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Cost Effective Use of Liquid Nitrogen in Cryogenic Wind Tunnels

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"COST EFFECTIVE USE OF LIQUID NITROGEN

IN CRYOGENIC WIND TUNNELS"

PROJECT SUMMARY

This study had two independent objectives. One was to
investigate the feasibility of reliquefying a portion of
the cold, pressurized exhaust vapor from the tunnel. The
second objective was to survey cryogenic equipment and
procedures at the Langley 0.3 m tunnel to suggest safer and
more efficient use of liquid nitrogen in the facility.
Both study objectives were achieved with qualified positive
results for the first part and detailed recommendations for
the second portion of the work.

Extensive reliquefaction calculations have been made with
the aid of a computer program developed for the project.
These calculations indicate that liquid yields of from 12
to nearly 20% of flow can be obtained by utilizing low
temperature pressure energy in the tunnel exhaust vapor in
a simple system consisting of a counterflow heat exchanger
and positive displacement wet expander. Technical and
economic success of the reliquefaction scheme hinges on the
expander. Computer modeling and calculations of a

proprietary rotary positive displacement expander by
Milburn Stirling Corporation indicate that high adiabatic
efficiency can be obtained. Despite higher than
anticipated preliminary cost estimates, use of the Milburn
Stirling "Turgine" expander appears economically feasible,
and Cryolab recommends a scale model development program.

Upgrade of the 0.3 m wind tunnel cryogenic system is
feasible and, overall, economically justified. Aside from
the obvious conclusion that the 28,000 gallon liquid
nitrogen storage dewars should be refurbished, Cryolab
found that the largest liquid nitrogen loss results from
the blowdown/repressurization procedure necessary to
subcool liquid for pumping. Cryolab recommends the use of
a subcooler to reduce these losses. Improved safety and
better system control can be realized by locating a
cryogenic control panel in the wind tunnel Control Room and
installing motor operators on all functioning valves.
Cryolab recommends incorporating vacuum-jacketed lines
along with the subcooler and remote operated valves to
bring the system up to current technology and achieve
maximum liquid nitrogen utilization efficiency. The system
upgrade recommendations are low-risk because the proposed
work is well within the state of the art and cost estimates
are reasonably accurate.

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REFERENCES

[1] R.O. Voth and T.R. Strobridge, "Cryogenic Design and Safety Review, NASA-Langley Research Center 0.3 Meter Transonic Cryogenic Tunnel," NBSIR 77-857, April 1977.

[2] R.B. Zwicker, "National Transonic Facility, Facility Description Document, Section C, NTF's Nitrogen System," NASA LRC Report D-17, March 1986.

[3] T.J. Webster, "A Report on Possible Safety Hazards Associated With The Operation of The 0.3 m Transonic Cryogenic Tunnel At The NASA Langley Research Center," NASA Contractor Report 166026, October 1982.

[4] R.F. Barron, "Cryogenic Systems," Oxford University Press, New York (1985).

1. INTRODUCTION

1.1 Background

The 0.3 m transonic cryogenic wind tunnel at NASA Langley
Research Center was set up as a temporary demonstration in
the early 1970's. The cryogenic facility has been enhanced
somewhat over the years as valuable contributions of the
tunnel earned permanent status for it. Throughout its
history, NASA personnel have been concerned about the
safety and efficiency of the facility, and two previous
studies [1],[3] have addressed these problems. Cryogenic
deficiencies identified in these reports were generally
rectified, but no cost-effective method of recovering or
reliquefying nitrogen was identified.

In May 1986 Cryolab found that the 28,000 gallon storage
dewars were performing poorly, the condition of foam
insulated pipe varied from good to fair, the piping itself
was routed with excess lengths in order to allow personnel
to reach manual valves, and a significant portion of tunnel
run preparations required personnel to be in the cryogenic
area. No specific hazards or unsafe practices were
identified during the study, but it was observed that the
blowdown/repressurization procedure to get subcooled liquid
for pump inlets caused large quantities of nitrogen vapor
to be vented.

1.2 Summary

Cryolab performed the Phase I study in two parts as
originally proposed. Technical and, to an extent, economic
feasibility of a partial reliquefaction scheme was
investigated in Part 1. Results showed that 12 to 19% of
tunnel inlet flow could be reliquefied with a simple system
which would generate a modest amount of power under normal
operating conditions. It was determined that success of
this system depended on the efficiency, reliability and
cost of an innovative rotary positive displacement expander
called a "Turgine" by its developer, Milburn Stirling
Corporation. Although the calculated performance of the
Turgine supported feasibility of Cryolab's reliquefier
scheme, a small-scale development program was suggested
because machines of this type had not been used in
cryogenic service.

In Part 2, Cryolab made a series of recommendations to
improve efficiency, convenience and safety of the cryogenic
system for the 0.3 m wind tunnel. Recommended upgrades
included refurbishing the dewars, adding a subcooler to
reduce liquid nitrogen losses, locating a remote control
panel in the wind tunnel Control Room and installing a
complete set of motor-operated valves on the system and,
finally, converting to vacuum-jacketed piping to further

reduce liquid nitrogen losses and provide a consistent
level of technology for the system. Part 2 recommendations
were all based on established technology for immediate
implementation with little technical or economic risk.

1.3 Accomplishment of Phase I Objectives

1.3.1.1

By means of the computer program, "RECOVERY", the nitrogen
cold gas reliquefier was analyzed for a variety of inlet
conditions and expander efficiencies and was found to be
technically feasible.

1.3.1.2

Studies by Milburn Stirling Corporation indicated no
fundamental reason why the Turgine should not be successful
as a cryogenic expander.

1.3.1.3

Milburn Stirling prepared a computer program to size and
calculate performance of cryogenic Turgines. Summaries of
design values for two sizes appear in paragraph 4.2. The
larger size would be one of four parallel units for the
0.3 m wind tunnel.

1.3.1.4

A Turgine development and refrigerator test program is
mentioned in paragraph 6.0. This program would consist of
designing a 1/12 scale refrigerator and 1/3 scale Turgine.
The test program would necessarily be done at the 0.3 m
wind tunnel facility in order to have a supply of cold
nitrogen vapor.

1.3.2.1

Cryolab pesonnel spent most of the week of May 12-16, 1986
at the 0.3 m wind tunnel facility examining the system and
observing operations.

1.3.2.2

Schematic of the optimized cryogenic system for the wind
tunnel is presented as drawing VJ 10029-2.

1.3.2.3

The schematic of VJ 10029-2 is actually specific for the
0.3 m wind tunnel although it would match any similar
system with storage dewars capable of modest pressurization.

1.3.2.4

Specific hardware suggestions for upgrading the 0.3 m wind
tunnel cryogenic system are included in the text of the
report and are shown on drawings VJ 10029-1, 3 and 4.

1.3.2.5

Cryolab personnel intend to present the results of the
study in a one-day trip to NASA Langley to be scheduled in
mid-December 1986 or early January 1987.

1.3.2.6

Specific suggestions for upgrading cryogenic hardware for
the 0.3 m wind tunnel are included in paragraph 9.0.
Estimated costs are developed in paragraph 10.0, and
overall conclusions for implementation are given in
paragraph 11.0.

1.4   Phase II Recommendations

Phase II work on the two parts of this study should be
handled separately.   Hardware upgrade for the 0.3 m wind
tunnel is a defined project which can be accomplished over
a nine- to twelve-month period.   Specific follow-on is not
likely.

The Part 1 nitrogen reliquefier study better fits the SBIR program. A Phase II program is necessary to establish feasibility of using a Turgine as a cryogenic expander and the practicality of reliquefying a portion of nitrogen flow from a wind tunnel. Potential Phase II opportunities include installing a full-scale nitrogen reliquefier for the 0.3 m wind tunnel and modification of the Turgine for other cryogenic expander applications.

PART I

Nitrogen Reliquefaction

2.0 Background

High consumption of costly* liquid nitrogen in the 0.3
meter Transonic Cryogenic Tunnel leads to consideration of
ways to recover nitrogen and its available refrigeration
that is presently "wasted" up the vent stack. However, a
study [1] conducted for NASA Langley Research Center
correctly concluded that reliquefaction and/or recovery of
the nitrogen was uneconomical. The primary basis for this
conclusion was that the tunnel operates at a high liquid
nitrogen consumption rate only a small percentage of the
time, implying a disproportionately large recovery system
which would mostly sit idle.

Cryolab's approach to nitrogen reliquefaction is to focus
on the "free" pressure energy and refrigeration that is

* In a March 1986 Document [2], the cost of liquid nitrogen
for the National Transonic Facility is stated at $90/ton or
$0.304/gallon. Since liquid to the 0.3 m wind tunnel must
be supplied by truck, Cryolab has arbitrarily assigned a
higher price of $0.10/litre or $0.3785/gallon.

available and utilize it in a low cost system which recovers only 12 to 20% of the liquid nitrogen consumed. This may seem like a small fraction but, at a consumption rate of 200 gallons per minute, a typical 17% recovery rate recaptures 34 gpm or over 2,000 gallons per hour of liquid nitrogen.

A schematic of Cryolab's system is shown in Figure 1. The four elements of the system are the heat exchanger, wet expansion engine and electric motor/generator, liquid receiver and a pump to move liquid back to storage. Functionally, the heat exchanger receives nitrogen vapor at essentially tunnel temperature and pressure (a little above saturation) and cools it in counterflow with low pressure exhaust gas. Even at quite high inlet temperatures, above 120 K, some condensation takes place in the heat exchanger and the expander inlet is in the wet region. The expander is a special positive displacement machine which expands the wet inlet mix down to near 1 atmosphere with formation of additional liquid. Expander exhaust falls into the liquid receiver which provides a liquid sump and directs unliquefied vapor up into the low pressure side of the heat exhanger. The system is completed by a transfer pump which returns liquid nitrogen to storage or the wind tunnel supply line.

VENT

COLD GAS FROM
WIND TUNNEL

HEAT
EXCHANGER

MOTOR-
GENERATOR

EXPANDER

LIQUID NITROGEN
RECEIVER DEWAR

TRANSFER PUMP

LN$_2$ TO STORAGE
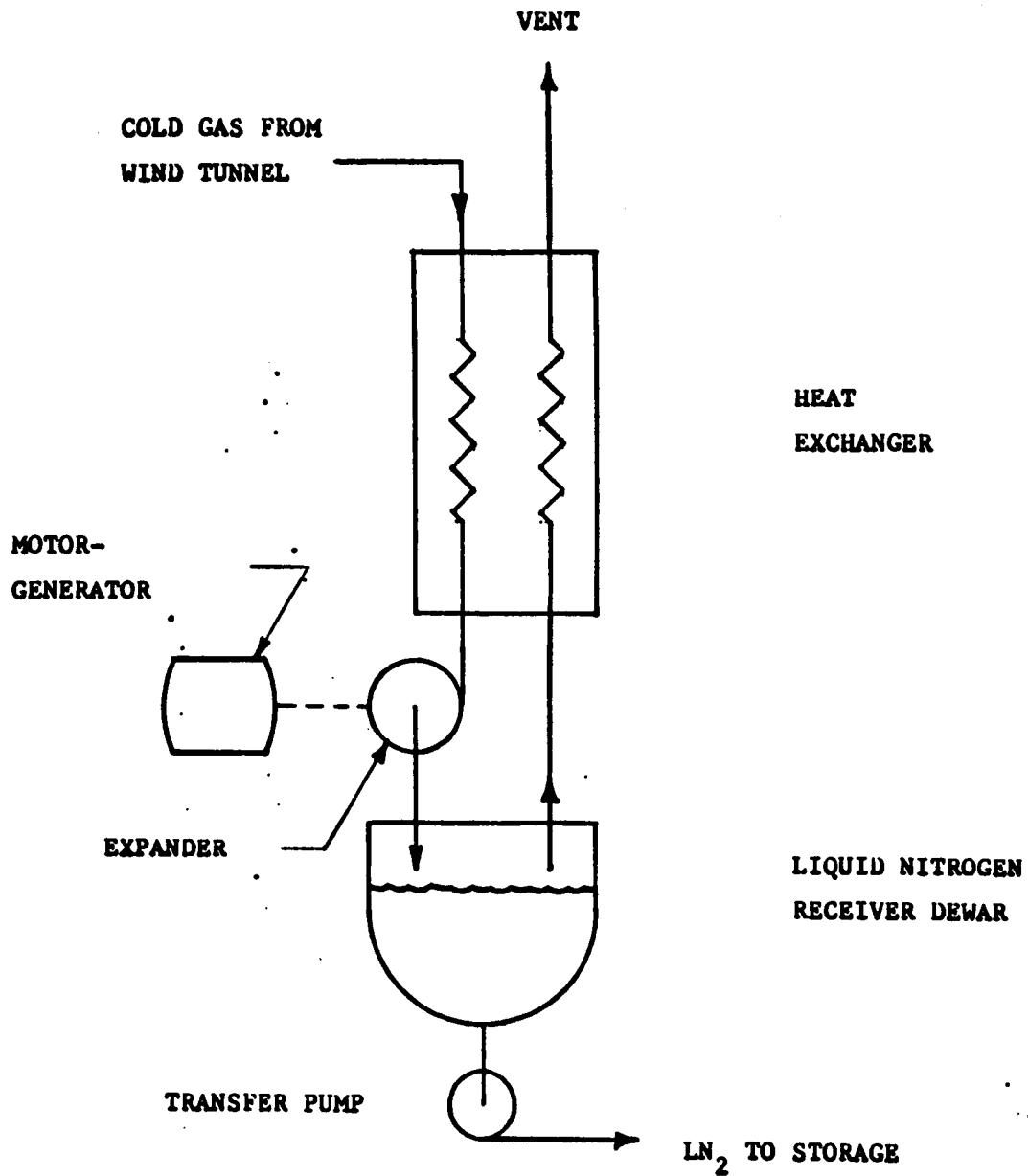
FIG. 1
COLD GAS RELIQUEFIER

3.0 Analysis and Calculations

A thermodynamic schematic of the reliquefaction cycle is
shown in Figure 2. Pertinent heat balance equations are
given alongside the schematic with terms defined as follows:

$h[1]$ = enthalpy of entering nitrogen vapor

$h[2]$ = enthalpy of wet mixture at expander inlet

E = isentropic efficiency of the expander

$h[3]$ = actual enthalpy of expander exhaust

$h[3']$ = ideal enthalpy of expander exhaust

X = fraction of nitrogen flow reliquefied

$h[L]$ = liquid nitrogen enthalpy

$h[g]$ = enthalpy of saturated nitrogen vapor

$h[4]$ = enthalpy of exhaust nitrogen gas

$s[2]$ = entropy of wet mixture at expander inlet

$s[L]$ = entropy of liquid nitrogen

$s[g]$ = entropy of saturated nitrogen vapor

Equation (1) can be solved for x as follows:

$$x = 1 - (h[1] - h[2])/(h[4] - h[g]) \qquad (5)$$

Equations (2), (3) and (4) can also be solved for x:

$$x = (h[2](1-E) + Eh[L] - h[g])/(h[L]-h[g]) -$$

$$E(s[2] - s[L])/(s[g] - s[L] \qquad (6)$$
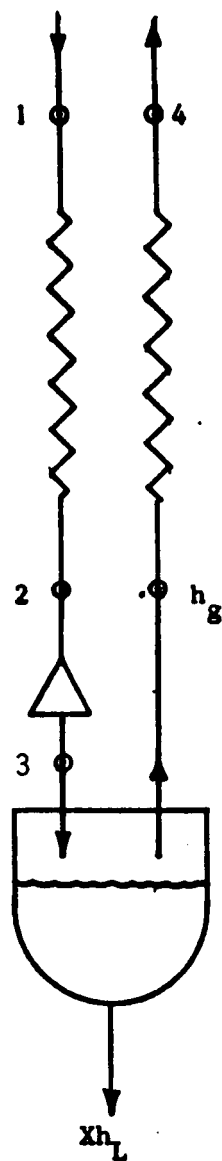
$$h_1 - h_2 = (1 - X)(h_4 - h_g) \qquad (1)$$

$$h_3 = h_2 - E(h_2 - h_3') \qquad (2)$$

$$h_3 = Xh_L + (1 - X)h_g \qquad (3)$$

$$h_3' = h_L + \frac{(s_2 - s_L)(h_g - h_L)}{(s_g - s_L)} \qquad (4)$$

FIG. 2

RELIQUEFIER THERMODYNAMIC SCHEMATIC

By substituting a series of related values for h[2] and
s[2], x can be iterated until equations (5) and (6) result
in the same value.

3.1 Liquid Nitrogen Recovery Calculations

The equations and procedure described above were utilized
to calculate a number of points. However, this iterative
technique is tedious and time consuming. To ease this
problem and provide a convenient check for those less
thermodynamically diligent, the Principal Investigator and
his associate, Dr. Mostafa K. Abdelsalam of the University
of Wisconsin-Madison, prepared a computer program,
RECOVERY, which calculates a data point in approximately 10
seconds using a Personal Computer equipped with an 8087 or
equivalent math co-processor. RECOVERY, which is written
in FORTRAN 77, is particularly convenient because it also
incorporates subroutines for the necessary nitrogen
thermodynamic data from the National Bureau of
Standards' program, MIPROPS.

A copy of RECOVERY on a diskette is furnished to NASA with
this report and may be used on an unrestricted basis. The
program has been extensively checked against manual
calculations and is believed to give liquefier yields
accurate to +/- 0.002 except for inlet temperature of

77 K. The program currently has a "bug" for this inlet temperature. and results should be disregarded.

A printout of the format for RECOVERY is included as page 14. As illustrated. a set of calculations is initiated by asking for all of the pertinent data. Then, after the calculation results are printed, the program asks which variable is to be changed. Thus, it is easy to make a series of calculations as a function of one variable. RECOVERY was used to make several sets of calculations for nitrogen reliquefaction. Results of these calculations are plotted in Figures 3, 4, and 5. Figure 3 is most definitive in that it shows reliquefier yields for 75 and 80% expander efficiencies with heat exchanger temperature difference of 2 K for inlet temperatures just above saturation at each pressure. For 80% expander efficiency, the reliquefaction yields range from 12.9% at 4 atm to 19.9% at 8 atm. 75% expander efficiency reduces the yield range to 12.2% to 18.9% for the same spread of inlet conditions.

Figures 4 and 5 zero in on the more practical operating pressure of 6 atm. Figure 4 shows the effect of expander efficiency on yield for varying inlet temperatures and a constant heat exchanger temperature difference of 2 K. Figure 5 illustrates the impact of heat exchanger

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THIS PROGRAM IS DESIGNED TO RUN IN INTERACTIVE MODE . HOWEVER , IT ALLOWS
THE USER TO KEEP A RECORD OF THE OUTPUT . THIS COULD BE EITHER AN OUTPUT FILE
OR A PRINTED COPY .
   THREE OUTPUT OPTIONS ARE AVAILABLE IN ADDITION TO THE INTERACTIVE MODE :
         1. NO RECORD OF THE OUTPUT
         2. SELECTIVELY RECORD PORTIONS OF THE OUTPUT (YOU WILL
                     BE PROMPTED FOR A DECISION)
         3. COMPLETE RECORD OF THE OUTPUT (NO PROMPT)

         WHICH OPTION DO YOU PREFER (1/2/3) ?   : 1

PLEASE ENTER A TITLE FOR THIS RUN (ONE LINE)
Demonstration   :

         INLET PRESSURE (ATM)   : 6

         INLET TEMPERATURE (K)   : 97

         TEMPERATURE DIFFERENCE BETWEEN NODES 1 AND 4   : 2

         EXPANDER EFFICIENCY (%)   : 80

         DO YOU WANT TO MAKE CHANGES IN YOUR INPUT (1/0) ?   : 0

Demonstration   :

         T1   T2   T3   T4
        97.0000   96.5753   77.3627   95.0000

      INLET PRESSURE   P1 =   6.0000   ATM
      OUTLET PRESSURE   P4 =   1.0000   ATM
      QUALITY AT EXPANDER INLET   Y =   90.7745   %
      NITROGEN YIELD   X =   0.1692

DO YOU WANT TO CHANGE :
      1) INLET PRESSURE   ,
      2) INLET TEMPERATURE ,
      3) TEMPERATURE DIFFERENCE BETWEEN NODES 1&4,
      4) EXPANDER EFFICIENCY ,
   OR
      5) RESTART
      6) QUIT

         PLEASE ENTER NUMBER CORRESPONDING TO YOUR CHOICE   :

FIG. 3
BEST RELIQUEFIER
YIELD vs PRESSURE FOR
ΔT = 2K & EXPANDER
EFF. = 75 & 80%

DATA		
P—atm	75%	80%
4	.1221	.1288
5	.1428	.1504
6	.1609	.1692
7	.1763	.1850
8	.1893	.1985

N2 FRACTION RELIQUEFIED

INLET PRESSURE — ATM. ABS.

FIG. 4
RELIQUEFIER YIELD vs EXPANDER EFFICIENCY & INLET TEMPERATURE FOR 6ATM & ΔT = 2K

N₂ FRACTION RELIQUEFIED vs INLET TEMP. — K

DATA				
T	70%	75%	80%	85%
97	.1527	.1609	.1692	.1774
98	.1509	.1591	.1674	.1756
99	.1492	.1574	.1656	.1738
100	.1475	.1557	.1639	.1721
101	.1460	.1541	.1623	.1705
102	.1445	.1526	.1607	.1689
103	.1430	.1511		

FIG. 5
RELIQUEFIER YIELD vs
HEAT EXCHANGER ΔT
FOR 6ATM & 80%
EXPANDER EFFICIENCY

N2 FRACTION RELIQUEFIED

INLET TEMP. — K

DATA

T	1.5K	2K	2.5K
97	.1709	.1692	.1674
98	.1691	.1674	.1656
99	.1673	.1656	.1639
100	.1656	.1639	.1622
101	.1640	.1623	.1606
102	.1625	.1607	.1509
103			

temperature difference when the expander efficiency is held
constant at 80%.

Principal conclusions that can be drawn from these
calculations include:

* Practical reliquefaction yields of 12 to 18% can be
  achieved with the system.
* The system is only moderately sensitive to inlet
  temperature. Data from Figure 5 indicates
  yield reduction of less than 5% for inlet
  increase of 5 K.
* Heat exchanger temperature difference decrease of
  1 K from 2.5 to 1.5 K improves best performance
  only 2.1% implying reasonable insensitivity to
  this variable.
* Liquid yield is almost directly proportional
  to expander efficiency. Data from Figure 4 at 97 K
  inlet temperature indicates yield improvement
  of 16.2% for expander efficiency increasing 15
  percentage points (21.4%) from 70 to 85%.

4.0 Reliquefier Components

The following paragraphs include discussion of the physical
components of a reliquefier for the 0.3 m wind tunnel. All
calculations are based on a liquid nitrogen consumption

rate of 200 gallons per minute (12.617 litres/s), which is equivalent to a flow rate of 9.828 kg/s.

4.1 Heat Exchanger

The reliquefier heat exchanger receives nitrogen vapor at tunnel pressure and slightly above saturation temperature and exhausts low pressure gas several degrees colder. On the high pressure side, incoming vapor is cooled to saturation and some condensation takes place. Exit quality is between 91 and 92% vapor for 6 atm operating pressure and 80% expander efficiency with 2 K temperature difference at the top end. (The heat exchanger should be oriented vertically to facilitate draining of condensed liquid.) Low pressure saturated vapor at 78 to 79 K enters the cold end of the heat exchanger and exits to vent from 1.5 to 3 K colder than the inlet stream. Typical service requirements for the heat exchanger are given in Table 1.

Table 1

Reliquefier Heat Exchanger Service

High Pressure	4 - 7 atm abs.
Low pressure	1 - 1.25 atm abs.
Flow	9.83 kg/s
Typical heat load	1.905 E5 j/s
Typical top end temp. diff.	2 K

Typical cold end temp. diff.   18 K

Log mean temp. diff.   7.282 K

Nominal high pressure

surface area   30 sq. metres

Likely, the most economical heat exchanger for this service
would be a commercial brazed aluminum unit, but vendors
have not been contacted. Preliminary design of a Hampson
heat exchanger made with copper tubes was done. This
design was based on use of 0.635 cm OD x 0.0762 cm wall
(1/4 OD x 0.030 in wall) copper tubes 4.572 m long. The
heat exchanger requires 1,500 parallel tubes arranged in 20
wraps with 75 tubes per wrap. Overall dimensions of the
heat exchanger vacuum jacket are 0.61 m OD x 3.1 m high.
Estimated weight of the assembly is 1455 Kg, and its cost
will be approximately $50,500.

4.2 Wet Expander

Key to Cryolab's proposed liquid nitrogen recovery system
is a wet expander. This machine receives two phase
nitrogen from the heat exchanger at nearly tunnel pressure
and expands it down to approximately 1 atmosphere.
Requirements for the expander are unusual because of the
large volume of flow and wet mixture in addition to bearing
and seal problems unique to cryogenic applications. The
most common solution to large cryogenic expander flows is

to use radial inflow turbines, but they are impractical in the wet region because of rapid impeller erosion by liquid droplets. Piston expanders have been developed for wet applications for flows generally smaller than for the 0.3 m wind tunnel (200 gpm consumption in the tunnel at 6 atm results in expander inlet flow of 0.3587 cubic metres at 96.5753 K.). Multi-cylinder piston expanders may be feasible for the nitrogen reliquefier, but their size, cost and only moderate reliability have encouraged Cryolab to seek an alternate machine.

Cryolab's alternate expander is a rotary positive displacement machine named a "Turgine" by its developer, Milburn Stirling Corporation. The Turgine is a rotary nutating machine which may be used as either a compressor or expander (gas motor). A cutaway view of a four element balanced Turgine is shown in Figure 6, and Figure 7 tracks one chamber through an intake/exhaust cycle. The advantages of a Turgine include:

* Large displacement for compact machine size.
* Variable displacement is possible.
* High adiabatic efficiencies have been measured on air motors and are predicted for expander applications.
* Linear seal forces are very low.

Disadvantages include:

Cross Slides

Crank Shaft

Housing

Nutating Valve Slots

Nutating Piston

Patent Pending
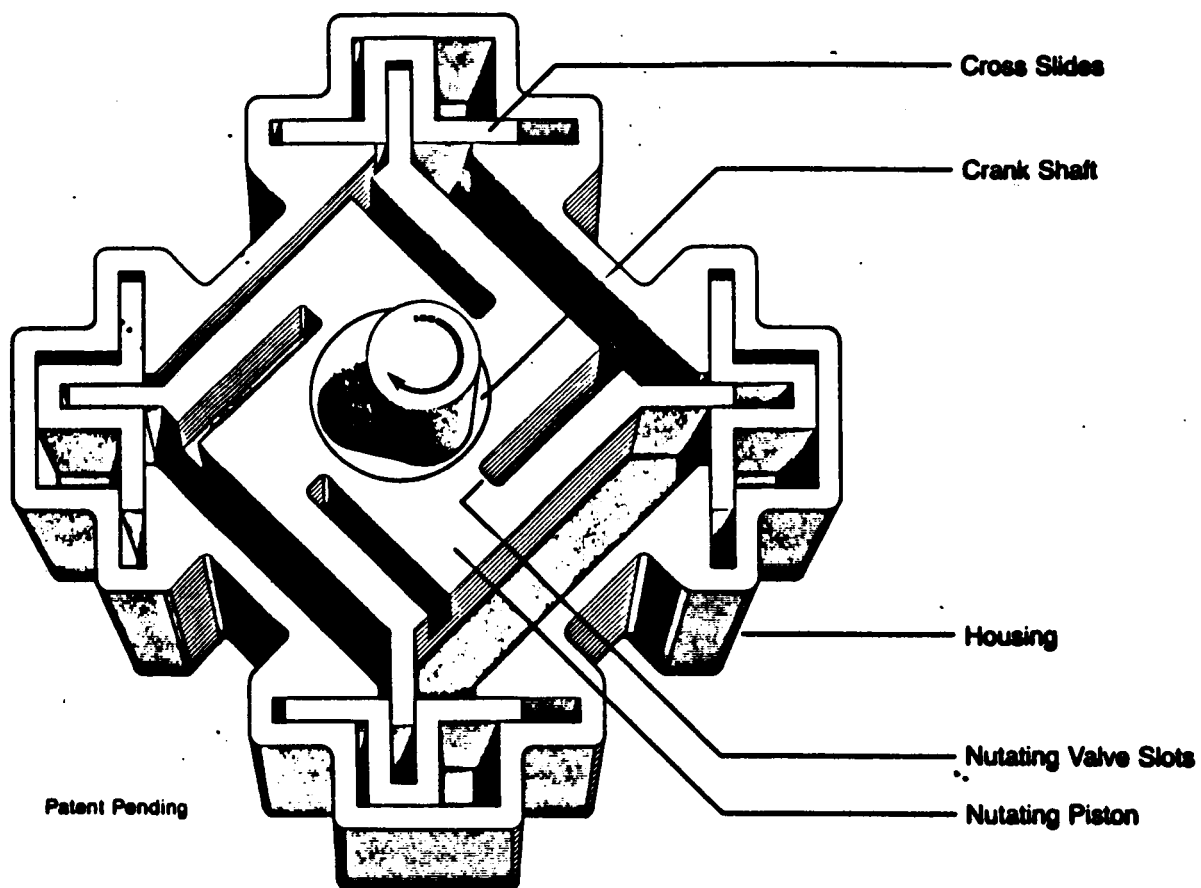
FIG. 6

TURGINE CUTAWAY DIAGRAM

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End of Intake Stroke, begin Discharge Stroke

Halfway through Discharge Stroke

Patent Pending

End of Discharge Stroke, begin Intake Stroke

Halfway through Intake Stroke
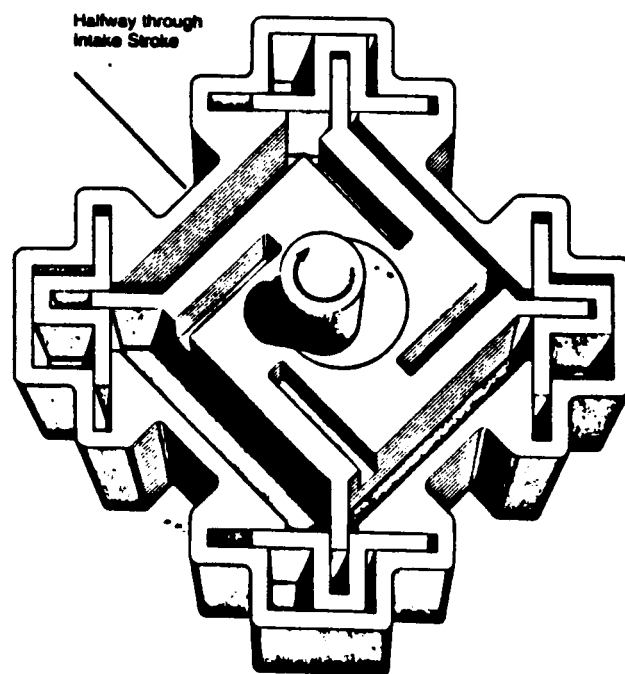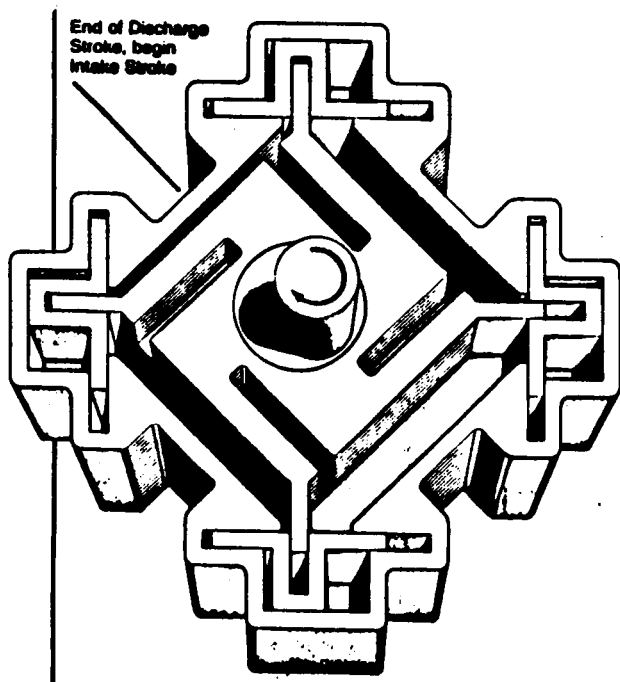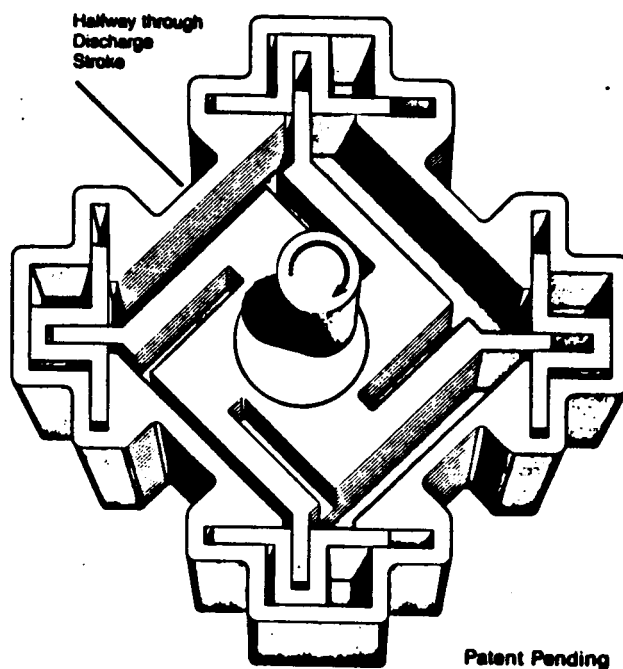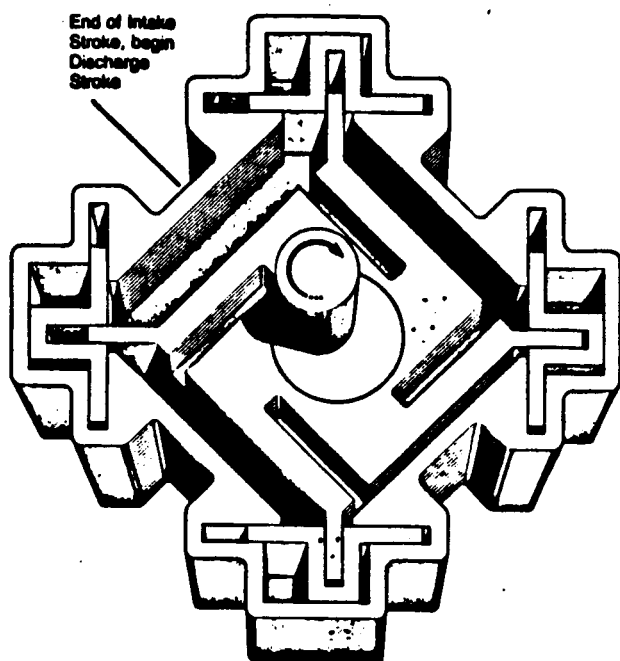
FIG. 7

TURGINE OPERATING CYCLE

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* Multiple large sliding surfaces requiring precision machining.

* More parts than a piston expander.

Despite the development that needs to be done, Cryolab has selected a Turgine for the nitrogen reliquefier because of its large displacement, high calculated efficiency and potential for other cryogenic applications.

Milburn Stirling has prepared a proprietary computer program to size Turgine expanders and compute their performance. A summary of calculations for non-optimum machines sized for inlet flows of 1.415 and 5.38 cubic metres/min (50 and 190 cfm) is presented in Table 2.

Table 2

Turgine Sizing and Performance Calculations

Item	1.415 m(3)	5.38 m(3)
Inlet pressure — atm	6.0	6.0
Inlet temperature — K	96.6	96.6
Outlet pressure — atm	1.1	1.04
Outlet temperature — K	78.0	77.6
Maximum displacement — m(3)	0.02378	0.09113
Overall width & height — m	0.497	0.856
Overall length — m	0.597	0.825
Seal preload — N/m	4.425	4.425
Speed — rpm	1200	1200
Net power — kw	12.2	51.0
Adiabatic & aero. efficiency — %	85.5	76.8

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Proposed X-4 Gas Motor
for Nitrogen Expansion
for Cryolab

Rotary output shaft

Intake

Milburn Research

Length

Side View

Exhaust
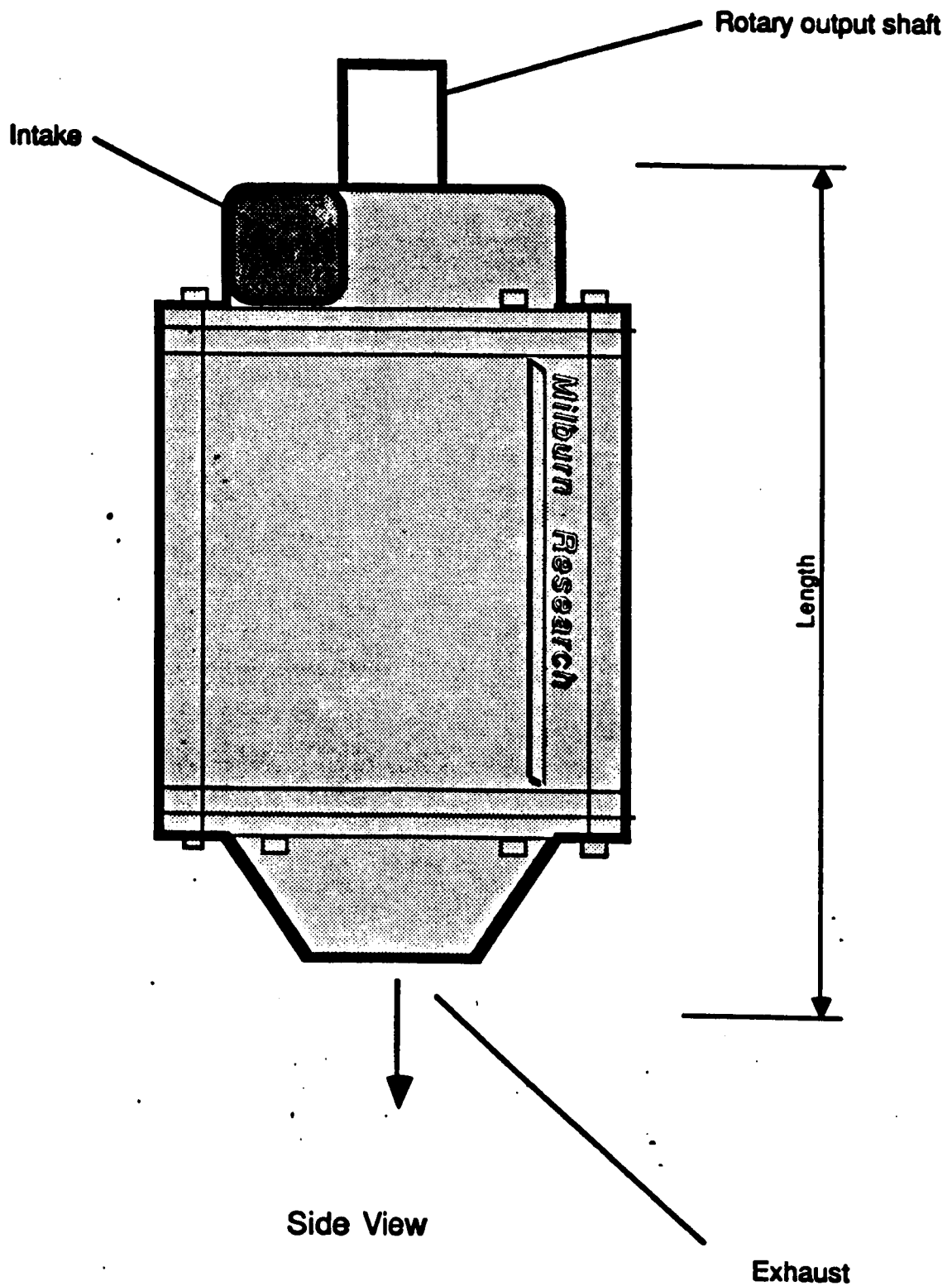
FIG. 8

TURGINE SIDE VIEW

Proposed X-4 Gas Motor
for Nitrogen Expansion
for Cryolab

Rotary output shaft

Heigth

Intake

Width
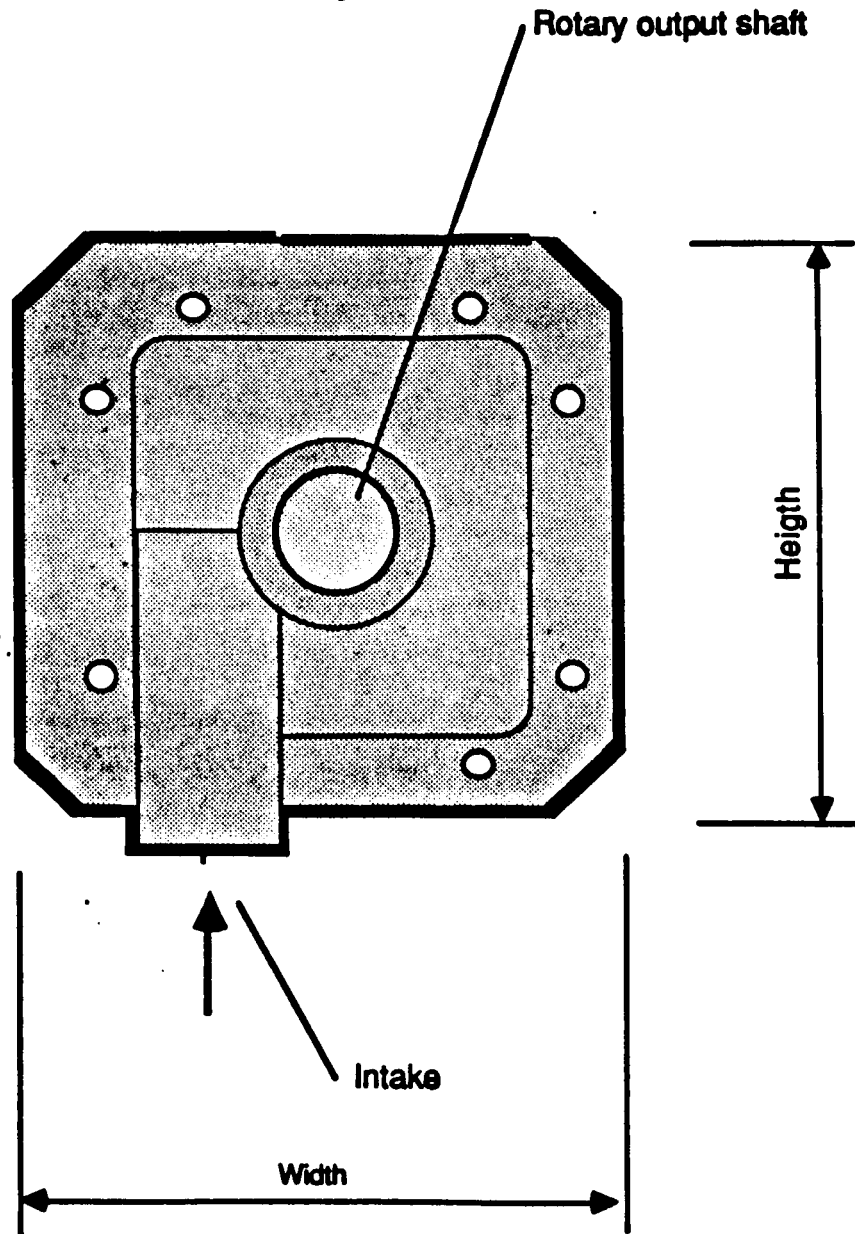
Top View

FIG. 9

TURGINE TOP VIEW

Physical sizes listed in Table 2 relate to outline drawings of two views of a Turgine expander shown in Figures 8 and 9. The significance of the two sizes is that the smaller is appropriate for a developmental reliquefier, and the larger handles one-fourth of the calculated flow from the 0.3 m wind tunnel when operated at 6 atm with liquid nitrogen consumption of 200 gpm.

The bottom line in Table 2 indicates an efficiency of 85.5% for the smaller Turgine and 76.8% for the larger. According to Milburn Stirling, the higher efficiency results from a width/length ratio of 0.75 compared to a ratio of 1 for the 5.38 m(3) machine. Higher calculated performance, above 80%, should be obtainable with the larger machine with a similar 0.75 width/length ratio. The important conclusion is that Turgines utilized as Cryogenic expanders predict efficiency values well within the feasibility range of a nitrogen reliquefier.

Cost of a set of four parallel Turgine expanders for 200 gpm flow into the 0.3 m wind tunnel has been estimated by Milburn Stirling. Since no cryogenic Turgines have been built, Milburn Stirling's total estimate of $841,000 for the four machines must be considered quite preliminary.

4.3 Liquid Receiver

At a maximum practical reliquefaction rate of 18%, liquid
production would be 136 litres per minute (36 gallons). If
the transfer pump is sized for 150 litres per minute, the
receiver should have "High" and "Low" settings which allow
some over- and under-shoot without creating operating
problems. Thus, the receiver dewar is sized at 450 litres
by allowing a minute's pumping above the "High" setting, a
minute between the settings, and a minute's flow below the
"Low" setting. Configuration of the dewar is not critical,
but a vertical cylinder with dished heads forms a
convenient sump ahead of the transfer pump. The dewar
could be a modified commercial 500 litre unit and should be
available for about $3,500.

4.4 Transfer Pump

An industrial gas transfer pump will be used to move liquid
produced back to storage. The pump will be rated at 50
psig and 150 litres/minute (40 gpm) and will require a
1 1/2 to 3 hp electric drive. An external pump to meet
these requirements will cost about $1,500. A more
sophisticated submerged pump would have lower heat leak and
should be investigated for an actual system.

5.0 Economics of Reliquefaction

Estimated costs of a Turgine-based reliquefier system sized
for the 0.3 m wind tunnel are summarized as follows:

Heat exchanger	$ 50,500
Turgine expander - 4 parallel units	841,000
Electric motor/generators for Turgines	12,000
Liquid receiver dewar	3,500
Transfer pump	1,500
System engineering	12,500
Installation	25,000
Total cost	$946,000

Against this total cost, the system should recover about
16.5% of nitrogen consumed in the wind tunnel. At the 200
gpm figure used throughout the study, recovery would
approximate 33 gpm, worth $12.49 at $0.3785 per gallon. On
an hourly basis, value of recovered liquid nitrogen is
about $750. For a rounded up installed cost of $1,000,000,
payout would be realized after 1333 hours of operation at
the assumed rate. However, any such projection should be
treated with caution on two counts.

(1) Cryolab recommends testing a scale model

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Turgine-based reliquefier before going ahead with a full-size system for the 0.3 m wind tunnel. Thermodynamic and mechanical performance of a small Turgine could impact the desirability of the whole scheme.

(2) Projected cost of the four Turgines stands out as the major item in a nitrogen reliquefier. Successful work with a scale model Turgine would reduce technical and cost uncertainties permitting more realistic pricing.

6.0 Reliquefier Conclusions and Recommendations

Theoretical feasibility of a nitrogen reliquefier using waste pressure energy from wind tunnel exhaust vapor has been demonstrated. It appears that nitrogen reliquefaction is cost effective if usage is sufficiently great, expander efficiency is about 70%, and costs are less than or a little greater than preliminary estimates.

As noted in Paragraph 4.0, Cryolab believes that conclusions about the Turgine expander are sufficiently qualified that it would be unwise to immediately proceed with a full-scale reliquefier. A 1/12 scale model reliquefier with a single 1/3 scale Turgine expander is recommended. A reliquefier of this size will prove out the system and establish a scaleable design of the Turgine

expander permitting valid technical and economic

projections.

PART 2

0.3 m Wind Tunnel Cryogenic System

7.0 Existing System

The cryogenic system for the 0.3 m wind tunnel continues to

suffer from its start in life some 14 years ago as a

"temporary" demonstration. Since then, the tunnel has

become established as a valuable research facility, but

vestiges of its origin still exist in the cryogenic support

system. Upgrades have been made in vent piping, a new fill

location and some of the valves have been converted to

remote or automatic power operation, but most of the

foam-insulated piping layout is below industry standards in

terms of loss rates and arrangements.

Specifically, the cryogenic system for the wind tunnel

consists of two, 28,000 gallon liquid nitrogen dewars, a

free standing heat exchanger for pressurization, 150 and

250 gpm parallel pumps and the aforementioned

foam-insulated piping to interconnect the dewars and supply

liquid to the tunnel and carry away excess flow to the

off-service dewar. NASA drawing LD-740188 (not a part of

this study) is a substantially accurate representation of

the arrangement. All liquid valves associated with the

28,000 gallon dewars are manual as are the main vent valves.

Thus, setup for operation of the tunnel requires personnel
to enter the nitrogen storage area to set valves properly.
When the manual valves are set, the tunnel can be operated
with power-actuated valves until it is necessary to shut
down or to switch from one dewar to the other. Although
safety procedures are well worked out [1], [3] and low
oxygen sensors are located throughout the facility, the
present system does expose personnel to some degree of
hazard from low oxygen atmosphere and possible accidental
contact with liquid nitrogen or cold vapor in the event of
a line or component failure.

8.0 Operating Loss of Existing System

Liquid nitrogen losses fall into three categories:
essentially constant losses of the two storage dewars,
blowdown-repressurization cycles prior to start of a run,
and piping system losses during operation. During its
on-site survey, Cryolab measured the loss rates of the two
dewars and calculations have been made for the other losses
as reported in the following paragraphs.

8.1 28,000 Gallon Dewar Losses

Boiloff tests were made on both tanks "A" and "B" on May
15, 1986. These were fairly low precision measurements
utilizing an instantaneous flow meter as compared to a more

desirable totalizing meter. No corrections were made for changes in barometric pressure during the brief test periods, and it was not possible to measure dewar vacuums. However, it was noted that Dewar A was being pumped throughout the week of Cryolab's visit to Langley.

Measured loss rates on the two dewars were as follows:

Dewar A   69 gal/day
                 0.246%/day loss rate
                 487.5 j/s heat leak

Dewar B   128 gal/day
                 0.457%/day loss rate
                 904.4 j/s heat leak

This data indicates that performance of Dewar A was enhanced by use of the vacuum pump. Boiloff values for both dewars were high compared to a reasonably acceptable loss rate of 0.1% per day which is equivalent to 28 gallons per day. If the vacuum pump was sufficient to improve Dewar A by 59 gallons per day over Dewar B, it would seem prudent to, at a minimum, put pumps on both dewars. At the assumed liquid nitrogen cost of $0.3785 per gallon, the 59 gallons per day saved would have a value of $22.33, not counting fill losses. This would pay for an adequate vacuum pump in four to six months. Of course, the

preferred solution is to take the dewars out of service, leak check and repair as necessary, re-insulate and re-evacuate them. This would get the losses on each dewar down into the range of 20 to 30 gallons per day.

8.2 Pressure Cycle Losses

Current procedure is to allow a filled dewar to build pressure until a preset value is reached and then vent periodically under pressure switch control. Prior to a wind tunnel run, the supply dewar is vented down to approximately atmospheric pressure and then repressurized to 30 to 35 psia to provide subcooled liquid (Net Positive Suction Head) to the pumps. This blowdown/repressurization process consumes a great deal of liquid nitrogen.

Using equations developed in Appendix A, a sample calculation was made for a 28,000 gallon dewar initially containing 21,000 gallons of liquid at 50 psia (35 psig) which was vented down to 1 atm and then repressurized to 30 psia using the Saturation Rule [4]. Resultant significant values are as follows:

Initial quantity of liquid & vapor	60,010.6 kg
Liquid & vapor at 1 atm	52,493.2
Blowdown loss	7,517.4 kg
Pressurization liquid loss	224

| | Net Loss | 7,741.4 kg |
| | Net loss percentage | 12.9% |

As will be shown subsequently, this 2500 gallon loss
relatively dwarfs other operating losses and points to the
use of a subcooler as described in a following paragraph.

8.3 Piping System Losses

Heat leak of the flow system has been calculated (omitting
the two pumps) using optimistic assumptions for insulation
effectiveness around valves and riser pipes. The results
of these calculations are summarized in Table 3.

Table 3

Piping System Heat Leak and Losses

Item	Unit Heat Leak Watt	No./ Length	Total Heat Leak Watt	Loss gal/hr
Supply line	36.7 w/m	50.3 m	1845.0	10.9
Return line	30.2 w/m	50.3 m	1518.2	9.0
Wet valves	23.5 w	8	187.6	1.1
Vent/relief risers	5.54 w	9	49.8	0.3
Instrument line risers	2.1 w	7	14.6	0.1
Totals			3,615.2	21.4
New Fill Line	32.0 w/m	74.7 m	2,390.8	14.1

8.4 Total Loss in Existing System

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Because filling a dewar and blowing it down are batch processes, losses of the existing system are based on filling a dewar from the 10% level up to 28,000 gallons and then making a run at 200 gpm until the level falls to 10%. Data is presented as a series of line items.

(1) Dewar fill: 28,000 - 2800 = 25,200 gallons. Assume fill rate of 200 gpm for 126 minutes or 2.1 hours. Actual filling loss, including valve and coupling, will approximate 16 gal/hr for a total loss of 33.6 gallons. (Actual fill rate would be 200.27 gpm to make up for losses.)

(2) Blowdown/repressurization: loss is approximately 12.9% or (0.129)(28,000) = 3,600 gallons.

(3) Piping System: 21.4 gpm x 25,200/200 x 60 = 45 gallons

(4) Summary:

Fill	34. gallons
Blowdown, etc.	3600.
Piping System	45.
Total	3679. gallons

This does not include continuous dewar losses, pump heat leak, flow work in pipes and higher or lower piping losses

as a function of actual flow rate to the tunnel. In any case, it is clear that the dominant loss is the blowdown/repressurizing operation. Even if the pressures are lower than assumed, this loss will approximate 10% of dewar capacity per cycle and represent about 95% of the total liquid nitrogen loss for a tunnel operating cycle from one dewar.

Although there is room for improvement of the hardware, there is more to be gained by a change in procedures. It is recommended that the storage dewars be held at the lowest feasible pressure consistent with purge gas requirements in the tunnel area. (If purge gas is the pacing item, it can be supplied less expensively from a small dewar.) This can significantly reduce blowdown losses and speed transfer from one dewar to the other during sustained operations.

9.0   Recommended System

Cryolab has evaluated the 0.3 m wind tunnel cryogenic system using the following criteria:

    Safety and convenience

    Liquid nitrogen losses

    Economics

    Technical image

Key elements of Cryolab's recommended system are:

* Make entire system operable from a graphic panel in the Control Room.

* Replace foam-insulated piping and valves with a vacuum-jacketed system.

* Replace the blowdown/repressurization procedure with a combination subcooler and vapor/liquid separator to permit continuous operation from either or both supply dewars.

* Refurbishment of both 28,000 gallon supply dewars.

Operation of the cryogenic system from the Control Room adds a measure of safety since pesonnel will not have to enter the liquid nitrogen dewar area for any phase of wind tunnel operations. In addition, at least one less operator will be required, time will be saved and communication improved by centralizing operations where it properly belongs in the Control Room.

Two principal changes are required to bring cryogenic operations into the Control Room: first, all of the functional valves and controllers must be remotely operated and, second, a control panel similar to that shown on Cryolab drawing VJ 10029-4 must be installed in the Control Room with appropriate connections to the cryogenic area. Although the documentation supplied with this report

assumes new vacuum-jacketed piping and use of a subcooler, this recommendation for operation from a control panel is independent of other suggested upgrades.

Use of vacuum-jacketed piping is part economics and part aesthetics. Economics show up in lower liquid nitrogen loss rates and lower maintenance costs. Heat leak elements for the vacuum-jacketed system are shown in Table 4 which has the same format as Table 3 for foam-insulated valves and lines.

Table 4

Losses in Vacuum-Jacketed Line System

Item	Unit Heat Leak Watt	No./ Length	Total Heat Leak Watt	Loss gal/hr
Supply line	0.8 w/m	50.3 m	40.2	0.24
Return line	1.1 w/m	50.3	55.3	.33
2 IPS Valve	8.0	7	56.0	.33
3 IPS Valve	20.0	3	60.0	.35
Vent/Relief Risers	1.85	9	16.7	.1
Instrument Line Risers	0.7	7	4.9	.03
Sub-cooler	5.0	1	5.0	.03
System Totals			238.1	1.41
Fill line	.08	74.7	59.8	0.35

Operating loss in the vacuum-jacketed system is 238 w compared with 3,615 w for the existing system, which saves 21.4 - 1.4 = 20 gallons/hr. of liquid nitrogen. At the

assumed rate of $0.3785, this would total $7.57 saved per
hour of tunnel operation. Overall economics of the
vacuum-jacketed line system are discussed in a following
paragraph. No price tag can be put on the aesthetics of a
vacuum-jacketed system, but there is no question that this
suggested modification would bring the technology level of
the cryogenic system up more nearly to that of the wind
tunnel itself. Although all details are not included, the
revised piping layout shown on Cryolab drawing VJ 10029-3
indicates substantial simplification over the existing
layout. Eliminating the necessity to bring valves down so
that they can be reached for manual operation is a major
factor in simplifying the piping.

Large losses resulting from the current
blowdown/repressurization procedure have been quantified in
paragraph 7.2. Cryolab's recommended system shown on
drawing VJ 10029-2 includes a subcooler and vapor/liquid
separator. Details of this device are shown on drawing VJ
10029-1. As a subcooler, a small portion of liquid
withdrawn from the supply dewar is directed into the volume
surrounding the heat transfer tubes. This liquid is
maintained at essentially atmospheric pressure which
enables the down-flowing main liquid nitrogen stream to be
cooled to about 79 K. The main liquid nitrogen stream
enters the top of the subcooler at just below supply dewar
pressure. This liquid, along with return liquid from the

wind tunnel, passes through the subcooler tubes to pump
inlet.

The advantage of the subcooler over the existing system is
that only a small portion of dewar contents need be vented
down to atmospheric pressure. Thus, the overall venting
losses are substantially smaller. For the same initial
conditions as discussed in paragraph 8.4, 50 psia
saturation, the ratio of subcooler flow to pump inlet flow
is 7.8% or 7.24% of the total flow. This compares with
12.9% blowdown/repressurization loss with the existing
procedure. 7.24/12.9 = 0.56, making the subcooler loss
some 40% less or, for the example of paragraph 8.4, the
subcooling loss would drop to about 2,160 gallons for a
1,440 gallon saving per dewar. In round numbers, the
subcooler will reduce liquid nitrogen consumption 5% and
save about $530 per dewar fill.

Subcooler savings do not include the small contribution due
to routing return flow back to the subcooler. In this
case, the subcooler first serves as a vapor/liquid
separator and then as a subcooler for the remaining
liquid. Savings come from the fact that the vapor/liquid
return mixture is not vented down to low pressure which
preserves a maximum amount of liquid to be recycled. The
fact that the tunnel can operate with only one dewar is a
convenience because it frees up the second unit to be

filled, pressurized or whatever is necessary for almost instantaneous switchover to supply the tunnel operation.

Losses for a dewar operational cycle with the recommended system are calculated to compare with the example of paragraph 7.4.

(1) Dewar fill:

Loss = (2.1 hours)(59.8 + 7 + 0.7) = 141.8 w-hr

= 0.84 gallons

(2) Subcooler:

(0.0724)(25,200 gallons) = 1824.5 gallons

(3) Piping System:

1.41 gal/hr x 25,200/200 x 60 = 2.96 gallons

(4) Summary:

Fill	.84 gallons
Subcooler	1824.5
Piping System	2.96
Total	1828.3 gallons

As in the previous example, this total does not include continuous dewar losses, pump heat leak, flow work in lines and piping cooldown losses. However, on a comparative basis, the recommended system reduces losses about 1851

gallons per dewar most favorably and in excess of 1500
gallons for less optimum conditions, resulting in savings
of $568 to $700 per 28,000 gallon cycle.

10.0 Economics of Proposed System

Economic value of the proposed changes are a function of
cost, potential savings in liquid nitrogen consumption,
wind tunnel usage rate and delivered cost of liquid
nitrogen. Assessing the value of labor savings is beyond
the scope of this work. Principal assumptions made for
economic calculations include tunnel operation at 200 gpm,
liquid nitrogen cost of $0.3785 per gallon and 25,200
gallons of liquid nitrogen available from each dewar. Cost
estimates used are not firm prices but should be within 10%
of Cryolab's subsequent fixed price quotation.

10.1 Cost of Recommended System

Costs summarized are for all of the hardware needed to
bring the 0.3 m cryogenic wind tunnel up to the level shown
on F and ID drawing VJ 10029-2 for remote operation from
the Control Room. Vacuum-jacketed line costs include all
attached valves and operators, relief devices and locally
mounted instrumentation. The subcooler includes all the
controls mounted on it and all of the controls and
instrumentation for the system which are to be mounted on

the graphic panel shown on drawing VJ 10029-4. Costs do

not include on-site installation, but four weeks of field

engineering is included as a line item.

Components and Estimated Cost

Principal vacuum-jacketed 3 IPS process lines	$129,166
Auxiliary 1 1/2 IPS lines	29,439
Vacuum-jacketed 1 1/2 IPS fill line	26,879

Sub-total of all vacuum-
      jacketed lines and
      attachments
	$185,484

Subcooler, attached instruments and controls and Graphic Panel components	80,000
Graphic Panel	4,000
Non-jacketed valves, safety devices and remote instrumentation for dewar vents	8,336
Hardware sub-total	$277,820
System Engineering	12,000
Installation Engineering - 4 weeks on-site in two trips	11,300
Hardware and Engineering	$301,120

These costs do not include minor modifications to existing

vent piping manifolds and system installation labor.

10.2 Potential Cost Savings Compared to Investment

Cryolab is not in possession of enough operating data to accurately project a payout for the recommended system based on saving liquid nitrogen. However, two values have been developed which can be used to calculate reasonably accurate payout times: first, the installed cost of Cryolab's recommended system is about $350,000 including an allowance of $50,000 for installation labor and, second, liquid nitrogen saved per 25,200 gallon tankfull should be 1500 gallons or greater (worth $568 at $0.3785 per gallon). With no other consideration, the payout requires 616 tanks of liquid nitrogen, which is the equivalent of 1294 hours of tunnel operation at a consumption rate of 200 gmp. Actual payout can be calculated readily from a projected operating schedule weighted by required tunnel conditions which dictate the rate of liquid nitrogen consumption. For instance, a program of 8 hours per week, 50 weeks per year at 200 gpm would total 400 hours per year leading to payout in 3 1/4 years.

Potential savings from refurbishing the two, 28,000 gallon dewars is fairly clear-cut. Estimated cost of refurbishing each dewar to a loss rate of 28 gallons per day (0.1%/day) is $7500. From an unpumped dewar, this conveniently results in saving 100 gallons per day worth $37.85. Since the dewars are cold continuously, the payout is 198 days. A one year payout requirement would support a refurbishment

budget of $13,800 which should considerably exceed

commercial cost of doing the work.

11.0   Part 2 Conclusions

The cryogenic system for the 0.3 m wind tunnel can be
improved and cost-effective reductions in liquid nitrogen
consumption can be realized. Further, operational safety
and convenience can be improved significantly. Recommended
steps and reasons for them are presented in order of
precedence.

(1)   Change operating procedures so that liquid in the
28,000 gallon dewars is held at the lowest feasible
pressure. This change only involves resetting or replacing
the vent pressure switches and, possibly, adding a cut-out
switch to the pressure switch circuit. Cost of
implementation is negligible, and this change directly
impacts blowdown losses which are the largest in the system.

(2)   Refurbish the dewars. Cost of implementation is
low and payback should be less than one year.

(3)   Install a graphic panel in the Control Room and
replace remaining manual valves with motor-operated valves
to provide safety and convenience of remote operation of
the cryogenic system. Payback of this modification is hard

to quantify but, operationally, this is the most significant improvement of the recommendations.

(4) Install a subcooler to replace the present method of subcooling liquid nitrogen supplied to the pumps. Adding the combined subcooler and vapor/liquid separator improves flexibility of operations and results in large liquid nitrogen savings. Payback depends on a number of factors, but liquid nitrogen usage will always be less than with the blowdown/repressurization procedure.

(5) Install vacuum-jacketed pipe and valves. VJ lines by themselves are a slow payback in this facility because there are other, much greater, losses. However, VJ process, auxiliary and fill lines save 33.74 gallons per hour, worth $12.77, over the present installation. More importantly, VJ lines are consistent with the remotely operated state-of-the-art system which Cryolab proposes.

APPENDIX A

Blowdown and Repressurization Losses in a Dewar

Blowdown:

Nomenclature:

$M[1]$ = total initial mass in dewar, kg

$M[v]$ = mass of vapor vented

$M[2L]$ = mass of liquid at blowdown pressure

$M[2G]$ = mass of vapor at blowdown pressure

$s[1]$ = initial unit entropy of dewar contents, j/kg-K

$s[v]$ = average unit entropy of vented vapor

$s[2L]$ = unit entropy of blowdown liquid

$s[2G]$ = unit entropy of blowdown vapor

$s[1G]$ = initial unit entropy of vapor

V = total volume of dewar, cubic metres

S.G. = specific gravity, cubic metres/kg

Equations:

$$M[1]s[1] = M[v]s[v] + M[2L]s[2L] + M[2G]s[2G] \qquad (1)$$

$$s[v] = (s[1G] + s[2G])/2 \qquad (2)$$

$$M[1] = M[v] + M[2L] + M[2G] \qquad (3)$$

$$V = V[2L] + V[2G] \qquad (4)$$

From which:

$$M[2L]S.G.[2L] + M[2G]S.G.[2G] = V \qquad (5)$$

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$$M[1](s[1]/s[v]-1) =$$

$$M[2L](s[2L]/s[v]-(S.G.[2L]/S.G.[2G])(s[2L]/s[v]-1)-1) +$$

$$V/S.G.[2G](s[2G]/s[v]-1) \tag{6}$$

Method of solution:

1. Solve (6) for M[2L]

2. Solve (5) for M[2G]

3. Solve (3) for M[v], the vapor vented.

Repressurization:

Nomenclature:

M[G] = mass of liquid vaporized for

pressurization, kg.

V[1] = initial vapor volume, cubic metre

V[2] = final vapor volume

D[1] = initial saturated vapor density,

kg/cubic metre

D[2] = final saturated vapor density

Equation:

$$M[G] = V[2]D[2] - V[1]D[1] \tag{7}$$

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SYMBOL LEGEND

PRESSURE INDICATOR, LOCALLY MOUNTED
PRESSURE INDICATOR, BOARD MOUNTED
TEMPERATURE INDICATOR, BOARD MOUNTED
LEVEL INDICATING CONTROLLER
HAND INDICATING CONTROLLER
PRESSURE INDICATING CONTROLLER
PRESSURE CONTROL VALVE

MANUAL VALVE
DIAPHRAGM ACTUATED VALVE
SOLENOID ACTUATED VALVE
METAL INJECTION VALVE
CHECK VALVE
BURST DISC
RELIEF VALVE

NON JACKETED LINE
VACUUM JACKETED LINE
INSTRUMENT PIPING
ELECTRICAL

VENT
DRAIN
TRANSDUCER
PUMP (EXISTING)

TUNNEL

DEWAR B

DEWAR A

PROPOSED VAPOR/LIQUID SEPARATOR-SUB COOLER

TO BLC RETURN

TO BLC DEWAR

PROPOSED VACUUM JACKETED PIPING

EXISTING PIPING

EXISTING VAPORIZER

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Cryolab
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SAN LUIS OBISPO, CA
(805) 541-2794

TITLE
NASA/LANGLEY
.3M CRYOGENIC WIND TUNNEL
PROPOSED
LIQUID NITROGEN SYSTEM

FSCM NO. 16570
DWG NO. VJ10029-2
SIZE D
SHEET 1 of 1

DRAWN   J. ENRIGHT   11/29/8_
CHECKER   C. McBRIDE   11/29/8_
DESIGN
DESIGN   D. LOMBARD   11/29/8_
DESIGN ACTIVITY
CUSTOMER

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VAPOR/LIQUID/SEPARATOR/
SUBCOOLER

DEWAR
B

ELEV: 1200

ELEV: 000

3000

6400

PUMPS

LIQUID SUPPLY
TO TUNNEL

DEWAR
A

ELEV: 305

LIQUID/VAPOR
RETURN
FROM TUNNEL

9000

BLC
DEWAR

ELEV: 5400

JACKET
TERMINATION

EXISTING
VAPORIZER

NOTES:

1. PIPING INTO BUILDING &
FIELD FABRICATED VENT
PIPING IS OMITTED FOR
CLARITY.

2. △ INDICATES VENT RISER
TO INCLUDE REMOTE OPERATED
VENT VALVE, RELIEF VALVE &
BURST DISC.

3. ALL VALVES SHOWN ARE REMOTE
OPERATED ON/OFF VALVES.

4. ⋈ INDICATES BAYONET CONNECTION.

5. APPROXIMATE DIMENSIONS IN MILLIMETERS.

6. ELEVATIONS GIVEN ARE ABOVE GROUND LEVEL
AND ARE APPROXIMATE.

CONTRACT NO.

Cryolab
3915 SANTA FE RD.
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(805) 541-2791

NASA/LANGLEY
.8M CRYOGENIC WIND TUNNEL
TITLE
LIQUID NITROGEN
SYSTEM ISOMETRIC

DRAWN T. WITTMAN DATE 11/26/86
ENGINEER G. McINTOSH 11/26/86
DESIGN D. LOMBARD 11/26/86
DESIGN ACTIVITY
CUSTOMER

SIZE D FSCM NO. 16570 DWG. NO. VJ10029-3 REV.

SCALE NONE RELEASE DATE SHEET 1 OF 1

PREPARED BY:
THE GRAPHICS SHOP
302-B N. DEXTR ST.
LOMPOC, CA 93436

VJ10029-3
B

-53-

Cryolab
4175 SANTA FE RD.
SAN LUIS OBISPO, CA
(805) 541-2786

TITLE: NASA/LANGLEY
.3M CRYOGENIC WIND TUNNEL
GRAPHIC
CONTROL PANEL

| | | | FSCM NO. 16570 | DWG. NO. VJ10029-4 | REV. |
| SIZE D | | | | | |

SCALE: NONE | RELEASE DATE | SHEET 1 of 1

CONTRACT NO.

	DATE	
DRAWN: T. WETHMANN	11/28/86	
ENGINEER: G. McENTOSCH	11/28/86	
DESIGN: D. LOMBARD	11/28/86	
DESIGN ACTIVITY	
CUSTOMER	

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Langley Technical Monitor: Robert A. Kilgore

16. Abstract

A method of reliquefying from 12 to 19% of the nitrogen exhaust gas from a cryogenic wind tunnel has been developed. Technical feasibility and cost effectiveness of the system depends on performance of an innovative positive displacement expander which requires scale model testing to confirm design studies.

The existing cryogenic system at the 0.3-m transonic cryogenic tunnel has been surveyed and extensive upgrades are proposed. Upgrades are generally cost effective and may be implemented immediately since they are based on established technology.

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