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COMPARISON STUDY OF LIQUID OXYGEN (LOX) SUPPLY SYSTEM TO AN ELECTROCHEMICAL OXYGEN SUPPLY SYSTEM

A. J. ADDUCI, LT, USAF

TECHNICAL REPORT AFFDL-TR-66-193

JANUARY 1967

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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COMPARISON STUDY OF LIQUID OXYGEN (LOX) SUPPLY SYSTEM TO AN ELECTROCHEMICAL OXYGEN SUPPLY SYSTEM

A. J. ADDUCI, LT, USAF

FOREWORD

This report was written as technical background to substantiate a new aviator's oxygen supply system.

The information reported was gathered from organizations throughout the Air Force.

It is gratefully acknowledged that the following people aided in providing information for this report: Mr. Dave Geiger, Air Force Flight Dynamics Laboratory; Mr. Pasquele Mosconi, ASD Limited War Office; Mr. Al Paulson, SEG; Mr. Hale, Petroleum Branch, AFLC; Mr. Ryder Payne, Cost Factors Division of Hq USAF, and the ASD C-130 System Program Office.

The manuscript was released by the author in September 1966 for publication as an AFFDL technical report.

Distribution of this report is limited because it covers an area of technology that is embargoed under the Department of State International Traffic in Arms Regulations and U.S. Export Control Act of 1949.

This technical report has been reviewed and is approved.

WILLIAM C. SAVAGE
Chief, Environmental Control Branch
Vehicle Equipment Division

ABSTRACT

The current operational LOX system cost and a newly proposed LOX system cost are compared in the light of procurement, transportation, and operation expenses. The comparison also covers non-cost elements, such as ease of erection, uniform fuel used, fire hazards, and etc. An electrochemical oxygen concentrator system is also described, showing a tangible and intangible cost projection on a squadron level of operation. The procurement and installation costs of aircraft on-board equipment is not considered in any systems.

The final section compares both LOX systems with the concentrator system; cost, equipment, and intangible items are estimated to show the savings per squadron that can be realized with the concentrator system in a 90-day period.

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INTRODUCTION

Aviation system advancements have brought higher altitudes and faster speeds into operational aircraft. This has created the problem of supplying the pilot with his personal oxygen supply so that he can fly these high performance planes.

The first solution to this problem was a compressed air or oxygen bottle placed on-board the aircraft, but as mission time lengthened and oxygen supply requirements increased, bottles became larger until the weight and volume penalty were so great that a new oxygen supply system had to be found.

The Liquid Oxygen (LOX) System for supplying oxygen to the pilot was the advancement that replaced the compressed oxygen bottle. The liquid oxygen took less space, weighed less and gave a significant increase in the length of time a pilot can be sustained during high-altitude flights. The LOX system involves a three-part ground support equipment package, plus men and accessory equipment. This system came into use in the 1940's.

Due to the many advancements in electrochemical science and technology in the past years, it was felt that there should be another and more effective method of supplying breathing oxygen to the pilot of a fighter aircraft.

The Air Force Flight Dynamics Laboratory has conducted exploratory development programs on such a system. It uses an electrochemical process to extract oxygen from the air and concentrate it for pilot use; this system is termed "concentrator."

The concentrator system is completely contained on-board the aircraft. Air flows into one side of the cell and the oxygen removed from the air is changed into a hydroxyl ion by electrochemical action at the cathode. The ion passes through an asbestos matrix which is impregnated with potassium hydroxide electrolyte. The ion then releases its oxygen at the annode electrode. The concentrator system needs electrical power from the aircraft power supply. However, the amount of power is not prohibitive to the use of the concentrator on a fighter aircraft. For more details on the concentrator operation see AFFDL-TR-65-32.

Currently, the Air Force has had to change its mode of operation in tactical air missions due to remote and limited air warfare encounters. Air operations are presented with the problem of establishing new "Bare Bases" to support a variety of tactical efforts. Time is essential. It was found that many ground support items needed to maintain a fighter squadron were big, bulky, and difficult to transport. One of these ground support items was the LOX production and support equipment. The oxygen concentrator was proposed as a solution to the elimination of the LOX ground support problem.

A short-term, mid-term, and long-term objective was established by the working group in the Aeronautical Systems Division of AFSC concerned with the Bare Base problem. Their short-term improvement was to purchase a new lightweight LOX generator. The mid-term solution was idealizing the LOX support ground equipment, but not eliminating any of its components, or manpower. The long-term objective was to use the oxygen concentrator and eliminate the LOX ground support equipment completely. A complete discussion of the Bare Base LOX ground support advancements is contained in Bare Base Support Task Force Report, Vol. I, Part IX.

The study presented in this report is to show the actual savings in time, people, money, and equipment that can be realized at the squadron level by the use of the oxygen concentrator system for aviators oxygen supply. However it must be understood that the cost does not include procurement and installation of aircraft on-board equipment associated with any of the three systems. The report is based solely upon ground support equipment needed for each system.

ON-BASE LIQUID OXYGEN GROUND SUPPORT

The Tactical Air Command's mobile capability has come under study by the Bare Base Task Force. The study covered all phases of Bare Base Concepts. Part of the study was concerned with the current Liquid Oxygen (LOX) Systems currently used on Tactical fighter aircraft as a supply of breathable oxygen for the pilot. The first step of the study was to determine the best method of lightening and lessening the ground support equipment; and reducing the manpower needed to operate the equipment.

SATS LOX SYSTEM

The Task Force has recommended a near-future change (6 to 18 months in the future). The change includes a new LOX generator, a cryogenic storage tank, and two aircraft service carts. Fifteen men are needed to operate the equipment on a 24-hour basis. (This does not include the ground service personnel to supply LOX to the aircraft.) The following gives the procurement costs for the equipment, and the training of the cryogenic specialists to operate the equipment.

The prominent piece of equipment in this package is a SATS (Short Airfield Tactical Support) LOX generator which is currently in use by the Navy. The generator produces 350 gallons of LOX in 24 hours. The particulars as to size, weight, and cost of the generator are in Table I. A cryogenic storage tank is to be used in conjunction with the generator to store the generator's production of LOX. The storage tank has a 2000-gallon capacity. The specifics on the storage tank are in Table I. Two service carts are used with the system to transfer LOX from the storage tank to the aircraft. The dimensions and procurement cost are shown in Table I.

The generator is most economical when run continuously 24 hours a day until a sufficient LOX supply is established. To do this a 15-man team of cryogenic production specialists are needed. The complete technical training course takes 1 year and costs $4,750 for each man. The cost for training these specialists is also summarized in Table I.

Transportation

Assuming that the equipment is purchased and the men are trained, we must transport them to their Bare Base. For this report the Bare Base site has been chosen as Saigon, Vietnam. A C-130E is the vehicle selected for the transportation estimate since this aircraft is in wide use by Tactical Air Command at the present time. A C-130E costs $500/per flying hour. The mileage from CONUS (San Francisco) to Saigon is 9,325 miles.

One C-130E has the cargo capacity to carry the complete LOX ground support equipment package, less the manpower. A C-130E has a capacity load of approximately 75 men with full equipment for stationing at a permanent base. Since the LOX system takes 15 men to operate and maintain it, only part of the cost of a second C-130E is to be used.

The total transportation cost of men and equipment is contained in Table II.

Maintenance For a 90-Day Operation

The cost is estimated as a 90-day operation of 24 hours per day, running the LOX generator 4 days out of 7 or approximately 60 days of the 90.

The fuel for the LOX generator is JP-4 or JP-5 (in this discussion we will use JP-4). Air Force Logistics Command negotiates for JP-4 at a flat rate of 9.4 cents/per gallon delivered anywhere in the world. The price then in Vietnam is the same as in CONUS. The LOX generator uses JP-4 at the rate of 525 gallons of JP-4 for every operating day. A chart of this complete fuel cost for the 90-day period is shown in Table III.

The manpower needed for a 24-hour operation of a LOX generator is 15 men. The

TABLE I

SATS LOX EQUIPMENT AND TRAINING REQUIREMENTS BREAKDOWN

Equipment	Vol. (ft^3)	Wt. (lb)	Cost ($)
LOX generator (Navy SATS unit) 350 gal/24 hrs)	896	14,500	230,000
LOX storage tank (2000 gal. cap.)	1,600	12,000 (Empty)	10,000
Aircraft service tank (TMU-27/M) (50 gal. cap.)	400	600	3,500
(2 tanks/squadron)	400	600	3,500
TOTAL	3,296	27,700	247,000

Training	Cost/man	Manpower	Total cost ($)
Cryogenic production specialist	4,750	15	71,250

TABLE II

SATS LOX TRANSPORTATION* REQUIREMENTS BREAKDOWN

	Vol. (ft^3)	Wt. (lb)	Cost ($)
Equipment	3296	33,200	16,500
Manpower (15 men)			4,125
	3296	33,200	20,625

*Via C-130E (San Francisco to Saigon)

TABLE III

ONE-MONTH COST OF MANPOWER FOR OPERATION OF THE SATS LOX PRODUCTION SYSTEM

	E-2	E-3	E-4	E-5	E-6	E-7
Men/grade	4	4	2	2	2	1
Base pay	507.00	682.20	466.20	557.40	694.20	398.40
Prorated pay	120.00	120.00	60.00	60.00	60.00	30.00
Quarters	220.80	220.80	140.40	210.00	220.20	114.90
Clothing	16.80	16.80	20.40	12.00	12.00	6.00
Subsistence	308.40	308.40	154.20	154.20	154.20	77.10
Separation	120.00	120.00	60.00	60.00	60.00	30.00
TOTAL PAY	1,293.00	1,468.20	901.20	1,053.60	1,200.60	710.40
Operational & maintenance expense/man	3,440.00	3,440.00	1,720.00	1,720.00	1,720.00	860.00
TOTAL/MAN/ MO.	4,733.00	4,908.20	2,621.20	2,773.60	2,920.60	1,570.40

TOTAL COST FOR A 15-MAN LOX PRODUCTION GROUP FOR ONE MONTH ON STATION - $19,527.00

manning and grade structure for this study is (This spread may vary with manning available.):

E-2	4
E-3	4
E-4	2
E-5	2
E-6	2
E-7	1

The information gathered for computing the cost of the manpower is to use the base pay plus allowances and specialist pay to estimate the cost for one man per month. This computation is reflected in Table IV. The estimation however, is not complete unless $860 per month per man is added for operational and maintenance expenses. (This is Hq USAF estimation procedure.) The total manning cost is shown in Table IV.

The LOX generator is scheduled for major repair every 500 hours, or approximately every month. The cost for the repair should be approximately 5 percent of the original cost of the generator. The time for repair is not known but 2 days are considered maximum repair time. This cost is given in Table III.

Combined procurement, training, transportation, and maintenance; the price for making one Bare Base LOX "capable" for the support of one fighter squadron is over $400,000. A summary of the complete LOX system cost is contained in Table V.

COMPARISON OF THE OPERATIONAL AND NEW LOX SYSTEM

A comparison of the systems reflects the upgrading from the present to the new LOX system. It gives cost differential, manpower difference, and a maintenance cost comparison.

The upgrading of the LOX production system or SATS system has an increased cost of procurement and maintenance over the operational system. The new system savings is in the area of weight and volume. Thus a time savings from arrival to operation, is substantial. The fuel compatibility of the new LOX system with other base items is not shown in initial cost or maintenance, but it aids in eliminating the multiple fuel supply problem.

The price of the old system, the operational LOX generators, is $70,000 per unit and the new generator price is $230,000 per unit. This price is for the generator only and not the storage tanks, or accessory equipment. Both generator systems produce the same amount of LOX in a 24-hour period, and support equipment needed for each is the same. Manpower also is essentially equal, but with the operational generator (old system) one crew can operate more than one generator simultaneously if more than one is present.

The operational generators use Diesel fuel or electricity but the new generator uses JP-4 or JP-5. The use of jet fuel eliminates logistic supply problems of bringing in special fuel for the LOX Plant, and eliminates an installation problem in the case of electricity.

The operational generator has a weight of approximately 32,000 pounds while the new one weighs 20,000 pounds. The new generator also has a reduced volume which is an important factor in lessening transportation expenses. And, it is easier to erect into an operating mode than the old generator.

The old generator is a reciprocating type, using standard concepts which have been proved reliable. The new generator uses a turbine compressor which is a new concept and has just emerged as a new development in compressor state-of-the-art. The reliability of turbine compressors is reflected in the scheduled maintenance of the new generator. It is expected that the new generator will need major overhaul every 500 hours of operation or approximately once a month. The operational generator needs scheduled maintenance approximately every 18 months.

The operational generator must be installed in a shelter of some type for it to work efficiently. This is not the case with the new generator; although a shelter is advisable for prolonged base operation.

TABLE IV

MAINTENANCE OF THE SATS LOX SYSTEM FOR 90-DAY OPERATION

	Amount	Cost ($)
JP-4 9.4 cents/gal.	10,500 gal./month	2,961.00
Manpower	15 men; pay and allowances; other expenses	58,581.00
Equipment maintenance	5% of original equipment cost/month	34,500.00
	TOTAL	96,042.00

TABLE V

SUMMARY OF THE SATS LOX SYSTEM COST FOR 90-DAY OPERATION

Equipment	$247,000.00
Training	71,250.00
Transportation	20,625.00
Maintenance	96,042.00
TOTAL	$435,917.00

Table VI shows the cost for the operational LOX system in the same procurement training, transportation, and 90-day maintenance program as used in the new LOX system.

MISCELLANEOUS COST ITEMS

This section highlights problems that have an intangible cost factor but are very important in the overall Bare Base (LOX) system.

The first of these intangible factors or problems is selecting a suitable location for the LOX equipment. The generator and storage tank must be close enough to the flight line so that the least amount of time is consumed transporting the LOX to the aircraft. To erect the equipment, an area must be cleared and leveled. The proximity of the LOX production site to fuel supply and other combustible material is critical in choosing the correct area.

TABLE VI

SUMMARY OF LOX SYSTEM COST FOR 90-DAY OPERATION
(OPERATIONAL SYSTEM)

	Vol. (ft^3)	Wt. (lb)	Cost ($)
PROCUREMENT			
LOX generator	3,000	32,000	70,000
Storage tank (2,000 gal. cap.)	1,600	12,000	10,000
2 Service carts (50 gal. cap.)	400 400	600 600	3,500 3,500
	5,400	45,200	87,000
TRAINING			57,000
TRANSPORTATION			
LOX generator			16,500
Equipment and men			16,500
			33,000
MAINTENANCE			
Men (Grades)			
4(E-2)			4,733
4(E-3)			4,908
2(E-4) (Operational and admin. expense per month)			2,621
2(E-5)			2,773
2(E-6)			2,920
1(E-7)			1,570
			19,532
Equipment			4,000

TABLE VI (continued)

LOX COST		
SUMMARY		
1. Procurement and training		144,000
2. Transportation		33,000
3. Maintenance		
Men		49,596
Equipment		4,000
Lox cost		21,000
	TOTAL	251,596

LOX is not combustible itself, but does readily oxidize with other combustible materials. Due to this fire hazard, certain precautions must be taken in the area such as erecting danger signs, and providing fire alarms, extinguisher equipment, and other safety devices. A further explanation of the safety hazards is given in DOD Manual, "Handling and Storage of Liquid Propellants," Chapter 17, Part II.

Another problem with such equipment is the vulnerability to projectile damage (bullet or shrapnel). A critically placed projectile can heavily damage or completely destroy the generator. If this does occur; the loss of LOX production capability at the base can curtail or completely stop aircraft operations for a short or extensive period of time depending on the severity of damage.

Additionally, power must be provided to the LOX production area to have lights, alarm equipment, and other miscellaneous devices. This entails stringing wire, providing lights, erecting lights, and wiring the area. The time, money, and transportation of this equipment is a cost that will vary greatly with location and has not been estimated in this study.

In some cases, as previously mentioned, a shelter must be erected over the equipment which is another added expense which has not been estimated. The magnitude of this cost depends on the sophistication of the shelter and the environs in which it must be erected. The transportation of the shelter to the base is also a cost factor.

AIRCRAFT LIQUID OXYGEN SUPPLY

The alternative to having a LOX production plant on an operational base is to airlift the LOX into the base periodically, or as needed. Okinawa was chosen as the permanent base for LOX production in this study because it is an established base which has an established LOX production plant and is in close proximity to Vietnam. The flight LOX tank filled to capacity closely approaches 1/2 the maximum cargo volume and 1/10 the weight capacity of a C-130E. The figure of 21,000 gallons is used as the total amount to be transported because it is the amount of LOX produced in 90 days by both LOX systems mentioned in this report.

No added expense is incurred for manpower since the LOX production team cost is contained in the price of LOX per gallon. The on-loading and off-loading expense is negligible, and the aircrew time is part of the aircraft flying cost per hour.

A round trip cost does not occur because on the return trip certain supplies may be brought back along with the empty tank.

There is the expense of extra tanks as backup for every base receiving LOX by airlift, two to three tanks are needed due to limited storage space at a base, backup for a low tank, or other reasons. Two service carts are required for transferring LOX from the storage tank to the aircraft and is also counted as part of the cost. This is a less expensive method of putting a LOX capability on a base for a short period of time. However, if the base operates for over the 90-day period cited, the total cost increases by $10,000 per month flying expense, and becomes much more expensive over a long period. The item estimate and total cost is contained in Table VII.

Airlift supply of LOX to a Bare Base is not acceptable because of the many operational problems it presents. However, this method was included in the study in order to cover all available methods of achieving a LOX supply at a Bare Base.

TABLE VII

TRANSPORTING LOX INTO A BARE BASE FOR 90 DAYS

	Vol. (ft^3)	Wt. (lb)	Cost ($)
Flight tank for LOX (400 gal.)	1,400 (empty)	1,700	7,000.00
Aircraft service tank (50 gal cap.) 2. (TMU-27/M)	600 600	400 400	3,500.00 3,500.00
LOX	2,416	——	1,800.00
	5,016	2,500	
Transportation (from Okinawa to Vietnam (C-130) (1,500 miles) (75% of vol. of an aircraft)			2,025.00
Summary for a 90-day operation			9,000.00
LOX			
Transportation 2 aircraft service tanks Tank			101,250.00 7,000.00 7,000.00
		TOTAL	114,250.00
2 Extra backup flight tanks			14,000.00
		ESTIMATED TOTAL	128,250.00

OXYGEN CONCENTRATOR

To compare both the operational and new LOX generator systems with the oxygen concentrator, some facts must be known about the concentrator.

The oxygen concentrator system produces pure gaseous oxygen and may be completely contained on-board the aircraft. It is designed to fit in the area on-board the aircraft now used for LOX bottle storage. The system is composed of a concentrator (which is a series of electrolytic cells) and a rebreather circuit. The concentrator has demonstrated over 1000 hours of maintenance-free operation in the prototype model.

The rebreather circuit, requires ground maintenance, which consists of the replacement of a canister filled with a carbon dioxide absorbing material and possibly the addition of water to a reservoir in the system. The replaceable rebreather circuit canister is small and weighs about 5 pounds. The replacement operation consists of detaching the used canister and replacing it with a new one (an estimated 2-minute task). The addition of water is to provide the concentrator with a water reserve for the time that the electrolyte in the cells becomes too dry, and will probably be required every second or third canister change.

The storage of the new rebreather canisters can be in any type of container. The canisters present no fire hazard or corrosion hazard and no special storage is needed. The canisters, as long as they are individually sealed, have a long storage life (estimates, depending on climatic conditions, are for one year or better). Development is underway to design and fabricate a flightweight rebreather system that would regenerate itself during flight and eliminate the replacing of the canister. This would reduce ground maintenance to only occasional addition of water.

COMPARISON OF THE OXYGEN SUPPLY SYSTEMS

A comparison of the two types of support systems reveals that the oxygen concentrator system would eliminate approximately $71,000 in training cost for cryogenic specialists, and aircraft maintenance men would need only limited instruction in servicing the concentrator rebreather canister.

Concentrator transportation cost over the present system would be cut by $30,000 for each Bare Base established, since the only transportation needed would be for replacement canisters.

Maintenance cost over the present (the "old" operational LOX) system for men (cryogenic specialists) and for ground support equipment at the base would be eliminated; also, the procurement cost for the generators would be eliminated. This means a savings of another $96,000. This total cost savings is shown in Table VIII.

The advantages of the concentrator over the new (SATS) LOX system are in the same areas as the latter's advantages over the present LOX system, weight and volume, but with a much greater savings. A summary of the cost savings is shown in Table VIII.

As for time, ground maintenance of the concentrator rebreather can be accomplished in less time than it takes to refill aircraft LOX bottles. This saves some time for the aircraft ground crew and eliminates the 15 cryogenic specialists needed to operate the LOX generator 24 hours a day. This combines a savings of time, manpower, and money, shown under maintenance in Table VIII.

The most intangible item in the savings package is the elimination of the safety hazard which exists with LOX. The hazard is that LOX not only quickly oxidizes flammable substances as mentioned before, but it is also very injurious to personnel who come in direct contact with the liquid through splashing or spilling of the LOX during handling procedures.

Another intangible disadvantage which the concentrator eliminates is the preparing and securing of an area to erect the LOX generation equipment. The utilities, such as electricity and fire control devices take time to install and cost money to procure, as well as time and money to transport to the base.

The method of airlifting LOX into a base has been dropped from this comparison for reasons mentioned previously.

The total reduction the concentrator affords in ground support equipment volume, weight, manpower, and cost is substantial when comparing it to either LOX system.

The transportation savings are appreciable for both weight and volume except, of course, that transportation required to establish a remote base. The volume that must be transported with the concentrator system is 100 ft^3, which is 5,300 ft^3 less than the operational LOX system and, 3,200 ft^3 less than the proposed LOX system. The weight to be transported with a concentrator system is 15,120 pounds. This is 30,080 pounds less than the operational LOX system transportation weight, and 12,580 pounds less than the weight of the new LOX system. The cost differential for a 90-day period is $20,164 less than the operational LOX system, and $71,432 less than the new LOX system.

These savings in manpower, weight, volume, and dollars are most advantageous to Tactical Air Force mobility, in the establishment of a remote base. A summary of the volumes, weights, and costs for all three systems is shown in Table VIII. Using the Bare Base criteria of a landing strip and water supply, the oxygen concentrator, when operational, will place the aircraft's oxygen supply system ideally into this criteria.

TABLE VIII

COST SUMMARY OF OXYGEN SUPPLY SYSTEMS FOR 90-DAY BARE BASE OPERATION

	OPERATIONAL SYSTEM			NEW SYSTEM			OXYGEN CONCENTRATOR		
	VOL. (ft^3)	Wt. (lb)	Cost ($)	VOL. (ft^3)	Wt. (lb)	Cost ($)	VOL. (ft^3)	Wt. (lb)	Cost ($)
LOX Production Equipment (Gen., Tank, 2 Carts	5,400	45,200	87,000	3,296	27,700	247,000			*
Cryogenic Special Training (15 men)			57,000			71,250			
Transportation (Equipment & men)			33,000			20,625			8,250
Maintenance/90-day operation replaceable canister							100	15,120	45,360
Equipment			4,000			34,500			
Manpower			49,596			88,581			
LOX			21,000						
Fuel						2,961			
TOTAL			251,596			435,917			54,610

* Installed aircraft equipment not considered in this summary.

REFERENCES

1. Conference with Mr. Pasquele Moscani, and Mr. Al Paulson concerning Bare Base items. Also, telecon, Mr. Al Paulson, SEG.

2. Telecon, Mr. Ryder Payne, Cost Factor Division, Hq USAF.

3. Telecon, C-130 Systems Program Office.

4. Telecon, Mr. Hale, Petroleum Branch, Hq Air Force Logistics Command.

5. Telecon with San Antonio Air Materiel Center.

6. Conference with Mr. Dave Geiger, Air Force Flight Dynamics Laboratory, RTD, AFSC.

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13. ABSTRACT

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