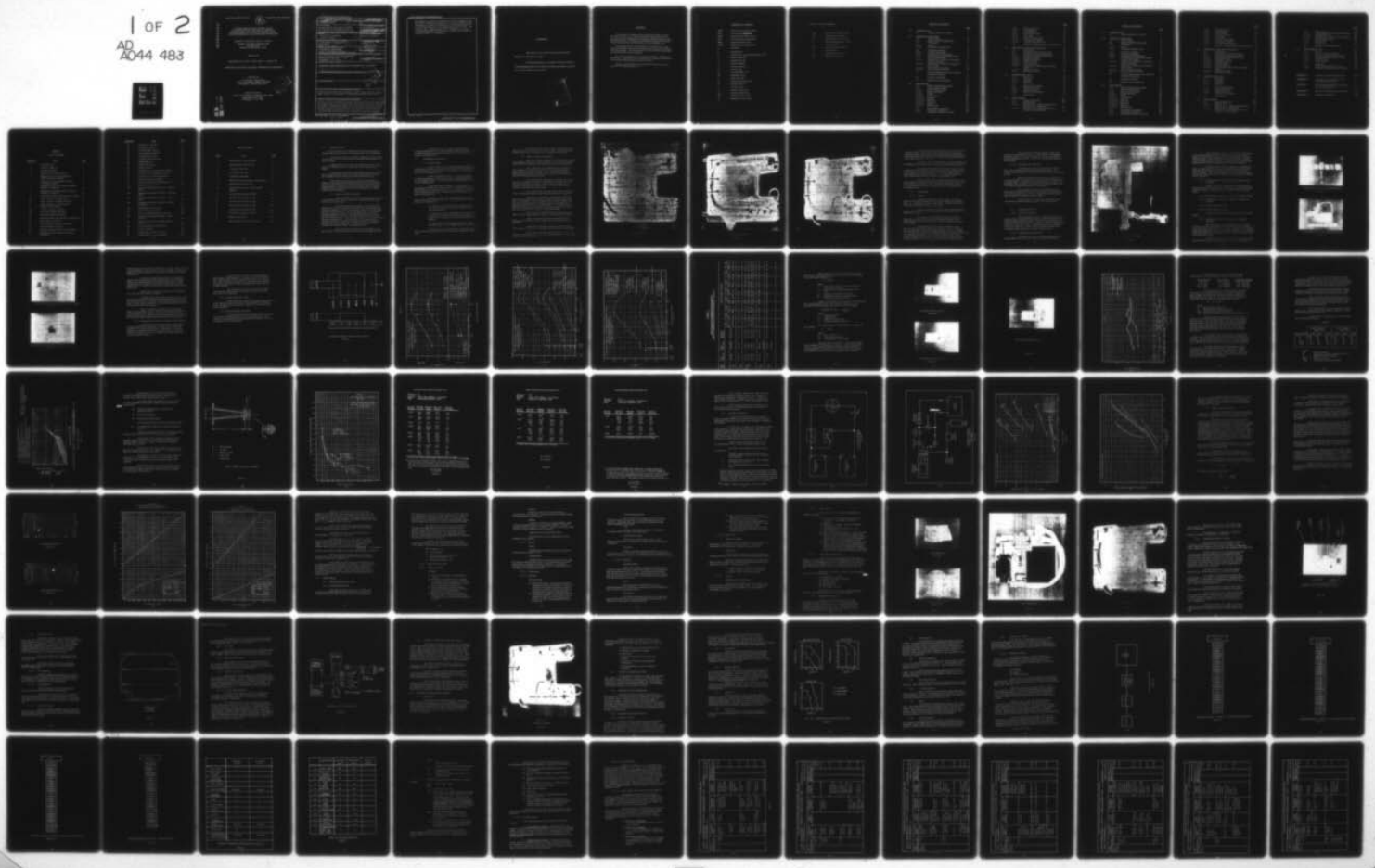
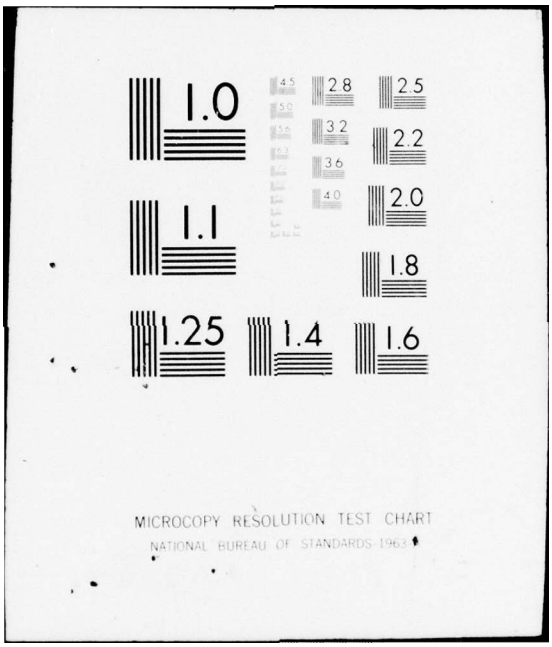
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DOWNED AIRMAN POWER SOURCE (DAPS) FOR INCLUSION INTO THE RSSK-8A AIRCRAFT EJECTION SEAT TO BE USED BY DOWNED PILOTS FOR ENVIRONMENTAL ANTI-EXPOSURE PROTECTION

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January 1977

Final Report for Period 9 April 1976 to 9 January 1977

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Prepared for

Crew Systems Department
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974



Monitoring Agency

NAVAL AIR SYSTEMS COMMAND (AIR-340B)
Department of the Navy
Washington, D. C. 20361

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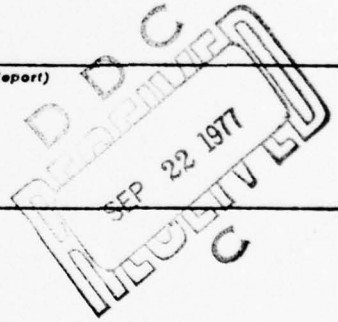
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1. REPORT NUMBER: NADC-75350-40	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Downed Airman Power Source (DAPS) for Inclusion into the RSSK-8A Aircraft Ejection Seat to be used by Downed Pilots for Environmental Anti-Exposure Protection.	5. TYPE OF REPORT & PERIOD COVERED: Final Report. 9 April 1976 thru 9 Jan 1977
	6. PERFORMING ORG. REPORT NUMBER: ESC-0239-1FR
7. AUTHOR(s): Richard E. LeCompte & Roger S. Christie	8. CONTRACT OR GRANT NUMBER(s): N62269-76-C-0239
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Energy Systems Corporation, 1 Pine Street, Nashua, N. H. 03060	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AIRTASK NO. 6W-SL14-001 & 6F51-523-400
11. CONTROLLING OFFICE NAME AND ADDRESS: Crew Systems Department, Naval Air Development Center, Warminster, Pennsylvania 18974 Code 4043	12. REPORT DATE: January 1977
	13. NUMBER OF PAGES: 151
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Naval Air Systems Command (AIR-340B), Department of the Navy, Washington, D. C. 20361	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)



18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Downed Airman Power Source (DAPS), Catalytic Heater, BTU/Hr, Watts, Rigid Seat Survival Kit (RSSK), portable thermoelectric power source.

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

A source of heat to extend survival time during search and rescue operations for downed airman in cold environments. The heat source is derived from the catalytic combustion of propane fuel with resultant release of chemical energy in the form of heat. The heat is picked up by a heat transfer fluid in heat exchangers and pumped to the man via umbilicals on the DAPS to a tubulated undergarment worn by the airman where the heat is dumped.

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The system is a closed loop and therefore, after dumping its heat the fluid is returned to the DAPS where it picks up additional heat. The system is capable of supplying up to 250 thermal watts to the airman at fluid temperature of approximately 100° to 105°F. The fluid flow rate is approximately .25 to .30 gallons per minute. The system also has a 12 VDC DC-DC converter used to power an emergency flasher or transmitter.

FOREWARD

This report is an account of work performed under Contract No. N62269-76-C-0239.

It has been prepared in accordance with MIL STD 847A: "Format Requirements for Scientific and Technical Reports Prepared by or for the Department of Defense".



SUMMARY

This report is a summary of work performed under Contract N62269-76-C-0239. The contract terminated with the delivery of two preproduction DAPS heater that would be stowable within the three RSSK-8A seat kits as manufactured by East/West Industries, Rocket Jet Division of American Flight Safety, and Scott Aviation, Inc.

The intended use of the DAPS heater is to supply heat, (up to 250 thermal watts) to an airman should he have to bail out in extreme cold environments. The heat supplied is used to extend survival time during search and rescue operations.

The source of heat is derived from the catalytic combustion of propane gas. The heated fluid is pumped to the airman via umbilicals to a tubulated undergarment worn by the airman.

The use of this system can extend survival time for up to six hours at 32°F water and 20°F air.

ACRONYMS & SYMBOLS

NADC	-	Naval Air Development Center
CSD	-	Crew Systems Department
DAPS	-	Downed Airman Power Source
ESC	-	Energy Systems Corporation
RSSK	-	Rigid Seat Survival Kit
SCFH	-	Standard Cubic Feet per hour
q	-	heat(BTU)
$\dot{q}$	-	heat(BTU/Hr)
h	-	Heat transfer coefficient (BTU/Hr °F ft^2)
A	-	Surface Area (ft^2)
T	-	Temperature (°F)
ρ	-	Density (lbs/ft^3)
V	-	Velocity (feet/sec.)
D	-	Diameter (ft)
μ	-	Viscosity (lb/hr. ft.)
Rn	-	Reynolds number
L	-	Path Length (ft)
D_e	-	Equivalent Diameter (ft)
θ	-	Included angle (°)
G	-	Air Gap (inch)
L	-	Diffuser Length (ft)
T_D	-	Throat Diameter (ft)
E_L	-	Running Voltage (volts)
I_L	-	Running Current (amps)

Acronyms & Symbols Continued

E_{OC}	-	Open Circuit Voltage (volts)
R_L	-	Load Resistance (ohms)
R_i	-	Internal Resistance (ohms)
C	-	Gas Constant (propane - 105)
F	-	Pressure Ratio
C_p	-	Specific Heat (BTU/lb°F)
P	-	Power(Watts)
T_η	-	Thermal Efficiency (%)
S_η	-	System Efficiency (%)

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RSSK-8A

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1.0 INTRODUCTION

The evaluation of the DAPS system has been developed by Energy Systems Corporation to an advanced state of pre-production.

All previous contracts on DAPS technology have been for the development of a system that would be compatible with the RSSK-1A seat kit design.

Contract N62269-76-C-0239 was awarded when the requirement for a DAPS system for the RSSK-8A seat kit design became evident.

Comparison of the RSSK-1A and RSSK-8A seat kits immediately revealed that the DAPS as designed for the RSSK-1A kit was not compatible with the configuration of the RSSK-8A design.

Past experience on the part of Naval Air Development Center, Crew Systems Department and Energy Systems Corporation concerning seat kit differences among manufacturers resulted in the award of Contract N62269-76-C-0239 to develop a DAPS compatible to RSSK-8A kit as fabricated by the major manufacturers of Rigid Seat Survival Kits (RSSK).

1.1 Contract N62269-76-C-0239

Contract N62269-76-C-0239 concluded with the delivery of two DAPS systems radically different in configuration and design from any previous designs.

The DAPS systems as delivered is interchangeable among the three kits as manufactured by the three fabrication houses: (East/West Industries, Rocket Jet Division of American Flight Safety Systems & Scott Aviation). This interchangeability is accomplished by incorporation of a bracket retrofit kit that mounts to existing mounting hardware in the kits. The requirement for these retrofit kits was mandated by the variances in the location of mounting hardware among the manufacturers. The utilization of this approach made possible the design of a DAPS system that was 100% interchangeable among the three kit designs with no changes to the basic DAPS as designed and minimum change in mounting hardware.

The design of the DAPS for use in the RSSK-8A seat kits required a totally new approach in design and packaging concepts.

The DAPS design problems, solutions and the rationale behind these design changes together with an in depth report of engineering tests and evaluation performed on this system are the subject of this Final Report.

2.0 TECHNICAL DISCUSSION

2.1 Seat Kit Study

So as to fulfill the contract requirements of delivering a DAPS heater suitable for packaging in the three kits as fabricated by the three major manufacturers it was necessary to procure one of each of the representative types.

These representative kits were supplied to Energy Systems Corporation as Government Furnished Equipment by Naval Air Development Center, Crew Systems Department (NADC, CSD) per contract requirements.

An in depth study of these three kits revealed the fact that although the RSSK-8A kit has but one Federal Stock Part number and that they are all fabricated to the same specification, there were several differences among the kits that hampered the design of the DAPS for the RSSK-8A.

Figures 1, 2 and 3 are photographs that depict the major differences among the three kits. The three major differences that were encountered are:

1. differences in the location of mounting holes for the various components used in the emergency bail out oxygen system.

2. differences in the configuration of the oxygen hard lines into the manifold which connects the regulated pressure side, pressure relief valve and output lines together.

3. differences in the mounting height of the oxygen tank with respect to the mounting surface for the DAPS

Several mock up configurations were built and tested for fit in the three seat kit designs to determine the optimum configuration.

Based on the above study, a least common denominator of void volume configuration was determined. The determination of this volume was the first step in the completion of the design.

2.2 Impact on DAPS Configuration

Once the available common void volume was determined it was apparent that major changes would have to be made in the basic DAPS design if the function of the DAPS was not to be compromised.

Two components in the DAPS that were considered non-essential to the unit performance were the fluid temperature gauge and the fuel pressure gauge. These components, although useful from an operating view point, were deemed to be expendable without affecting system performance.

The deletion of the temperature gauge did not require any further changes to the unit to compensate for its removal. It was decided that the level of comfort could be safely controlled by the operator seeing that this comfort level is a relative state varying markedly from individual to individual.

The removal of the pressure gauge required that some means of knowing at what rate fuel was being consumed be supplied.

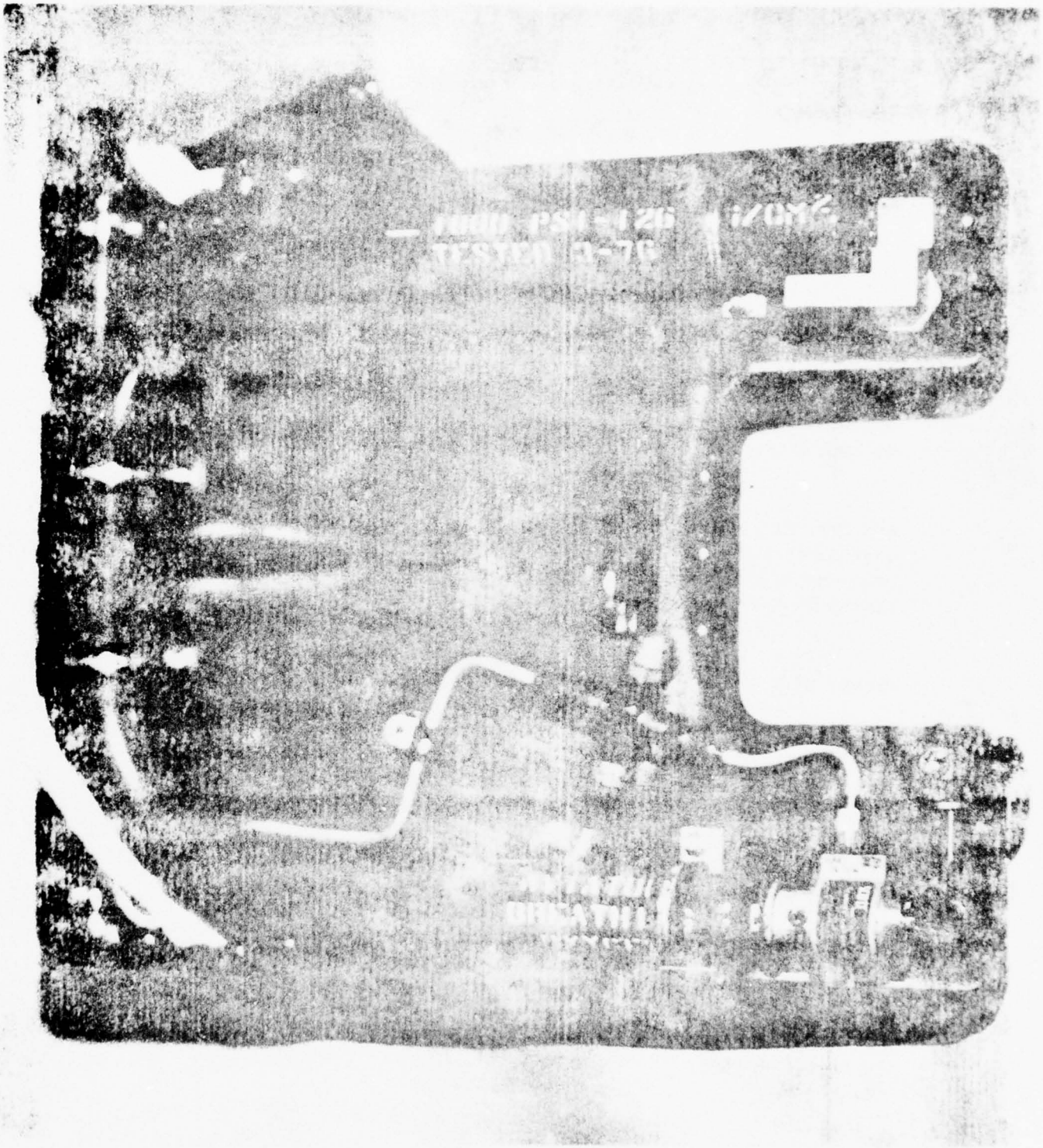
This was accomplished by modifying the lead of the thread on the regulator shaft, thereby allowing the full range of fuel rates to be obtained in one 360°rotation of the regulator control knob. This knob is equipped with a calibrated numerical face plate with numbers ranging arbitrarily from 0 through 10. The unit is delivered with a decal informing the operator of the approximate fuel duration that can be expected at the various numerical settings.

This information should enable the downed airman to select a proper balance between degree of comfort and fuel duration.

Another impact on the design of the DAPS for the RSSK-8A seat kit was the severe height restriction on the profile of the DAPS.

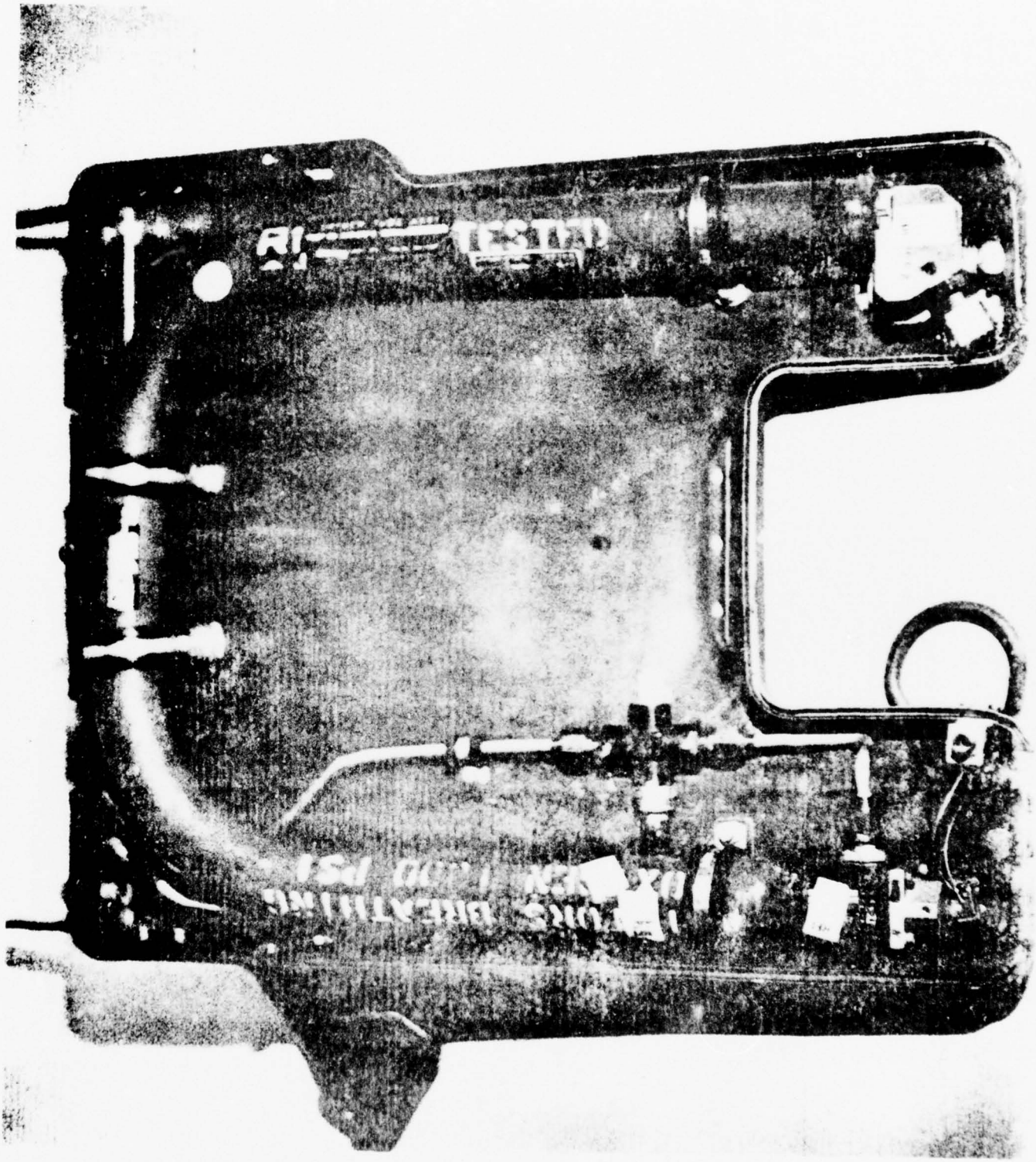
A study was conducted to determine how this height restriction would impact the components used in previous design DAPS.

The results of this study indicated that the combustion chamber configuration would have to be radically altered if it were going to fit within the allocated space.



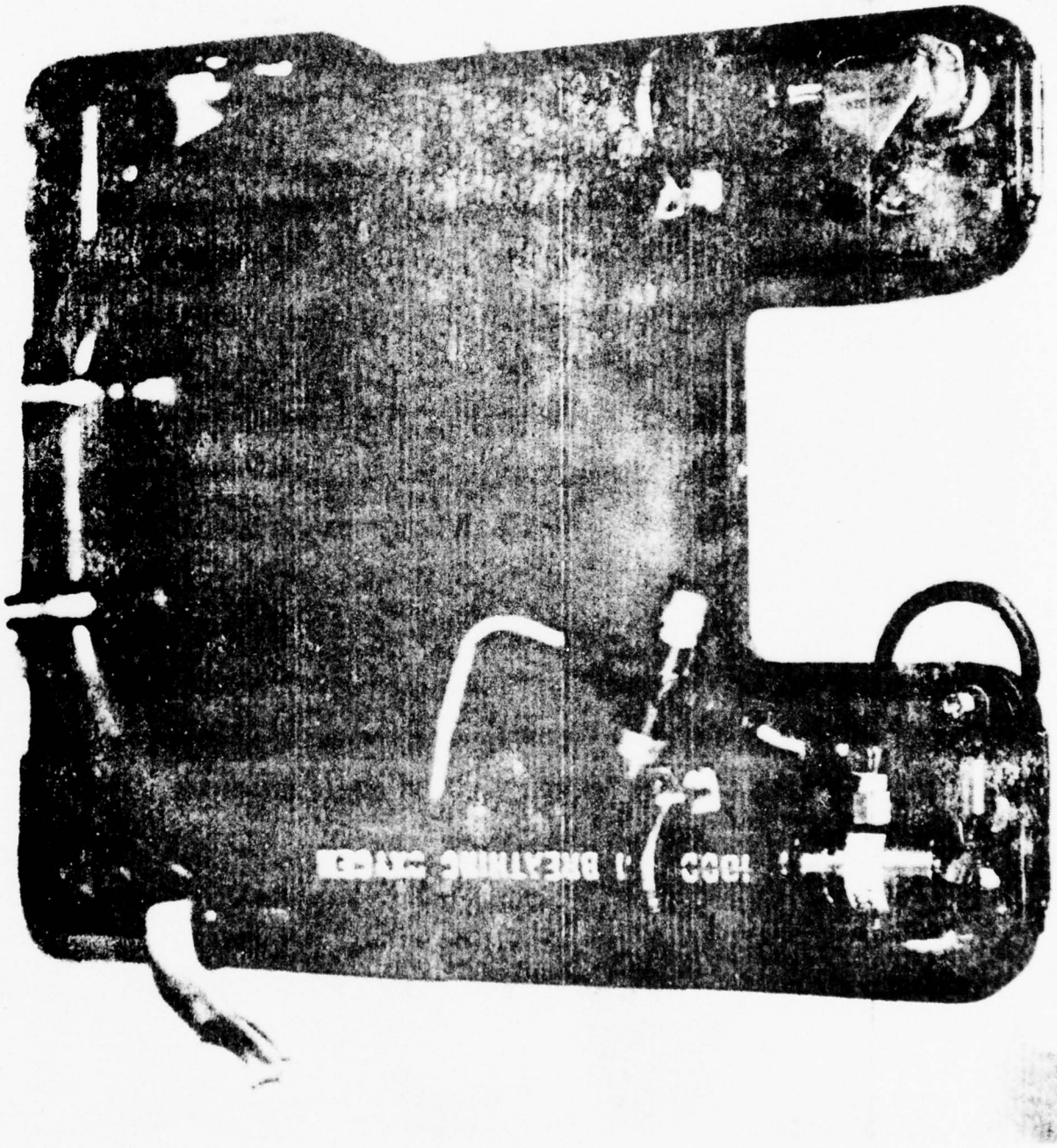
SCOTT RSSK-8A

Figure 1



ROCKET JET RSSK-8A

Figure 2



EAST /WEST RSSK-8A

Figure 3

A series of developmental tests were run to determine a suitable design. These tests resulted in a design of a low profile combustion chamber that would fit comfortably within the RSSK-8A kit. A description of the test run and their results may be found elsewhere in this report (Section 2.4 & 2.5).

Because of the radical differences between the RSSK-1A and RSSK-8A kits a totally new packaging concept had to be developed.

As a result of this difference it was decided to design a system that was totally self-contained, except for the tubulated liner worn by the airman. This design includes the fuel supply inside the same housing as the heater components. This approach enabled a system design that maximized utilization of available space.

The net result of this approach was the delivery of an easy to operate system that required the mere turning of a valve stem to admit fuel to the system. Previous systems had the fuel supply as a separate item requiring the mating of the two components prior to system start up.

2.3 Fuel Supply

2.3.1 Design

As stated in Section 2.2 of the report, the design approach taken with the RSSK-8A was to have a totally self-contained unit, i.e., combustion chamber, pump motor, DC-DC converter and associated components as well as fuel supply.

The incorporation of the fuel supply integrally with the housing required that a new design approach be taken with respect to the pressure vessel.

The contract requirements of 6 hours of fuel at a usage rate of 25 gms/hour eliminated the option of using a coiled tubing approach due to the larger loss of volume experienced with the use of tubing.

The final design decided upon consists of a solid block of 1020 carbon steel milled out to enclose a series of connected cells separated by walls for additional strength. The cover consists of a .125 inch sheet of 1020 steel welded around the perimeter of the vessel. For additional strength the cover had slots milled through it which coincide with the fuel cell walls. These slots were filled with weld thereby welding the cover to the cell wall as well as to the perimeter.

This construction although complex results in an extremely strong and safe pressure vessel capable of withstanding internal pressures of 260 psia encountered at a maximum stated storage temperature of 125°F. Figure 4 is a photo of the delivered tank assembly.

2.3.2 Fuel Tank Leak Rate Test

A prototype tank using parts identical to those of deliverable units was assembled and filled with propane. The purpose of this assembly is to monitor fuel leakage rates with respect to time.

Measured leakage rates have been on the order of 0.2 grams/month, coinciding with the leakage rates of commercially available tanks. The leakage rate of these commercial tanks was determined experimentally by actually monitoring the leakage rates of 12 tanks purchased specifically for this purpose.

These leakage rate tests were mandated by the apparently high leakage rates encountered in past fuel tank designs. Test results to date indicate that the components selected will eliminate the leakage encountered in past designs.

A leak rate of .15 grams per month would require a maintenance inspection schedule on the order of five years.

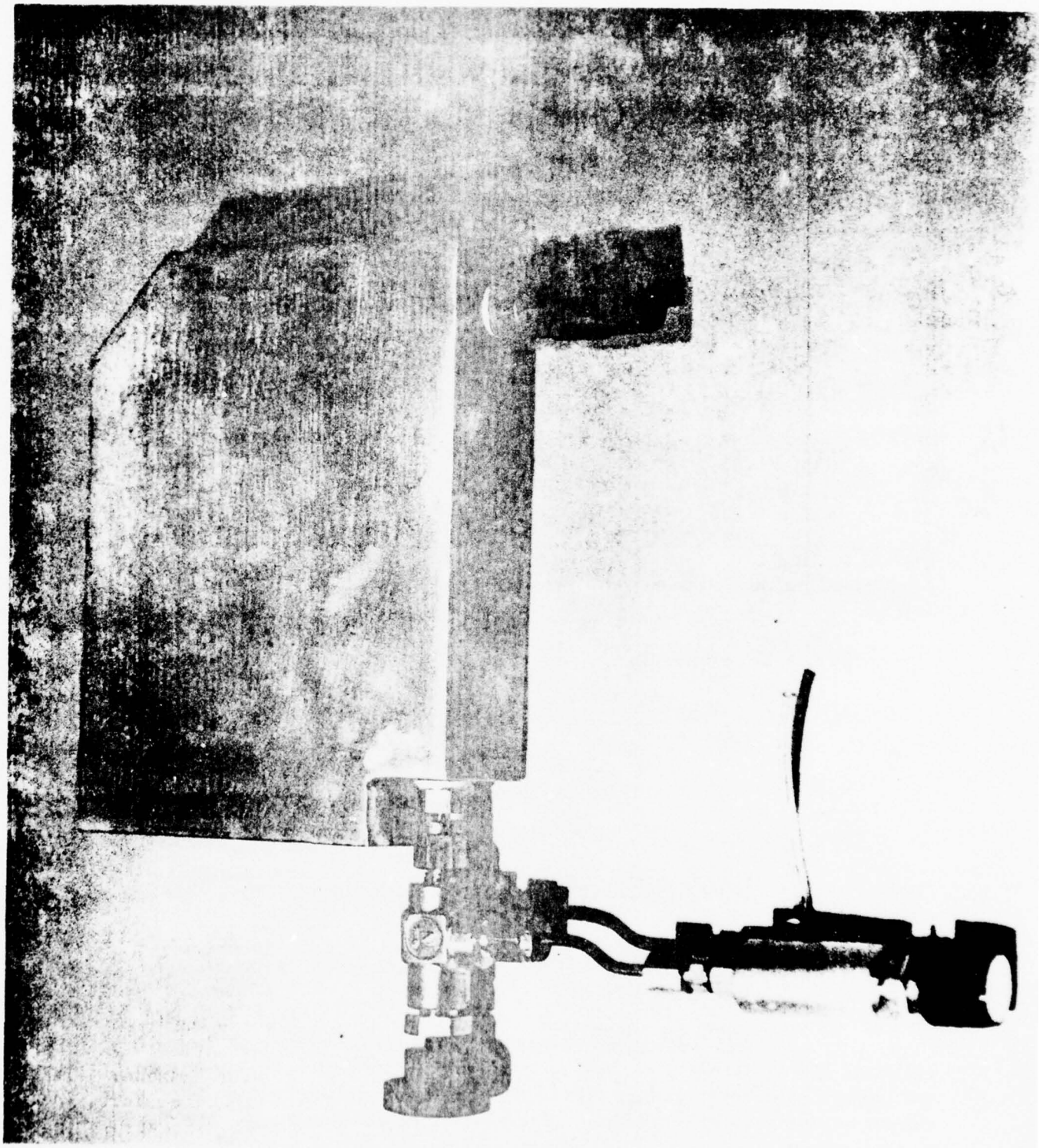
2.4 Combustion Chamber

2.4.1 Purpose of Redesign

After generating several design layouts it became apparent that the existing RSSK-1A DAPS combustion chamber could not be packaged within the available RSSK-8A void configuration as determined by the seat kit study. Combustion chamber redesign was required, and an effort of this magnitude was definitely beyond the scope of the contract. A lower profile combustion chamber was developed by ESC and this is the subject of this section.

2.4.2 Comparison of Two Designs

A comparison of the two designs together with the design analyses involved in developing the new design follows.



RSSK-8A FUEL TANK

Figure 4

The combustion chamber used in all one man heaters to date (DAPS and Arctic heater) consist of a cubical combustion chamber to which were mounted pin plates on either side. (Figure 5 Exploded View). On each of these hot plates are mounted a thermoelectric module and heat exchanger, the thermoelectric module being sandwiched between the heat exchanger and pin plate (Figure 6).

The new design markedly changes this configuration (Figure 7 Exploded View). The new configuration uses only one hot plate and heat exchanger although it still utilizes two (2) thermoelectric modules. Several advantages were realized with the design. Component costs were reduced slightly and assembly time was reduced by 50%. (Figure 8)

2.4.3 Developmental Combustion Chamber Analysis and Testing

Before arriving at a final design, extensive developmental testing had to be performed. The four major testing programs performed on this combustion chamber design and these are listed below:

2.4.3.1 Temperature profile as a function of catalytic bed size.

2.4.3.2 Temperature profile as a function of catalytic bed location

2.4.3.3 Power generation ability

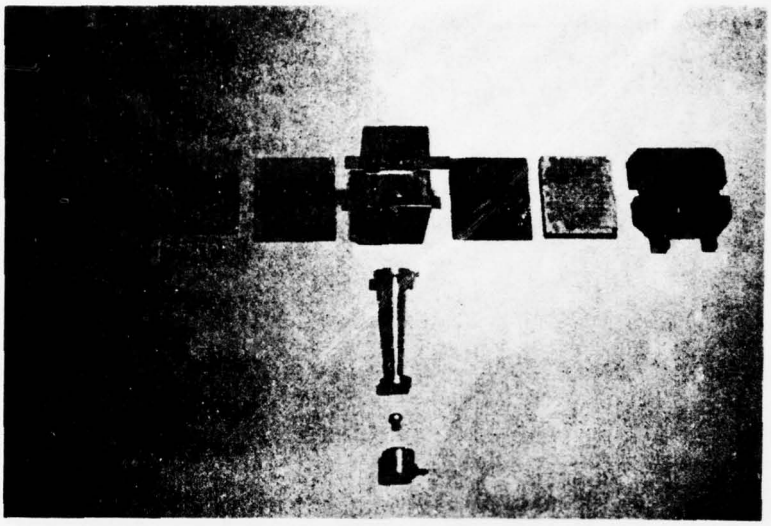
2.4.3.4 Heat exchanger efficiency

A brief description of each test along with test results follows:

2.4.3.1 Temperature Profile as a Function of Catalytic Bed Size

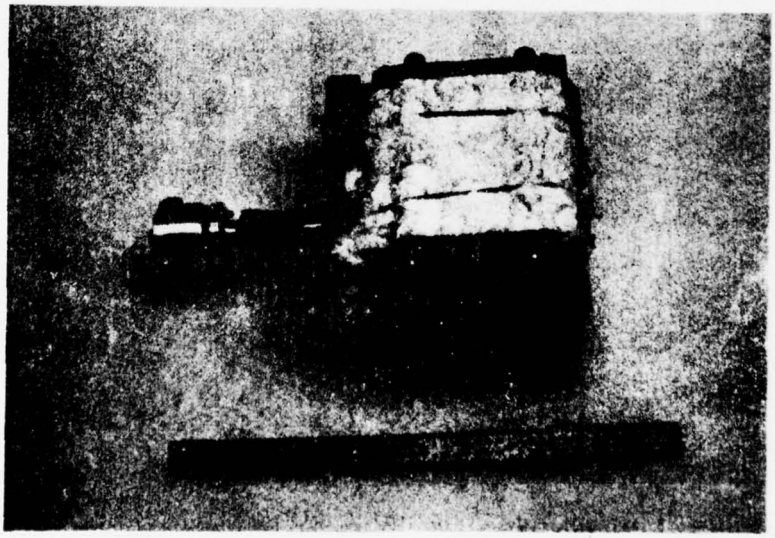
The temperature and combustion efficiency of the catalytic bed is directly related to its size. If the bed is too small, i.e., not enough catalyst present, all the fuel that is supplied to the chamber cannot be completely oxidized. This results in unburned fuel, therefore, wasted potential energy. This unburned fuel results in a net decrease in hot plate temperature.

Efficiency is also decreased if the bed size is too large. The major effect of too large a catalytic bed is the recombination of



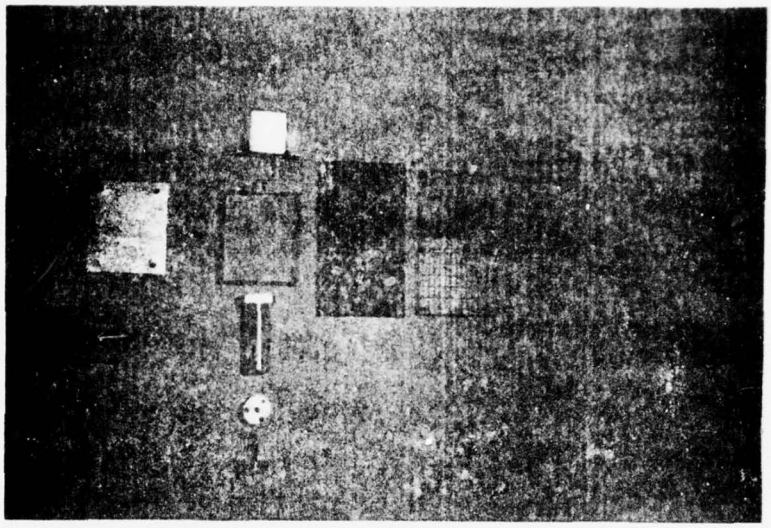
Exploded View of Old Combustion Chamber

Figure 5

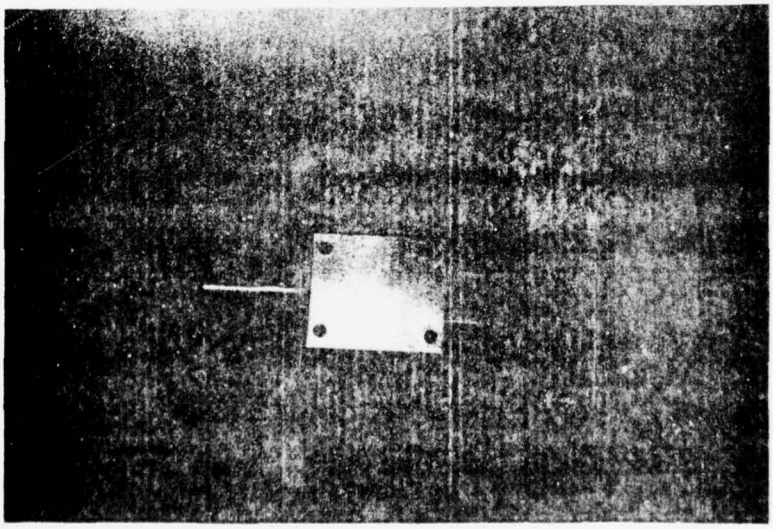


Assembled View of Old Combustion Chamber

Figure 6



Exploded View of New Design Combustion Chamber
Figure 7



Assembly View of New Design Combustion Chamber
Figure 8

exhaust product in an extremely endothermic reaction. These reversed reactions possible in the presence of excess catalyst or insufficient oxygen, absorb large amounts of heat thereby reducing the hot plate temperatures.

In order to measure these effects, a combustion chamber was instrumented with thermocouple wires at six equally spaced locations along the hot side pin plate (See Figure 9) and the temperature profile plotted at 10, 20 and 30 PSIG fuel pressures. Figures 13a, b, c show the positions and relative sizes of the various beds tested.

Three plots were made for bed size of 7.15 grams, 12.4 grams and 28.5 grams of catalyst.

Results of these tests (shown in Figures 10, 11 & 12) indicate that maximum temperatures are attained with the 12.4 gram bed and that too much or too little results in lower temperatures and, hence, a lower power output due to a decreased temperature difference across the thermoelectric modules.

Figure 9 shows the location of the thermocouple leads on the assembly. Figures 10 and 11 show how the temperature profile of the hot side changes as a function of catalytic bed size. From this data we see that of the three bed sizes used, the 12.4 gram bed yields the highest temperatures and, therefore, best results.

2.4.3.2 Temperature Profile as a Function of Bed Location

The thermoelectric modules generate the greatest electrical output if the temperature on the hot side is uniformly maintained across the entire surface. Although this is the ideal situation, it is difficult to achieve in actual practice. Tests were performed to attempt to locate the hottest area symetrically with respect to the two modules.

Referring to the location of peak temperatures with respect to the thermoelectric modules, it was observed that the maximum temperature is located at the front of the catalytic bed. This is shown by comparing the peak temperatures obtained in Figure 11 and Figure 12 and correlating these temperatures to the bed locations.

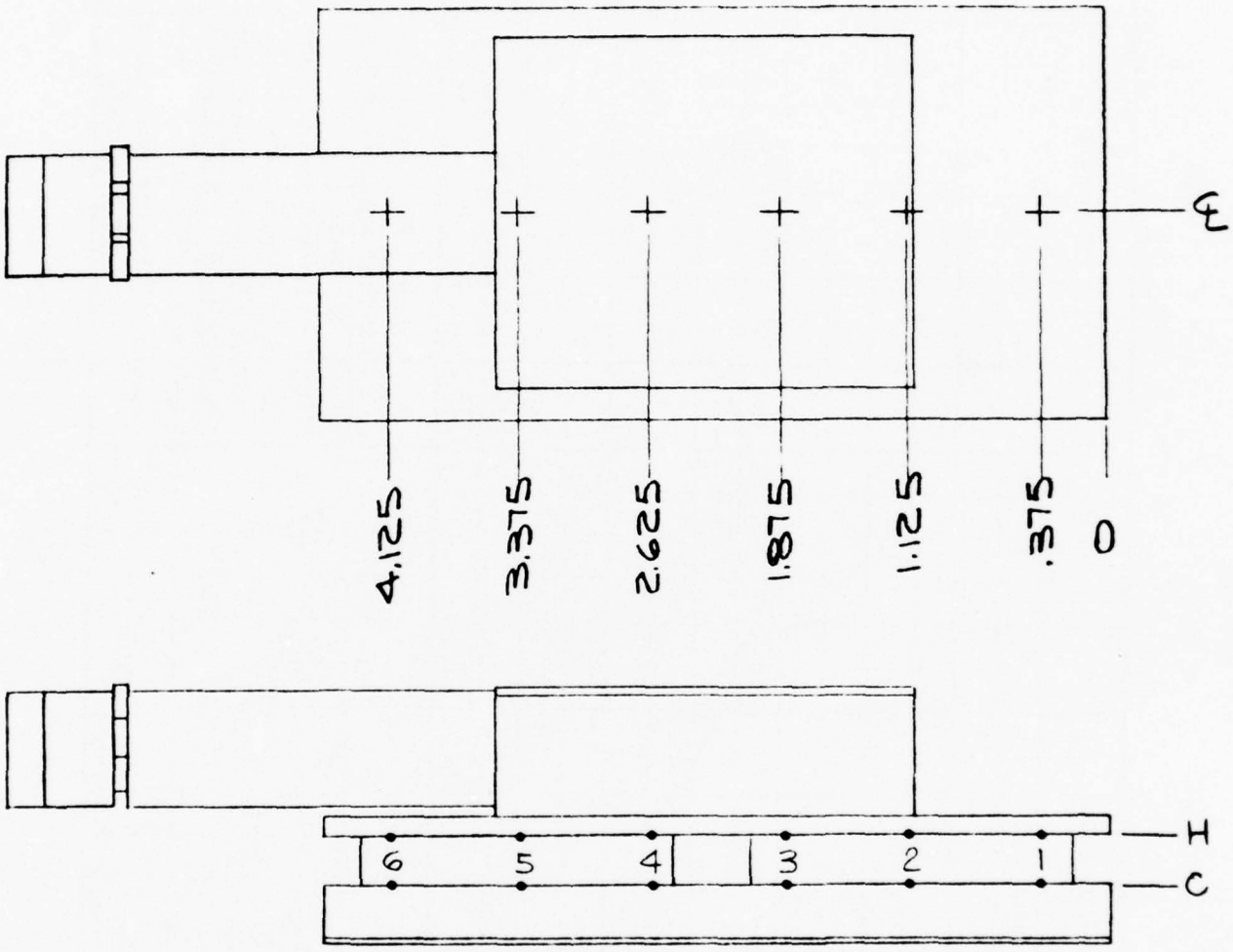
By examining the temperature profiles resulting from the tests it was possible to optimize catalyst bed location. (See Table 1 for Raw Data)

2.4.3.3 Power Generation Ability

Power generation output of the modules was monitored in the testing described above and it was found that the maximum power was generated once optimum catalytic bed size and location were determined.

2.4.3.4 Heat Exchanger Efficiency

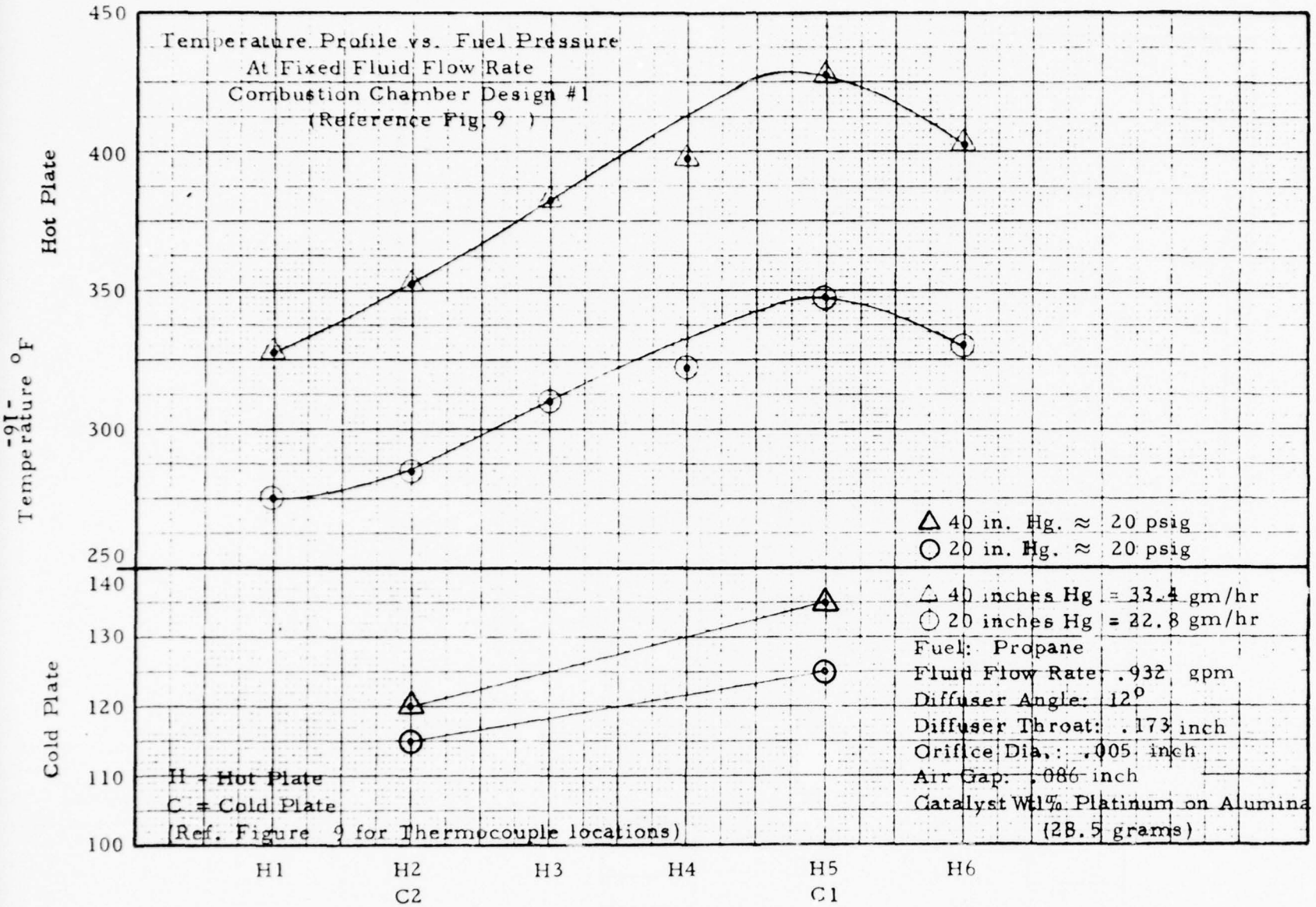
The efficiency of the heat exchanger used in previous designs had been optimized at the time of original design. The change to a new design required that additional testing be performed to optimize the new configuration.



Combustion Chamber Thermocouple Location

Figure 9

Figure 10


Temperature Profile vs. Fuel Pressure
At Fixed Fluid Flow Rate
Combustion Chamber Design #1
(Reference Fig. 9)
Hot Plate
Cold Plate
Temperature °F
450
400
350
300
250
140
130
120
110
100
40 in. Hg. ≈ 20 psig
20 in. Hg. ≈ 20 psig
40 inches Hg = 33.4 gm/hr
20 inches Hg = 22.8 gm/hr
Fuel: Propane
Fluid Flow Rate: .932 gpm
Diffuser Angle: 12°
Diffuser Throat: .173 inch
Orifice Dia.: .005 inch
Air Gap: .086 inch
Catalyst Wt% Platinum on Alumina
(28.5 grams)
H = Hot Plate
C = Cold Plate
(Ref. Figure 9 for Thermocouple locations)
H1
H2
C2
H3
H4
H5
C1
H6
Thermocouple Location

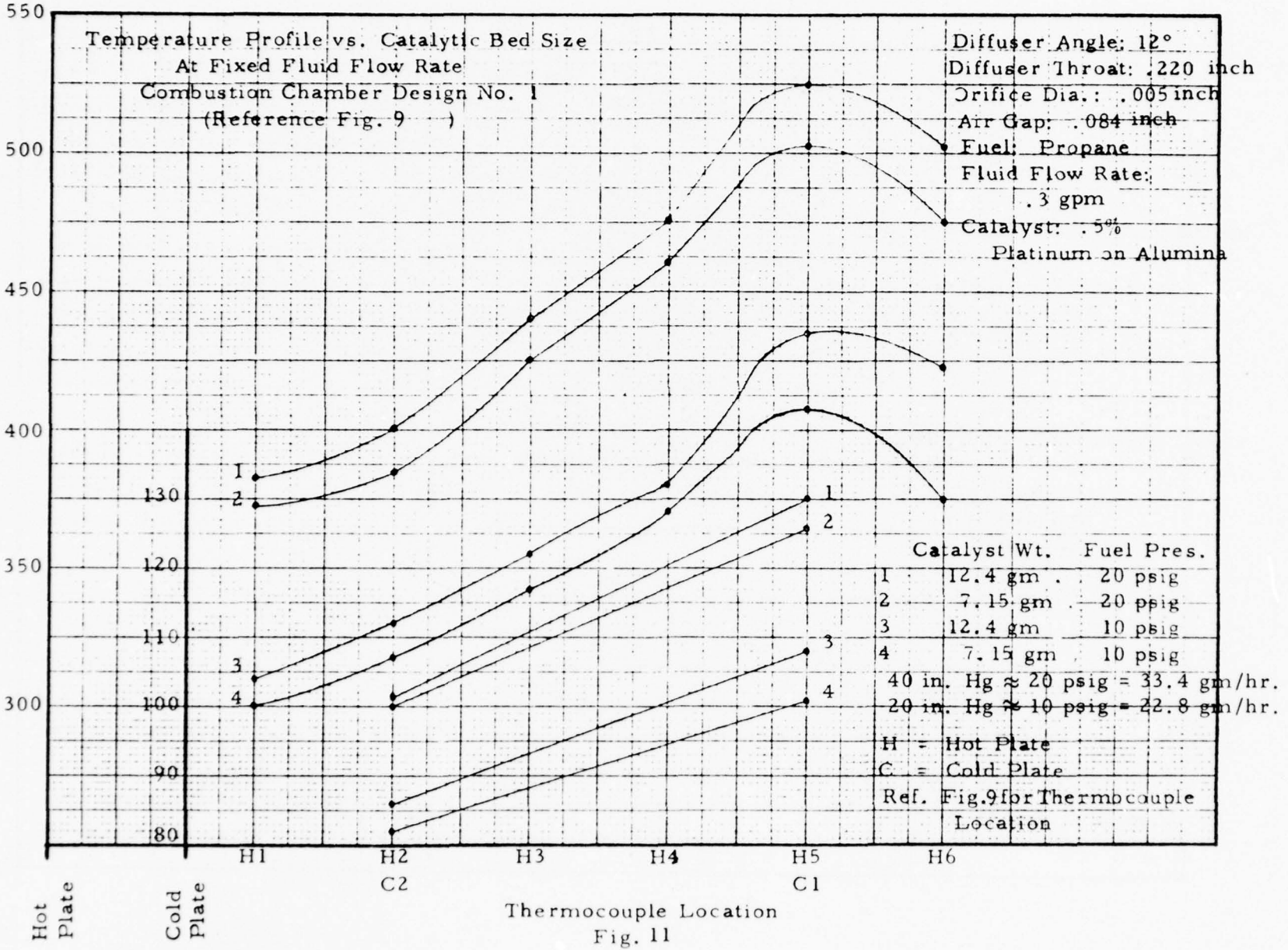

Temperature Profile vs. Catalytic Bed Size
At Fixed Fluid Flow Rate
Combustion Chamber Design No. 1
(Reference Fig. 9)
Diffuser Angle: 12°
Diffuser Throat: .220 inch
Orifice Dia.: .005 inch
Air Gap: .084 inch
Fuel: Propane
Fluid Flow Rate:
.3 gpm
Catalyst: .5%
Platinum on Alumina
Catalyst Wt. Fuel Pres.
1 12.4 gm 20 psig
2 7.15 gm 20 psig
3 12.4 gm 10 psig
4 7.15 gm 10 psig
40 in. Hg ≈ 20 psig = 33.4 gm/hr.
20 in. Hg ≈ 10 psig = 22.8 gm/hr.
H = Hot Plate
C = Cold Plate
Ref. Fig. 9 for Thermocouple Location
Temperature °F
550
500
450
400
350
300
130
120
110
100
90
80
H1
H2
H3
H4
H5
H6
C2
C1
Hot Plate
Cold Plate
Thermocouple Location

Fig. 11

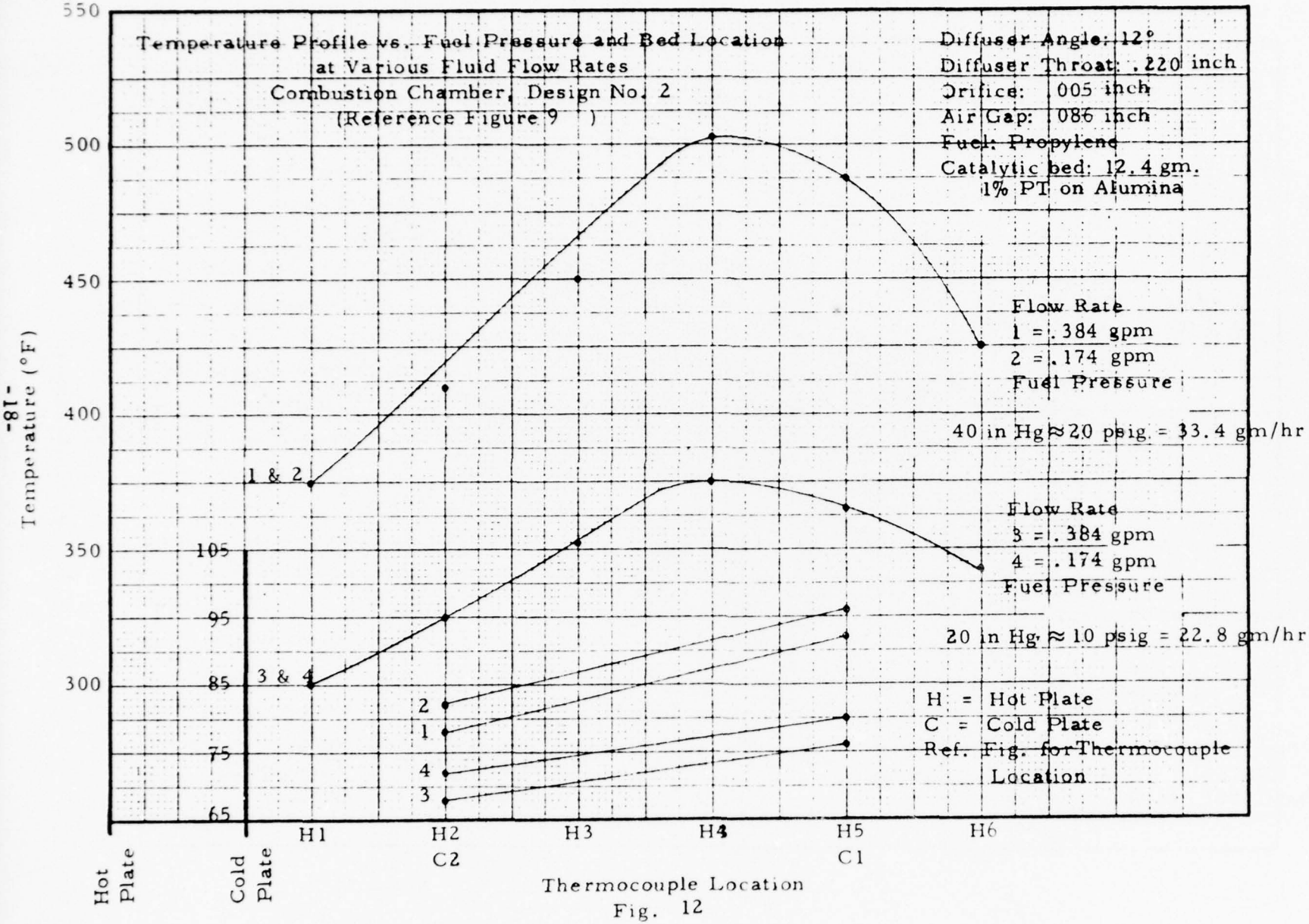

Temperature Profile vs. Fuel Pressure and Bed Location
at Various Fluid Flow Rates
Combustion Chamber, Design No. 2
(Reference Figure 9)
Diffuser Angle: 12°
Diffuser Throat: .220 inch
Orifice: .005 inch
Air Gap: .086 inch
Fuel: Propylene
Catalytic bed: 12.4 gm.
1% PT on Alumina
Flow Rate
1 = .384 gpm
2 = .174 gpm
Fuel Pressure
40 in Hg ≈ 20 psig = 33.4 gm/hr
Flow Rate
3 = .384 gpm
4 = .174 gpm
Fuel Pressure
20 in Hg ≈ 10 psig = 22.8 gm/hr
H = Hot Plate
C = Cold Plate
Ref. Fig. for Thermocouple Location
Temperature (°F)
550
500
450
400
350
300
105
95
85
75
65
1 & 2
3 & 4
2
1
4
3
H1
H2
H3
H4
H5
H6
C2
C1
Hot Plate
Cold Plate
Thermocouple Location

Fig. 12

TABLE 1

RAW DATA FOR TEMPERATURE PROFILE USED TO GENERATE PLOTS IN FIGURES 10, 11, & 12

Ref. Fig.	Fuel Pressure	Fluid Flow Rate	Catalytic Bed Size	Thermocouple Location													
				H1		H2		H3		H4		H5		H6		C1		C2	
				mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F	mv	°F
10 13C	20 psig	.932 gpm	28.5 gms	5.45	272	5.75	284	6.27	308	6.55	521	7.15	347	6.77	331	212	127	1.87	116
10 13C	10 psig	.932 gpm	28.5 gms	6.7	327	7.25	352	7.9	382	8.25	397	8.9	427	8.35	402	2.3	134	1.9	117
11, 13A, 13B	20 psig	.3 gpm	12.4 gms	7.7	373	8.32	401	9.15	438	9.9	477	11.22	529	10.65	504	7.2	130	1.5	99
	20 psig	.3 gpm	7.15 gms	7.61	370	8.34	402	9.07	433	9.77	465	10.80	510	10.00	475	2.10	125	1.50	100
	10 psig	.3 gpm	12.4 gms	6.25	308	6.7	328	7.25	357	7.9	381	9.05	433	8.62	414	1.68	108	1.18	85
	10 psig	.3 gpm	7.15 gms	6.05	298	6.55	321	7.1	345	7.60	370	8.5	410	7.77	375	1.55	122	1.16	82
12 13B	20 psig	.384 gpm .174 gpm	12.4 gms	7.76	375	8.58	412	4.55	455	10.85	512	10.05	477	8.96	430	1.42	96	1.16	82
12 13B	10 psig	.784 gpm .174 gpm	12.4 gms	6.04	297	6.62	325	7.35	357	8.42	405	7.90	380	7.08	345	1.06	80	.90	73

Heat exchanger efficiency depends directly on the heat transfer coefficient "h" and the surface area "A" as evidenced by the well known relationship:

$$\dot{q} = h \; A \; \Delta T$$

where

$\dot{q}$ = heat transferred from the heat exchanger to the water (BTU/Hr)

h = heat transfer coefficient (BTU/Hr - ft^2 - °F)

A = effective heat transfer area (ft^2)

ΔT = temperature difference between fluid and heat exchanger walls (°F)

Clearly, heat transfer into the water can be increased by increasing either h or A. Heat transfer coefficient, h, is a function of Reynolds Number, R_N, determined by the equation:

$$\text{Reynolds No. } (R_n) = \frac{\rho V D}{\mu}$$

where:

ρ = density (LBS/ft^3)

V = speed (ft/hr)

D = Hydraulic diameter (ft)

μ = viscosity of fluid (LBS/hr ft)

The velocity used to determine R_N is calculated by the equation:

$$V = Q/A_c$$

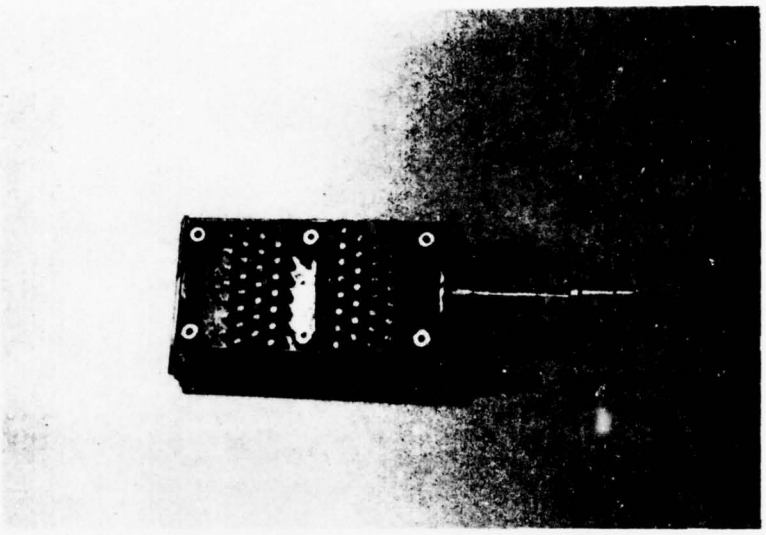
where:

Q = flow rate (ft^3/hr)

A_c = flow channel area (ft^2)

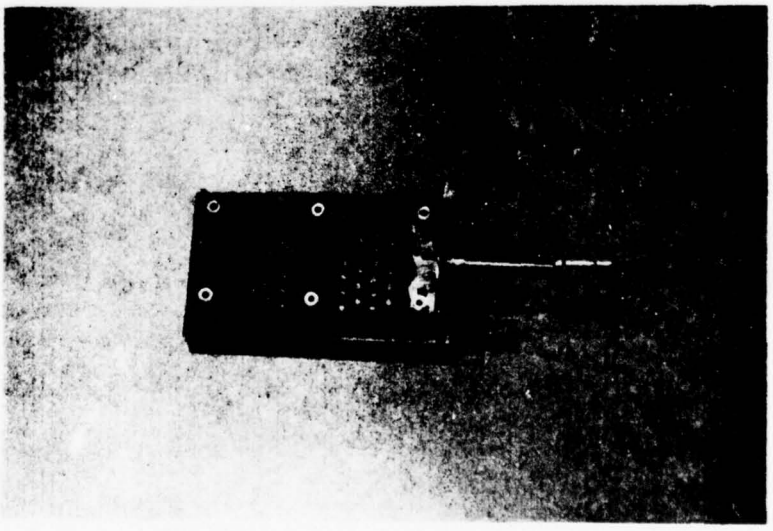
V = average flow velocity (ft/hr)

The test set-up consisted of a combustion chamber, heat exchanger and thermoelectric modules. The modules in this case were used only to simulate actual heat transfer and not for power generation. This was done so the flow rate could be varied independently of the level of power generation by the modules.



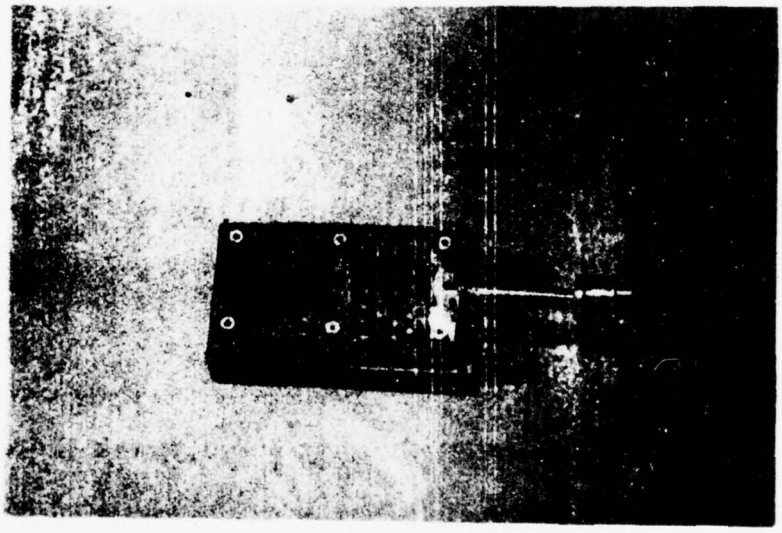
7.15 Gram Catalytic Bed Size

Figure 13a



12.4 Gram Catalytic Bed Size

Figure 13b



28.5 Gram Catalytic Bed Size

Figure 13c

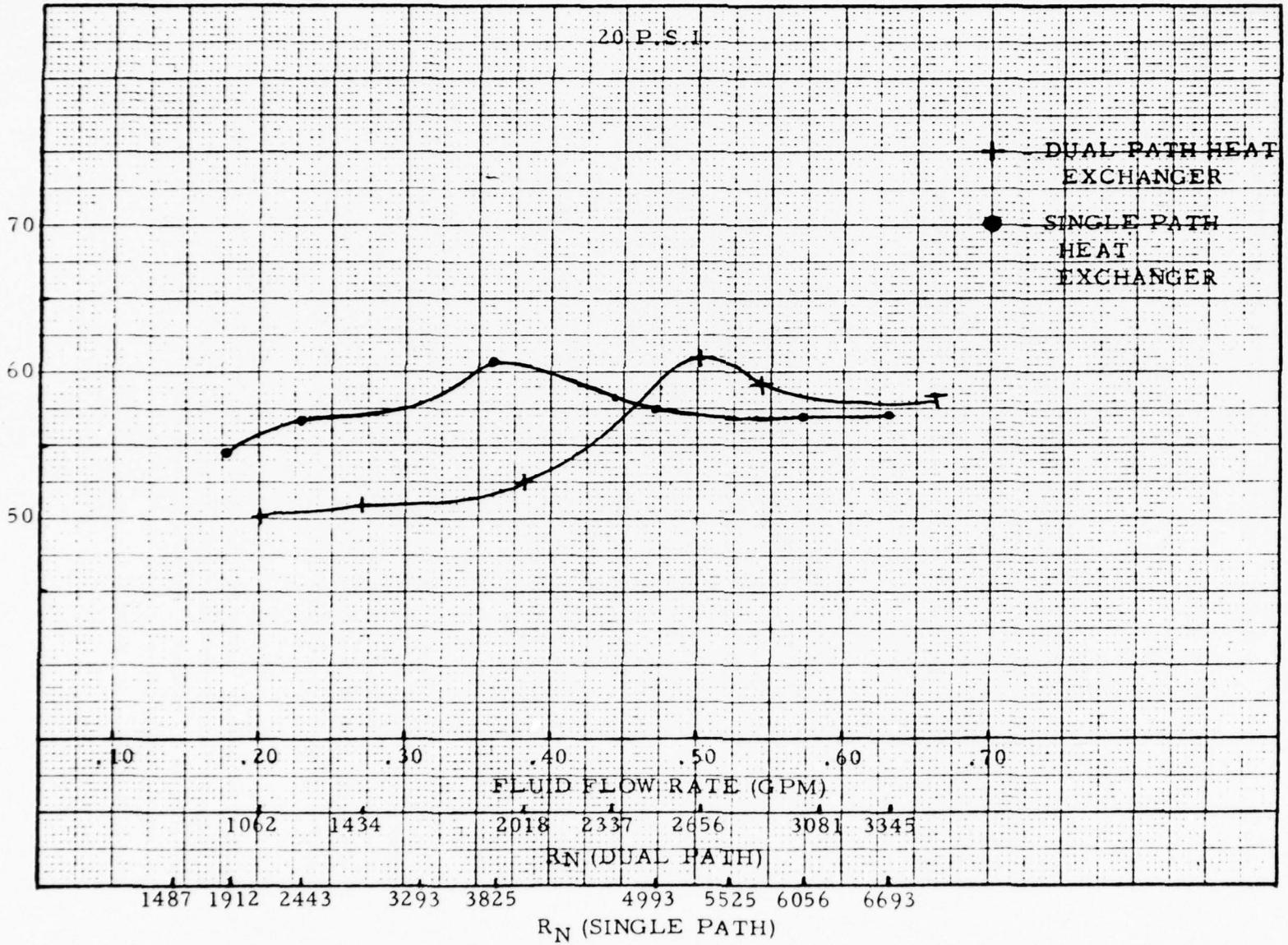

20 P.S.I.
DUAL PATH HEAT EXCHANGER
SINGLE PATH HEAT EXCHANGER
EFFICIENCY (%)
70
60
50
.10
.20
.30
.40
.50
.60
.70
FLUID FLOW RATE (GPM)
1062
1434
2018
2337
2656
3081
3345
RN (DUAL PATH)
1487
1912
2443
3293
3825
4993
5525
6056
6693
RN (SINGLE PATH)

FIGURE 14

Three fuel rates were used. These fuel rates along with their corresponding heat rates are tabulated below.

Fuel Pressure	Fuel Flow Rate	Fuel Energy Content
9.82 psig	27.8 GMS/Hr	1005 BTU/HR
20.13 psig	33.4 GMS/Hr	1470 BTU/HR
30.0 psig	40.6 GMS/Hr	1787 BTU/HR

At each fuel flow rate cooling fluid was circulated through the heat exchanger using a pump driven by an auxilliary power supply. The water flow rate and temperature difference between the fluid into and out of the heat exchanger was measured and the heat into the water was calculated by the equation:

$$\dot{q} = \dot{m} C_p \Delta T$$

where:

$\dot{q}$ = heat into water (BTU/Hr)
$\dot{m}$ = mass flow rate of water (LB/Hr)
C_p = Specific heat of water (BTU/Lb-°F) = 1.0
ΔT = difference between inlet and outlet temperatures (°F)

Figure 14 shows a plot of system efficiency as a function of fluid flow rate showing that efficiency increases as flow rate increases. For each of these flow rates, the corresponding Reynolds number was calculated and plotted along the same axis. Clearly, system efficiency can be increased by increasing the Reynolds number independently of the flow rate. This could be done by decreasing the flow path diameter, thereby, increasing the velocity.

A second generation dual path heat exchanger with a smaller total cross sectional area was fabricated and the test was repeated. These results are plotted in Figure 14 and correlate very well with what was theoretically predicted, i.e., a higher efficiency can be obtained at a lower flow rate by increasing the fluid velocity.

The major drawback with attempting to increase heat transfer by increased heat transfer coefficient "h" is that a disproportionate increase in power to pump the fluid is required to achieve a relatively small increase in flow velocity. This is due to the exponential increase in pressure drop across the system as the flow rate Q or velocity V is increased.

Analysis of the test results obtained from this second generation heat exchanger leads to the conclusion that the greater part of the increase in heat transfer was achieved because of a large increase in the surface area available for heat transfer and not to a large increase in the heat transfer coefficient, h .

Tests indicate that the dual path heat exchanger resulted in a 4% increase in heat picked up by the water. These results are adequate to satisfy the requirements of the design.

Once the results of the performance test were reduced it was possible to compare what effects varying h and A had on the two configurations. The change in the surface area was easily determined by examining the drawings but the values for h were not as easily determined.

This determination was made using the empirical Sieder-Tate correlation of the heat transfer coefficient, h, with Reynolds Number (See Figure 15).

Table 2 shows a comparison of the values of this test on both heat exchangers.

TABLE 2

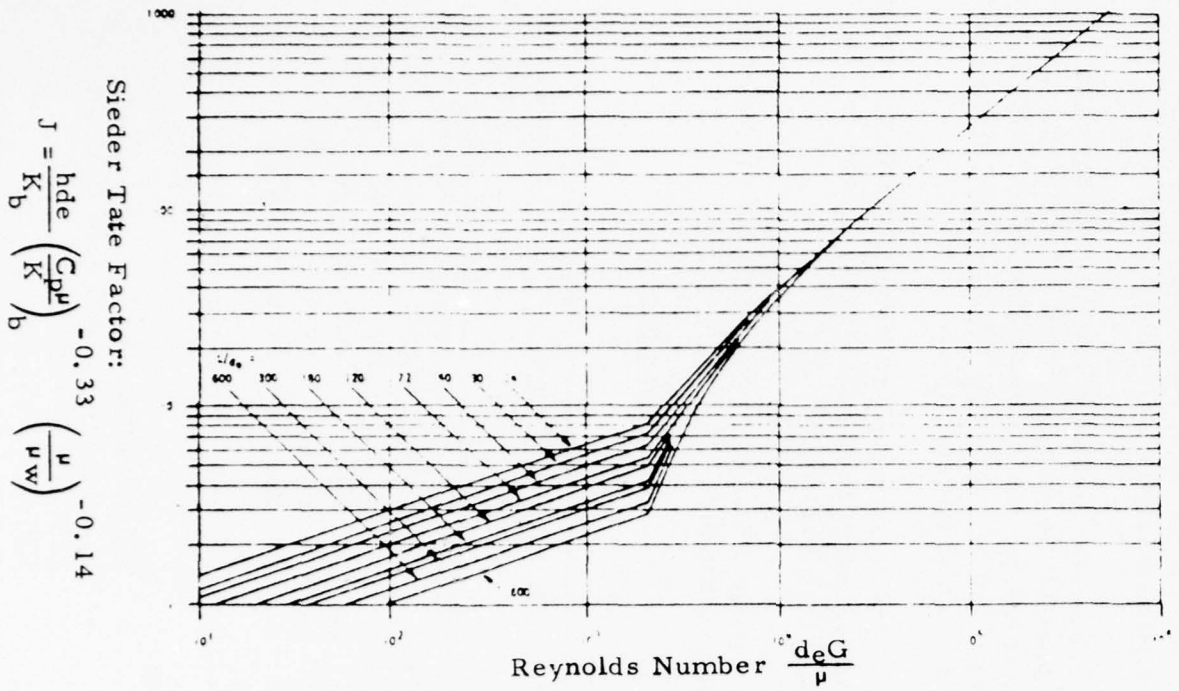
	Heat Exchanger #1 (Single Pass)			Heat Exchanger #2 (Dual Pass)		
Fuel Pressure	10psig	20psig	30psig	10psig	20psig	30psig
Rn	3825	3825	4462	3612	2656	3346
h	251	251	282	238	150	213
A	20	20	20	30	30	30
% Eff.	65.7	65.6	59.5	74.0	65.6	59.5
L/D_e	86.6	86.6	86.6	145	145	145

where:

R_n = Reynolds Number
h = heat transfer coefficient (BTU/Hr-ft^2-°F)
A = Effective surface area (in^2)
%Eff. = Efficiency of unit
L/D_e = Path length/Equivalent Diameter

J = Sieder Tate Factor (Dimensionless)
G = Mass Velocity (lb/hr. ft)
h = Heat Transfer Coefficient (BTU/hr ft^2 °F)
d_e = Equivalent Path Dia. (ft)
k = Thermal Conductivity of Fluid (BTU/Hr ft °F)
Cp = Specific Heat of Fluid (BTU/lb °F)
μ = Dynamic Viscosity of Fluid (lb/hr ft)

Subscript b = Bulk Fluid Property
Subscript w = Fluid Characteristics at wall



Graphical representation of Sieder Tate correlation for the heat transfer coefficient for fluids flowing within tubes, ducts, pipes, and annuli. (Kraus, A. D., Cooling Electronic Equipment, p. 139)

Sieder-Tate Correlation

Figure 15

Examination of these results indicate that the increase in efficiency was due to an increase in heat transfer surface area, rather than a significant increase in h.

Several other tests and analyses were performed on other components of the DAPS. Those of major interest are listed below.

- Fuel/Air Mixture Ratios as a Function of Diffuser Geometry
- DC Motor Evaluation
- Exhaust Gas Concentration

A description of these tests and test results follows:

2.5 Fuel/Air Mixture Ratios as a Function of Diffuser Geometry

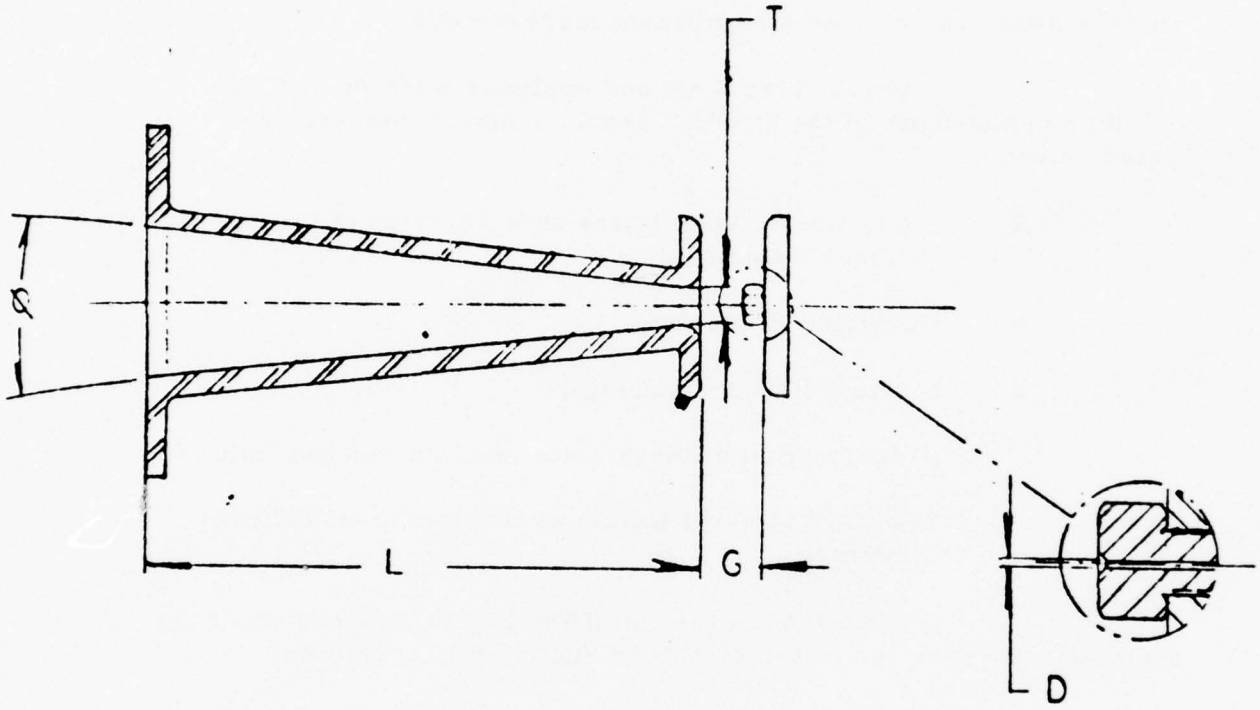
Optimum combustion efficiency is obtained when the air/fuel ratio is in the order of 4-4.5% fuel to air by volume.

This fuel/air ratio is affected by diffuser-orifice geometry and extensive tests were performed to determine the optimum diffuser geometry. Figure 16 defines the parameters affecting fuel/air ratios.

Figure 17 is a plot of the fuel/air ratio vs. the air gap ("G" dimension on Figure 16). Tables 3, 4 & 5 present the raw data from which the plots were generated.

Although the 7° diffuser gives the best results, the length "L" is too long and precludes its use in the system. The 12° diffuser gives satisfactory results and will be used in these systems.

The fuel/air ratios were measured using a Miran Infrared Spectrometer. This device detects a gas concentration by measuring the absorption of this infrared energy as compared to the absorption of the pure gas.



θ = Included Angle

G = Air Gap

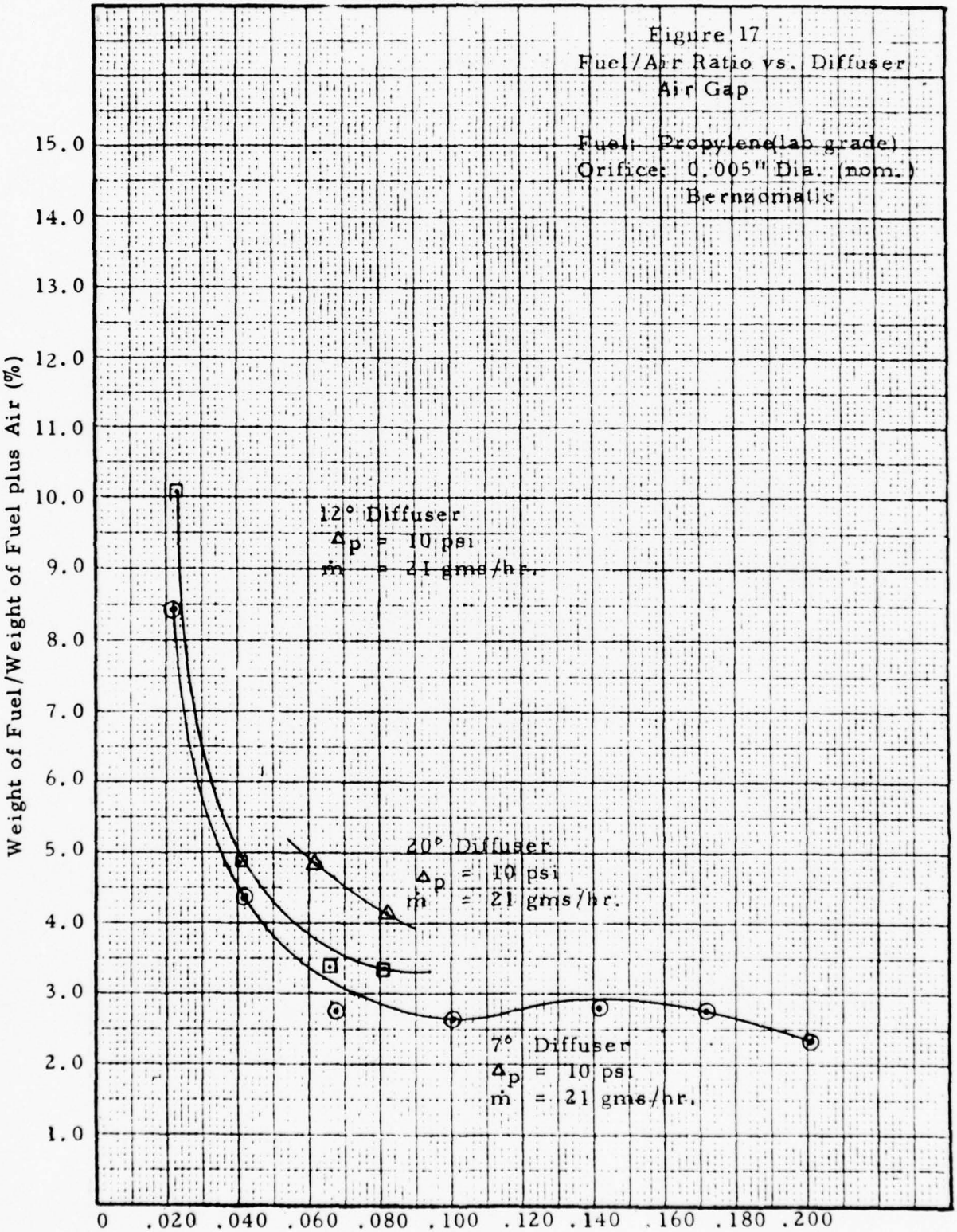
L = Diffuser Length

D = Orifice Dia.

T = Throat Dia.

Orifice - Diffuser Geometric Variables

Figure 16


Figure 17
Fuel/Air Ratio vs. Diffuser Air Gap
Fuel: Propylene(lab grade)
Orifice: 0.005" Dia. (nom.)
Bernzomatic
Weight of Fuel/Weight of Fuel plus Air (%)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
12° Diffuser
Δp = 10 psi
ṁ = 21 gms/hr.
20° Diffuser
Δp = 10 psi
ṁ = 21 gms/hr.
7° Diffuser
Δp = 10 psi
ṁ = 21 gms/hr.
0
.020
.040
.060
.080
.100
.120
.140
.160
.180
.200
Diffuser Air Gap (in.)

Venturi/Diffuser Fuel-Air Mixing Tests

Diffuser: 7°
Orifice: 0.005 " Dia. Nominal - Bernzomatic
Fuel: Propylene,**Laboratory Grade

Air Gap (Inches)	Pressure (In. Hg)	Pressure (psig)	Mass Flow (gm/hr)	Fuel/Air Ratio (%)
0.200	41.2	20.2*	30.7	2.3
	20.7	10.1	21.0	2.3
0.150	40.2	19.7*	30.3	2.7
	20.9	10.2	21.0	2.7
0.124	20.4	10.0	21.0	2.7
0.100	41.0	20.1*	30.6	2.7
	30.7	15.0*	26.1	2.7
	20.5	10.0	21.0	2.6
0.067	20.9	10.2	21.0	2.7
	10.5	5.1	19.4	2.7
0.066	10.5	5.1	19.4	3.0
	4.5	2.2	15.3	3.1
	2.1	1.0	11.3	3.3
	1.2	.6	9.0	3.9
0.041	40.5	19.8*	30.3	4.1
	21.0	10.3	21.0	4.3
0.022	20.7	10.1	21.0	8.4
	10.6	5.2	19.5	8.8
	4.0	2.0	14.8	9.9

* Choked flow (occurs when pressure greater than 25.5 psia or 10.8 psig)

** Commercially available Propane can contain a significant amount of other hydrocarbon compounds which would significantly increase the difficulty of accurate air fuel analysis therefore because the fuel values of commercial propane is within 5% of laboratory grade Propylene was used.

Air Gap Data
7° Diffuser

TABLE 3

Venturi/Diffuser Fuel-Air Mixing Tests

Diffuser: 12°
Orifice: 0.005 " Dia. Nominal - Bernzomatic
Fuel: Propylene, Laboratory Grade

Air Gap (Inches)	Pressure (In. Hg.)	Pressure (psig)	Mass Flow (gm/hr)	Fuel/Air Ratio (%)
0.080	40.9	20.0*	30.5	3.5
	19.7	9.7	21.0	3.3
0.065	41.4	20.3*	30.8	3.5
	20.3	9.9	21.0	3.3
	6.2	3.0	16.9	3.2
	1.5	.7	9.6	3.6
0.040	40.1	19.6*	29.7	5.0
	20.5	10.0	21.0	4.8
	6.4	3.1	17.1	5.0
	2.3	1.1	11.7	5.2
0.022	40.8	20.0*	30.5	9.9
	21.1	10.3	21.0	10.0
	2.6	1.3	12.5	13.0

* Choked flow (pressure greater than 10.8 psig)

Air Gap Data

12° Diffuser

TABLE 4

Venturi/Diffuser Fuel-Air Mixing Tests

Diffuser: 20°
Orifice: 0.005" Dia. Nominal - Bernzomatic
Fuel: Propylene, Laboratory Grade

Air Gap (Inches)	Pressure (In. Hg.)	Pressure (psig)	Mass Flow (gm/hr)	Fuel/Air Ratio (%)
0.081	41.3	20.2*	30.7	4.4
	20.8	10.2	21.0	4.1
	10.8	5.3	19.6	3.6
	5.6	2.7	16.4	3.9
	2.2	1.1	11.7	3.5
0.061	40.0	19.6*	29.7	4.5
	21.0	10.3	21.0	4.8
	10.5	5.1	19.4	4.5
0.061	40.0	19.6*	29.7	25.3**

* Choked flow (occurs when pressure greater than 10.8 psig)

** Combustion chamber exhaust hole closed off - through flow due to leakage only. No measurable pressure in chamber (inches of alcohol).
An attempt was made to measure pressure recovery through the diffuser so that the maximum back pressure against which the air/fuel mixture could be passed could be determined. Alcohol was used due to its lower specific gravity. No significant data was derived from this test.

Air Gap Data
20° Diffuser

TABLE 5

As an example, assume that a 3000 microliter sample of the pure gas, propylene[1] in this case, results in a Miran meter reading of .497 absorption units. A 3000 microliter sample of mixture of unknown concentration of the gas in question can be determined, i.e., .0174/.497 X 100% = 3.5%.

These fuel/air mixtures were measured for a wide variety of diffuser configurations, the best of which was incorporated into the system.[2]

2.6 DC Motor Evaluation

In order to determine which of the many DC motors available would be best suited for the DAPS, tests were performed to determine the pumping rate and power consumption of each type.

For this test, six motors were individually coupled to the same Micro-pump and this pump/motor assembly in turn connected to the combustion chamber equipped with live thermoelectric modules for power. The system was run at three fuel pressures (10, 20 and 30 PSIG) and load voltage, load current, open circuit voltage, and fluid flow rate were measured. This test set-up is schematically represented in Figures 18 & 19.

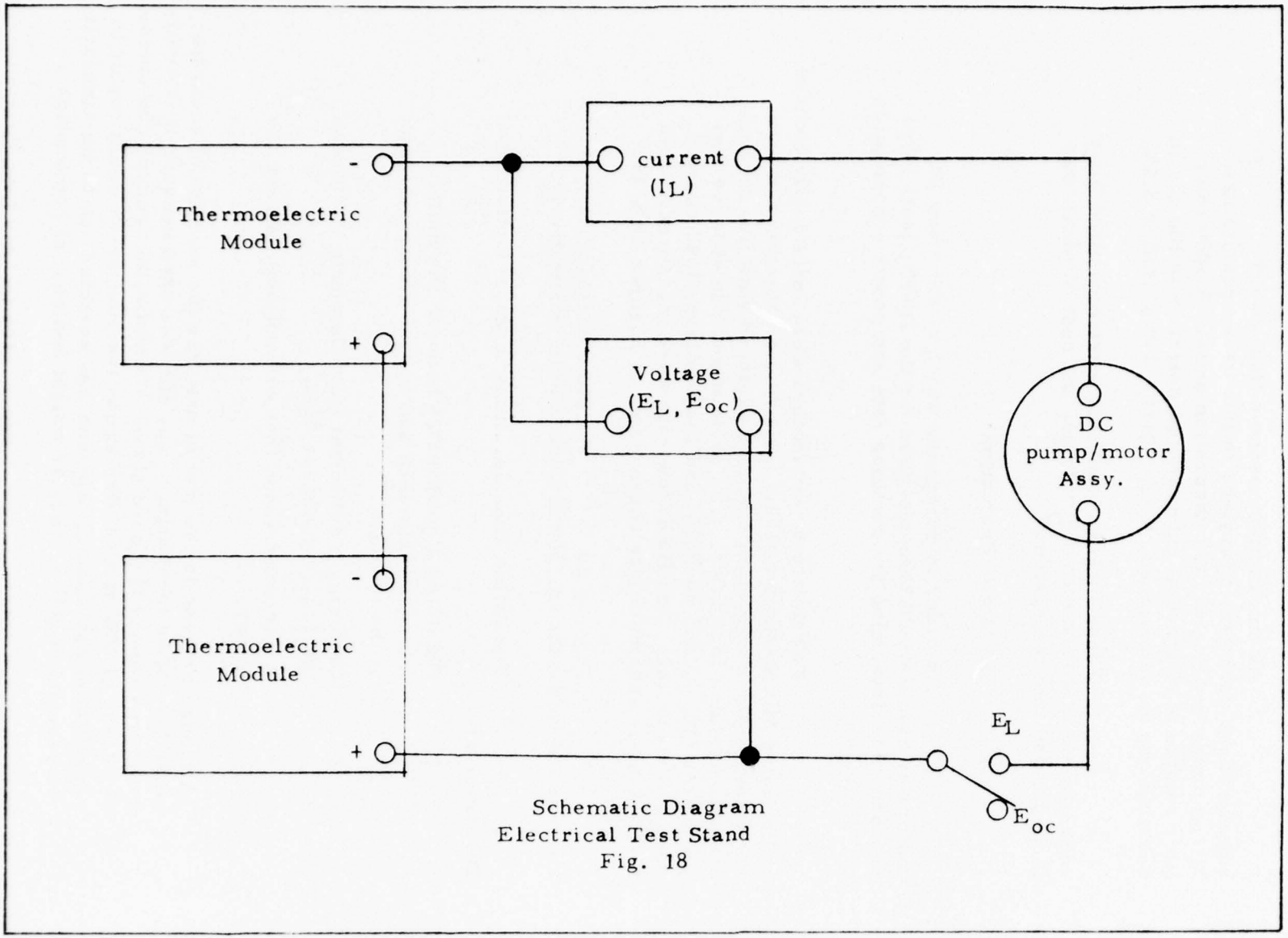
Figures 20 and 21 are plots of flow rate vs. current and flow rate vs. power consumption respectively.

The prime considerations in the selection of a DC motor are:

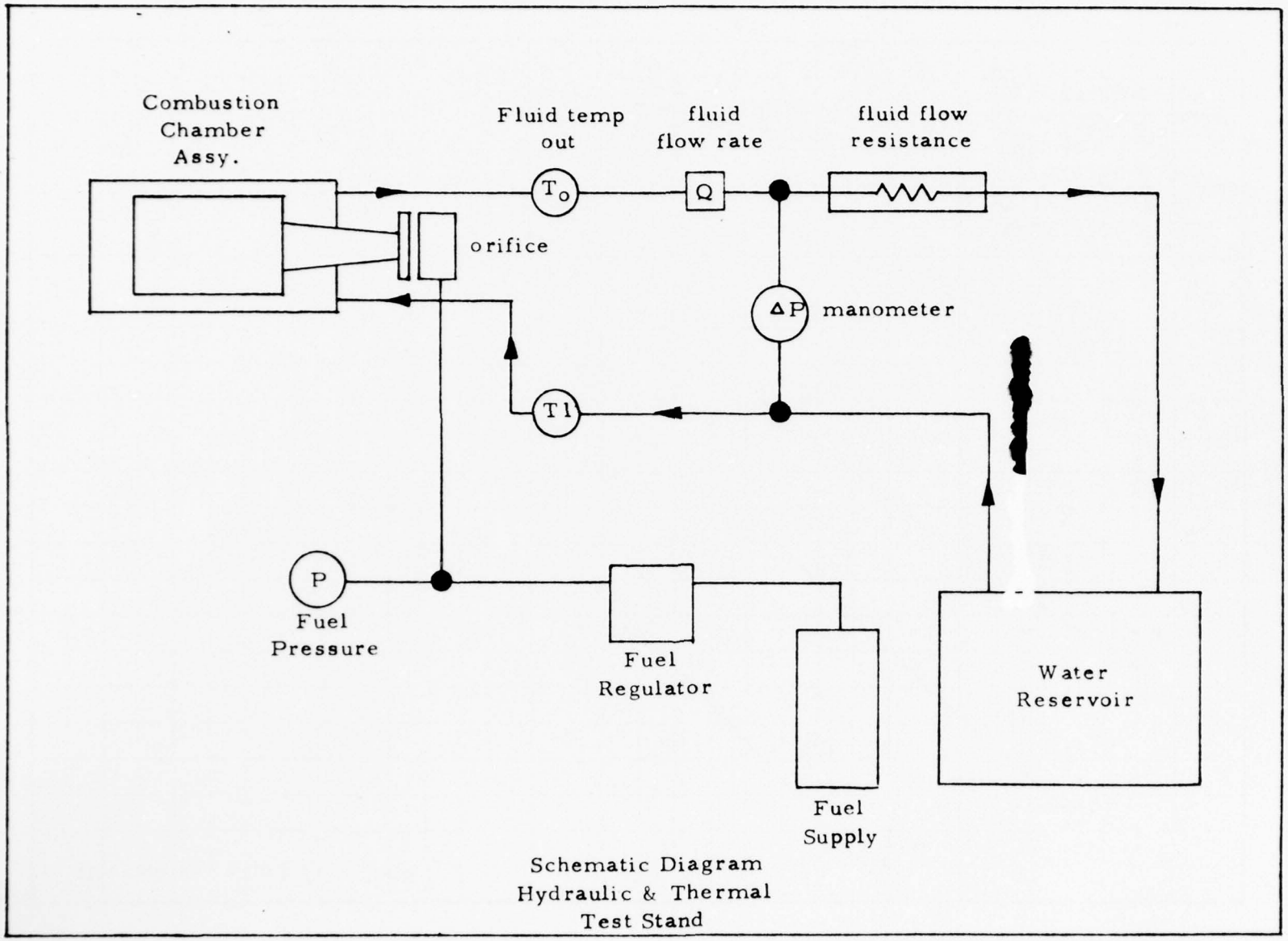
1. Obtaining a good match between the motor internal resistance and the internal resistance of the modules.
2. Obtaining a sufficient fluid flow rate to satisfy the requirement for heat.
3. A current demand that will not over-stress the motor.

[1] Although propane is the fuel of use, for the purpose of accurate fuel/air ratios measuring propylene was used because it is available in a chemically pure state. Commercial propane can contain upwards of 30% other hydrocarbon fraction which would result in unreliable test data. Propylene was selected due to its similarity to propane in both molecular weight and heat of combustion.

[2] 12° Diffuser; .005 in. Dia. orifice; .100 in. Air Gap.



Schematic Diagram
Electrical Test Stand
Fig. 18



Schematic Diagram
Hydraulic & Thermal
Test Stand

Fig. 19

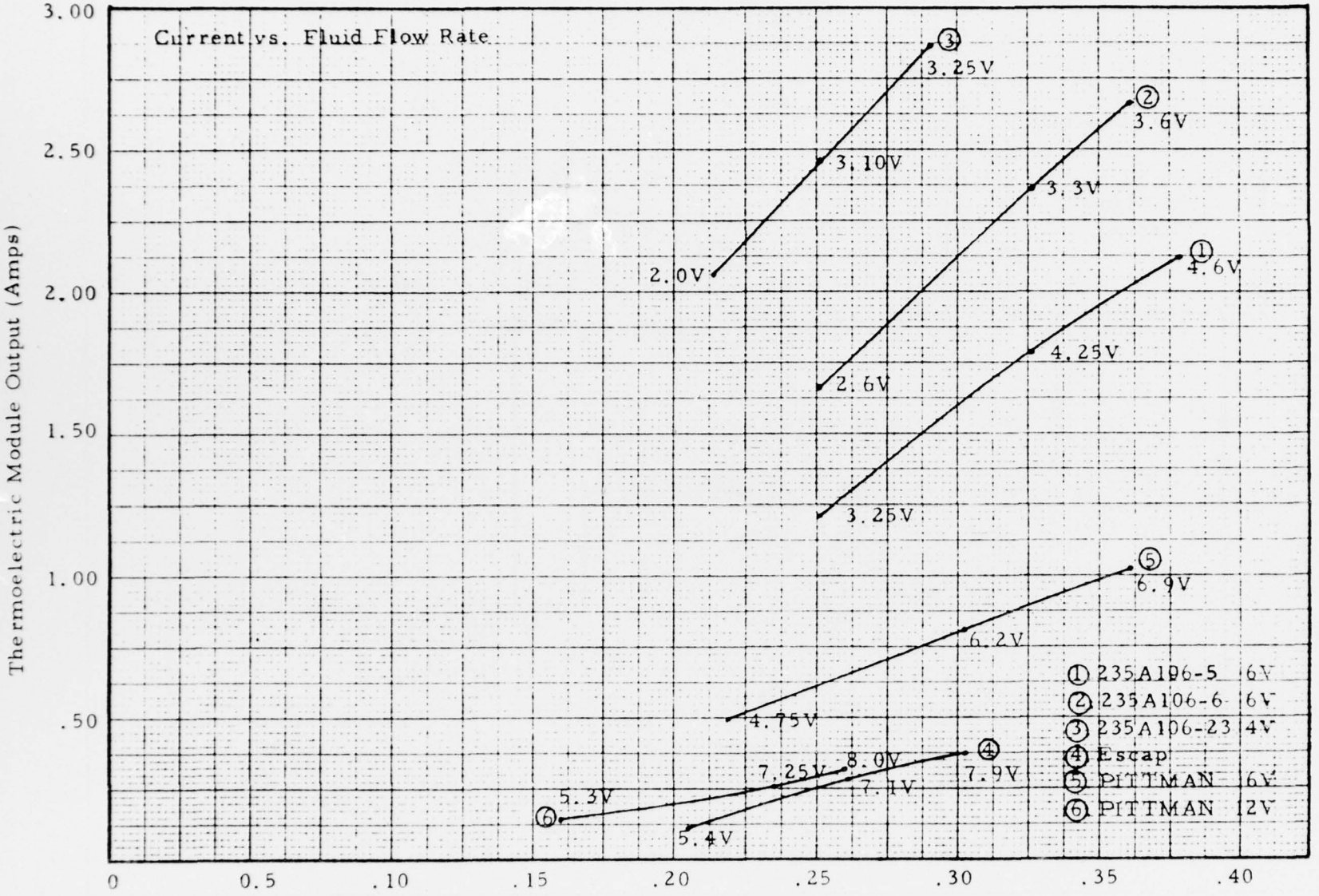

Current vs. Fluid Flow Rate
Thermoelectric Module Output (Amps)
3.00
2.50
2.00
1.50
1.00
.50
0
0.5
.10
.15
.20
.25
.30
.35
.40
Flow Rate (GPM)
3.25V
3.6V
3.10V
3.3V
2.0V
4.6V
2.6V
4.25V
3.25V
6.9V
6.2V
4.75V
8.0V
7.25V
7.9V
7.1V
5.3V
5.4V
① 235A106-5 6V
② 235A106-6 6V
③ 235A106-23 4V
④ Escap
⑤ PITTMAN 6V
⑥ PITTMAN 12V

Figure 20

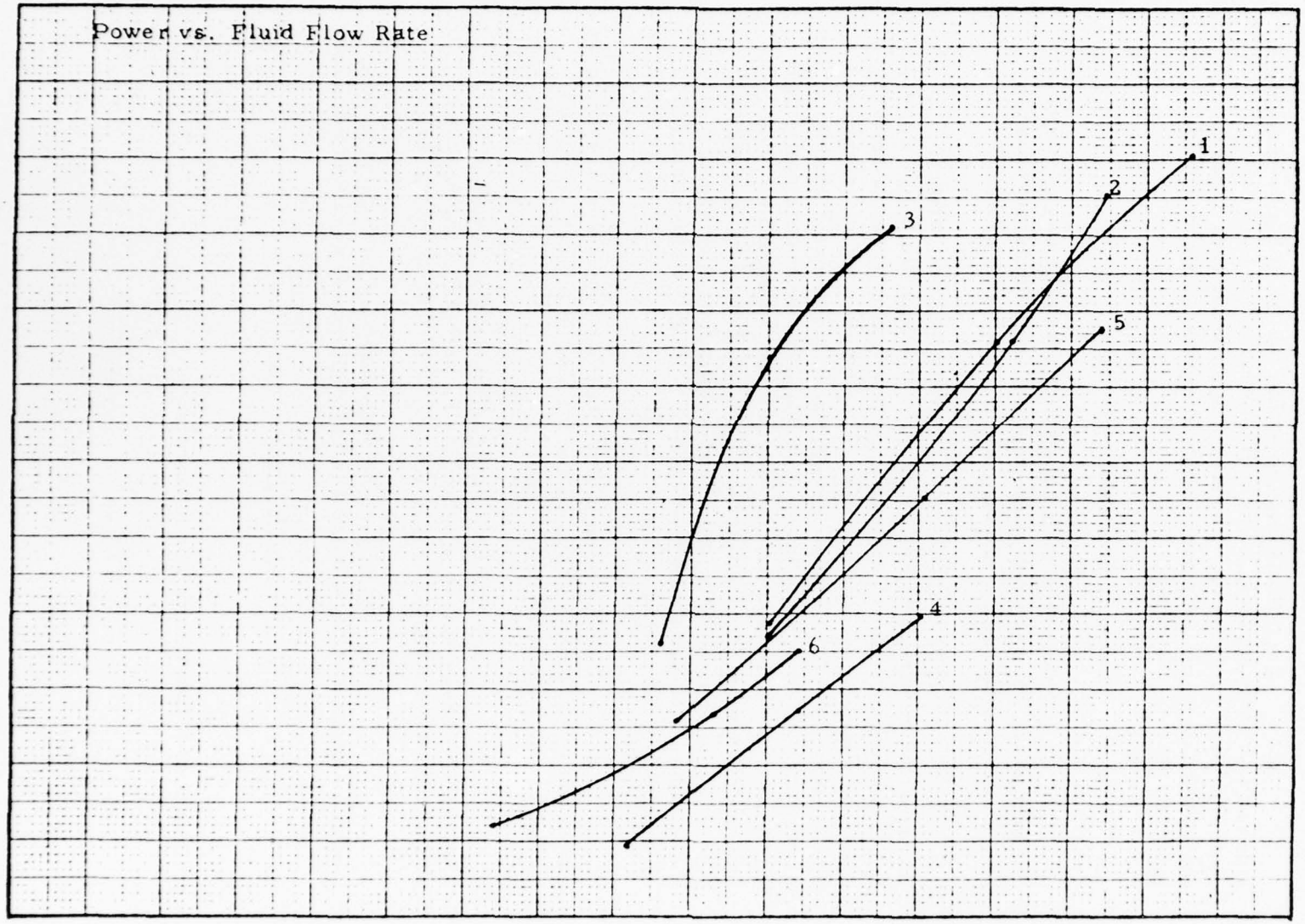

Power vs. Fluid Flow Rate
Thermoelectric Module Output (Watts)
12
11
10
9
8
7
6
5
4
3
2
1
2
3
4
5
6
0
0.5
.10
.15
.20
.25
.30
.35
.40
Flow Rate (Gal/Min)

FIGURE 21

The results indicate that the TRW Globe motor number 235A106-5 gives the best flow characteristics for a realistic current demand. Further analysis indicates that the internal resistance is almost identical to that of the modules, typically five to six ohms.

2.7 Exhaust Gas Concentration

A series of tests were performed on the DAPS exhaust gas. The purpose of the test was to determine what the exhaust gas constituents are and the concentration of each.

The tests were performed using a portable infrared (IR) instrument manufactured by Wilks Scientific Corp., South Norwalk, Conn. The instrument is a single-beam scanning spectrophotometer with solid state electronics and a variable pathlength gas cell (0.75 to 20 meters). The gas cell can be pressurized to 10 atmosphere (150 PSIA) for increased sensitivity although this featurewas not required in our application. The usable IR range for the instrument is from 2.5 to 14.5 u (4000 to 690 cm^{-1}) which can be scanned automatically or manually in three segments. The output of the instrument can be observed on a meter or plotted on a strip chart.

The instrument detects the presence of a particular gas in the exhaust by measuring the amount of energy absorbed by the gas at a specific wavelength.

Each gas has a unique bandwidth in which it absorbs IR energy and by setting the instrument to the specific absorption wave length of a gas its presence can be detected.

The absorption of radiation at a particular wavelength by an absorbing material is given by the Beer-Lambert Law:

$$T = \frac{I}{I_o} = e^{-\alpha lc}$$

or given as a function of absorbance A:

$$A = -\log_{10} T = \frac{\alpha\, lc}{2.303}$$

This data is supplied as theoretical background data. All data is read directly from the meter on the instrument.

Referring to a calibration chart the concentration in parts per million (PPM) can be determined as a function of absorbance, (read directly from the meter or strip chart).

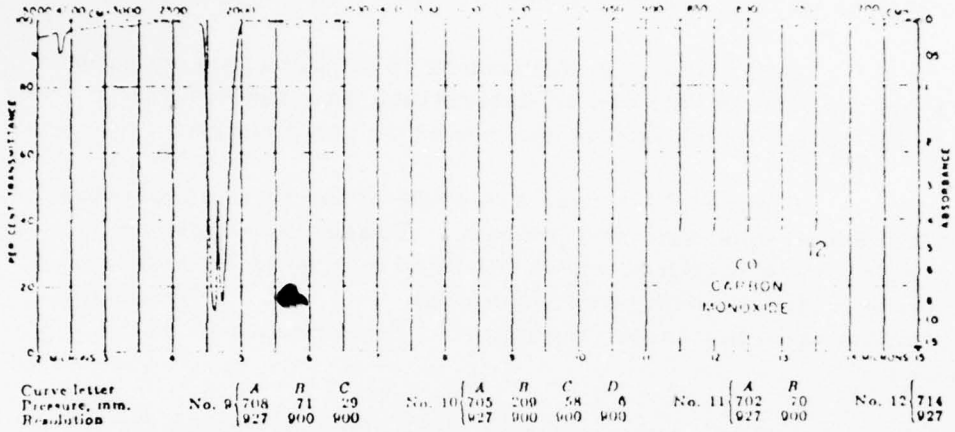
Figures 22 and 23 are plots of the total absorption spectra of carbon monoxide and propane. These plots indicate the particular wave length at which infrared energy is best absorbed. By selecting a strong absorption wavelength that is not adjacent to other compounds in the same frequency, interference can be eliminated.

Based on the spectral plots, calibration charts were generated for carbon monoxide (CO) and propane (C_3H_8) so as to accurately determine the concentration of these two gases in PPM (See figures 24 & 25). Plots of the exhaust gases of each unit were generated at 10, 20 and 30 PSI fuel pressure so as to maintain a permanent copy of the test results and also to facilitate comparing changes in exhaust gas constituents concentration as a function of fuel pressure.

A secondary benefit that could be determined from these plots, over and above determining the concentration of these two potentially dangerous compounds, was an indication of fuel combustion efficiency.

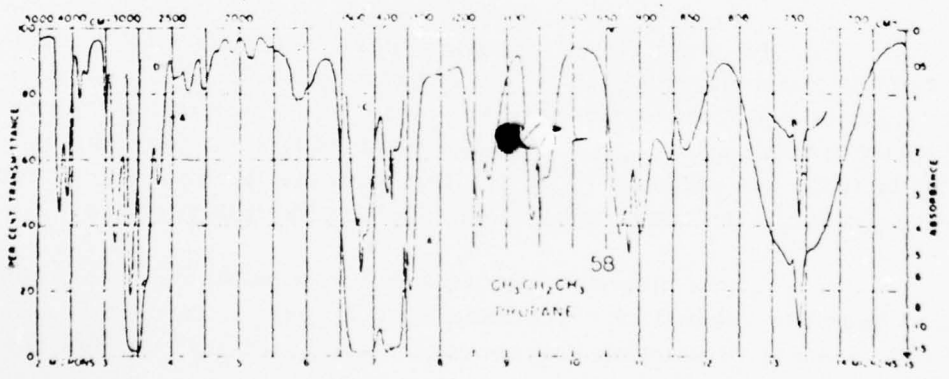
In complete combustion there would only be carbon dioxide (CO_2) and water (H_2O) in the exhaust gas. Because catalytic combustion is not a perfectly efficient method of combustion, some incomplete products of combustion are produced, i.e., carbon monoxide (CO) and propane (C_3H_8). The smaller the concentrations of these products the more efficient is the combustion process.

The concentration of carbon monoxide in the exhaust gas has been the subject of much debate in the past. To clarify this question, a study of exhaust gas concentration build-up rate has been performed.



CO Absorption Spectra

Figure 22



C_3H_8 Absorption Spectra

Figure 23

Figure 24
Carbon Monoxide Calibration Curve
Concentration Vs. Absorption

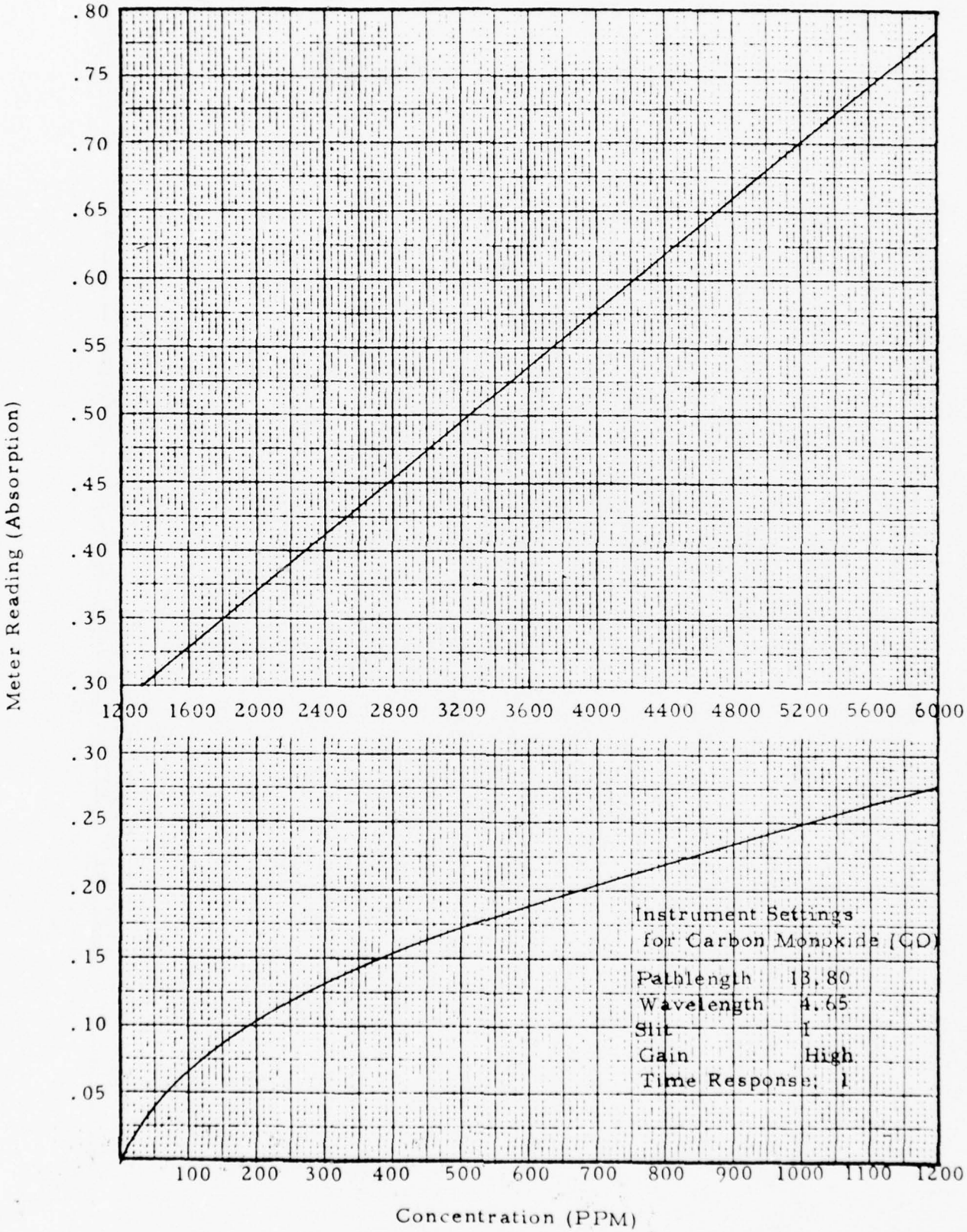
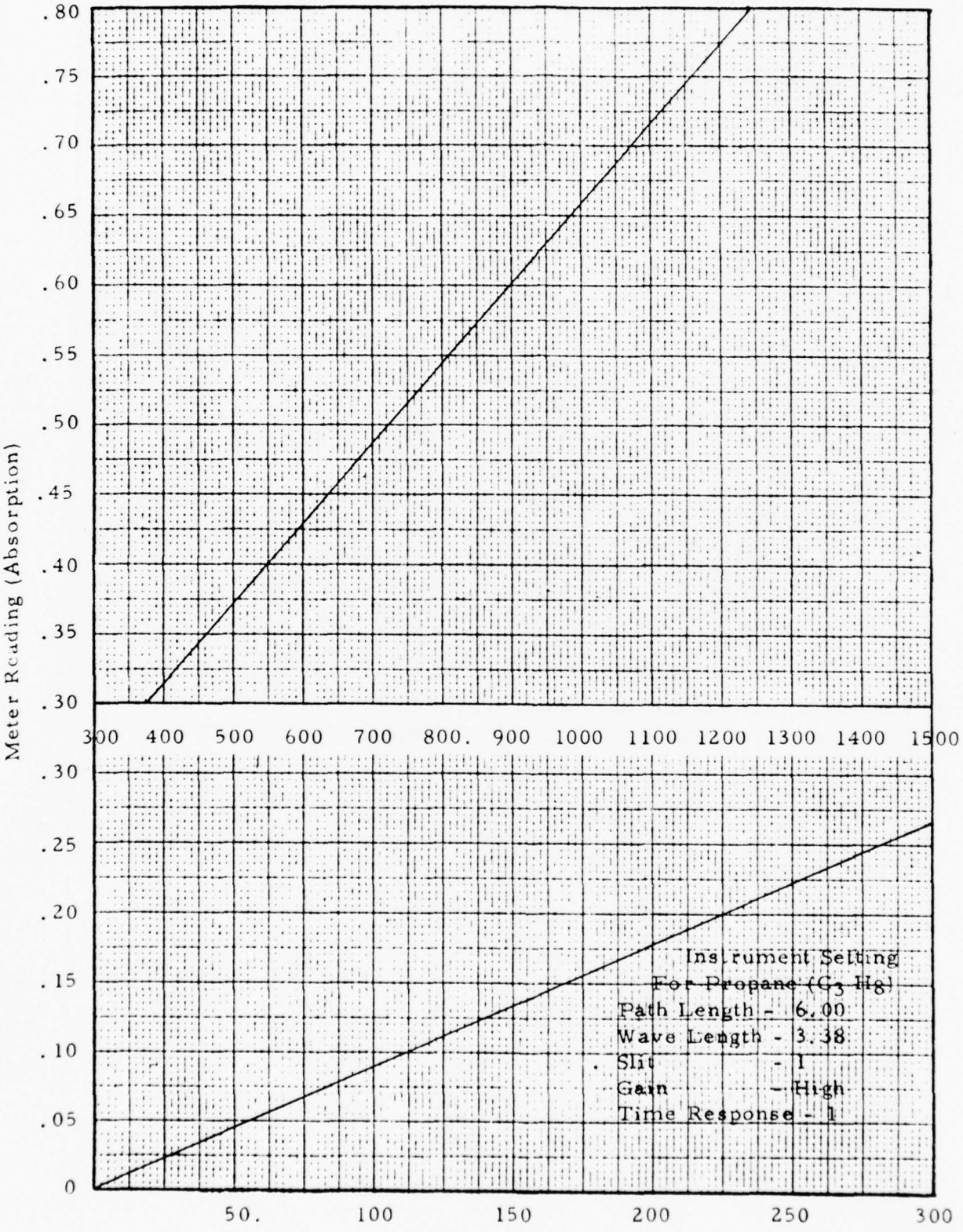


Fig. 25
Propane Calibration Curve
Concentration vs. Absorption



The typical concentrations of CO in the exhaust stream of older DAPS units has been as high as 400 PPM. On first inspection, this may seem high, but when the rate of CO production is considered, the concentration can be viewed with better perspective. Note, however, that CO concentrations in the RSSK-8A DAPS are much lower, i.e. less than 50 PPM. (Page 103)

At a fuel flow rate of 40 grams per hour based on a 20 to 1 ratio of air to fuel, exhaust gas is generated at the rate of approximately 550 grams per hour.

400 PPM of CO based on 550 grams per hour is the equivalent of .22 grams per hour of CO.

An enclosure 6' x 6' x 6' has a volume of 216 ft^3. Air has a density of .074 LBS/ft^3 or 34.1 grams/ft^3. The total weight of air in the enclosure is 216 ft^3 x 34.1 grams/ft^3 = 7365.6 grams. A CO production rate of .22 gms/hr diffused in this chamber would result in a CO build-up rate of $\frac{.22 \text{ gms/hr}}{7365.6 \text{ gms}}$ = 29.8 PPM/Hr which is well within the OSHA recommended safety limits of 50 PPM/hr.

The above analysis is based on a closed chamber in which there is no exchange of air and the building up of exhaust products increases at a constant rate.

In an actual life-raft situation the life-raft will not be sealed tightly and the raft will also be flexible. These two factors will allow the life-raft to "breathe". This breathing results in an exchange of air that will be induced by the airman motion inside the raft and/or by wave motion. These factors preclude the possibility of an excessively high concentration of exhaust gas build-up inside the raft.

3.0 DAPS DESIGN

3.1 RSSK-8A DAPS Requirements

3.1.1 General Requirements

The Downed Airman Power Source (DAPS) must integrate functionally with and enable the proper operation of all interfacing elements of the modular Downed Airman Integrated

Survival system. These interfacing elements are the airman and his clothing most specifically a liquid loop thermal garment, his parachute, and encapsulating liferaft, and the ejection seat kit (into which are incorporated an emergency descent oxygen supply and miscellaneous survival kit elements, DAPS and the liferaft).

The DAPS must heat and circulate heated fluid through a full length liquid loop garment worn by the airman. Operation is airman initiated upon entry to the water in his liferaft. Subsequent thereto DAPS must provide this principle function for up to twenty-four hours. An additional subsidiary function of DAPS shall be electrical power generation for operation of survival communications equipment.

In addition, the DAPS System must be interchangeable among the seat kits as manufactured by the three (3) major suppliers with minimum modification or rework to the kits.

These suppliers are:

(1) Scott Aviation

(2) Rocket Jet Division of American Safety Flight System, Inc.

(3) East/West Industries, Inc.

3.1.2 Specific Requirements

3.1.2.1 System Operation

Operation

(a) Thermal output shall be initiated by the airman.
(b) A minimum capability for five re-starts of operation shall be provided. No resort to auxiliary re-start means shall be permitted in meeting this requirement.
(c) The airman will be provided means to modulate DAPS thermal output in the minimum range of 100 to 300 watts.
(d) Emergency operation must be possible when sea water is used in the fluid loops of DAPS and the airman's liquid loop thermal garment.

Controls

Those necessary to provide Operations as indicated above are required. Visual indicators to facilitate airman in-raft operation may be included.

Ignition

A ceramic piezoelectric crystal generates a high voltage spark when struck by a spring loaded button. The spark ignites the fuel/air mixture. No batteries shall be used in the system. A built-in restart capability shall be provided.

Temperature of Fluid at DAPS Outlet

The temperature of fluid exiting DAPS shall be adjustable by the operator.

3.1.2.2 Design

Weight

The DAPS less fuel supply and liquid umbilicals shall weigh three pounds or less.

Configuration

The DAPS with a minimum six (6) hour fuel supply @ 25 GMS/hr shall fit within the lid of a Scott Aviation, Rocket Jet Engineering, or East/West Industries RSSK-8A. Components currently mounted within seat kit lids must be retained without their relocation to accommodate the DAPS.

3.1.2.3 Performance

3.1.2.3.1 Thermal

Thermal Output

(a) DAPS shall supply a minimum of 250 watts of thermal output from an ambient air source for a minimum of twenty-four hours, one time, following a separation of the airman from the aircraft in any emergency abort situation.
(b) DAPS shall be capable of supplying a minimum of 6000 thermal watt-hours of output from an ambient air supply over a twenty-four hour period, one time, following performance as in (a) above.

Fuel Consumption Rate

At a fuel rate of 25 grams per hour of propane, sufficient fuel shall be available to allow DAPS Operation for six (6) hours. At this fuel flow rate a minimum of 250 thermal watts shall be supplied to the airman.

Fuel

Propane shall be the fuel of use; a minimum of 150 grams shall be storable in the seat kit lid.

Combustion Products

These shall consist of water vapor, carbon dioxide, and non-toxic concentrations of other products of incomplete combustion.

Insulation

System components shall be insulated as necessary to obtain specified performance. Insulation shall insure against hot spots that may cause injury to the airman, his life raft and other interfacing items.

3.1.2.3.2 Hydraulic

Hydraulic Output

DAPS shall provide the necessary fluid flow rate to deliver required thermal outputs at an airman's liquid loop garment inlet maximum temperature of 110°F. The foregoing requirement must be met when the liquid loop garment pressure drop at 0.25 gpm flow rate does not exceed five (5) psi at normal operating temperature with water the fluid of reference.

Fluid

The fluid stored in DAPS will be of a type to prevent freezing at low temperature, vaporization at high temperature, and corrosion of interfacing surfaces.

Disconnects

The DAPS, as mounted in the seat kit, must interface external fluid loops via manually operated quick disconnects. In addition to performing the foregoing functions:

(a) Quick disconnects will not leak fluid out or admit air to the fluid subsystem in an amount detrimental to system operation.
(b) Quick disconnects will be light weight, low volume, standard parts of materials compatible with liquid loop system fluids.
(c) The quick disconnect to interface the liquid loop garment to the DAPS umbilical shall be provided as GFE.

3.1.2.3.3 Electrical

Electrical Outputs

DAPS connectors shall be readily accessible and protectively capped in the as-stored condition. Each shall be connectable to but one specific, identified, auxiliary load.

Auxiliaries

Fuel required in auxiliaries operation shall be an allowable addition to fuel required to meet specified thermal outputs.

Survival communications transceiver input power shall be within specified limits when DAPS thermal output is in the range 150 to 300 watts. Specified limits are:

(1) Output voltage 12 volts ± 5 percent when load is varied from 10 ma to 100 ma and
(2) Ripple voltage 150 mv peak to peak

3.1.2.4 Storage

Exhaust and Air Inlet Ports

These shall be capped in the unit as-stored condition to prevent introduction of foreign matter. The exhaust shall be vapor sealed from the unit insulation to prevent condensate degradation of insulation.

3.1.2.5 Environment

The system shall be designed to withstand the following conditions:

(a) Pressure Altitude Non-operating; sea level to 100,000 ft. Operating, sea level to 5,000 ft.
(b) Hydrostatic Pressure - Non-operating without leakage; 30 psia.
(c) Operating Ambient Temperature - in air; 20° to plus 80°F.
(d) Storage Ambient Temperature - -20°F to + 125°F.
(e) Shock - Operable after drop of ten (10) feet to concrete surface, all axes, as mounted in seat kit. Operable after drop of four (4) feet to concrete surface, all axes, as packaged for delivery.
(f) Other - Consider that aircraft vibration spectrum will be imposed in period preceeding DAPS use. Consider that relative humidity will be high in in-raft operation and air required for combustion will be salt laden; unit will be subject to salt spray.

3.2 Final DAPS Configuration

As a result of the design analysis as described in Section 2.0 of this report a final RSSK-8A DAPS design was determined. Figure 26 is a photograph of the heater assembly with cover in place while figure 27 is a photograph of the unit with cover removed. Figure 28 shows the DAPS heater with fuel system as mounted in the Scott Kit.

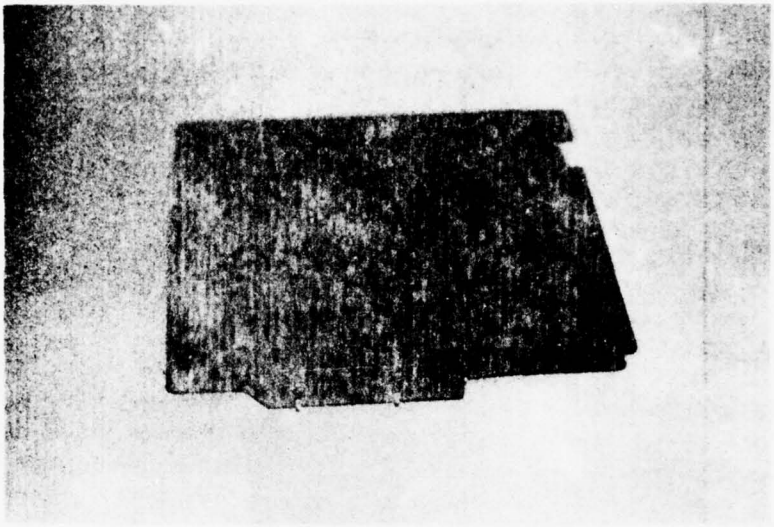
The major components called out on the photograph of Figure 27 are listed below:

(1) Pump/motor assembly
(2) Combustion chamber assembly
(3) DC-DC converter
(4) Fuel regulators
(5) Fluid Manifold
(6) Fuel input connector

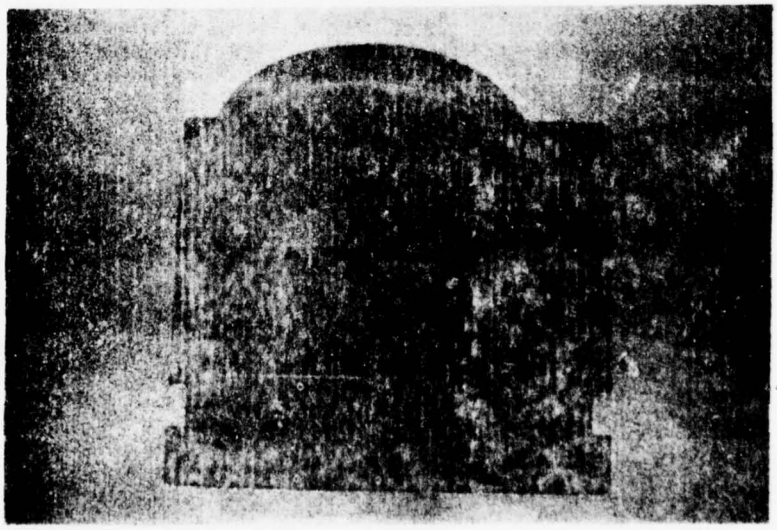
A description of these major components together with their operating characteristics are presented below:

3.2.1 Pump/Motor Assembly

The pump is manufactured by Micro Pump Corporation Part No. 08-00-103. It is a positive displacement gear pump comprised of a delrin plastic housing with teflon gears. It requires no dynamic seals as the drive mechanism utilizes a magnetic drive requiring only static seals. The pump is capable of pumping approximately 30 gph at 0 psi head.

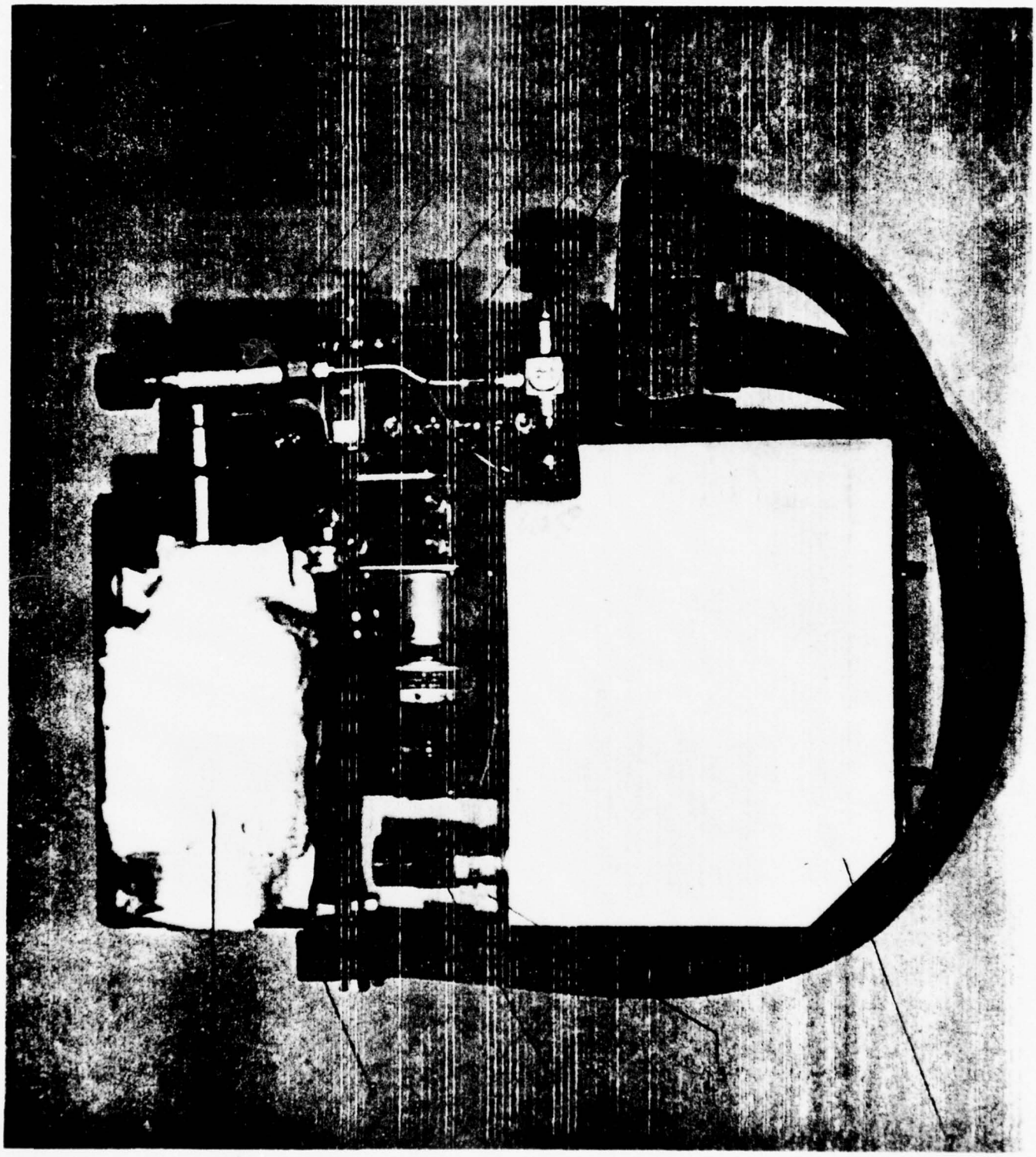


DAPS with Cover
Top View



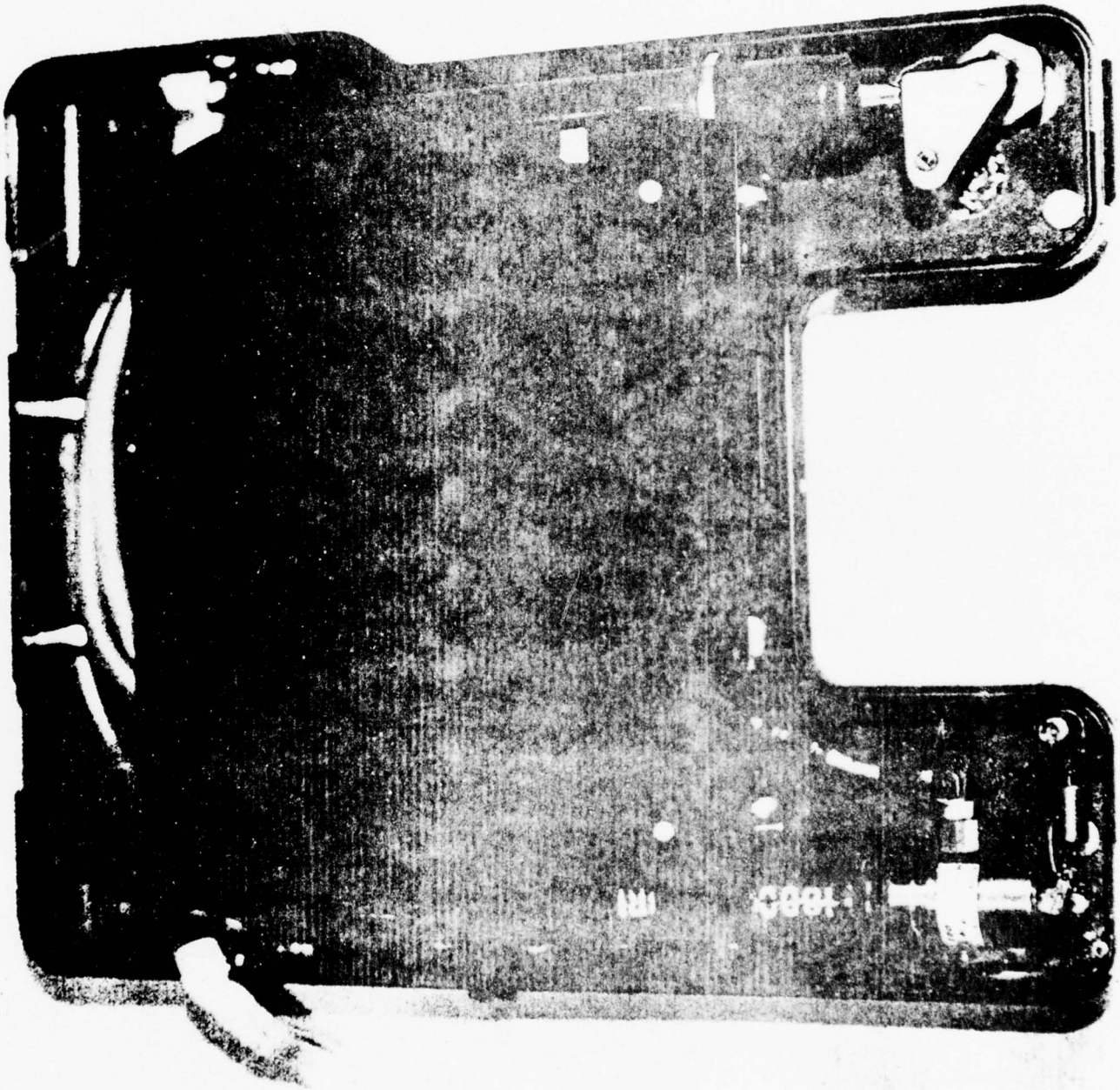
DAPS With Cover
Bottom View

Figure 26



DAPS Without Cover

Figure 27



DAPS In Seat Kit

Figure 28

The pump is coupled to a TRW Globe 6 VDC motor (Part No. 235A106-5) with a no-load speed of from 12000 RPM to 14000 RPM.

This pump/motor combination is capable of pumping .25 GPM (15 GPH) against a 4 PSI head.

3.2.2 Combustion Chamber Assembly

The combustion chamber assembly consists of a pin plate, 2 thermoelectric modules, heat exchanger, combustion chamber housing and cover, diffuser and catalyst, alignment board, exhaust duct, igniter electrode and orifice assembly. (See Figure 39)

Fuel is admitted to the unit through a precision .005 inch orifice manufactured by The Lee Company (Part No. JETA1872240H). The orifice assembly has a filter in front of the orifice to prevent blockage from impurities in the fuel. The gas leaves the orifice and enters the diffuser where the velocity head is converted to pressure head thereby allowing the gas to diffuse through the catalytic bed. The diffuser also is responsible for obtaining the proper air fuel mixture.

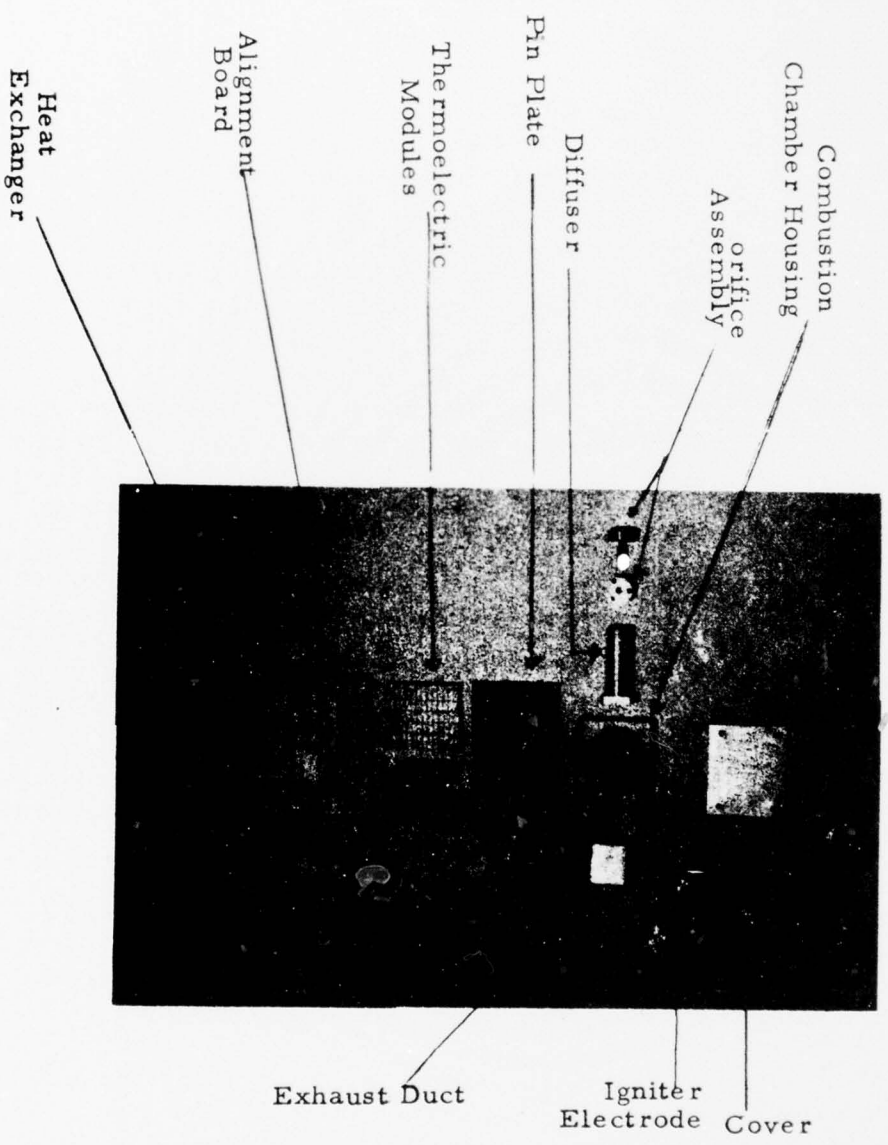
The air-fuel mixutre contacts the catalytic bed and reacts, thereby liberating its stored thermal energy.

The catalyst is 1% platinum deposited on an alumina matrix. The catalyst is manufactured by Matthey Bishop Corporation. The advantage of using platinum catalyst lies in the fact that the stored energy is released at a slower rate resulting in a lower combustion temperature.

The liberated heat is picked up by the pins in the pin plate and conducted through the thermoelectric modules.

These modules are made of bismuth telluride semi-conductor material. Each module is capable of delivering 5.5 watts of electrical power at 2.5±.25 volts provided a hot junction temperature of 270°C and cold junction temperature of 70°C is maintained.

The heat liberated in the catalytic reaction is conducted through the modules to the heat exchanger where it is picked up by the circulating heat transfer fluid and pumped to the man.



Exploded View of Combustion Chamber
As Delivery Under Contract N62269-76-C-0239

Figure 29

3.2.3 DC-DC Converter

The DC-DC converter (output converter) manufactured by Vintor Electrical Associates, Part No. CV2-12 accepts an input voltage of between 2.6 and 5 VDC and produces a regulated 12 VDC ± 5% at 100 milliamps. This output can be used to operate an emergency transmitter or Xenon flasher. The connector is capable of being wired either with a floating ground or common ground and is wired into the system such that there is power consumption only when a load is attached to the DAPS.

This is accomplished by completing the input circuit of the DC-DC converter at the time of connecting the load (See Figure 30).

The output connector is a four pin bulkhead mountable type manufactured by Bendix Connector Corporation, Part No. PT02E-8-4S.

3.2.4 Fuel Regulator

The fuel regulator is manufactured by Clippard Controls Corporation, Part No. MAR1-NR. The major function of the regulator is to step down the vapor pressure of the fuel in the tank to a pressure compatible with the DAPS design.

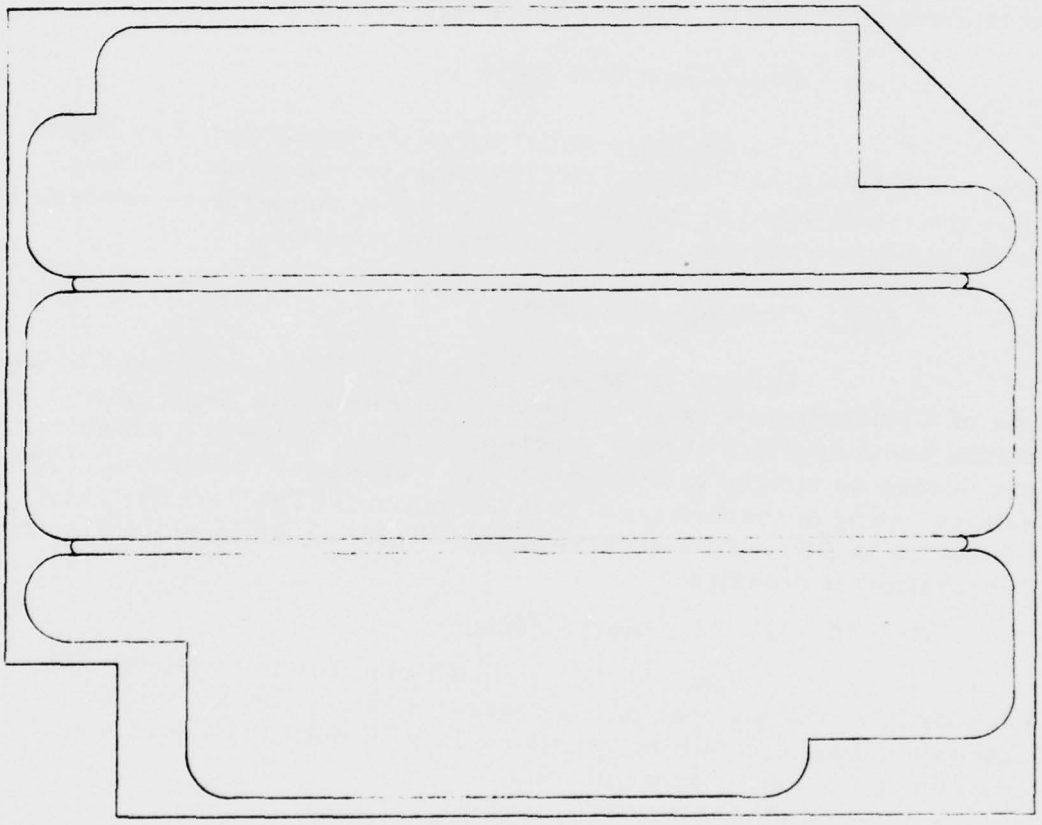
3.2.5 Fluid Manifold

The fluid manifold consists of an aluminum block to which have been dip brazed aluminum tubing.

The manifold serves the function of eliminating difficult flexible tubing lines which require additional space for runs and are also susceptable to kinking and rupture. The manifold block also serves the function of a strain relief on the internal fluid runs.

3.2.6 Fuel Shut off Valve

Pressure regulators although capable of positive shut off are not designed for this application for long periods of time. Because of this, a positive shut off valve has been incorporated into the RSSK-8A DAPS design.



Cell Structure of
RSSK-8A
Fuel Tank

Figure 30

The valve selected is manufactured by Nupro Company. The part number is B-2JA and it has a pressure rating of 600 PSI and an operating temperature range of -40°F to 300°F.

3.2.7 Fuel Tank

The fuel tank, as stated previously, is integrally mounted within the RSSK-8A housing. The design is described in Section 2.3.1 of this report. Figure 30 shows the internal structure of the fuel cells.

3.2.8 Pressure Relief Valve

The pressure relief valve is manufactured by Nupro Co., Part #A-4CPA2-150DC. It is pre-set to release at 250 psig. This pressure would be reached if the ambient temperature corresponds to the maximum storage as specified by the contract.

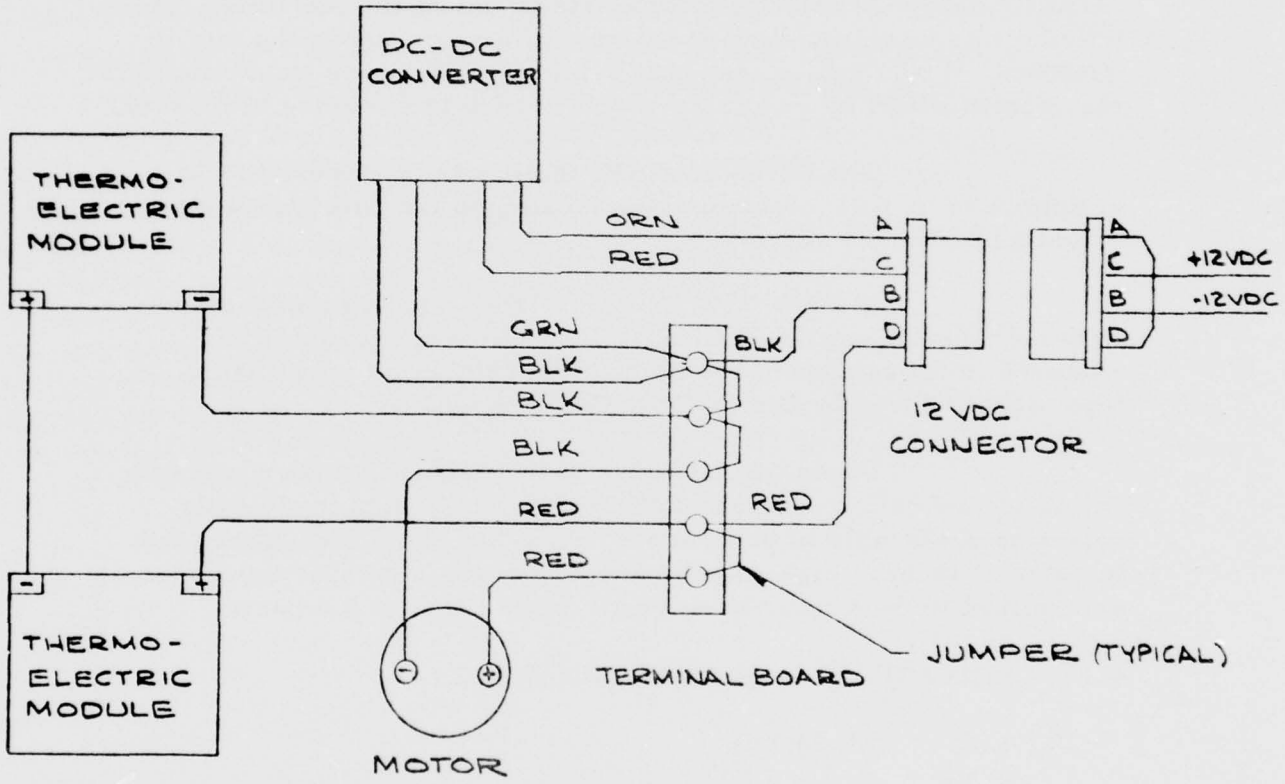
3.2.9 Piezoelectric Starter

Ignition of the air fuel mixture is accomplished by the use of a piezoelectric igniter. Ignition is initiated by depressing a spring loaded hammer which strikes a ceramic crystal releasing a high voltage arc across an air gap through which the fuel mixture is flowing. The voltage rating of the device is 13 KV minimum. The part number of the device is EF1-AF27 and it is manufactured by Matsushita Electric Corporation of America.

3.2.10 12 VDC Output Connector

A 4 pin, 12 VDC output connector is supplied with each DAPS. The purpose of the connector is to make available a convenient way of obtaining regulated 12 VDC output to operate an emergency flasher or transmitter.

The connector is also used to activate the converter which is normally in the off function. This is accomplished by placing a jumper across two of the pins. This jumper completes the input circuit to the connector and simultaneously gives 12VDC output (Fig. 31). This procedure eliminates chances of DC-DC converter damage and system failure should the converter short out internally. The connector used is manufactured by Bendix Connector Company and is part No. PT 02E8-4S. The mating connector attached to the load (i.e. flasher or transmitter) is part No. PT06E8-4P.



DC-DC Converter Wiring Diagram

Figure 31

3.3 Interface of DAPS System With the Seat Kit

The method of attachment consists of four relatively equally distributed snap slides mounted on the underside of the DAPS cover. These snap slides hard mount the DAPS to brackets which in turn mount to existing holes already in the kits. The only difference in DAPS mounting among the three manufacturer's kits is the retrofit package consisting of brackets to mount the fuel coil. These bracket kits were required due to the difference among the kits in question. It was determined that a design of this type would minimize the retrofit effort by requiring only a change in mounting bracketry.

The RSSK-8A DAPS in all kits is removed by a simple push or pull motion on tabs located on the DAPS/seat kit mounting bracketry (Figure 32).

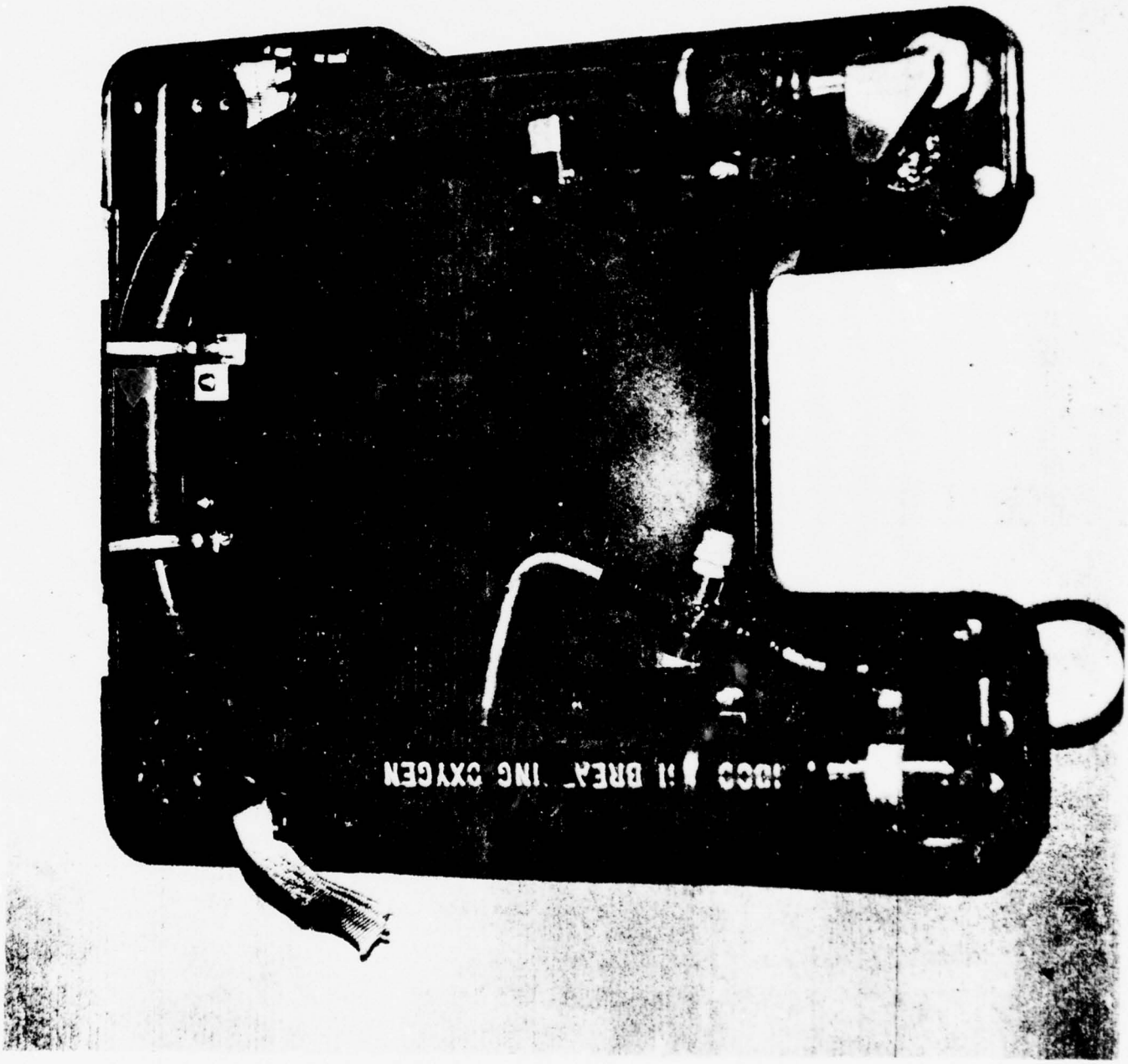
A study of various available latching mechanisms to determine the degree of manual dexterity and coordination required to operate them resulted in the selection of the snap slide type manufactured by Dimco Gray Corporation.

These catches have been assigned military specification identification numbers (MS 21332) which also made their selection preferable to other types. The forces on the catches due to catapult launch, high speed maneauvers and seat ejection, were determined to be within the strength capabilities of the parts.

4.0 RELIABILITY AND MAINTAINABILITY

4.1 Introduction

As required by the RSSK-8A contract, production models of these units shall have a success probability of .976. This value is based on a MTBF (Mean Time Between Failures) of 1000 hours and an operational life of 24 hours. The current Reliability Program was incorporated into the RSSK-8A Design Program to provide information to the designer which would help him achieve this success probability.



RSSK-8A

Mounting Bracketry

Figure 32

The major effort, during this contract, was in developing a Reliability Program Plan that could be used interchangeably with each of the Navy heater systems, and includes the following:

- Identification of the system mission profile
- Reliability Dependency Diagram
- Math Model
- A Failure Modes Effects and Criticality Analysis
- Current reliability and maintainability predictions
- Recommendations for future reliability programs

4.2 Reliability Program Description

The Reliability Program was broken down into three major tasks, per paragraphs 5.1 through 5.3 of MIL-STD-785A (Reliability Program for Systems and Equipment. Development and Production): (1) Reliability Program Management, (2) Reliability Design and Evaluation, and (3) Reliability Testing. The following is a description of work performed under each task.

4.2.1 Reliability Program Management

A Reliability Program Manager was assigned to the program on a full time basis and was responsible for organizing, coordinating, and carrying out the work required for each of the three major tasks. To assist in this early program phase, a reliability consultant, with considerable experience in Navy hardware Reliability and Maintainability Programs, was retained. He assisted at the beginning of the program in defining the analytic effort that was pursued. At the end of the program he assisted in drafting the future Reliability Program Plan.

4.2.2 Reliability Design and Evaluation

4.2.2.1 Design Techniques

An improvement in component part and equipment reliability can be realized by applying the techniques of stress derating. The failure rate of most parts is dependent upon the applied stress. As the applied stress is reduced, the failure rate decreases. The reverse is also true. Therefore, by increasing the strength of the part, the failure rate can be reduced, and the reliability improved.

Those components in the RSSK-8A DAPS for which stress derating is necessary include: (1) D.C. motor, (2) DC-DC converter, (3) fuel lines, (4) fluid lines, (5) thermo-electrics, (6) pressure regulator, (7) fuel shut-off valve, (8) 12 VDC connector, (9) pump, (10) fluid connectors and (11) piezoelectric igniter. Following is a brief list of these parts and their operational loads.

(1) D.C. Motor

The D.C. motor currently being used is operated at a stress level of 125 percent. The predicted success probability for this motor is .99924. Although operation at this load decreases the useful life, it is felt that this motor is sufficient, for use in the RSSK-8A, considering a maximum operating time of 30 hours (6 hours testing and 24 hours in-raft operation).

(2) DC-DC Converter

The DC-DC converter is operated at 80 percent of its maximum input voltage. The major components of the converter are: (a) silicon transistors, (b) silicon diodes, (c) CSR capacitors, and (d) carbon composition resistors. Figure 33 shows the derating guidelines for these parts, as presented by the Rome Air Development Center, in the Reliability Design Handbook, No. RDH 376.

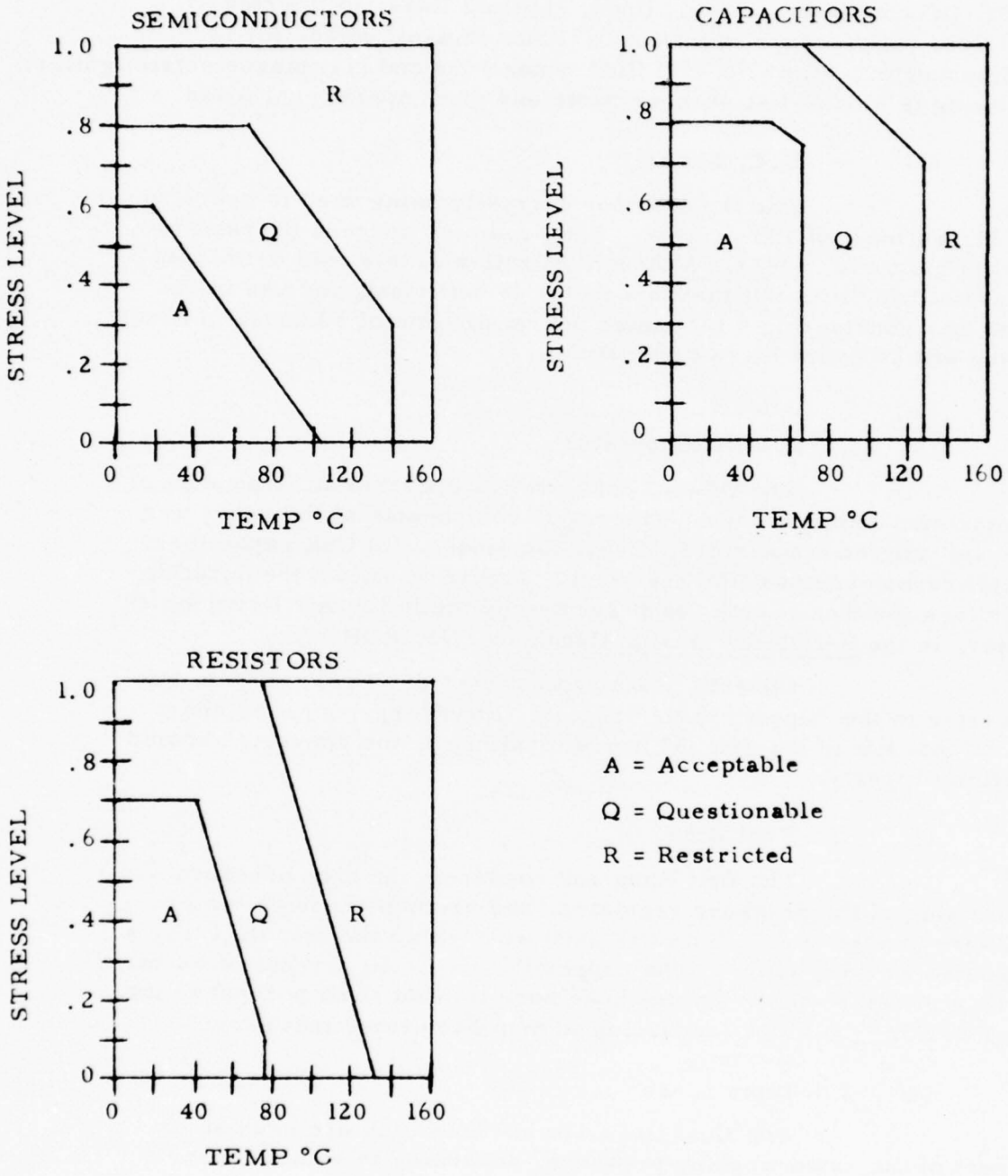
Operation at a stress level of 80 percent puts the converter in the "Questionable" region. However, due to the short operational life of the unit (30 hours maximum), the converter should function properly.

(3) Fuel Line

The fuel lines are copper on the high pressure (input) side of the pressure regulator, and urethane hose on the low pressure (output) side. Both are used well within the manufacturer's suggested working range. The copper is used at 10 percent of its rated working pressure while the urethane hose is used at 25 percent of its rated working pressure (according to manufacturer's test data).

(4) Fluid Lines

The fluid lines are silicone, and are used at 15 percent of the rated working pressure, according to manufacturer's test data.



D.C. D.C. CONVERTER DERATING GUIDELINES

Figure 33

(5) Thermoelectrics

The maximum recommended operating temperature is 550°F. Using the thermoelectrics at temperatures higher than this can cause two failure modes: (1) diffusion of contaminants into the thermoelectric material and (2) migration of solder and thermoelectric material constituents causes embrittlement and higher resistivity of the solder joint. The maximum temperature seen by the thermoelectrics in the RSSK-8A is 500°F. Therefore, these two failure modes should not be encountered.

(6) Pressure Regulator

The pressure regulator has a working range of 0-300 p.s.i., and a delivery pressure of 0-100 p.s.i. The maximum input pressure seen by the regulator is 250 p.s.i. and the maximum delivery pressure is 30 p.s.i.

The working temperature range is from -30°F to +230°F. The temperatures seen by the regulator range from +20°F to +80°F. Therefore, it is felt that this regulator is sufficient for use in the RSSK-8A system.

(7) Fuel Shut-off Valve

The fuel shut-off valve has maximum pressure rating of 600 psi. The maximum pressure seen by the shut-off valve is 250 psi.

(8) 12 VDC Connector

The 12 VDC electrical connector in the DAPS has a contact rating of 7.5 amps. The maximum current seen by the connector is 100 milliamps. With a success probability of .99994, the connector should function properly for the entire life of the unit.

(9) Pump

The pump used is a miniature, magnetic drive, gear pump. This pump utilizes a Viton o-ring seal which is compatible with ethylene glycol and has a working temperature range from -15°F to +400°F. The temperature range seen by the pump is +20°F to +110°F. Since the pump is non-operational during the storage stage the -20°F storage temperature is not expected to cause any problems.

(10) Fluid Connectors

The fluid connectors used for the RSSK-8A DAPS were supplied to Energy Systems Corporation as government furnished equipment. Data available indicates no degradation in the temperature range of -65°F to +180°F using a 60 percent ethylene glycol solution.

(11) Piezoelectric Igniter

Fuel ignition is accomplished by use of a ceramic crystal which when struck by a spring loaded hammer generates an electric spark of 12KV. The spark gap is located in the exhaust port to guarantee ignition of the fuel/air mixture. The maximum allowable spark gap is .118 inches and the mechanism is rated for 30,000 cycles minimum.

4.2.2.2 Reliability Analysis

A reliability dependency diagram showing the dependency of the overall RSSK-8A DAPS reliability on the reliability of the individual components was generated during this program. The diagram was broken down into four separate stages, to represent the stages of the mission profile:

(1) Storage
(2) In-Flight
(3) Eject
(4) In-Raft Operation

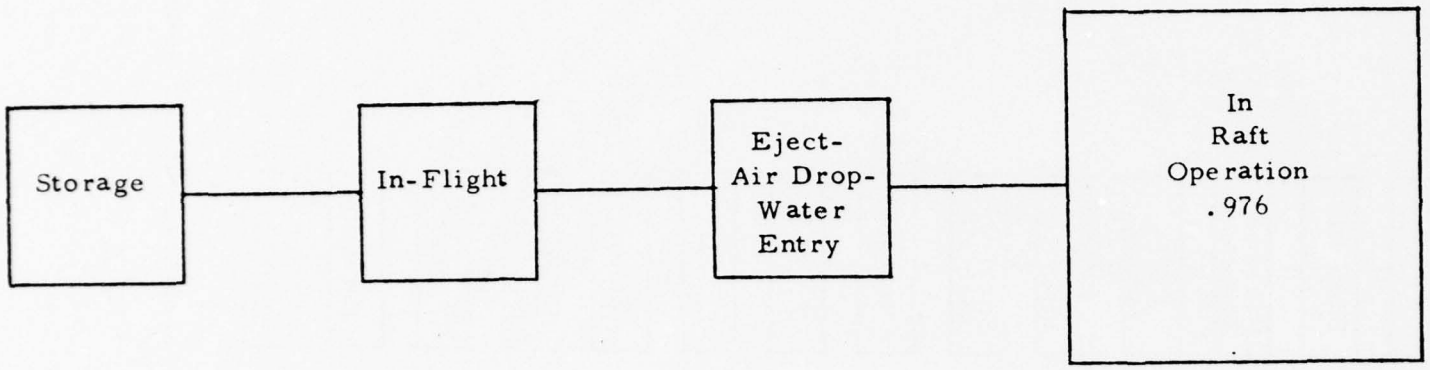
Figure 34 gives a visual representation of the system mission profile. Each of the four mission profile stages was then broken down to show the series reliability dependency of the individual components (Figures 35a, 35b, 35c, 35d).

Expected replacement schedules, Table 6, have been assigned to each part, based on available data, during the Storage and the In-Flight stages, as the unit is non-operational during these times. The Ejection stage has not been included in this Table since component replacement would not be possible by the downed airman in the raft.

Initially, failure rates were allocated to each component, in the In-Raft Operation stage, based on an overall success probability of .976 (see Table 7). The calculations for these failure rates are included in this report as Appendix A. As reliability data was obtained, the success probability for each component was updated. These predicted failure rates are also shown in Table 7. The calculations for the predicted failure rates are included as Appendix B.

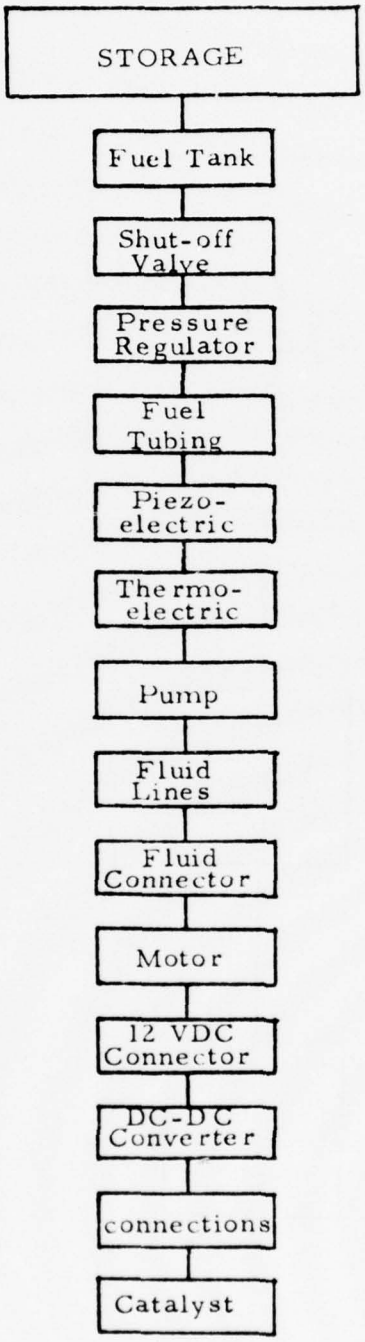
The math model used to calculate each success probability is essentially a mathematical statement of the relationship depicted in the reliability dependency diagram. Since a series configuration model was used to evaluate the reliability of the unit, the probability of success during in-raft operation was calculated as follows:

$$P = \exp - (\lambda_1 t + \lambda_2 c)$$



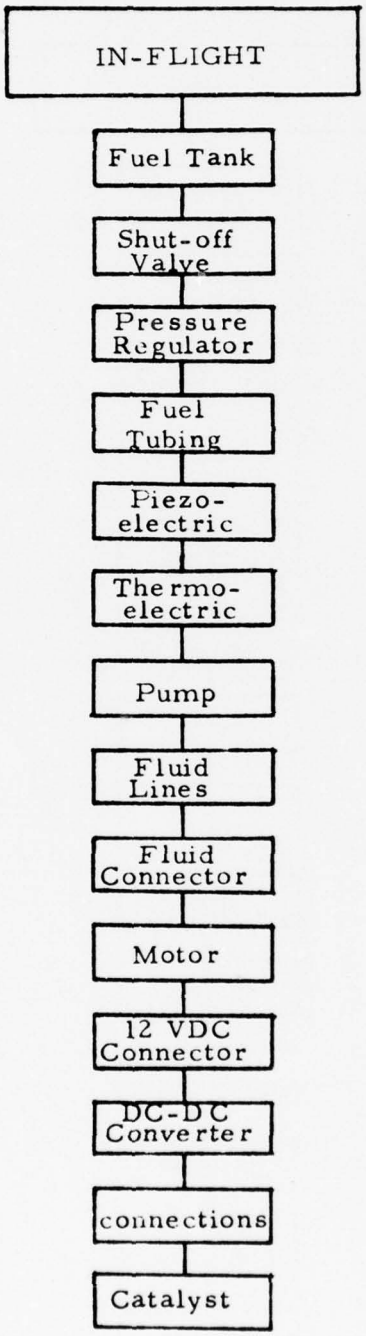
System Mission Profile

Figure 34



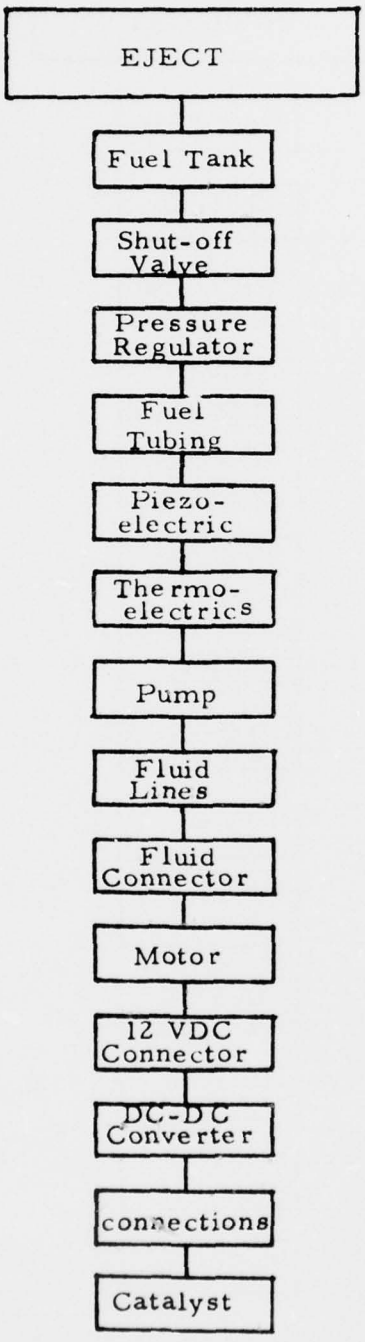
Reliability Dependency Diagram - Storage Stage (non-operating)

Figure 35a



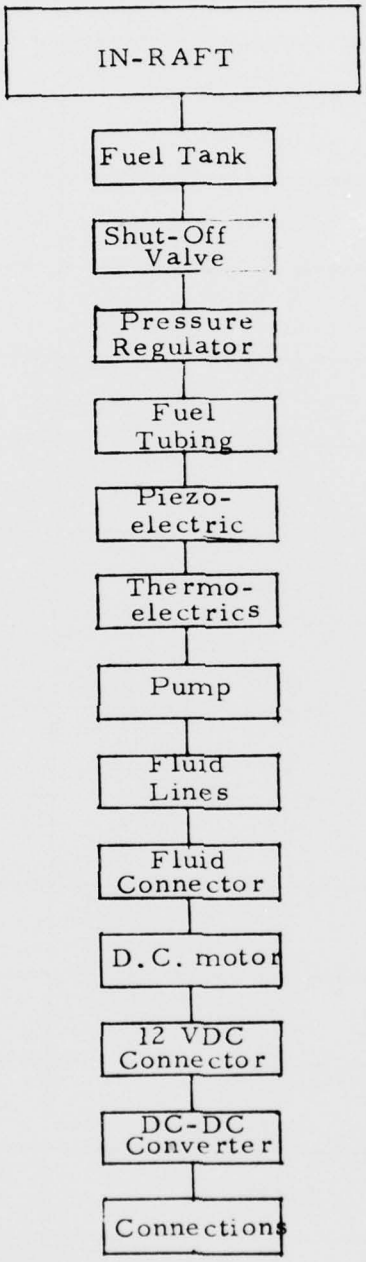
Reliability Dependency Diagram - In-Flight Stage (non-operating)

Figure 35b



Reliability Dependency Diagram - Eject Stage (non-operating)

Figure 35c



Reliability Dependency Diagram - In-Raft Operation

Figure 35d

	STORAGE (Years)	IN-FLIGHT (Years)
FUEL TANK	8	4
SHUT-OFF VALVE	5	5
PRESSURE REGULATOR	5	5
FUEL TUBING	5	5
PIEZOELECTRIC	Indefinite	Indefinite
THERMO-ELECTRIC	20	5
PUMP	15	15
FLUID LINES	5	5
FLUID CONNECTOR	15	15
MOTOR	2	2
12 VDC CONNECTOR	5	5
DC-DC CONVERTER	Indefinite	Indefinite
CATALYST	10	5
CONNECTIONS (solder, dip braze weld, pipe, clamps)	Indefinite	Indefinite

RSSK-8A COMPONENT REPLACEMENT SCHEDULE

TABLE 6

	COMPONENT	ALLOCATED ($x10^{-6}$)	PREDICTED ($x10^{-6}$)	ACTUAL ($x10^{-6}$)
A 4	FUEL TANK	100	100	
A 5	SHUT-OFF VALVE	20	15	
A11	PRESSURE REGULATOR	30	15	
A 6	FUEL LINE	50	50	
A12	PIEZO-ELECTRIC	100	100	
A13	THERMO-ELECTRIC	100	328	
A14	PUMP	80	80	
A15	FLUID LINES	20	20	
A16	FLUID CONNECTORS	170	100	
A18	D.C. MOTOR	70	25.1	
A19	12 VDC CONNECTOR	30	1.9	
A17	DC-DC CONVERTER	30	11.2	
A 3	CONNECTIONS (solder, dip braze, weld, pipe, clamp)	10	2.6	

RSSK-8A FAILURE RATE DATA

TABLE 7

where:

t = time of operation in hours

c = number of cycles during the misson profile

λ_1 = the sum of the failure rates of all time dependent parts

λ_2 = the sum of the failure rates of all cyclic dependent parts

Individual component failure rates were calculated as follows:

$$\lambda_p = (\lambda_b)\ (\pi_E)\ (\pi_Q)$$

where:

λ_p = component failure rate

λ_b = base failure rate. These values are functions of λ_1 and/or λ_2, and are based on data from the following sources: (1) manufacturers, (2) *MIL-HDBK-217B, (Reliability Prediction* of Electronic Equipment), (3) the Reliability Design Handbook (presented by the Reliability Analysis Center), (4) the Government-Industry Data Exchange Program (GIDEP), and (5) Nuclear Systems, Inc.

π_E = The environmental adjustment factor accounts for the influences of environments which the equipment is expected to experience.

π_Q = the quality adjustment factor, which is used to account for the degree of manufacturing control with which the part was fabricated and tested prior to shipment.

The environmental adjustment factor and the quality adjustment factor were used to alter the base failure rates so as to obtain a more accurate picture of the component failure rates.

During its life, the RSSK-8A DAPS will be subjected to the following environmental conditions, as specified in the contract:

(1) Pressure altitude Non-Operating; sea level to to 100,000 feet.

(2) Pressure Altitude Operating; sea level to 5,000 feet.

(3) Operating Ambient Temperature, in air; +20°F to +80°F.

(4) Storage Ambient Temperature; -50°F to +125°F.

(5) Vibration spectrum of aircraft

(6) High relative humidity

(7) Salt Spray

(8) Hydrostatic Pressure - Non-Operating without leakage; 30 p.s.i.a.

(9) Shock - Operable after drop of ten (10) feet to concrete surface, all axes, as mounted in seat kit. Operable after drop of four (4) feet to concrete surface, all axes as packaged for delivery.

Components were chosen for use in the RSSK-8A DAPS system that would survive and operate most satisfactorily under these conditions.

4.2.2.3 Problem Areas

Two major problems were encountered during this program:

1. Lack of failure rate data. At present time most suppliers of the RSSK-8A DAPS components are not involved in reliability testing. Therefore, failure rate data for the majority of the components has not been obtained. Other sources such as MIL-HDBK-217B, the Reliability Design Handbook and GIDEP have been investigated with only limited success.

2. Limited unit life history. To date only a small amount of data is available for study. This lack of data greatly hinders the evaluation of the system components. There has also been a lack of accurate and complete failure documentation in the past which further hinders the evaluation of the components in use.

4.2.2.4 Parts Reliability

A tabular presentation of the component failure rates is included as Table 7 of this report. The calculations, for the predicted failure rates and success probabilities of the individual components, are presented in Appendix B. Along with these calculations are the sources of information and the assumptions made. The calculation of the actual success probabilities for the individual components was hindered by the lack of failure rate data. Until this data can be acquired, from either a central information agency such as GIDEP, or by actual testing, the predicted failure rates are considered best estimates. Based on these predictions the current MTBF for the RSSK-8A DAPS is 950 hours and the current success probability .9748.

4.2.2.5 Failure Mode, Effects and Criticality Analysis

A preliminary Failure Mode, Effects and Criticality Analysis (F.M.E.C.A.) Table 8, which identifies the basic faults at the part level and shows the effects on higher levels of assembly, was performed during this contract. Included in the F.M.E.C.A. are both actual failure modes from past testing, and hypothesized failure modes from design analysis.

Hazard levels have been assigned to each failure mode and indicate the effect of the failure on the downed airman. The hazard levels used for the failure criticality are those of MIL-STD-882 (System Safety Program for Systems and Associated Subsystems and Equipment: Requirements for) and are defined as follows:

(a) Category I - Negligible
. . . . will not result in personnel injury or system damage.

(b) Category II - Marginal
. . . . can be counteracted or controlled without injury to personnel or major system damage.

(c) Category III - Critical
. . . . will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Fuel	1. Fuel Tank	A. Initial Supply too low	A. Tank leakage	A. Fuel supply may not last the required length of time	A. System will not operate for the required length of time.			A. Crit.
		B. Fuel tank empty			B. Combustion not sustained unit shuts down			B. Crit.
		C. Fuel is liquid; not gaseous	C. No vapor pressure in bottle.	C. No fuel to the combustion chamber	C. Unit will not operate			C. Mar.
		D. Vapor pressure too low.		D. Insufficient fuel to comb. chamber.	D. Combustion not sustained			D. Mar.
		E. Damaged fuel connector.	E. Possible fuel leakage	E. Tank cannot be interfaced with unit.	E. No fuel & no combustion			E. Crit.
		F. Gas valve sticks closed.			F. No fuel and no combustion.			F. Mar.

Table 8.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Fuel	1. Fuel tank	G. Tank Bursts						G. Catastrophic
	2. Pressure regulator	A. Sticks in closed position		A. No fuel to combustion chamber	A. No combustion			A. Mar.
		B. Fails to regulate properly			B. Can cause overheating and damage to the thermo-electrics			B. Mar.
	3. Tubing	A. Leakage thru end connections			A. Unit may not operate for required length of time			A. Mar.
		B. Breaks from vibration		B. Little or no fuel to combustion chamber	B. Little or no combustion			B. Crit.
		C. Fuel line puncture		C. Insufficient fuel to comb. chamber	C. Little or no combustion			C. Crit.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A-DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Combustion chamber	1. Orifice	A. Blockage by impurities or frost.	A. Will not allow fuel to pass into combustion chamber	A. No fuel for combustion	A. No combustion; no heat			A. Crit.
		B. Partial blockage by impurities.	B. (1) Reduced fuel flow rate (2) change in the air/fuel ratio	2. Decreased efficiency	B. Reduced Heat 2. Fuel supply will not last the required length of time			B. Mar. 2. Mar.-Crit.
	2. Catalyst	A. Break-up caused by vibration	A. Catalyst settles and packs into bottom of chamber.	A. Gas passes over top of catalyst & not thru it.	A. Little or no combustion; little or no heat.			A. Crit.
		B. Wetted	B. Catalytic combustion not initiated	B. No combustion	B. No heat output			B. Mar.
		C. Leaks out of combustion chamber into diffuser.	C. Insufficient amt. of catalyst for optimum combustion.	C. Partially blocks air gap causing a change in the air/fuel ratio.	C. (1) decreased efficieny; (2) increased fuel consumption.			(1)Mar. (2)Mar.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Combustion Chamber	2. Catalyst				C. (3) Possibility of excess carbon monoxide in exhaust gas.			(3) Crit.
	3. Piezo	A. Spring hammer not strong enough to generate spark.	A. No spark to ignite gas.	A. No combustion	A. No heat unless combustion initiated by other means			A. Mar.
		B. Spark gap too great	B. No spark to ignite gas.	B. No combustion	B. No heat, etc.			B. Mar.
		C. Spark shorting back along electrode to duct wall	C. No spark to ignite gas	C. No combustion	C. No heat, etc.			C. Mar.
		D. Wire lead to electrode breaks.	D. No spark to ignite gas	D. No combustion	D. No heat, etc.			D. Mar.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Combustion Chamber	3. Piezo	E. Button Sticking	E. No spark	E. No ignition	E. No combustion and no heat.			E. Mar.
	4. Thermo-electrics	A. Low voltage output		A. Reduced output voltage	A. No DC motor start or reduced operating speed; inefficient or non operating auxiliaries.			A. Mar.
		B. Broken lead or tab	B. No electrical output		B. Motor will not start; no auxiliaries			B. Crit.
		C. Cracked module	C. No electrical output		C. Motor will not start; no auxiliaries.			C. Crit.
		D. Overheated	D. No electrical output.		D. No heat to airman.			D. Crit.
	5. Exhaust duct	A. Breaking away or disconnecting from housing.		A. Exhaust gases fill inside of housing	A. Insufficient fresh air to sustain combustion -- No heat to airman			A. Mar.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A-DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Fluid System	1. Pump	A. Flow blockage	A. Reduced pumping action	A. Reduced fluid flow	A. Possible overheating of thermo.			A. Mar. Crit.
		B. Excess friction on gear shafts	B. Excessive wear and decreased life of pump	B. Reduced or no fluid flow	B. (1) Excessive load on motor (2) Little or no heat to airman			B. Mar-Crit.
	2. Fluid lines	A. Leak	A. (1) Loose end connection. (2) break in line	A. (1) Excessive fluid loss (2) Excessive fluid loss	A. (1) System overheating (2) System overheat			(1) Mar. (2) Crit.
		B. Collapse	B. Restricts fluid flow	Pressure build-up; thermo-electrics overheat	B. Loss of electric power, no heat to airman			B. Crit.
		C. Complete blockage or crimped lines	C. No fluid flow	C. Thermoelectrics overheat & prevent DC motor start	C. No heat to airman			C. Mar.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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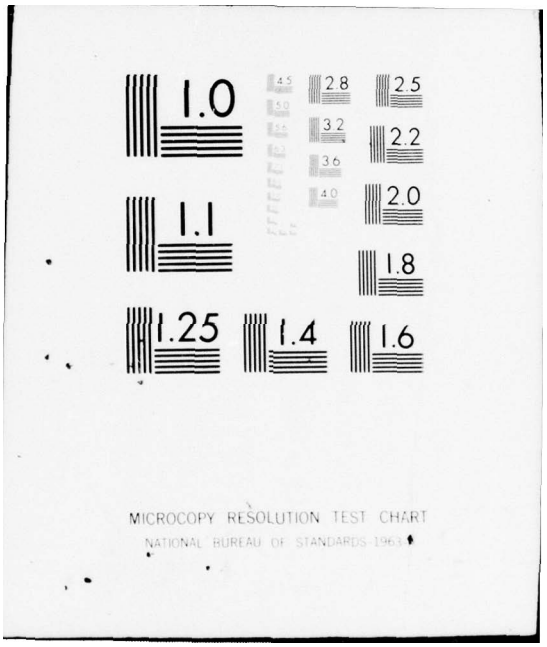
SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Fluid System	3. Fluid connectors	A. Frozen fluid or moisture in connector	A. Will not connect	A. No heated fluid to airman	A. Unit not operable			A. Mar.
		B. Damaged connector	B. Cannot connect mating halves	B. No heat to airman	B. Unit not operable			B. Crit.
		C. Seal malfunction	C. Connector leaks	C. Excessive fluid loss	C. System overheats causing damage to thermoelectrics.			C. Mar.
	4. Anti-freeze	A. Not capable of being pumped	A. Too viscous	A. No heat transfer to airman	A. System overheats			A. Crit.
	5. Internal fluid connections	A. Leaks		A. Excessive fluid loss	A. System overheats causing damage to thermoelectrics			A. Crit.

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DOWNED AIRMAN POWER SOURCE (DAPS) FOR INCLUSION INTO THE RSSK-8--ETC(U)
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FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Electrical	1. DC-motor	A. Overlead	A. Motor stops functioning	A. No power to drive the pump	A. No heat to airman; unit overheats damaging the thermoelectrics			A. Crit.
		B. Broken Lead	B. No DC motor operation	B. No power to drive pump	B. No heat to airman; unit overheats damaging the thermoelectrics			B. Crit.
		C. Failure to operate at design speed			C. Reduced fluid flow, possibly causing overheat of thermoelectrics			C. Mar.
		D. Operates at too high a speed	D. Decreased life of motor		D. Fluid delivered at lower than normal temperature to airman.			D. Mar.

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

SYSTEM RSSK-8A DAPS CONTRACT N62269-76-C-0239 DATE 20 July 1976

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SUB SYSTEM	PART	FAILURE MODE	PART EFFECT	SUBSYSTEM EFFECT	SYSTEM EFFECT	FAIL. RATE (x10-6)	FAIL. FREQ.	CRIT.
Electrical	2. 12 VDC Connector	A. Broken lead to the connector		A. No regulated 12 VDC output	A. No auxiliaries			A. Crit.
		B. Broken con pin	B. Connection not possible		B. No auxiliaries			B. Crit.
		C. Bent con. pin	C. Connection not possible		C. No auxiliaries			C. Crit.
		D. Ice in either half of connector	D. Connection delayed		D. No auxiliaries			D. Mar.
	3. DC-DC converter	A. Operation below design Spec.	A. Insufficient power into the converter	A. Thermoelectric output too low	A. Weakened or no auxiliaries			A. Mar-Crit.

(d) Category IV - Catastrophic

. . . . will cause death or severe injury to personnel, or system loss

During this contract, corrective actions and recommendations dealt solely with those failure modes labeled as critical. Most of the critical failure modes have had some form of corrective action taken. Further testing would be required to determine whether or not the corrective actions taken were sufficient. A list of corrective actions taken is included below:

A. Protective caps for the fuel, electrical and fluid connectors have been added to help reduce the possibility of damage.

B. Tubing and wires have been sufficiently supported or tied down, in order to minimize the effects of vibration.

C. A fuel filter has been included on the upstream side of the orifice to reduce the number of impurities to the orifice thereby reducing the chances of clogging.

D. The pin plate has been re-designed to eliminate the possiblity of catalyst leaking out of the combustion chamber, past the front screen, and into the diffuser.

E. The internal fluid lines have been changed from fluorocarbon to silicone. Fluorocarbon at low temperatures tends to become very brittle whereas the silicone tubing, at the same temperatures, remains flexible.

F. Those fittings that had previously been epoxied are now being dip brazed.

G. Hose clamps have been added to all fluid lines to help reduce fluid leakage and air inclusion.

H. The fuel pressure and fluid temperature gauges have been removed, thereby eliminating four possible leak paths.

I. The fluid connectors have been changed, thus reducing the amount of fluid leakage and air inclusion per connect disconnect cycle.

4.2.2.6 Effects of Storage

As the unit is scheduled to be heat sealed upon delivery, the effects of storage should be minimal. The following is a list of predicted storage effects:

(1) Demagnetization of the D.C. motor permanent magnet can occur if the RSSK-8 A unit is stored in an area of excessive external magnetic field.

(2) The D.C. motor has a specified shelf life of two years, due to the bearing lubricant. However, the manufacturer feels that a five year shelf life is more accurate.

(3) The fuel tank does have a small leakage rate and should be weighed periodically. The predicted refill schedule is shown in Table 6. Initially, however, the fuel tank should be weighed on a yearly basis.

4.2.3 Reliability Testing

During this contract funds were not provided specifically for reliability testing and, therefore, only a minimal amount of testing was accomplished.

Plans and procedures for future reliability testing were drawn up and are included in Section 7.2 of this report. These tests would be performed to help the Reliability Program Manager achieve the .976 success probability as specified in the contract.

Failure identification reports and failure record forms were drawn up and are of the format of MIL-STD-781B (Reliability Tests: Exponential Distribution). They will be used for all future testing to accurately record all failure modes encountered. Sample copies of these forms appear as Figures 36a, b, c, d, e, f.

EQUIPMENT FAILURE RECORD

TEST TYPE _____ UNIT SERIAL NO. _____

EQUIPMENT TYPE _____ DATE TEST INITIATED _____

Failure Report No.	Rem. for Repair		Return to Test		Description of Failure	Tech. Initials
	Date	Op. Time	Date	Op. Time		

FAILURE SUMMARY RECORD

TEST TYPE _____ DATE TEST INITIATED _____

EQUIPMENT TYPE _____

Date	Fail. Report No.	Unit Serial No.	Unit Time	Description of Failure	Test Status - All Units			Tech. Init.
					Total Fail.	Total hours	MT BF	

FAILURE IDENTIFICATION REPORT (PART A)

SYSTEM _____ ASSEMBLY _____ SUBASSEMBLY _____ PART NO. _____
COMPONENT _____ SERIAL NO. _____ DATE _____ TIME _____
TOTAL UNIT TEST TIME _____ REPORT NO. _____
TEST TYPE _____ TEST REFERENCE _____

TEST AND ENVIRONMENTAL CONDITIONS _____

IDENTIFICATION OF TEST EQUIP: _____

FAILURE SYMPTOMS: _____

ADJUSTMENT REQUIRED _____

OTHER EQUIP. FAIURES OBSERVED SIMULTANEOUSLY WITH SUBJECT FAILURE _____

Figure 36c.

FAILURE CONFIRMATION AND REPAIR REPORT (PART B)

SYSTEM _____ ASSEMBLY _____ SUBASSEMBLY _____ PART NO. _____
COMPONENT _____ SERIAL NO. _____ DATE _____ TIME _____
FAILURE SYMPTOM _____ NAME _____
_____ UNIT TIME _____
TEST TYPE _____ TEST REFERENCE _____ REPORT NO. _____

TEST EQUIP. USED	SERIAL NO.	TEST PERFORMED	DATE BEFORE REPAIR

CONFIRMATION OF SYSTEMS REPORTED _____
_____
REASON FOR PART FAILURE _____
_____

TEST EQUIP. USED	SERIAL NO.	PART TEST USED TO ESTABLISH PART FAIL	DATE ON DEFECT. PART

DEFECTIVE PART _____ PART NO. _____ MFG. _____
Use copy of this form for each failure at this time. Check ☐ if more than one failure found.

Figure 36d.

FAILURE CONFIRMATION AND REPAIR REPORT (PART C)

SYSTEM _____ ASSEMBLY _____ SUBASSEMBLY _____ PART NO. _____
COMPONENT _____ SERIAL NO. _____ REPORT NO. _____
TEST TYPE _____ UNIT TIME _____ NAME _____

MULTIPLE PART FAILURE
IDENTIFICATION OF DEPENDENT FAILURES
PARTS FAILING

(1) _____ (4) _____
(2) _____ (5) _____
(3) _____ (6) _____

CAUSE OF MULTIPLE FAILURES

_____
_____
_____
_____
_____
_____
_____

IDENTIFICATION OF INDEPENDENT FAILURES
PARTS FAILING

(1) _____
(2) _____
(3) _____

Figure 36e.

FAILURE ANALYSIS REPORT (PART D)

SYSTEM _____ ASSEMBLY _____ SUBASSEMBLY _____ PART NO. _____
COMPONENT _____ SERIAL NO. _____ DATE _____ REPORT NO. _____
TEST TYPE _____ TEST REFERENCE _____

COMPONENT ANALYSIS _____

DESIGN ANALYSIS _____

RECOMMENDATIONS FOR CORRECTIVE ACTION _____

SIGNATURE _____

Figure 36f.

5.0 SYSTEM FINAL TEST

5.1 Test Set Up

System final testing was performed on a test stand designed specifically for the purpose of characterizing DAPS heater performance.

The test stand is shown in Figure 37. It consists of three major sub-systems.

1. Thermal
2. Hydraulic
3. Electrical

5.1.1 Thermal

The thermal sub-system is designed to measure the temperature rise of the fluid across the heat exchanger.

Two precision thermometers are used for this measurement. They have a temperature range from 69°F to 116°F and have .2°F increments for accurate measurement.

The fuel flow rate is measured using a Dwyer flow meter Part No. RMA-1. This meter is capable of measuring the flow of air from .05 SCFH to .5 SCFH. This converts to .05 SCFH to .40 SCFH for propane.

5.1.2 Hydraulic

The hydraulic sub-system is comprised of a mercury manometer, flow meter and flow resistance. The mercury manometer is used to measure the pressure drop against which the system must pump. The flow measurements are accomplished using two Dwyer flow meters depending upon the anticipated flow.

Dwyer flow meter Part No RMB-84 has a capacity of from 0 to 40 Gallons per hour while the Dwyer flow meter Part No. RMC-142 has a capacity of .2 GPM to 2.2 GPM.

A flow resistance is used in the system to simulate a pressure drop as would be realized when the system was pumping into a tubulated under garment.

5.1.3 Electrical

The electrical test stand is comprised of a volt meter, ammeter and normally closed switch with which to measure open circuit voltage of the thermoelectric modules under a no load condition.

5.2 Required Calculations

5.2.1 Thermal efficiency as used in this case is the ratio of potential heat available in the fuel in BTU/Hr. to the heat picked up by the water in the heat exchanger also measured in BTU/Hr.

The potential fuel heat value is determined by two methods. Method #1 is the most accurate and consists of actually measuring the weight change of the fuel supply at a given fuel pressure for a given length of time.

Example: 43 Grams of Propane per hour

$$\text{Heat Value (BTU/Hr)} = \left(43 \text{ Gms./Hr}\right)\left(\frac{1 \text{ lb.}}{453.6 \text{ Gm}}\right)\left(19944 \text{ BTU/lb.}\right)$$

Method #2 uses an empirical formula derived by the manufacturers of the orifice used in the RSSK-1A DAPS System (Lee Co.)

$$\text{Lohms} = \frac{C \times F \times P1}{SCFM \times \sqrt{T1}}$$

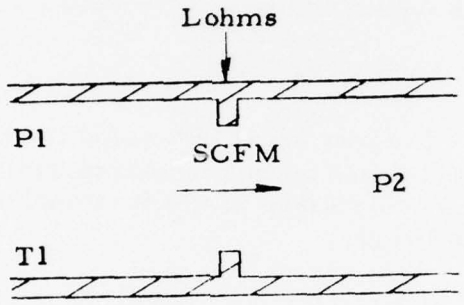
Lohms = Resistance as specified by manufacturer

C = Gas constant (Propane = 165)

F = Ratio of High Pressure (before orifice) to low Pressure(after orifice) = (P1/P2)-1: for (P1/P2)-1 >1 use F=1.0

SCFM = Standard Cubic Feet per Minute

T1 = High Pressure side temp (°R ≈ °F + 460)



Example: $SCFM = \frac{C \times F \times P1}{Lohm \times \sqrt{T1}}$

From these two calculations we see that the correlation is very good. For the purposes of the calculation, the flow rate as determined from actual measurement is used.

The heat into the water is determined from the formula $q = \dot{m} C_p \Delta T$

Where:

q = heat into the water (BTU/hr)

$\dot{m}$ = Mass flow rate of fluid (lb/Hr)

C_p = Specific heat of fluid (BTU/lb °F)

ΔT = change in temperature through the heat exchanger (°F).

Example: $q = \dot{m} C_p \Delta T$

$$q = \left(\frac{.25 \text{ Gal}}{\text{Min.}}\right)\left(\frac{8.34 \text{ lb}}{\text{Gal.}}\right)\left(\frac{60 \text{ Min}}{\text{Hr.}}\right)\left(\frac{1 \text{ BTU}}{\text{lb°F}}\right)\left(4.5°\text{F}\right) =$$

562.95 BTU/hr

5.2.2 System Efficiency

System overall efficiency is defined as the ratio the sum of the heat into the fluid plus the heat converted into electrical energy (typically 4%) to the heat potentially available in the fuel.

Example: (1.04) (heat into fluid) 100% = Total Efficiency

5.2.3 Electrical Performance

Electrical characteristics are measured to monitor thermoelectric efficiency.

The required formulae for determining the electrical parameter are listed below:

Internal Resistance of Module

$$R_i = \frac{E_{oc} - E_L}{I_L}$$

Resistance of Circuit

$$R_L = \frac{E_L}{I_L}$$

Power Delivered

$$P = \left[\frac{E_{oc}}{R_i + R_L}\right]^2 \left[R_L\right] = E_L I_L = I_L^2 R_L$$

Max Power

$$P_{max} = \frac{(E_{oc})^2}{4R_i}$$

System off design power ratio P/P max

R_i = Internal resistance of module (ohms)

R_L = Resistance of circuit (ohms)

E_L = Load Voltage (volts)

E_{oc} = No load voltage (volts)

I_L = Load Current (amps)

P = Power (watts)

5.2.4 Exhaust Gas Test

Exhaust gas tests were performed to determine the concentration of unburned fuel and carbon monoxide in the exhaust gas. A detailed explanation of the theory and equipment is found in Section 2.7.

5.3 Test Results

The results obtained from tests on the DAPS System are tabulated and explained below.

The fuel used for these tests was propylene although the systems are delivered for use with propane. The reason for this is that commercial propane is a mixture of several hydrocarbon compounds. The compounds would make it impossible to monitor exhaust gas components accurately because the analyzer is only capable of measuring one compound at any one setting.

The actual results are minimally effected by this change because of the close similarity in chemical structure and heat of combustion values of the compounds.

Propane (C_3H_8) has a net heat of combustion of 19944 btu/lb while propylene (C_3H_6) has a net heat of combustion of 19578 btu/lb. This amounts to a difference of only 366 btu/lb or 2.0%.

The systems were tested for output characteristics at 10, 20 and 30 psig. These settings correspond to regulator settings of 2.5, 5.8 and 9.

These results are tabulated in Tables 9 thru 14. Tables 9 thru 11 are test results for SN0001 while Tables 12 thru 14 are results for SN0002.

TABLE 9

Test Results at Regulator Setting of 6.5
Unit #1

Regulator Setting: 6.5 — Grams of Fuel Per Hour: 35.56

Fuel Pressure: 20 PSIG — Fuel Heat Value(BTU/Hr): 1560

Time	Electrical				Hydraulic	
Min.	Volts E_L	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
0.0	.25	.18				
1.0	.65	.68				
2.0	1.2	.88				
3.0	2.90	1.00				
4.0	3.75	1.44				
5.0	4.20	1.60				
10.0	4.70	1.95				
20.0	4.85	2.05	8.20	9.94	28.8	240.2
25.0	4.85	2.02	8.30	9.79	28.5	237.7
30.0	4.80	2.05	8.20	9.84	28.8	240.2

Time	Thermal					
Min.	Temp. in °F	Temp. Out °F	ΔT	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
20.0	74.0	78.2	4.2	1008.8	64.6	67.2
25.0	75.1	79.3	4.2	982.3	62.9	65.4
30.0	76.0	80.2	4.2	1008.8	64.6	67.2

TABLE 10

Test Results at Regulator Setting of 9
Unit #1

Regulator Setting; 9 Grams of Fuel Per Hour: 42.5

Fuel Pressure: 27 Fuel Heat Value(BTU/Hr): 1866

Time	Electrical				Hydraulic	
Mins.	Volts E_L	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
40.0	5.2	2.1	9.1	10.92	30.0	250.2
45.0	5.2	2.1	9.1	10.92	30.0	250.2
50.0	5.2	2.1	9.1	10.92	30.0	250.2

Time	Thermal					
Mins.	Temp. in °F	Temp. Out °F	ΔT	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
40.0	79.0	83.6	4.6	1150.9	61.7	64.1
45.0	80.3	84.9	4.6	1150.9	61.7	64.1
50.0	81.2	85.8	4.6	1150.9	61.7	64.1

TABLE 11

Test Results at Regulator Setting of 3.5
Unit #1

Regulator Setting; 3.5 Grams of Fuel Per Hour: 23

Fuel Pressure: 10 Fuel Heat Value(BTU/Hr): 1010

Time	Electrical				Hydraulic	
Mins.	Volts E_L	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
60.0	3.9	1.45	6.0	5.65	23.0	191.8
65.0	3.85	1.48	6.0	5.69	23.0	191.8
70.0	3.85	1.48	6.0	5.69	23.0	191.8

Time	Thermal					
Mins.	Temp. in °F	Temp. Out °F	ΔT	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
60.0	83.9	87.2	3.3	633	62.6	65.2
65.0	84.1	87.4	3.3	633	62.6	65.2
70.0	84.6	88.0	3.4	652	64.5	67.1

TABLE 12

Test Results at Regulator Setting of 6.5
Unit #2

Regulator Setting: 6.5 Grams of Fuel Per Hour: 33

Fuel Pressure: 20 PSIG Fuel Heat Value(BTU/Hr): 1449

Time	Electrical				Hydraulic	
Mins.	Volts E_I	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
0.5	.10	.1				
1.0	.30	--				
2.0	.55	--				
3.0	1.90	.84				
4.0	2.90	1.14				
6.0	3.90	1.80				
10.0	4.70	2.20	8.0	10.34	28.1	234.3
15.0	4.70	2.20	8.0	10.34	28.3	236.0
20.0	4.75	2.20	8.0	10.45	28.1	234.3
25.0	4.75	2.20	8.0	10.45	28.2	235.2

Time	Thermal					
Mins.	Temp. in °F	Temp. Out °F	ΔT	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
10.0	84.5	88.5	4.0	937	64.7	67.3
15.0	85.0	89.1	4.1	968	66.8	69.4
20.0	85.6	89.6	4.0	937	64.7	67.3
25.0	85.9	89.9	4.0	941	64.9	67.5

TABLE 13

Test Results at Regulator Setting of 9
Unit #2

Regulator Setting; 9 Grams of Fuel Per Hour: 42.5

Fuel Pressure: 27 PSIG Fuel Heat Value(BTU/Hr): 1866

Time	Electrical				Hydraulic	
Mins.	Volts E_L	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
35.0	5.20	2.35	8.80	12.22	29.6	246.8
40.0	5.20	2.35	8.80	12.22	29.6	246.8
45.0	5.20	2.35	8.80	12.22	29.6	246.8

Time	Thermal					
Mins.	Temp. in °F	Temp. Out °F	Δ T	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
35.0	86.5	90.8	4.3	1061.2	56.9	59.2
40.0	87.1	91.4	4.3	1061.2	56.9	59.2
45.0	88.2	92.5	4.3	1061.2	56.9	59.2

TABLE 14

Test Results at Regulator Setting of 3.5
Unit #2

Regulator Setting; 3.5 — Grams of Fuel Per Hour: 22.5

Fuel Pressure: 10 PSIG — Fuel Heat Value(BTU/Hr): 988

Time	Electrical				Hydraulic	
Mins.	Volts E_L	Amps I_L	Open Ckt. Volts E_{oc}	Power Watts	Flow Rate Gal/Hr.	Flow Rate Lbs/Hr
60.0	3.8	1.6	5.8	6.08	22.7	189.3
65.0	3.8	1.6	5.8	6.08	22.7	189.3
70.0	3.8	1.6	5.8	6.08	22.7	189.3

Time	Thermal					
Mins.	Temp. in °F	Temp. Out °F	ΔT	BTU/Hr In Fluid	Thermal Eff. %	System Eff. %
60.0	84.5	92.8	3.3	624.7	63.2	65.8
65.0	90.0	93.4	3.4	643.6	65.1	67.7
70.0	90.4	93.7	3.3	624.7	63.2	65.8

TABLE 15

Exhaust Gas Concentrations

Unit #1

Regulator Setting	Fuel Pressure (PSIG)	Absorption*	Carbon Monoxide (CO)	Absorption	Propane (C_3H_8)
3.5	10	.0019	18.3 PPM	.0052	23.8 PPM
6.5	20	.0024	23.1 PPM	.0044	19.5 PPM
9	27	.0030	28.9 PPM	.0062	27.5 PPM

Unit #2

3.5	10	.0015	14.45 PPM	.0012	5.3 PPM
6.5	20	.0023	22.1 PPM	.0028	12.4 PPM
9	25	.0038	36.6 PPM	.0020	8.86 PPM

*Absorption is an arbitrary scale dependent upon the instrument path length setting. This path length is the distance that the infrared beam travels through the sample and is varied according to the expected concentration and IR energy absorptivity of the compound being analyzed. A calibration curve is generated at a suitable path length and the concentration of the sample is quantitatively determined based on this calibration curve. For any given compound increasing the path length results in a corresponding increase in IR energy absorbed by the sample due to the greater distance through which the IR beam must travel. Decreasing the path length has the opposite effect, i.e., decreasing the amount of IR energy absorbed by the sample.

Figures 38 and 39 show a plot of how the voltage and flow rate increase with time at various fuel settings.

The curve indicates the voltage rise as a step function with respect to fuel pressure in steps starting at 20 PSIG, increasing to 27 PSIG and decreasing to 10 PSIG.

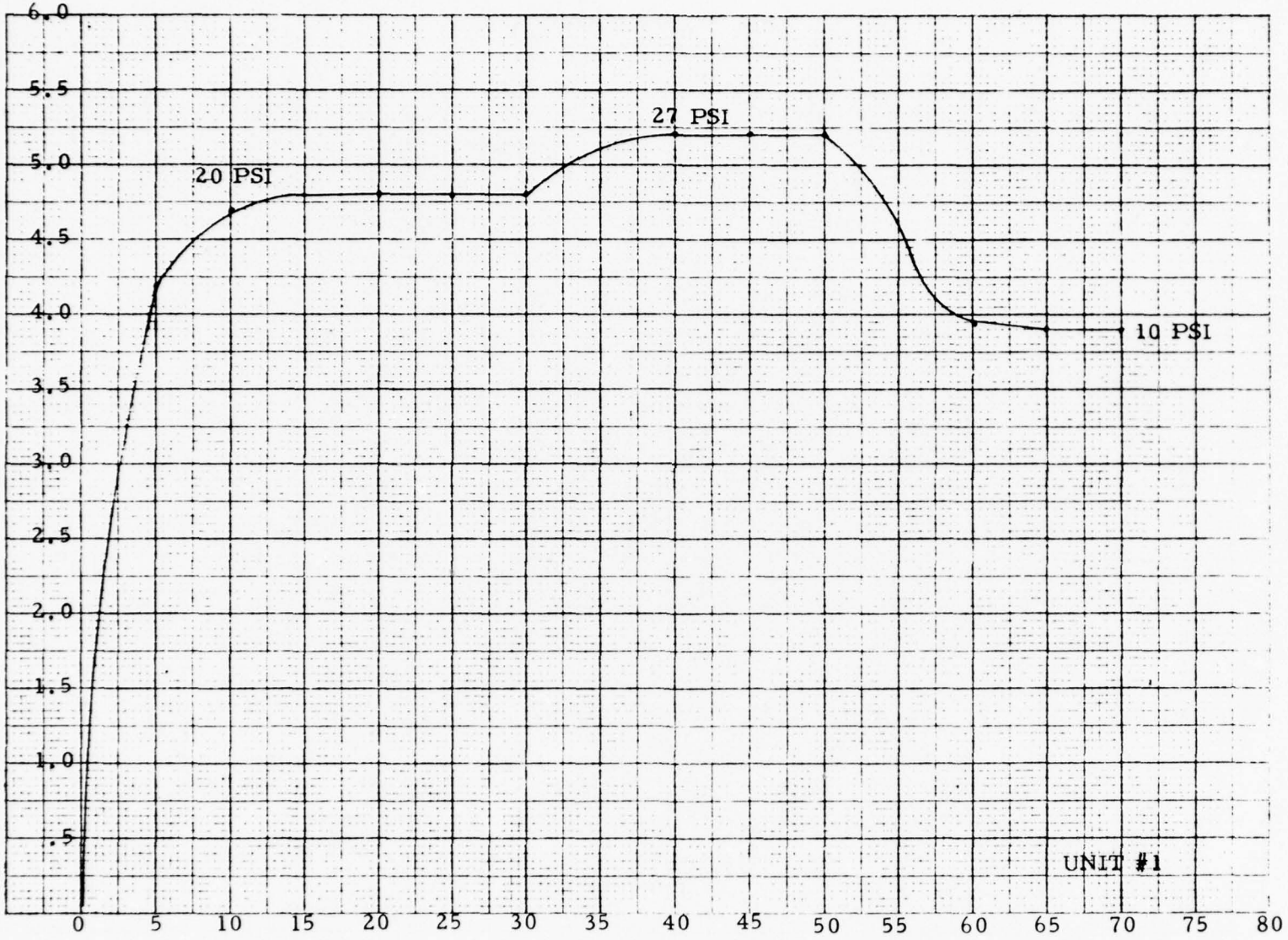
Table 15 tabulates the exhaust gas results obtained at various fuel settings.

Table 16 tabulates the test results obtained from evaluation of the DC-DC Converter. This data indicates that the unit can be used at the lower fuel settings which was not possible in previous units due to the higher input voltage required.

TABLE 16

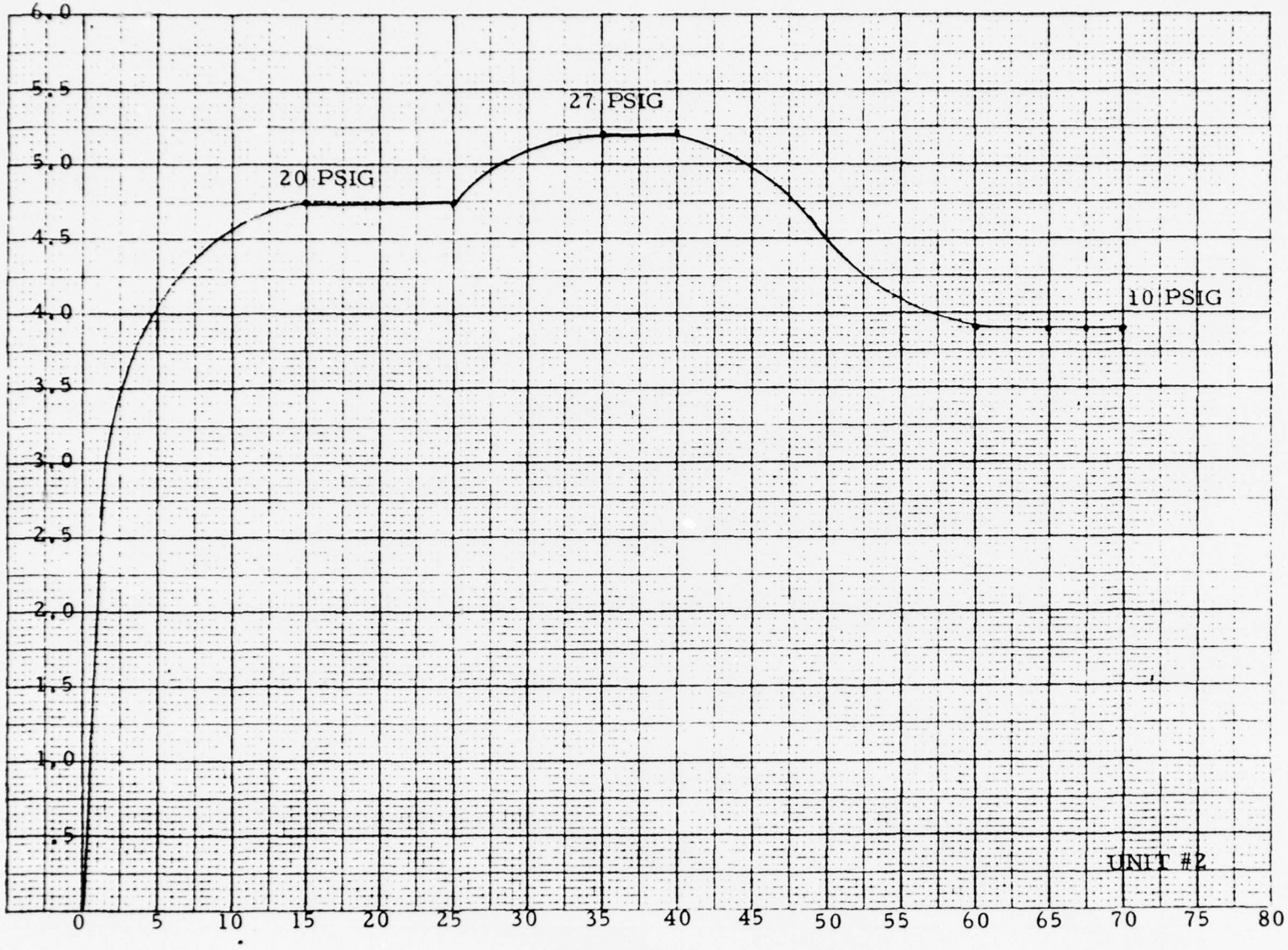
Voltage Input	Unit #1 Votage Output	Unit #2 Voltage Output
1.0	3.1	3.3
1.5	6.3	6.2
2.0	9.2	9.1
2.5	12.1	11.8
3.0	11.3	11.8
4.0	12.3	11.8
5.0	12.3	11.8
6.0	12.3	11.8

This data indicates that a fuel setting of 3 provides sufficient input voltage to the converter to give a 12 VDC output.



Voltage Rise Vs. Time .

Figure 38



Voltage Rise Vs. Time

Figure 39

6.0 CONCLUSIONS

6.1 Design Conclusions

Contract N62269-76-C-0239 can be broken down into six distinct stages each having their own conclusion. These stages are listed below together with a summary of work done.

6.1.1 Seat Kit Study

The first four to six weeks of the contract were spent determining the relevant differences among the various RSSK-8A seat kits as manufactured by Scott Aviation, Rocket Jet Division of American Flight Safety and East/West Industries. The result of this study are stated in depth in Section 2.1.

In addition to the differences among RSSK-8A seat kits among manufacturers, two other potential problems exist that could cause potential interchangeability problems. These are:

6.1.1.1 Differences in a Single manufacturer's Seat Kit Due to Tolerances

Lack of detailed internal RSSK-8A sub-component placement specifications allows manufacturers to work to liberal tolerances in the installation of these components. (e.g. oxygen tank, oxygen valves, mounting bracketry, etc.) Because of severe DAPS volume limitations in any seat kit, small variations in RSSK-8A component placement might well prevent an already close fitting DAPS from being installed in a given kit.

Because of the unavailability to date of manufacturer's production drawing packages, ESC has not been able to take into consideration DAPS space restrictions which might result from seat kit component placement tolerance variations.

6.1.1.2 Differences in a Single Manufacturer's Kit Due To Production Run

The Navy purchases Rigid Seat Survival Kits from one or more manufacturers at any given time in large quantities and presumably, on the basis of lowest sealed bid. This "batch" procurement practice results in the manufacturer gearing up for production in order to deliver some number of seat kits, then suspending operations until the next seat kit buy.

Although no hard evidence has been identified to date to prove that seat kits vary from run to run, it is highly probable that such differences do occur. Because of the latitude allowed by the envelope specification, it is possible that the variation between a single manufacturer's production runs is of the same order of magnitude as the variation already observed between manufacturers.

6.1.2 Design Layout

Several weeks were spent generating design layouts so as to determine optimum component location and maximum void volume utilization.

Based on these layouts, it was determined that radical changes would have to be made to the existing design if the RSSK-8A DAPS was to be interchangeable among the three kit manufacturers.

The major conclusion was that the existing combustion chamber design was not suited for packaging in the available space. This mandated that a new combustion chamber be designed.

Other conclusions arrived at from the layout were that the pressure gauge and temperature gauge would have to be deleted. The deletion of these gauges minimally impacted the design primarily due to the fact that regardless of what the gauges indicated, the degree of comfort would ultimately be determined by the user and the comfort level is a very subjective thing varying greatly from individual to individual.

6.1.3 Developmental Testing & System Design

Extensive testing was performed on several prototype combustion chambers that would fit into the available space for the new DAPS design.

Several important facts became evident as a results of this testing. The three major points that affect combustion chamber design are catalytic bed size, thermoelectric thermal contact and heat exchanger design. These points are discussed in more detail below.

6.1.3.1 Catalytic Bed Size

For any given fuel consumption rate there is a

very narrow limit between too much and too little catalyst. The affects of too little catalyst is obviously an excess of unburned fuel in the exhaust with a resulting waste of fuel. The affects of too much catalyst is not as obvious. It was learned from conversations with Matthey Bishop Corporation, the manufacturer of the catalyst, that if too much catalyst is present the air fuel mixture becomes richer and richer with a resulting decrease in available oxygen for combustion.

When this state exists, the products of combustion start to recombine to form methane gas in an extremely endothermic reaction. This reaction absorbs large amounts of heat thereby decreasing the temperature of the hot side. The net effect of this situation is also a decrease in system performance.

It was concluded that the proposed design operated on the extreme edge of having sufficient catalyst to combust the required amount for the required heat.

6.1.3.2 Thermoelectric Module Thermal Contact

In the course of developmental testing it was determined that the power generating ability of the modules is extremely sensitive to surface finish of the mating surfaces and also to contact pressure.

It is important that the maximum amount of module surface area is in contact with the maximum amount of surface area on the hot pin plate and cold heat exchanger sides of the modules.

When there are large areas of poor contact, there results a corresponding drop in power generation which feeds back into system efficiency.

Even when the mating surfaces are perfectly flat and smooth the power output of the modules is extremely sensitive to clamping force. Too little force also results in a drop in power generated.

6.1.3.3 Heat Exchanger Design

The third major conclusion resulting from the combustion chamber test is the degree of effect the design of the heat exchanger has with respect to heat extraction and pick up.

As stated in Section 3.0 of this report, the efficiency of the heat exchanger is dependent upon the heat transfer coefficient and available heat pick up area. Test results indicate that depending upon heat exchanger design, the thermal efficiency can be affected by 8 to 10%.

6.1.4 System Build

Previous systems were difficult to build and test due to the packaging density and the number of flexible tube runs. The new design is much easier to assemble and test. Assembly time required to build the combustion chamber has been reduced by 50% with the incorporation of the new design.

The removal of the temperature and pressure gauge also resulted in a decrease in assembly time due to the reduction in the number of connections that had to be made in the fuel and hydraulic lines.

Another innovation incorporated into this design is the use of preformed hard line fluid lines. These dip brazed fittings enable sharp bends to be made without danger of kinking a line with resultant loss of fluid flow.

The use of soft line fluid runs has been used only in the case of easily accessible runs. These above mentioned design changes have greatly facilitated the assembly of the units.

6.1.5 System Test

The results of the testing indicate that the new design RSSK-8A DAPS is superior in performance to the previous DAPS designs. The combustion efficiency has improved from 10% to 15% to a thermal efficiency of 60 to 65%.

This increase is attributed to proper combustion chamber sizing, resulting in more complete combustion, good thermal contact, resulting in more available power, and optimized heat exchanger efficiency, resulting in more heat transfer into the water.

6.1.6 Reliability and Maintainability

The reliability effort, during this program, was in developing a Program Plan that could be used interchangeably with each of the Navy heater systems.

The availability of reliability data for mechanical systems proved to be a major problem in determining the actual reliability for the DAPS: This problem has led Energy Systems Corporation to recommend the follow-on Reliability Program outlined in Section 7.2.

The manufacturers of the majority of the components used in the RSSK-8A system did not have any reliability data for their products. Where no data was available an approximation of the reliability of the component was made based on available data for similar components. This problem has led Energy Systems Corporation to recommend the follow-on Reliability Program outlined in Section 7.2.

7.0 RECOMMENDATIONS

7.1 Design

Energy Systems Corporation has developed the DAPS System to an advanced preproduction state.

At this point in time there are two routes that NADC can pursue.

1) Design DAPS Systems for each seat kit design as they become qualified for field use.

2) Design a Universal DAPS that could possibly be interchangeable among the majority of the RSSK designs.

The potential problems likely to be encountered, should option 1 above be selected, are outlined in Section 6.1.1 of this report.

Should this be the selected course of action several controls would have to be implemented to guarantee interchangeablity of the DAPS system among the kits manufactured by the various RSSK-8A manufacturing houses.

These controls would require as an absolute minimum rigid control of interior seat kit dimensions as well as component location and orientation be placed on all current and future fabrications. Current specifications only define outside dimensions which affect aircraft interface and allow vertually unlimited leeway with internal component placement.

This procedure would guarantee that the DAPS would be interchangeable among the kits as designed by all manufacturers.

These controls would, however, have to be instituted by the Navy as they are the seat kit user who can dictate seat kit specifications to the manufacturer and strictly enforced if interchangeability is to be a reality.

The second approach, and that preferred by Energy Systems Corporation is the concept of a "Universal DAPS".

Energy Systems Corporation recommends that Naval Air Development Center, Crew Systems Department, initiate a program whereby the feasibility of such a system could be determined.

Recent discoveries and developments by ESC indicate that such a system might be possible. Further DAPS miniaturization appears possible and some new concepts in packaging should they prove satisfactory could allow a great deal of flexibility in RSSK/DAPS installation.

Details of the conceptual "Universal DAPS" design are discussed below.

The DAPS System concept is primarily designed to extend survival time during a search and rescue operation, not to provide comfort for the downed airman.

Energy Systems Corporation has performed extensive theoretical studies of heat loss by a man in an encapsulating life raft to the ambient and the results indicate that a heat production rate of 100 watts is sufficient to compensate the heat loss by a man in the expected range of temperatures (See Appendix E for Calculations).

Based on these calculations, it seems that the existing system is over designed from a thermal output stand point.

Work under the RSSK-8A design contract has indicated that further DAPS miniaturization is possible. These size reductions, coupled with overall DAPS simplification and radical

component packaging concepts, open the door for realistic consideration of a universal DAPS.

It has been demonstrated by ESC that by proper selection of thermoelectric modules and by proper mating surface preparation, that the rated power output (5.5 to 6.5 watts) of the individual module can be obtained. The first feature of a Universal DAPS, then, would be a reduction in the number of thermoelectric modules from two to one.

Use of one module, given that it can be practically implemented, will allow construction of a combustion chamber of approximate dimensions: 1" x 2" by 2". Other features of a reduced size combustion chamber are discussed below;

7.1.1 Reduced Volume of Catalyst

The latest RSSK-8A DAPS combustion chamber contains 15 to 17 grams of Matthey-Bishop 1% platinum catalyst. This amount of catalyst is sufficient to oxidize propane at a rate of 40 grams per hour and results in a thermal output of 900 BTU/Hr. (264 thermal watts). The 15 grams of catalyst is easily contained within the above mentioned chamber volume.

If the DAPS thermal output requirement could be reduced, say to 150 or even 100 thermal watts, further reduction in catalyst volume, thus combustion chamber volume, could be made. Appendix E addresses this problem and derives the DAPS thermal output required to maintain the interior of the encapsulating liferaft at 60°F.

7.1.2 Optimized Heat Exchanger Design

ESC tests have shown that DAPS heat exchanger efficiency is very sensitive to changes in heat transfer area and heat transfer coefficient (a function of Reynolds Number). An optimum heat exchanger configuration for the minimum size combustion chamber would be designed analytically, then proven experimentally.

7.1.3 Optimized DAPS Electrical Network

The reduction in number of modules from two to one presents some electrical constraints not seen in current model DAPS. First, a single module system exhibits an output impedance one-half that observed in two module systems. In order to draw maximum power from the single module, a DC motor with approximately

one-half the motor resistance must be selected. Similarly, the motor voltage available (approximately 4.0 VDC in current DAPS) is reduced to approximately 2.5 VDC. Obviously a new motor must be found for the Universal DAPS.

The second and more obvious constraint is that of one-half the available power from only one thermoelectric module. Proper module selection will allow a ceiling power availability of 6.5 watts. Careful attention must, therefore, be paid to power budget allocations to the various DAPS sub-components.

Optimizing the DAPS electrical network is a complex exercise, often impossible with standard components. First, the motor must exhibit an input impedance (at operating speed and temperature) which matches as closely as possible the thermoelectric module output impedance at its operating temperature. Generally, the motor impedance of standard off-the-shelf motors is not as low (typically less than one ohm) as is required by the thermoelectric circuit. Secondly, the motor operating speed must be at the point of maximum motor efficiency, as well as at the point of maximum pump efficiency. Selection of a positive displacement pump which yields the proper output (pressure and flow) at a torque and speed input compatible with the motor has proven difficult in the past. In addition to input/output matching, the DAPS pump must be of certain dimensions, be driven by a zero leakage magnetic coupling, and exhibit high pumping efficiencies at the corresponding motor speed. To date, selection of the ideal pump from commercially available products has resulted in few alternatives.

Design of the Universal DAPS will represent a systems engineering effort which will take into consideration, and possibly modify, overall DAPS heat delivery requirements. Working backwards from the heat output requirement, the optimum heat exchanger design will be effected to give maximum heat delivery at a flow rate consistent with reduced power constraints. Flow and pressure considerations and the thermoelectric module characteristics will then dictate motor selection.

7.1.4 Improved Pump

Although technically, the pump is part of the electrical system discussed in Paragraph 3 and one of the largest single consumers of power as discussed in Paragraph 5, it warrants separate consideration because of its importance to the successful design of the Universal DAPS. The problem to date has been one of

finding a commercial pump which will pump the required DAPS flow at DAPS pressure drops yet still match up operationally with the rest of the thermoelectric/motor network. In particular, the existing pump experiences very high torque losses at the speeds at which it is driven by the existing motor. Two possible solutions exist, both of which would be pursued by ESC under a Universal DAPS program.

A. Custom design and fabricate the proper pump for DAPS application. This approach would also include custom modification of existing commercial pumps to suit other DAPS requirements. This approach appears to be the most attractive, since it would allow ESC to assure maximum efficiency at the required design point. In addition, ESC could tailor the size of the pump to Universal DAPS specifications.

B. A gear reduction could be used to run the pump at a slower speed, thereby cutting down considerably the speed dependent torque losses now experienced. The gear train losses would be more than compensated for by increased pump efficiency, but the gearing mechanism would require more space and add to DAPS weight.

7.1.5 Power Sharing

As has been pointed out in previous paragraphs, several engineering approaches to designing a DAPS which will perform to specification using only one module (6.5 watts) have been discussed, Each approach offers, in itself, a viable solution to the Universal DAPS design problem. There is, however, one more approach which warrants discussion and which points out once again the many engineering approaches available in successful DAPS design.

The hydraulic pumpand the DC-DC converter are the only two DAPS components consuming electrical power. It is conceivable, and practical, that these two components could share the limited electrical power available in a Universal DAPS. A downed airman in an emergency situation needs regulated 12 VDC power and he needs heat to warm his body - but not necessarily at the same time. The price to be paid in designing such a DAPS is, of course, increased system complexity and decreased system reliability (due to the complexity and added number of parts).

A power sharing arrangement might be designed to allow the DC-DC converter to draw all the power it requires (say for a PRC 90 radio) at the expense of the pump. As the pump slowed down, the temperature of the thermoelectric modules and the heat exchangers would rise. When the heat exchanger temperature exceeded a safe level, a temperature actuated switch would return power to the pump allowing excess heat to be carried away to the tubulated garment. As the temperature fell to acceptable levels, maximum power would be returned to the DC-DC converter, thus to the radio. The required switching would take place electronically, with all necessary components being solid state.

The most radical change from current generation DAPS would be the removal of the fuel pressure regulator. The DAPS will be designed such that a single fixed rate of heated water will be supplied to the airman's tubulated suit. An in-depth analysis will be first performed to determine just what this heat delivery rate should be. Connecting the fuel umbilical to the fuel tank will automatically start fuel flow to the combustion chamber. The airman will then press the ignition button and the DAPS will operate on its own. If too much heat is being delivered, the airman has the option of disconnecting the fuel line from the tank.

The resulting benefits to be realized with this approach are many:

Cost Reduction
Size Reduction
Ease of Storing in Seat Kit
Simplicity of Operation
Seat Kit Interchangeablity

Based on these advantages Energy Systems Corporation strongly recommends that NADC fund a R & D contract to determine the feasability of the Universal DAPS concept.

7.2 Reliability

The problems listed in Section 4.2.2.3 have led Energy Systems Corporation to recommend a follow-on Reliability Program geared specifically towards obtaining the reliability data required to confidently predict the RSSK-8A DAPS reliability. The major effort during this program would be in the area of Reliability Development Testing and Reliability Demonstration. These two tasks are outlined below:

7.2.1 Reliability Development Testing

Plans and procedures for reliability development testing have been established and would be implemented during this program. The purpose of this testing is three fold: (1) to estimate the achieved reliability and to provide feedback of data as a basis for making reliability improvements, (2) to confirm the adequacy of the individual components, and (3) to identify additional failure modes and failure rates.

Those components that would be tested during this contract include: (1) complete DAPS units, (2) pump/motor assemblies (3) combustion chamber, (4) fuel tanks and (5) piezoelectric igniters. The sample size for testing has yet to be determined.

Tests, and their basic formats, that would be performed during this program include:

1. Operating Temperature Test

This test would be performed to determine whether or not the unit (or component) will operate satisfactorily over the temperature range specified in the contract. The basic format of this test would be that of test procedure 4.1.2 and 4.2.1 of MIL-E-5272C (Environmental Testing, Aeronautical and Associated Equipment, General Specification for).

2. Temperature Cycling Test

This test would be performed for the purpose of determining the effects of temperature cycling on the operation of the unit (or component). The basic format would be that of test procedure 5.2.3.1 of MIL-STD-781B (Reliability Tests: Exponential Distribution).

3. Temperature Storage

The objective of this test would be to determine whether or not the storage temperature range has a harmful effect on the unit (or component).

4. Vibration Test

The objective of this test would be to determine whether or not the unit will operate satisfactorily after being subjected to the vibration spectrum of the aircraft. The basic format of this test would be that of test procedure 4.7.10.1 of MIL-S-81018A (Survival Kit Container, Aircraft Seat with Oxygen; General Specification for).

5. Shock Test

This test would be performed to determine whether or not the unit will survive and operate satisfactorily after being ejected from the aircraft. The basic format of this test would be test procedure 4.7.5.4 of MIL-S-81018A.

6. Life Test

The purpose of this test would be to obtain additional information on the operating characteristics, the life, and the failure rate of each of the major components in the DAPS System.

This reliability testing would offer a partial solution to the problems listed in Section 4.2.2.3 of this report. Since these tests would be used for reliability evaluation and not reliability demonstration, they should be performed by qualified in-house personnel.

7.2.2 Reliability Demonstration Test Support

The actual reliability demonstration should be conducted by NADC or by an impartial outside agency chosen by NADC. However, it is proposed that Energy Systems Corporation support this Reliability Demonstration as follows.

The Program Manager would develop plans and procedures for the demonstration test and would include the ground rules and criteria for deciding whether the results of any particular test be classified as a success or failure.

Energy Systems Corporation would provide detailed test plans and procedures for the testing and would supply on-site testing, evaluation, and analysis support as required by the Reliability Demonstration Test agency.

APPENDIX A

CALCULATION OF INITIAL FAILURE RATES FOR THE RSSK-8A DAPS BASED ON AN OVERALL SUCCESS PROBABILITY OF .976

APPENDIX A

CALCULATION OF INITIALLY ALLOCATED FAILURE RATES FOR THE RSSK-8A DAPS BASED ON AN OVERALL SUCCESS PROBABILITY OF .976

Assume:

Δt = 30 operating hours (6 hours testing plus 24 hours in-raft operation)

$$P(\Delta t) = \exp - (\lambda \Delta t)$$

$$.976 = \exp - (\lambda \times 30)$$

$$\ln (.976) = \ln \exp - (\lambda \times 30)$$

$$- .0243 = - 30\lambda$$

$$\lambda = 810 \times 10^{-6}$$

Let:

λ_1 = the failure rate of the external fuel components.

λ_2 = the failure rate of the DAPS components.

λ_3 = the failure rate of the internal connections (solder, dip braze, weld, pipe, clamp).

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3$$

Allocate:

$$\lambda_1 = 170 \times 10^{-6}$$

$$\lambda_2 = 630 \times 10^{-6}$$

$$\lambda_3 = 10 \times 10^{-6}$$

EXTERNAL FUEL SUB-SYSTEM

$$\lambda_1 = 170 \times 10^{-6}$$

Let:

λ_4 = the failure rate of the fuel tank

λ_5 = the failure rate of the shut-off valve

λ_6 = the failure rate of the fuel line

$$\lambda_1 = \lambda_4 + \lambda_5 + \lambda_6$$

Allocate:

$$\lambda_4 = 100 \times 10^{-6}$$

$$\lambda_5 = 20 \times 10^{-6}$$

$$\lambda_6 = 50 \times 10^{-6}$$

DAPS SUB-SYSTEM

$$\lambda_2 = 630 \times 10^{-6}$$

Let:

λ_7 = the failure rate of the internal fuel assembly

λ_8 = the failure rate of the combustion chamber assembly

λ_9 = the failure rate of the fluid assembly

λ_{10} = the failure rate of the electrical assembly

$$\lambda_2 = \lambda_7 + \lambda_8 + \lambda_9 + \lambda_{10}$$

Allocate:

$$\lambda_7 = 30 \times 10^{-6}$$
$$\lambda_8 = 200 \times 10^{-6}$$
$$\lambda_9 = 270 \times 10^{-6}$$
$$\lambda_{10} = 130 \times 10^{-6}$$

INTERNAL FUEL ASSEMBLY

$$\lambda_7 = 30 \times 10^{-6}$$

Let:

λ_{11} = the failure rate of the pressure regulator

$$\lambda_7 = \lambda_{11}$$

Allocate:

$$\lambda_{11} = 30 \times 10^{-6}$$

COMBUSTION CHAMBER ASSEMBLY

$$\lambda_8 = 200 \times 10^{-6}$$

Let:

λ_{12} = the failure rate of the piezoelectric

λ_{13} = the failure rate of the thermoelectrics

$$\lambda_8 = \lambda_{12} + \lambda_{13}$$

Allocate:

$$\lambda_{12} = 100 \times 10^{-6}$$
$$\lambda_{13} = 100 \times 10^{-6}$$

FLUID ASSEMBLY

$$\lambda_9 = 270 \times 10^{-6}$$

Let:

λ_{14} = the failure rate of the pump

λ_{15} = the failure rate of the fluid lines

λ_{16} = the failure rate of the fluid connector

$$\lambda_9 = \lambda_{14} + \lambda_{15} + \lambda_{16}$$

Allocate:

$$\lambda_{14} = 80 \times 10^{-6}$$
$$\lambda_{15} = 20 \times 10^{-6}$$
$$\lambda_{16} = 170 \times 10^{-6}$$

ELECTRICAL ASSEMBLY

$$\lambda_{10} = 130 \times 10^{-6}$$

Let:

λ_{17} = the failure rate of the DC-DC converter

λ_{18} = the failure rate of the D.C. motor

λ_{19} = the failure rate of the 12 VDC connector

$$\lambda_{10} = \lambda_{17} + \lambda_{18} + \lambda_{19}$$

Allocate:

$$\lambda_{17} = 30 \times 10^{-6}$$
$$\lambda_{18} = 70 \times 10^{-6}$$
$$\lambda_{19} = 30 \times 10^{-6}$$

APPENDIX B

CALCULATION OF PREDICTED INDIVIDUAL COMPONENT FAILURE RATES

APPENDIX B

CALCULATION OF PREDICTED INDIVIDUAL COMPONENT FAILURE RATES

MIL-HDBK-217B (2.8.5-1)

D. C MOTOR

Definitions:

λ_b = base failure rate

π_F = motor family and quality factor

λ_E = electrical failure rate

T_{op} = operating time

P_{pop} = % of motor mechanical failures during operating period, T_{op}.

λ_W = mechanical failure rate

π_E = environmental factor

$$\lambda_b = Ae^x \quad \text{where} \quad x = \left(\frac{T + 273}{N_T}\right) G$$

T = operating hot spot temp. in °C

= ambient temperature + 50°C

T = 75°C

Assume the rated insulation hot-spot temperature = 105°C

$\therefore A = 7.20 \times 10^{-4}$

$N_T = 352$

$G = 14.0$

$$x = \left(\frac{T + 273}{N_T}\right)^G = \left(\frac{75 + 273}{352}\right)^{14}$$

$x = .852$

$$\lambda_b = Ae^x = (7.20 \times 10^{-4})(e^{.852})$$

$$\lambda_b = 1.68 \times 10^{-3}$$

From Table 2.8.1-2 $\pi_F = 24$

$$\lambda_E = \lambda_b \pi_F = (1.68 \times 10^{-3})(24)$$

$$\lambda_E = 4.032 \times 10^{-2}$$

From Figure 2.8.1-3 The MTTF = 4000 hours

Operational time = 30 hours

Operating at 125% of hours rated capacity

$$\frac{T_{op}}{MTTF} = \frac{30}{4000} = .0075$$

Inserting this value into Figure 2.8.1-5 yields a wear-out percent of population of .03.

$$\lambda_W = \frac{P_{pop}(10)^4}{T_{op}} = \frac{.03 \times 10^4}{30} = 10 \text{ failures}/10^6 \text{ hours}$$

$$\lambda_E + \lambda_W = 10.04 \text{ failures}/10^6 \text{ hours}$$

$$\lambda_p = (\lambda_E + \lambda_W)\pi_E$$

$$\lambda_p = (10.04)(2.5)$$

$$\lambda_p = 25.1 \text{ failures}/10^6 \text{ hours}$$

$$P(\Delta t) = e^{-\Delta t \lambda_p}$$

$$P(30) = e^{(-30)(25.1 \times 10^{-6})}$$

$$P(30) = .99924$$

λ_W = mechanical failure rate

π_E = environmental factor

D.C. - D.C. CONVERTER

PARTS COUNT REL. PREDICTION
INFOR. SOURCE: (MIL-HDBK-217B)

$$\text{EQUIP} = \sum_{i=1}^{i=n} N_i \left(\lambda_G \pi_Q\right)_i$$

Where: λ_{EQUIP} = total equipment failure rate (failures/10^6 hours)

λ_G = generic failure rate for the i^{th} generic part (failures/10^6 hours).

π_Q = quality factor for the i^{th} generic part

n = number of different generic part categories

N_i = quantity of i^{th} generic part

PART	# of Parts per Converter	π_Q	λ_G
REGULATOR	1	5.0	1.12×10^{-6}
RESISTOR	2	0.1	$.018 \times 10^{-6}$
CAPACITOR	2	0.1	$.26 \times 10^{-6}$
DIODE	2	1.0	1.1×10^{-6}
TRANSFORMER	1	1.0	$.12 \times 10^{-6}$
TRANSISTOR	2	1.0	1.6×10^{-6}

$$\lambda_{EQUIP} = \left[(1)(1.12\times10^{-6})(5)\right] + \left[(2)(.018\times10^{-6})(.1)\right] + \left[(2)(.26\times10^{-6})(.1)\right] + \left[(2)(1.1\times10^{-6})(1)\right] + \left[(1)(.12\times10^{-6})(1)\right] + \left[(2)(1.6\times10^{-6})(1.0)\right]$$

$$\lambda_{EQUIP} = 1.11756 \times 10^{-5}$$

$$P(\Delta t) = e^{(-\Delta t)(\lambda_{EQUIP})} = e^{(-30)(1.11756\times 10^{-5})} = .9997$$

12 V.D.C. ELECTRICAL CONNECTOR

Information Source: MIL-HDBK-217B (2.11-1)

Definitions:

λ_p = the connector failure rate

λ_b = base failure rate

π_E = environmental adjustment factor

π_p = failure rate modifier

N = number of active pins

λ_{cyc} = cycling failure rate

A = constant

T_o = constant

N_T = constant

G = constant

P = constant

T = operating temperature (°C)

i = amperes per contact

$$\lambda_p = \lambda_b (\pi_E \times \pi_p) + N\lambda_{cyc} \text{ (failures/}10^6\text{ hours)}$$

Insert Material: Neoprene (Type D)

$$\lambda_b = Ae^x$$

$$\text{Where } x = \left(\frac{T + 273}{N_T}\right) G + \left(\frac{T + 273}{T_o}\right) P$$

From Table 2.11-1 (MIL-HDBK-217B)

$A = 12.3$

$T_o = 358$

$N_T = -1528.8$

$G = -1$

$P = 4.72$

T = operating temperature (°C)

= ambient temperature + temp. rise (Table 2.11-4)

maximum ambient temperature = 25°C

$$\text{Temperature rise} = .64\,(i)^{1.85}$$

$$= .64\,(.050)^{1.85}$$

$$= .0025\ ^\circ C \text{ (negligible)}$$

$$x = \left(\frac{T + 273}{N_T}\right) G + \left(\frac{T + 273}{T_o}\right) P$$

$$= \left(\frac{25 + 273}{-1528.8}\right) -1 + \left(\frac{25 + 273}{358}\right) 4.72$$

$$x = -4.7095$$

$$\lambda_b = Ae^x$$

$$= 12.3e^{-4.7095}$$

$$\lambda_b = .1108$$

$N = 4$ pins

$\pi_E = 10.0$ (Table 2.11-6 Assume A_u environment)

$\pi_p = 1.72$ (Table 2.11-7)

$\lambda_{cyc} = .0011$ (Table 2.11-8) Assume 10 cycles/10^3 hours)

$\lambda_p = {}_b(\pi_E \times \pi_p) + N\lambda_{cyc}$ (failures/10^6hours)

$= (.1108)(10 \times 1.72) + (4)(.0011)$

$\lambda_p = 1.9104$ Failures/10^6 hours

$$P(\Delta t) = e^{-\Delta t \lambda_p} = e^{(-30)(1.9104 \times 10^{-6})} = .99994$$

THERMOELECTRICS

Source of Information:

Nuclear Systems, Inc.

Instrument Division

---

82 couples/module

164 elements/module

328 solder joints/module

Using an average failure rate of 5×10^{-8} for each solder joint (from NSI Instrument Division) of a thermoelectric cooling module, the failure rate of the module can be calculated.

$\lambda_p = (\pi_E)(5.0$ failures/10^8hours/solder joint)
(328 solder joints)

$\lambda_p = (10)(5 \times 10^{-8})(328)$

$\lambda_p = 1.64 \times 10^{-4}$/module

$P(\Delta t) = e^{-\Delta t \lambda_p}$

$$P(30) = e^{(-30)(1.64 \times 10^{-4})}$$

$$P(30) = .995 \text{ (per module)}$$

The RSSK-8A DAPS has two modules in series. Therefore:

$$P_{overall}(\Delta t) = .995 \times .995 = .990$$

FLUID CONNECTORS

Assume:

(1) No vibration effects (manufacturers data)

(2) 1 failure per 10,000 connectors

$$\lambda_T = 1 \times 10^{-4}$$

$$P(\Delta t) = e^{-\Delta t \lambda_T}$$

$$P(30) = e^{(-30)(1 \times 10^{-4})}$$

$$P(30) = .997$$

PRESSURE REGULATOR

λ_T = part failure rate

λ_b = base failure rate

π_E = environmental adjustment factor

π_Q = quality adjustment factor

Works in excess of 100 million cycles (manufacturers data)

Assume:

Δ_C = 30 cycles

π_E = 10 (from Reliability Design Handbook, IIT Research Institute)

π_Q = 150 (from Reliability Design Handbook, IIT Research Institute)

$$\lambda_b = 1 \times 10^{-8}$$

$$\lambda_T = (\lambda_b)(\pi_E)(\pi_Q)$$

$$\lambda_T = (\lambda_b)(10)(150)$$

$$\lambda_T = 1500\lambda_b$$

$$\lambda_T = 15 \times 10^{-6}$$

$$P(\Delta c) = e^{-\Delta c \lambda_T}$$

$$P(30) = e^{(-30)(15 \times 10^{-6})}$$

$$P(30) = .99955$$

CONNECTIONS

Approximate number of connections per RSSK-8A DAPS:

3	- weld
23	- solder
9	- pipe
7	- dip braze
10	- hose clamps
52	- total connections

Assume:

(1) The average failure for each of the above is 5.0×10^{-8}. This value is taken from NSI data on solder connections for thermoelectric modules.

Therefore:

$$\lambda_T = (52 \text{ connections/unit})(5 \times 10^{-8} \text{ failures/connection})$$

$$\lambda_T = 2.6 \times 10^{-6} \text{ failures/unit}$$

$$P(\Delta t) = e^{-\Delta t \lambda_T}$$

$$P(30) = e^{(-30)(2.6 \times 10^{-6})}$$

$$P(30) = .999922$$

PIEZOELECTRIC

Assume:

(1) 1 failure per 10,000 piezoelectrics

$$\lambda_T = 1 \times 10^{-4}$$

$$P(\Delta t) = e^{-\Delta t \lambda_T}$$

$$P(30) = e^{(-30)(1 \times 10^{-4})}$$

$$P(30) = .997$$

FUEL SHUT-OFF VALVE

Definitions:

λ_T = part failure rate

λ_b = base failure rate

π_E = environmental adjustment factor

π_Q = quality adjustment factor

Assume shut-off valve works in excess of 100 million cycles (manufacturers data)

Assume:

Δ_c = 30 cycles

π_E = 10 (from Reliability Design Handbook, IIT Research Institute)

π_Q = 150 (from Reliability Design Handbook, IIT Research Institute)

$$\lambda_b = 1 \times 10^{-8}$$

$$\lambda_T = (\lambda_b)(\pi_E)(\pi_Q)$$

$$\lambda_T = (\lambda_b)(10)(150)$$

$$\lambda_T = 1500\,\lambda_b$$

$$\lambda_T = 15 \times 10^{-6}$$

$$P(\Delta c) = e^{-\Delta c\,\lambda_T}$$

$$P(30) = e^{(-30)(15 \times 10^{-6})}$$

$$P(30) = .99955$$

APPENDIX C

THERMAL REQUIREMENTS FOR COLD WATER AND LIFE RAFT EXPOSURES

APPENDIX C

THERMAL REQUIREMENTS FOR COLD WATER AND LIFE RAFT EXPOSURES

This appendix is included as back-up information for the recommendation that a universal DAPS is feasible. As previously stated calculations indicate, a thermal input of 100 watts should be adequate to balance thermal heat losses of a man exposed to 20°F ambient air temperatures.

Following are the assemptions and definition of terms used in the calculations.

It is assumed that the airman enteres the life raft within five(5) minutes after immersion in 32° F water.

Insulation Values Estimates

Ig = Net effective insulation value of the body clothing worn. Insulation value of the dry anti-exposure suite (CWU-21/p) = 1.2 clo(1). The wetting reduces the clothing insulation by 25% to 0.9 clo.

I raft = Insulation value of the wet raft. Insulation value of the dry life raft, insulated canopy type (LRU-6/p) = 1.0 clo. The wetting reduces the raft insulation value by 30%, to 0.7 clo.

Ia, raft = Insulation value of the air inside the raft. The effective insulation value of the raft air is 0.5 clo.

Life Raft Heat Transfer Calculations

Ts = Mean skin temperature, °C.

Ta = Ambient Air Temperature, °C.

SA = Body Surface area (1.8 m^2)

---

(1) Definition of Clo: Clo is a unit of thermal insulation of the clothing system and the overlying still air. One clo insulation will result in 5.55 K cal per hour of dry heat transfer (convection plus radiation) per unit of temperature gradient (°C) from one meter square of surface area.

$\dot{M}$ = Metabolic heat production, Kcal/m^2/hr.

Assuming $\dot{M}$ = 75 Kcal/m^2/hr, of this 25% is lost by evaporation. Therefore, net metabolic heat lost by radiation and convection (dry heat);

= 75 x 0.75 x 1.8
= 100 Kcal/hr.

$-\dot{Q}$ = Heat loss through clothing and life raft, Kcal/hr.

$$-\dot{Q} = \frac{5.55\ (Ts - Ta\ SA}{Ig + (I\ raft + Ia,\ raft)}\ K\ cal/hr$$

for, Ta = -6.7°C (20°F)
Ts = 32°C (89.6°F)
SA = 1.8 m^2
Ig = 0.9 clo
I raft = 0.7 clo
Ia, raft = 0.5 clo

$$\dot{Q} = \frac{-5.55\ (32 + 6.7) \times 1.8}{0.9 + (0.7 + 0.5)}$$

= - 184 Kcal/hr

Therefore, net body heat loss (without DAPS heating),

= $\dot{Q} + \dot{M}$ (dry)

= -184 + 100

= -84 Kcal/hr (= - 98 watts)

This means that approximately 84 Kcal/hr (98 watts) of heat must be provided to the man-raft ambient to maintain the airman's body temperature constant. The heat requirement will be slightly lower if the body is allowed to cool within safe tolerance limits. The 84 Kcal/hr. heat delivery from the DAPS to the raft will provide indefinite tolerance at 20°F to the man in the raft without any cold exposure.

APPENDIX D

RSSK-8A DAPS OPERATING INSTRUCTIONS

APPENDIX D

RSSK-8A DAPS OPERATING INSTRUCTIONS

The following procedure is recommended to deploy and operate the DAPS.

1) Remove the DAPS heater/fuel coil assembly from the seat kit by unlatching catches located at positions A, B, C & D (Figure 1).

2) Connect fluid umbilical on DAPS to mating connection of suit.

3) Remove exhaust port cover

4) Admit fuel to DAPS by connecting fuel umbilical on fuel coil to mating connection on DAPS.

5) Admit fuel to the combustion chamber in DAPS by adjusting fuel regulator to a setting of 8.

6) Aim exhaust port away from clothing and raft.

7) Press ignition button to start fuel burning.

8) Check exhaust port for flame.

9) If no flame and heat visible repeat step 7 until ignition occurs.

10) System will start pumping fluid through tubulated garment within two minutes.

11) Allow system to reach equilibrium, approximately 15 minutes and set at desired thermal requirement. A higher fuel setting will result in a greater thermal input to the man with corresponding decrease in fuel duration. A decal showing approximate fuel duration vs regulator setting is provided to indicate expected fuel durations.

12) To operate auxiliary equipment from the 12V outlet, connect input jack on equipment to connector on DAPS. It is recommended that auxilliary equipment is used only between fuel settings of 4 and 7.

13) To secure the DAPS, turn regulator knob to zero setting, disconnect fuel umbilical and allow system to coast to a stop (approximately 5 minutes); disconnect fluid umbilical from suit. ---- Warning: under no circumstances should system be operated with fluid connectors unattached to a suitable thermal sink. Operating DAPS with no or inadequate flow will result in damage to the DAPS and possibly the operator.

APPENDIX E

MAINTENANCE AND REPAIR

APPENDIX E

MAINTENANCE AND REPAIR

Following is a list and description of basic maintenance items required on the RSSK-8A DAPS.

1. Replenishing Tubulated Suit and Power Source Fluid

Over a period of time and with repeated use, some loss of fluid and inclusion of air will occur in the system. The amount of spillage, for the Air lock connectors is negligible with rapid connection. However, with a slow or fumbling engagement, a fair amount could be realized. Air inclusion could be as little as .0033 cubic inches per connection. The DAPS will operate satisfactorily with a limited amount of air in the fluid lines.

INSPECTION: Connect the tubulated suit to the DAPS. Observe the suit fluid lines near the connector for air. If the air bubble is more than one inch long in either tube, the suit and DAPS should be refilled with a 50 percent ethylene glycol and 50 percent water solution. An extra connector will be required for replenishing the fluid in the DAPS.

Manufacturer: Air-Lock, Inc.
Gulf Street
Milford, Connecticut 06460

Part Number: 9575-01

The DAPS and the tubulated suit can be filled or replenished using the extra connector and a pump. The pumping rate should not exceed .75 gallons per minute.

2. It is recommended that the DAPS and the tubulated suit be flushed with a freshly mixed antifreeze solution once a year to avoid scale build-up.

3. The igniter electrode in the exhaust port should be cleaned periodically with abrasive paper or cloth.

Table E-1 gives the expected replacement schedule for the major components of the RSSK-8A DAPS System.

Following is a list of the most common failure modes, the possible causes, and the repair action to be followed to correct each failure (Table E-2). All repair work should be done by a skilled technician familiar with the system, and any major repairs that are required should be performed by ESC personnel only.

4. Refilling Fuel Tanks

The RSSK-8A fuel tank is a refillable type fuel tank. Caution should be exercised while refilling so as not to overfill. This tank has a fuel capacity of 150 grams maximum. A detailed procedure for refilling is outlined below. Refer to Figure E-1 for orientation of components.

(1) Remove top cover

(2) Loosen hex nut on pressure-regulator

(3) Remove remaining screws holding fuel tank to housing assembly and lift fuel tank out.

(4) De-couple fitting between pressure regulator and shut-off valve.

(5) Empty tank by opening shut-off valve (turn CCW)

(6) After tank has been emptied completely, install refill adapter to shut-off valve, close shut-off valve (turn CW) then weigh tank and record weight (gram type balance scale preferred).

(7) Refrigerate tank at 0-10°F for 30-60 minutes.

(8) Place cold tank on balance scale and screw bottle of propane gas into end of refill adapter then advance weights on scale 150 grams over actual weight of tank. Open shut-off valve, (turn CCW) slowly thus allowing fuel to flow from propane bottle to fuel tank

	STORAGE (Years)	IN-FLIGHT (Years)
FUEL TANK	8	4
SHUT-OFF VALVE	5	5
PRESSURE REGULATOR	5	5
FUEL TUBING	5	5
PIEZOELECTRIC	Indefinite	Indefinite
THERMO-ELECTRIC	20	5
PUMP	15	15
FLUID LINES	5	5
FLUID CONNECTOR	15	15
MOTOR	2	2
12 VDC CONNECTOR	5	5
DC-DC CONVERTER	Indefinite	Indefinite
CATALYST	10	5
CONNECTIONS (solder, dip braze weld, pipe, clamps)	Indefinite	Indefinite

RSSK-8A COMPONENT REPLACEMENT SCHEDULE

TABLE E-1

CAUTION: Should be exercised so as not to overfill tank. When indicator of balance reads (0) tank is full. Close shut-off valve (turn CW) and disconnect bottle from refill adapter (if over-filling occurs open and shut off valve and thus allow excess fuel to escape. Once proper weight is attained close shut-off valve (turn CW) tightly). Now disconnect other end of refill adapter from shut–off valve.

(9) Re-assemble and install fuel tank by reversing steps 1, 2, 3 and 4.

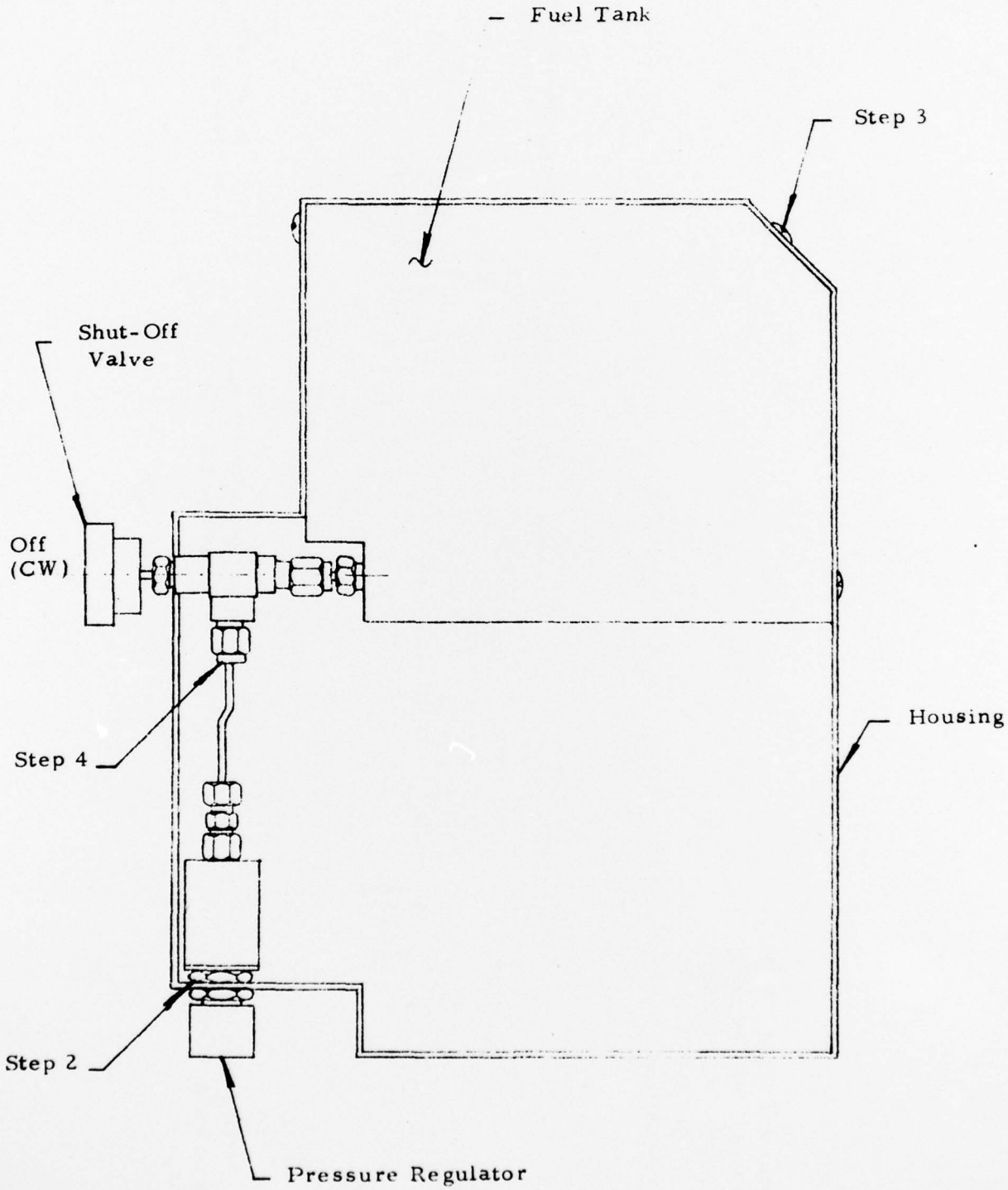

Fuel Tank
Step 3
Shut-Off Valve
Off (CW)
Step 4
Housing
Step 2
Pressure Regulator

Figure E-1

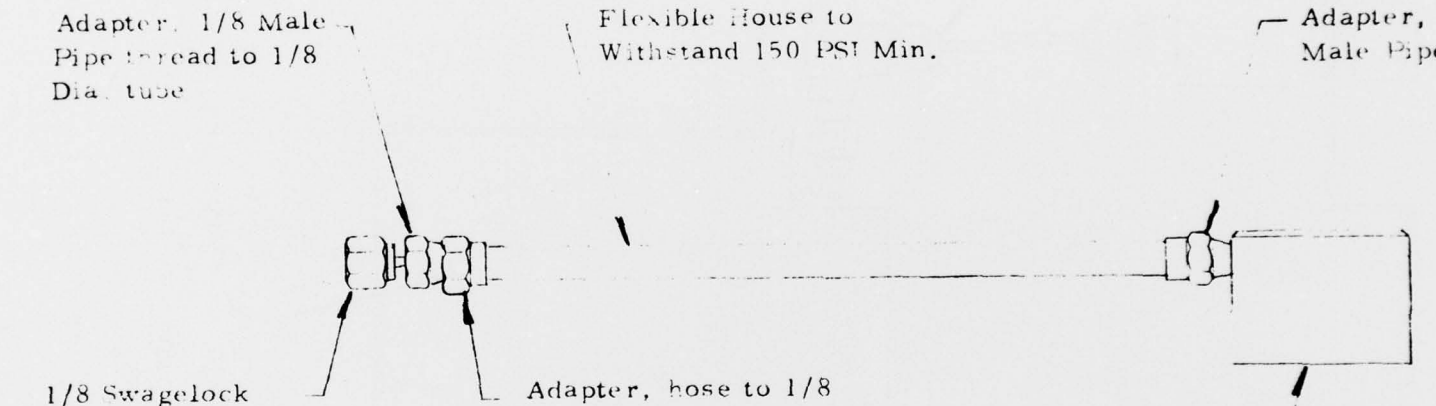

Adapter, 1/8 Male Pipe Thread to 1/8 Dia. tube
Flexible House to Withstand 150 PSI Min.
Adapter, Hose to 1/8 Male Pipe Fitting
1/8 Swagelock Fitting on Shutt-off Valve
Adapter, hose to 1/8 Female Hose Fitting
Adapter, Propane Cylinder ESC Pt. No. 10539P1. Pin, actuating ESC Pt. No. 10540P1. Gasket, ESC Pt. No. 10546P1. See ESC Dwg. 10537 for reference.

Figure E-2

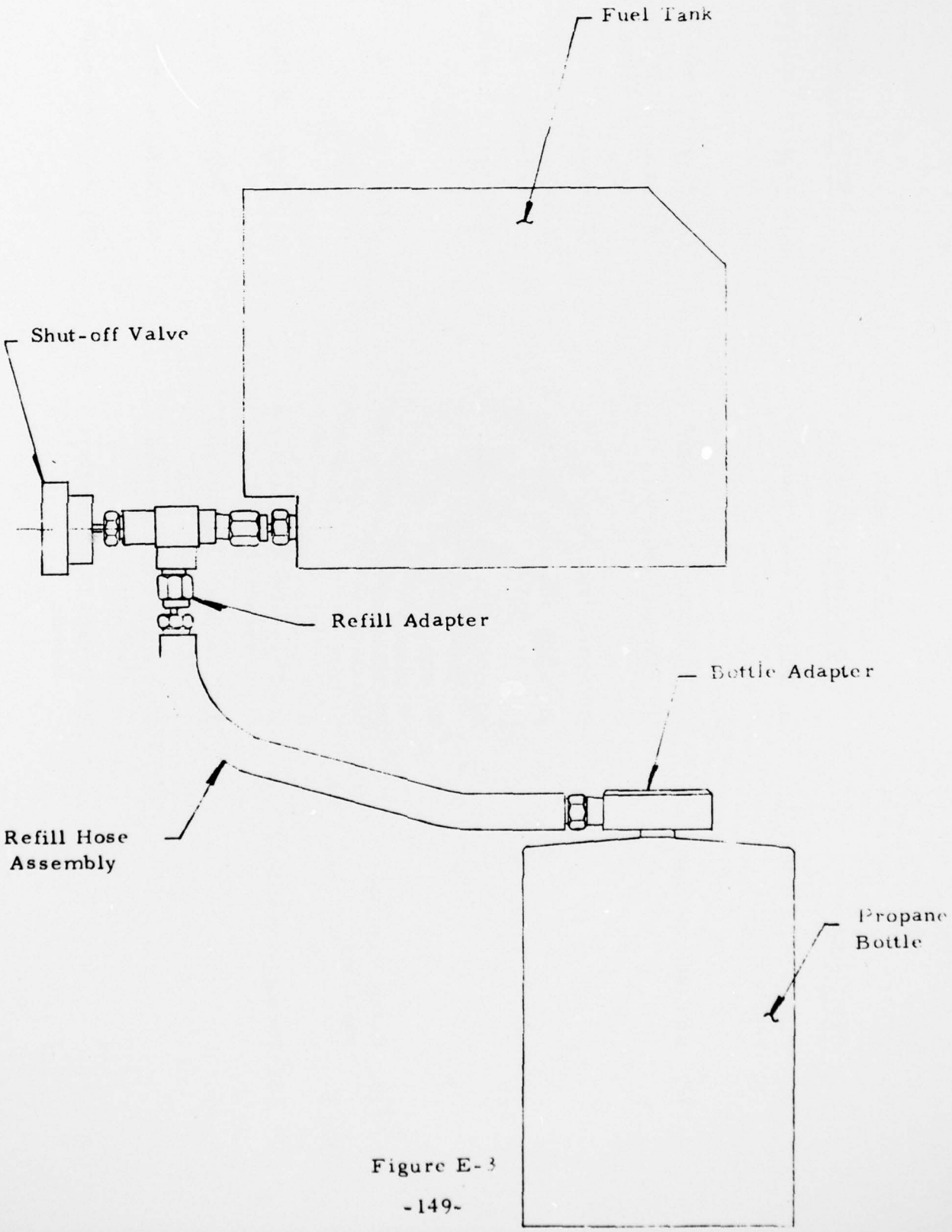

Fuel Tank
Shut-off Valve
Refill Adapter
Bottle Adapter
Refill Hose Assembly
Propane Bottle

Figure E-3

TABLE E-2

SYMPTOM	POSSIBLE CAUSE	REPAIR ACTION
(1) Cannot connect fuel supply to unit.	(A) Damaged fuel connector	(A) Replace Fuel connector
(2) Unit fails to ignite.	(A) Insufficient fuel supply	(A) Replace fuel cylinder
	(B) Clogged orifice	(B) Remove and either clean or replace orifice
	(C) Spark gap too great	(C) Readjust ground
	(D) Spark shorting back to duct wall	(D) Clean electrode and ground
	(E) Spark shorting at the piezoelectric	(E) Replace piezoelectric
(3) Combustion not sustained	(A) Insufficient fuel supply	(A) Replace fuel cylinder
(4) No pumping of fluid	(A) Excessive amount of air in system	(A) Replenish fluid
	(B) Broken or disconnected electrical lead	(B) Repair or reconnect
	(C) Crimped or collapsed fluid lines	(C) Replace tubing
	(D) Broken thermoelectric module	(D) Replace module

Symptom	Possible Cause	Repair Action
(5) Unit starts but then overheats	(A) Leak in fluid system	(A) Check all fluid lines and connections. Replace bad section of tubing or repair connection
	(B) Fuel flow rate too high	(B) Reduce the fuel setting
(6) No 12 VDC output	(A) Broken or disconnected electrical lead	(A) Repair or reconnect
	(B) Broken connecting pin	(B) Replace the electrical connector

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