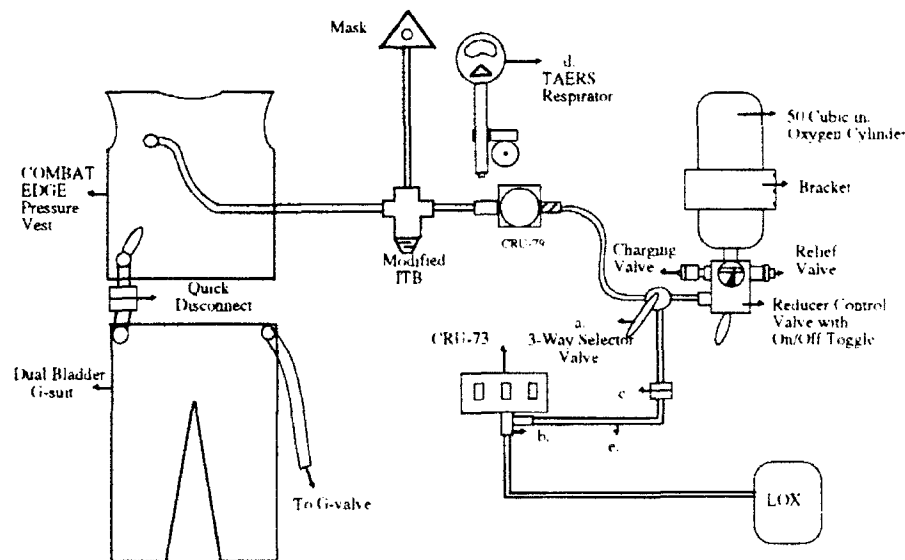


Figure 17. Components of Stage IV

The fourth stage completes the regulated emergency oxygen system. The addition of this stage provides a backup oxygen regulator, a choice between two oxygen sources, and the use of chemical defense equipment. The key to this stage is a three-way selector valve (Fig. 18).

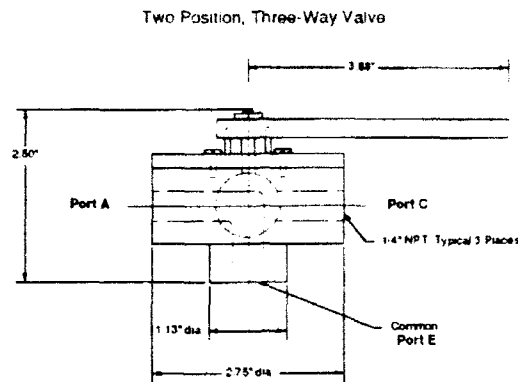


Figure 18. Provisional Three-Way Selector Valve Schematic

Manufactured by Collins Systems, the provisional three-way selector valve was machined from a five-way 1/4 inch selector valve. The output is on the bottom (E), and the two side ports are 180 degrees apart (A and C). Special reinforced back seals will tolerate 100 psi for shutoff of the port not selected. A no-flow condition will exist when the handle is perpendicular to ports A and C (90 degrees from either of the stops). The emergency oxygen cylinder or the LOX may be selected by pushing or pulling the handle until contact is made with the stops. The handle may be configured with an eyelet for attaching a lanyard mounted to the aircraft frame. With proper orientation and plumbing of the valve, the emergency oxygen port would automatically be selected upon ejection as the seat begins to move up the rails causing the lanyard to become taut. Then the lanyard must breakaway, or disconnect. Since the three-way valve is used to select between the LOX and emergency oxygen bottle, there is no need for the on/off reducer control valve. A simpler form of the reducer control valve with recharging capability, a quantity gauge, and a relief port is all that would be necessary in Stage IV. The On/Off reducer valve would be a redundant feature which is an unnecessary additional cost.

The three-way selector valve is located between the reducer control valve and the CRU-79 regulator. In order to provide LOX to the three-way valve, an additional pathway was needed. A 1/4 inch AN-fitting, in the shape of a T, placed at the inlet of the CRU-73 diluter demand regulator allows aluminum alloy tubing to make an additional pathway from the LOX source to the selector valve. A Swagelok self-sealing quick disconnect in the tubing will allow separation during ejection. The addition of a three-way valve and the parallel oxygen supply from the LOX enables the CRU-79 to serve as a backup regulator. If the main aircraft regulator has failed, the LOX may be accessed by selection on the three-way valve. The CRU-79 would be used in place of the main regulator. This capability allows for mission completion by avoiding a return to base (RTB) for a failed regulator. In addition, the emergency oxygen cylinder is still available for use should another emergency situation arise.

Chemical defense equipment may also be used with the implementation of Stage IV. The Tactical Aircrew Eye/Respiratory System (TAERS) is more compatible with REOS than with the current main oxygen system. The standard TAERS is normally plugged into a modified oxygen port that must be added to the CRU-73 panel-mounted regulator. The REOS TAERS is modified by replacing the CRU-79 with a male low pressure quick disconnect which is then connected directly into the modified CRU-79 female quick disconnect (Fig. 19). This configuration allows the user access to either the LOX backup pathway, or the emergency oxygen cylinder. Incidentally, the Protective Integrated Hood Mask System (PIHMS) could also be plugged directly into REOS, without modifications.

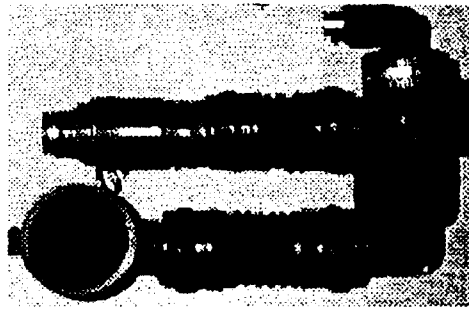


Figure 19. Tactical Aircrew Eye/Respiratory System (TAERS)

With the complete assembly of all four stages (Fig. 20), REOS provides the following capabilities:

- (1) An emergency oxygen supply at low altitudes in the event of a malfunction of the main, aircraft-mounted regulator.
- (2) Good protection against hypoxia and smoke and fumes at all altitudes.
- (3) Compatibility with APPB for G, high altitude protection, and tactical aircrew chemical defense systems.

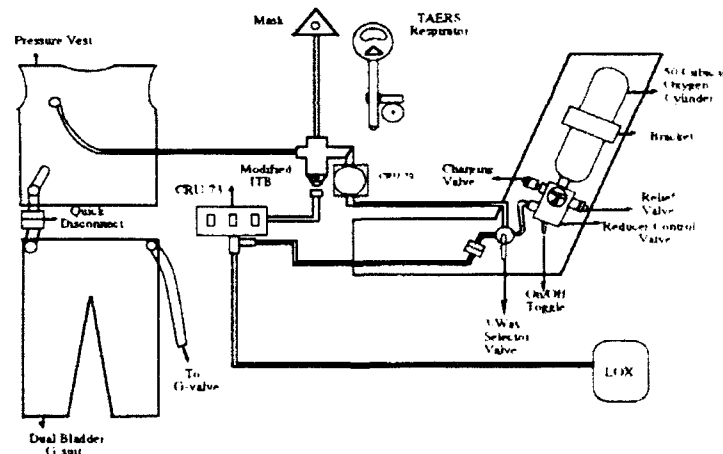


Figure 20. REOS Seat Diagram

G. TESTING

Unmanned system verification of REOS was performed at simulated altitudes up to 60,000 ft to assure system reliability, integrity, and function. REOS components were installed in hypobaric chamber number eight, located in building 160 at Brooks AFB, TX. Validyne variable reluctance differential pressure transducers were used to monitor pressures in the mask, vest, regulator and G-suit, and a flow meter was used to monitor the regulator outlet flow. Testing was performed with the Variable Profile Breathing Simulator (VPBS) which consists of a brass mannequin head, on which the mask and helmet are mounted, and a computer-controlled stainless steel bellows to simulate human breathing patterns. Use of the VPBS allows respiratory demands to be closely replicated and comparisons can be made

concerning the effect of various components on the overall impedance or effectiveness of a particular breathing system. A Styrofoam-based full-body mannequin was clothed in the counterpressure garments (vest and G-suit) and placed adjacent to the VPBS. The REOS components were tested across the full range of VPBS modes at various altitudes and rapid decompressions (Table 5). Testing was performed in the following areas:

- (1) CRU-79 output
- (2) Vest and G-suit Inflation Pressures
- (3) Vest and Altitude Suit Bladder Volumes
- (4) CRU-60/P emergency oxygen elbow assembly flow impedance
- (5) Modified CRU-60/P, CRU-94/P performance

Table 5. Variable Profile Breathing System (VPBS) Settings

#	Profile Setting	Breaths Per Minute	Peak Altitude	Amplitude	Style
1	4	8	17	5.0	Light
2	6	40	126	11.9	
3	6	20	94	8.6	Moderate
4	5	25	157	5.2	
5	5	24	188	6.4	
6	5	50	200	7.5	Heavy

H. RESULTS

1. The original output data of the CRU-79 regulator was provided by the manufacturer, the ARO Corporation (Table 6). Regulators 001 and 002 were tested to compare mask pressure readings with the manufacturer's data. The mask pressure measurement represents the output of the CRU-79 plus any pressure drop due to system impedance. Ideally, REOS mask pressure readings will be comparable to the manufacturer's data, indicating that system impedance is minimal.

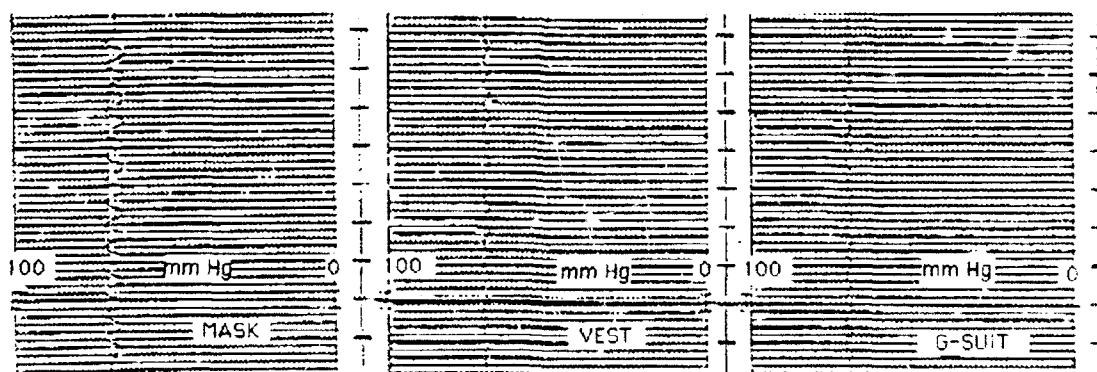
According to Dr. Harding, the mask pressure desired at 60,000 ft is between 68-72 mmHg. Both regulators tested were within the desired range, and are just short of the manufacturer's data. The shortfall can be attributed to system testing versus a specific component (namely a regulator) test. Any turbulent or indirect flow in the system would be enough to cause a differential of up to 6-10 mmHg. The less than 3 mmHg difference between REOS and the regulator alone is indicative of a tight, leak-free system.

Table 6. Regulator Output

Altitude	AL/CFT Mask Pressure 001 (mmHg)	ARO Corp. Mask Pressure 001 (mmHg)	AL/CFT Mask Pressure 002 (mmHg)	ARO Corp. Mask Pressure 002 (mmHg)
(kft)				
0	2	3	2	2
10	2	2	2	2
30	2	2	3	2
44	30	32	33	36
60	68	70	69	71

System Configuration: Regulator 001,002, CRU-94/P, VP: S, Mask Vest, G-suit
 Inlet Pressure: 70 psig
 VPBS: Profile #3 (Closest to 100 LPM flow)
 Flight Profile: Ascent to 60,000 ft with designated recording stops

2. The vest and G-suit were interconnected and tested to measure the inflation pressures of the garments at 60,000 ft. The measurements were taken at the vest hose connection, and the lower left calf bladder. The measurements were then compared to the mask pressure to prove that once the altitude bladders are inflated, oxygen consumption to maintain pressurization is minimal (Fig. 21). This is evident by noting that pressure changes in the vest and G-suit altitude bladders are a maximum of 3 mmHg, 50% of the change in pressure observed at the mask.

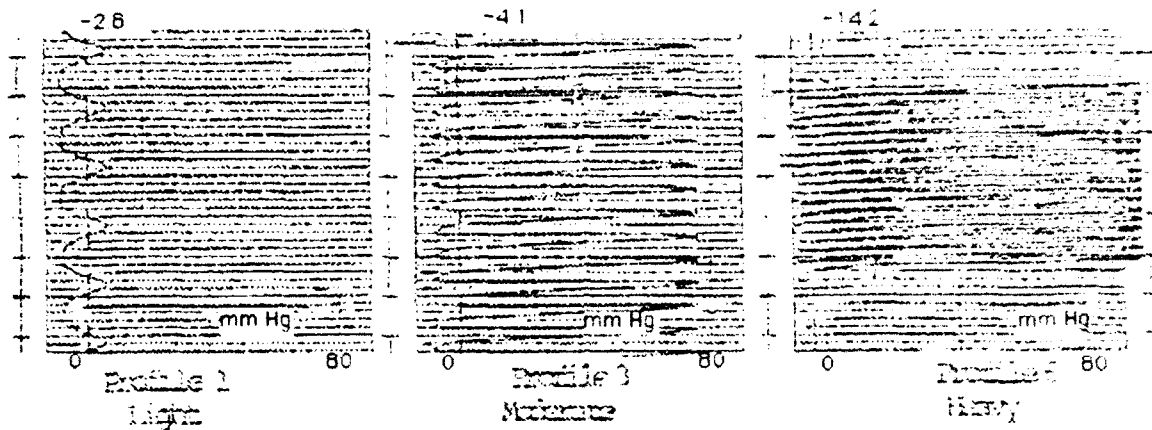


System Configuration: Regulator 001, CRU-94/P, VPBS, Mask, Vest, G-suit
 Inlet Pressure: 70 psig
 VPBS: Profile # 3
 Flight Profile: Ascent to 60,000 ft with designated recording stops

Figure 21. Vest and G-suit Inflation Pressures

3. The emergency oxygen elbow on the CRU-60/P was intended for use with 1800 psig. When the pressure was reduced to 70 +/- 10 psig, the inner diameter was found to be too restrictive, and would not

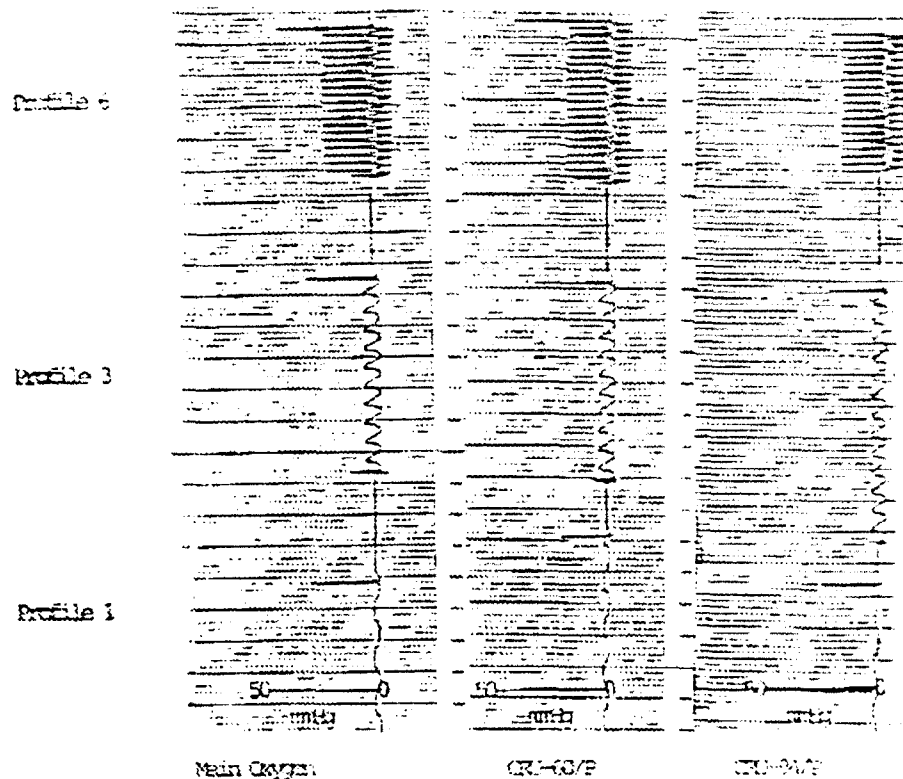
allow enough flow as seen by the negative pressures shown in Figure 22. According to the ASCC Air Standard 61/22, the negative pressure at 30 LPM should not exceed -2.8 mmHg. At 90 LPM the negative pressure should not exceed -4.1 mmHg. At 200 LPM, the negative pressure should never exceed -14.2 mmHg. The ASCC standard is marked on each profile to show how much it is exceeded by the CRU-60/P emergency oxygen elbow assembly.



System Configuration: Regulator 001, CRU-60/P, VPBS, Mask
 Inlet Pressure: 70 psig
 VPBS: Profiles 1, 3, 6
 Flight Profile: Ground Level

Figure 22. Flow Impedance Data of CRU-60/P Measured as a Function of Pressure. (Note that the trace for profile 6 is off scale indicating that impedance was greater than anticipated.)

4. After modifying the elbow on the CRU-60/P and the CRU-94/P with a three-prong connector and CRU-8/P, the performance with the increased diameter proved to be almost equal to the normal ship supply oxygen hose connection. At ground level, the standard oxygen inlet allows 21 mmHg versus 20 mmHg (CRU-94/P), and 18 mmHg (CRU-60/P) during simulated heavy breathing (Profile 6). The standard inlet allows 6 mmHg versus 6 mmHg (CRU-94/P) and 5 mmHg (CRU-60/P) during simulated moderate breathing (Profile 3). And finally, the standard inlet provides 4 mmHg versus 4 mmHg (CRU-94/P) and 3 mmHg (CRU-60/P) during simulated light breathing (Profile 1) (Fig. 23).



System Configuration: Regulator 001, CRU-60/P, VPBS, Mask
 Inlet Pressure: 70 psig
 VPBS: Profiles 1, 3, 6
 Flight Profile: Ground Level

Figure 23. Modified CRU-60/P and Modified CRU-94/P Flow Data as a Function of Pressure

I. DISCUSSION

REOS was developed to update protection for tactical aircrew members. The capabilities that are provided include: mission completion by backup regulator with two available oxygen sources (bypass of main regulator or emergency oxygen bottle), protection against hypoxia and smoke and fumes from ground level to 60,000 ft, compatibility with PBG and high altitude protective garments, and compatibility with tactical chemical defense systems (both TAERS and PIHMS). Although these capabilities exist in the hardware, decisive system testing and integration with other existing aircraft systems still need to be accomplished.

This modular design of REOS is just one proposal for a system with the above-mentioned capabilities. The developmental stages proved to be a process of assumptions and iterations. Perhaps a better system could have been designed using all new technology and equipment. However, the purpose of this program was to design a system using existing hardware under development, and to keep the cost down so a retrofit could be a realistic outcome. The most important step still remains, to actually implement such a regulated system into the field so life support equipment can keep stride with the rest of the modern technology our tactical aircraft possess.

REFERENCES

1. Ulosevich, Steven N., and Bomar, John B., Emergency Oxygen for Tactical Aircraft. Proceedings from 26th SAFE Symposium, Las Vegas, NV, 1988, pp 162.
2. Technical Manual, Operations and Maintenance Instructions with Parts Breakdown. Escape System Assemblies, T.O. 13A5-56-11, San Antonio ALC/Kelly AFB, TX, 1982.
3. Contract No. F33615-89-C-0603, KRUG Life Sciences, Incorporated, Task Order No. 0003, Regulated Emergency Oxygen System, Dec 1989, pp. 7.
4. Harding, Richard M., "Oxygen Equipment and Pressure Clothing." Aviation Medicine. Ernsting, J. and King, P. (eds.), Butterworths, 1988, pg. 110.
5. Ernsting, J., European Fighter Aircraft - Quantity of Emergency and Back Up Gaseous Oxygen Supply, Aircrew Equipment Report No. 541, J. Ernsting, Nov. 1986, pp. 1-16.
6. The Minimum Physiological Design Requirements for Aircrew Breathing Systems. ASCC Air Standard 61/22, 18 August 1982.

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APPENDIX

EQUIPMENT LIST

1. Government Furnished

- a. High-Pressure Oxygen Cylinder - 50 cubic inch- MIL-C-7905
- b. Reducer Control Valve - ARO - PN 226-1760-1
- c. Modified CRU-79 Oxygen Breathing Regulator - ARO - PN F241-1960-1
- d. Quick disconnects - 0.75 in. low pressure - PN 173C-100-3
- e. CSU-13B/P Anti-G Suit - PN F41608-88-D-3686
- f. CSU-17/P COMBAT EDGE Pressure Vest - Boeing - PN 89D7670
- g. Tactical Aircrew Eye/Respiratory System (TAERS) respirator - ARO - PN F171-2180-1
- h. Low pressure oxygen hoses - Redar - PN A10527-12, 249-CRU-94/P Integrated Terminal Block
- i. CRU-60/P Oxygen Mask Connector - Scott - PN 266-6018
- j. CRU-94/P Integrated Terminal Block - Gentex - PN G002-1078-01
- k. HGU-55/P COMBAT EDGE Helmet - Boeing - PN 81D5330-5
- l. KMU-511/P Helmet Mod Kit - Boeing - PN 89B7698
- m. MBU-20/P COMBAT EDGE Mask - Boeing - PN G010-1100
- n. CRU-8/P Connector - Sierra - PN 266-402
- o. Hysol Two Component Fast Setting Epoxy - FSN 80400000922816
- p. 3-prong Bayonet Connector - RHIMCO - PN MS27796
- q. Swagelok quick disconnects - PN QC4-B-4AN
- r. Aluminum alloy oxygen tubing - MS 24548-5-12, 24
- s. Redar quick disconnect - PN C10678-1

2. Modified

- a. CRU-60/P (Larger emergency oxygen inlet assembly)
- b. CRU-94/P - Integrated Terminal Block (Larger emergency oxygen inlet)
- c. CSU-17/P - COMBAT EDGE Pressure Vest (Add spout, quick disconnect)
- d. CSU-13B/P - Anti-G suit (add dual set bladders and fill port)
- e. TAERS - Respirator (remove CRU-79, add quick disconnect)
- f. Cylinder Mounting Bracket

3. Purchased

- a. 3-way Selector Valve - Collins Systems - PN 5228-BL-FNPT-SP
- b. Reducer Control Valve - Essex Industries - PN 1531180100-1
- c. On/Off Oxygen Valve - Essex Industries - PN K-4566-3