REPORT NO. 5-97

MAKO MODEL KA7 BA-D DIESEL DRIVEN PORTABLE DIVERS AIR COMPRESSOR (UNMANNED)

GEORGE D. SULLIVAN
December 1997

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
321 BULLFINCH ROAD
PANAMA CITY, FLORIDA 32407-7015

IN REPLY REFER TO:
TASK 97-18

NAVY EXPERIMENTAL DIVING UNIT

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Navy Experimental Diving Unit (NEDU) evaluated a Mako KA7 BA-D portable air compressor. The test took place at NEDU from 8 July through 17 July 1997. The purpose was to:

Determine if the compressor system provides compressed air at the manufacturer's advertised pressures, flow rates and the quality and cleanliness required by the U.S. Navy. With the information gathered from the evaluation NEDU made a recommendation to NAVSEA to add the Mako KA7 BA-D portable air compressor to the ANU list

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ILLUSTRATIONS

INTRODUCTION

In response to NAVSEA tasking[1], Navy Experimental Diving Unit (NEDU) evaluated a Mako KA7 BA-D portable air compressor.[2] The test took place at NEDU from 8 July through 17 July 1997. The purpose was to:

A. Determine if the compressor system provides compressed air at the manufacturer's advertised pressures and flow rates and quality and cleanliness required by the U.S. Navy[3].

B. Determine the adequacy of the manufacturer's information, instructions and guidance for the safe operation and overall management of the compressor.

C. Ensure that the compressor system discharged clean breathing air as required by the U.S. Navy[4].

EQUIPMENT DESCRIPTION

The Mako KA7 BA-D portable breathing air compressor[5] unit consists of a compressor block and drive motor, both mounted on a slide base to provide a means of adjusting the drive belts. It utilizes a splash lubricated 5405 compressor block (figure 1) which is of a three stage, three cylinder air-cooled, reciprocating configuration. It can be driven by either an electric, gasoline or diesel motor. For this evaluation a Yanmar L-A series air-cooled diesel engine was used as the prime mover. Rotational torque is transferred from the engine to the compressor by means of a V-belt. Electric motors purchased for use with this compressor must comply with Navy standards for sealed insulated systems[6].

Air is taken into the first stage by way of a 10 micron inlet air filter. Air leaving the first stage is cooled by an intercooler. Both the first stage cylinder and the intercooler are protected from over pressure damage by the first stage safety valve. First stage pressure is measured at a tap in the inlet plenum of the second stage. Pressure for the auto drain solenoid is also taken from a connection to the tap.

Air leaving the second stage is cooled by the second to third stage intercooler. The cooled compressed air enters the interstage separator. Inside the interstage separator, a centrally located tube conveys the air to the mid section of the chamber where it is directed on the chamber walls via small holes in the end of the tube. The abrupt change of direction when the air/moisture mixture strikes the chamber wall causes the moisture droplets to separate from the air stream. The air stream rises and exits the separator via a small hole in the top. The moisture collects on the inside surface of the separator chamber and flows down into the sump area at the bottom of the separator. The accumulated condensate is periodically drained by the auto drain system. The second stage cylinder, third stage intercooler and the interstage separator are all protected from over pressurization by the second stage safety valve located on the interstage separator. Second stage pressure is measured by a pressure gauge connected to a tap located in the interstage separator.

A pressure maintaining/non-return valve is located downstream of the purification system. The purpose of this valve is to prevent flow until a preset upstream pressure (typically 103 to 124 bar, 1500 to 1800 psi) is achieved. The pressure maintaining valve, in conjunction with a check valve on the outlet of the final separator, hold the purification chambers (even during compressor shutdown) at preset pressure and prevents absorbed moisture from being released from the molecular sieve. The final stage pressure gauge located on the compressor control panel indicates the pressure in the purification system. When preset pressure is reached, the valve opens if the downstream pressure is less.

The auto drain system blows down the separator at 15 minute intervals. This is accomplished by an electric timer which controls a solenoid valve. The purification system for this configuration was a Mako MK-1-C. Residual oil and water vapors not drained by the auto-drain system are removed by the cartridges. The treated air is free of oil, taste and smell. Carbon monoxide is eliminated when a MAKO filter PART No. PD 1801 is used.

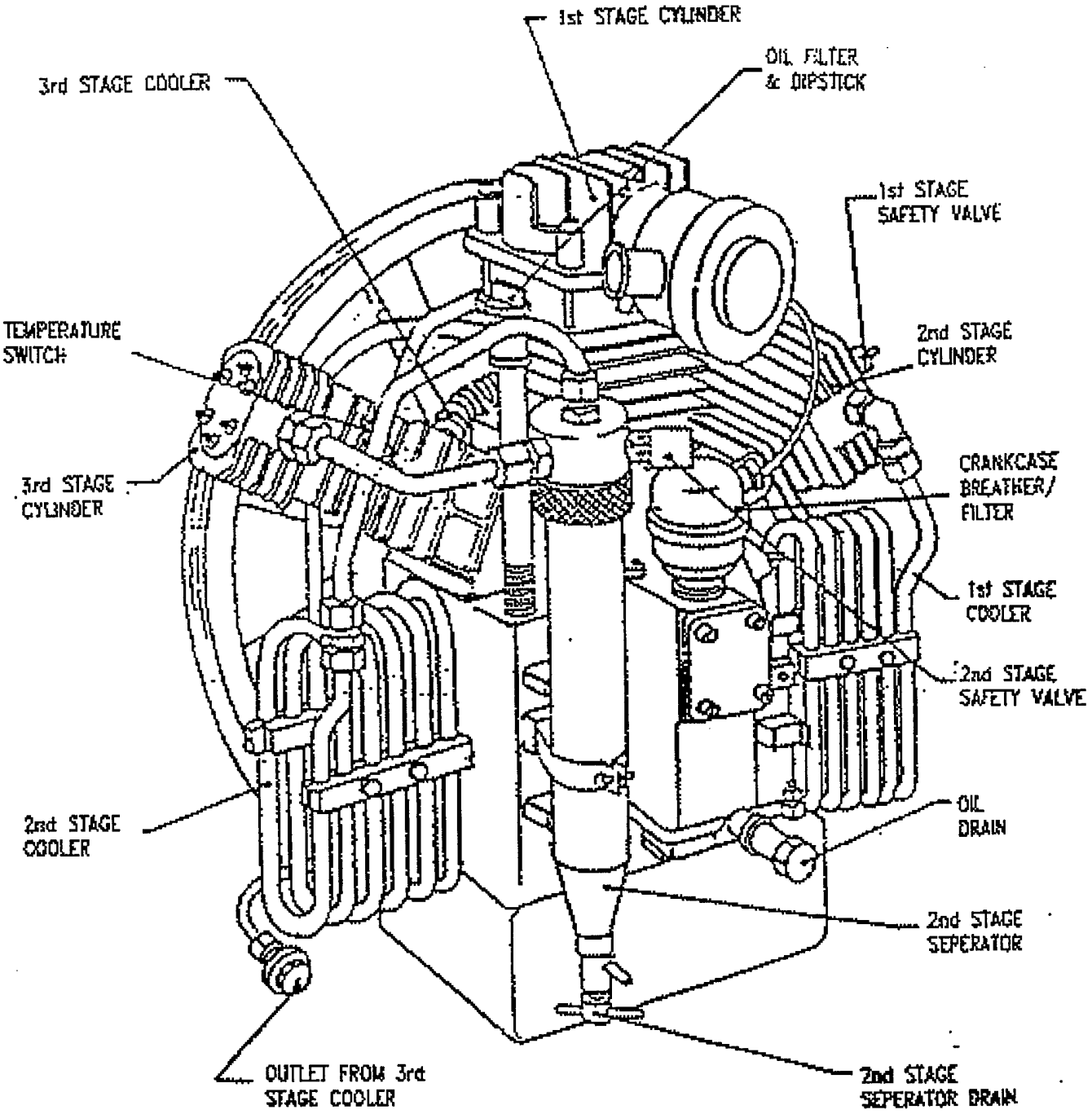

Figure 1. Major Compressor Components That Can Be Seen From The Outside.

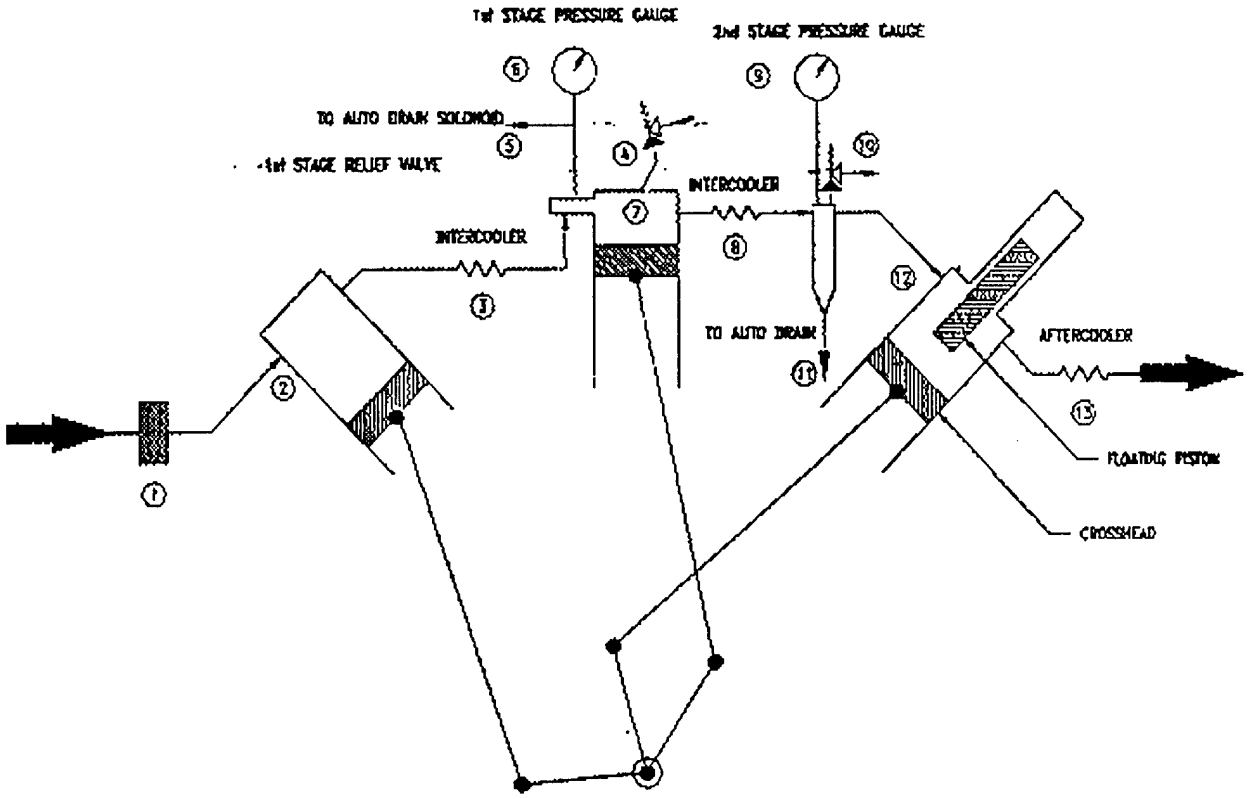

Figure 2. Compressor Internal Flow Schematic

In summary, air passing through the three stage machine travels the following path:

1. Inlet air filter
2. First compression stage
3. Intercooler (after first stage compression)
4. Relief valve (first stage)
5. Point where the auto drain solenoid is connected. Pressure at this point used to hold the auto drain piston valves closed
6. Point where first stage pressure is measured
7. Second compression stage
8. Intercooler (after second stage compression)
9. Point where second stage pressure is measured
10. Relief valve (2nd stage)
11. Moisture separator drain (piped to auto drain)
12. Third compression stage
13. Aftercooler

TEST PROCEDURE

GENERAL INFORMATION

There are various methods of testing compressor capacities, stability, and reliability[4]. For this compressor evaluation, NEDU chose to continuously run the compressor for extended periods charging a 3.15 cuft floodable volume (89.2 liter) cylinder from 0 psi to 0 to 5,000 psig (345 bars).

EVALUATION PROCEDURES

The compressor and all ancillary equipment was received and set up as per manufacturer's instructions[5]. A Cole Palmer Model 8502-14 temperature monitor and Yellow Springs Instruments 700 Series thermistor probes were attached for measuring compressor discharge and ambient temperatures.

The unit was operated in an exterior work area, open to ambient temperature and humidity. The testing included subjective evaluation of the system operation but did not include detailed mechanical review of the individual components of the system.

The compressor was operated using one purification/filter cartridge. A total of 50 test hours were expended. The following parameters were recorded: Appendix A is recorded data from the Test Log.

1. Date
2. Time
3. Total Test Hours
4. Ambient Temperature
5. Ambient Humidity
6. Compressor Air Discharge Temperature
7. Compressor Discharge Pressure
8. Cylinder Size
9. Cylinder Fill Time
10. Fuel consumption

AIR DELIVERY

Compressor capacity was determined to be 8.53 acfm (241.5 alpm) or 7.97 SCFM (225.7 SLPM) by calculating the average time to charge a 3.15 cuft (89.2 liter) floodable volume cylinder from 0 to 5,000 psig (0 to 345 bars). The average charging time for 23 cylinders was 126 minutes. A temperature correction factor was applied to correct ACFM to SCFM. Calculations were figured as follows:

From the ideal gas law we obtain: $V2 = \frac{P1 \cdot V1}{P2}$

Where V2 is the total volume compressed into a cylinder of floodable volume V1, P2 is atmospheric pressure, and P1 is the absolute compressed pressure. Absolute pressure is Pgauge + 1 atm.

Total Volume

$$V2 = \frac{psig + 14.7}{14.7} \times 3.15\ ft.^3 = \frac{5000 + 14.7}{14.7} \times 3.15\ ft.^3 = 1074.6\ ft.^3 \text{ or } 30429 \text{ liters}$$

Capacity was calculated as follows:

$$\textbf{ACFM} = \frac{Total\ \ Volume}{Filltime} = \frac{1074.6}{126\ \ \text{min.}} = 8.53\ acfm\ (241.5\ alpm)$$

A temperature correction factor to convert ACFM to SCFM was calculated as follows:

$$\textbf{Temp. Corr. Factor} = \frac{T2 + 460}{T1 + 460} = \frac{68 + 460}{105.4 + 460} = \frac{528}{565.4} = .934$$

T_1 = Mean Compressor Discharge Temperature 105.4°F
T_2 = Standard Temperature 68°F

SCFM = ACFM x .934 = 8.53 x .934 = 7.97 SCFM (225.7 SLPM)

AIR SAMPLING

An air sample was taken from the compressor purification system discharge after 1, 25 and 50 hours running time. The sample was sent to the CSS Laboratory, Code 5130, for purity analysis. Analysis of air sample are listed in Appendix B

OIL CONSUMPTION

At the beginning of the test, the compressor oil sump level indicated full. Oil level was checked every 30 minutes using the oil level sight glass. The oil used during the test was MAKO compressor oil. During the 50 hour testing[3], no oil was consumed or added to the compressor.

MAINTENANCE

At 25 hours of operation a factory recommended oil change was accomplished using synthetic oil supplied by the manufacturer.

CONCLUSIONS & RECOMMENDATIONS

1. The MAKO model KA7 BA-D diesel driven portable divers air compressor is sturdy, reliable, and readily maintained. It delivers air which exceeds the U.S. Navy standards[4] for purity. The compressor output averaged = 7.97 SCFM (225.7 SLPM). Individual charge times and temperatures are recorded in Annex A. This is approximately 8% less than the manufacturer's specification of 8.7 SCFM (246.4 SLPM) @ 68 °F (20 °C) but can be attributed to variance in gauge readings and the location that the discharge temperatures were taken.

2. Based on the results of testing, the MAKO model KA7 BA-D diesel driven portable divers air compressor system is recommended for inclusion on the Authorized for Navy Use List[5]. The vendor and NAVSEA should be contacted prior to purchase to ensure the unit meets the user's needs.

REFERENCES

1. Naval Sea Systems Command, Evaluation Of Mako Model KA7 BA-D Portable Air Compressor, Task 97-18, March 1997.

2. MR1 Frank Stout, Mako Model KA7 BA-D Diesel Driven Portable Divers Air Compressor Evaluation 97-16 (Unmanned), Navy Experimental Diving Unit, June 1997 (Limited Distribution).

3. Naval Sea Systems Command, Diving Equipment Authorized for U. S. Navy Use, NAVSEALTR, Ser OOC/3112, May 1997.

4. Naval Sea Systems Command, U.S. Navy Diving Manual, Vol. 1, Rev. 3, Para 5.3.2. Air Purity Standards, and 6.7.2.1. Air Compressors, Naval Sea Systems Command 0994-LP-001-9010.

5. COMPAIR MAKO, Universal Owners Manual. COMPAIR MAKO 1634 SW 17th Street Ocala, Florida.

6. Department of Defense, Sealed Insulated Systems, (Service A Use). MIL-M-17060 E Amendment 1.

LOG SHEET ANNEX 'A'

TIME	08:15 08 JUL	08 JUL	09 JUL	09 JUL	09 JUL	10 JUL	10 JUL	11 JUL
TOTAL TEST HOURS	1 HR	3:30	2:06	4:11	6:17	8:24	10:30	12:37
AMBIENT TEMPERATURE	89.2°	99.7°	80.2°	95°	93°	94°	93°	91°
COMPRESSOR DISCHARGE TEMPERATURE	92.7°	104.8°	102°	103°	104°	102°	105°	104°
COMPRESSOR DISCHARGE PRESSURE	75 PSIG	4400 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG
CYLINDER SIZE	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2
CYLINDER FILL TIME	N/A	2:26	2:06	2:05	2:06	2:07	2:06	2:07
FUEL CONSUMPTION	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL

REMARKS

A. One hour run without load; Air sample taken
B. Leak test, only went to 4400 psig due to rain, all leaks were taken care of

LOG SHEET ANNEX 'A'

TIME	11 JUL	11 JUL	11 JUL	14 JUL	14 JUL	14 JUL	15 JUL	15 JUL
TOTAL TEST HOURS	14:42	16:49	18:55	21:02	*23:08	25:14	27:21	29:27
AMBIENT TEMPERATURE	98°	97.8°	98°	94°	97°	96°	84°	91°
COMPRESSOR DISCHARGE TEMPERATURE	111.6°	109.6°	108°	107°	112°	109°	100.7°	110°
COMPRESSOR DISCHARGE PRESSURE	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG
CYLINDER SIZE	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2
CYLINDER FILL TIME	2:05	2:07	2:06	2:07	2:06	2:06	2:07	2:06
FUEL CONSUMPTION	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL

REMARKS

* 25 Hour air sample
Oil chamber in compressor 1/3 of a gallon used

Mako KA7 BA-D portable air compressor Evaluation
LOG SHEET ANNEX 'A'

TIME	15 JUL	15 JUL	16 JUL	16 JUL	16 JUL	16 JUL	16 JUL	17 JUL
TOTAL TEST HOURS	31:31	33:36	35:44	37:51	39:57	42:04	44:10	*46:17
AMBIENT TEMPERATURE	94°	94°	84°	93°	96°	90°	93°	85°
COMPRESSOR DISCHARGE TEMPERATURE	109°	107.8°	99.8°	107.8°	110°	103°	105°	99.4°
COMPRESSOR DISCHARGE PRESSURE	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG	5000 PSIG
CYLINDER SIZE	89.2	89.2	89.2	89.2	89.2	89.2	89.2	89.2
CYLINDER FILL TIME	2:04	2:05	2:08	2:07	2:06	2:07	2:06	
FUEL CONSUMPTION	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL	1/2 GAL

REMARKS

* 50 hour air sample taken
Compressor oil changed 1/3 of a gallon oil used

Mako KA7 BA-D portable air compressor Evaluation
LOG SHEET ANNEX 'A'

TIME	17 JUL	17 JUL						
TOTAL TEST HOURS	48:22	50:28						
AMBIENT TEMPERATURE	92°	92°						
COMPRESSOR DISCHARGE TEMPERATURE	107°	106°						
COMPRESSOR DISCHARGE PRESSURE	5000 PSIG	5000 PSIG						
CYLINDER SIZE	89.2	89.2						
CYLINDER FILL TIME	2:05	2:06						
FUEL CONSUMPTION	1/2 GAL							

REMARKS

Test completed 17 Jul 97

Memorandum

08 July 1997

To: Dave Sullivan, NEDU

From: Glen Deason, Code A53

Subject: Analysis of air sample taken from NEDU Compressor Test, Task 97-18 MAKO KA7BA-D. One hour sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21.0%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	288 PPM	1000 PPM[2]
Total Hydrocarbons[1]	3.3 PPM	25 PPM[2]
Carbon Monoxide	<0.5 PPM	20 PPM[2]
Methane	3.3 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	LIMTS
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist

Memorandum

14 July 1997

To: Dave Sullivan, NEDU

From: Glen Deason, Code A53

Subject: Analysis of air sample from NEDU test 97-16, MAKO KA7BA-D evaluation, 25 hour sample.

1. In accordance with your request, the gas sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	381 PPM	1000 PPM[2]
Total Hydrocarbons[1]	3.7 PPM	25 PPM[2]
Carbon Monoxide	0.7 PPM	20 PPM[2]
Methane	3.7 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	Limit
None		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist

Memorandum

21 July 1997

To: Dave Sullivan, NEDU

From: Glen Deason, Code A53

Subject: Analysis of air sample taken from NEDU Compressor Test, MAKO KA7BA-D. 50 hour sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21.0%	20-22%[2]
Nitrogen	78.1%	NONE[2]
Argon	0.9%	NONE[2]
Carbon Dioxide	366 PPM	1000 PPM[2]
Total Hydrocarbons[1]	3.0 PPM	25 PPM[2]
Carbon Monoxide	0.7 PPM	20 PPM[2]
Methane	3.0 PPM	1000 PPM[2]
Acetone	<0.1 PPM	200 PPM[2]
Benzene	<0.1 PPM	1 PPM[2]
Chloroform	<0.1 PPM	1 PPM[2]
Ethanol	<0.1 PPM	100 PPM[2]
Freon 113	<0.1 PPM	100 PPM[2]
Freon 11	<0.1 PPM	100 PPM[2]
Freon 12	<0.1 PPM	100 PPM[2]
Freon 114	<0.1 PPM	100 PPM[2]
Isopropyl Alcohol	<0.1 PPM	1 PPM[2]
Methanol	<0.1 PPM	10 PPM[2]
Methyl Chloroform	<0.1 PPM	30 PPM[2]
Methyl Ethyl Ketone	<0.1 PPM	20 PPM[2]
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM[2]
Methylene Chloride	<0.1 PPM	25 PPM[2]
Toluene	<0.1 PPM	20 PPM[2]
Trimethyl Benzenes	<0.1 PPM	3 PPM[2]
Xylenes	<0.1 PPM	50 PPM[2]

Other Components

Component	Level	LIMTS
NONE		
C4+	<0.1 PPM	NONE

[1]Expressed as methane equivalents.
[2]Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
[3]OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason
Chemist