Objective: Develop the cryogenic technology needed for future space missions.

Emphasis: Developing the technology needed for infrared astronomy missions.
Current Program:

A two part program

Technology development in support of the SHOOT (Superfluid Helium On-Orbit Transfer) Project

OAST Sponsored Technology development in support of future missions generic technologies and on-going development efforts
Brief History of the Ames Program:

OAST-funded program for more than ten years (started FY 77)

Thrust: Develop the cryogenic technology for space based science

Emphasis: Needs of future IR missions

Selected Accomplishments:

-1g cryogen containment
Superfluid leak sealant
Thermoelectric cooler (80K)
Self-contained He3 cooler (0.27K)
Portable He3 Cooler (0.3K)
ADR temperature stability theory
VCS optimization
Mini ADR (0.05K)
Pressed contact conductivity
TAO predictor
PODS-IV
Low cavitation helium pump
He-II flow meter

JTX demo (1.5K)
Temperature stabilized ADR (0.2K)
Cryo valve
Ruggedized thermometers
-1g He3 Cooler
VCS heat exchange model
0-g He3 design guide
PODS-III
Helium transfer workshop
Theory of FEP limits
Orifice pulse tube refrigerator (60K)
High Reynolds No. He-II dynamics

SHOOT Program Summary

Joint GSFC/ARC/JSC Program (Overview given in companion presentation)

ARC responsible for selected technologies

Centrifugal pump
  Including fluid management device

Flow meter

Friction factor of superfluid helium

EVA
  Including transfer line

Data/command system
  Including AFD controller
Centrifugal Pump

Single stage centrifugal pump (flow >800 l/hr, head <170 torr)

Two inducers tested:

6-bladed fan type
Pump cavitates for <300 mm NPSH in superfluid (desired 0 NPSH)

3-bladed screw
Pump cavitates for <100 mm NPSH in superfluid
<-100 mm NPSH in normal fluid

New inducer to be tested:

Jet type (part of pump's output is diverted to the inlet to entrain the fluid)

There is some evidence that the heat flowing from the pump through the screen can cause an additional head rise in the smallest sized screens, due to the thermomechanical effect.
Centrifugal Pump

with jet inducer

with screw inducer
Flow Meter

Two type tested:

**Turbine meter**

- Repeatable readings in both superfluid and normal fluid helium
- Cavitates easily in superfluid helium if backpressure is low
- Difficult to cryo rate the small bearings
- Gas flow/2-phase flow can over-spin rotor
- Not selected

**Venturi meter**

- Repeatable readings
- Cavitates easily in superfluid helium if backpressure is low
  (at about 0.05 psi below saturation)

  Candidate meter to be used with 2 differential pressure guages
venturi meter
Friction Factor of Superfluid Helium

Helium flow test facility:

- Flow path: Multiples of 5 m < 20 cm diameter
- Temp/pres: 1.5-5 Kelvin svp - 5 bar
- Flow rates: < 2500 l/hr

Straight tube results:

At high Reynold numbers (10^4 - 10^6) superfluid helium behaves like a Newtonian fluid

Bellows section results:

Pressure drop approx. 50% greater than predicted
   Based on modelling bellows as a series of orifices (a correlation that works for water and for liquid nitrogen

Planned work:

- More tests with bellows
- Flow coefficient for valves

Liquid Helium Flow Test Facility
EVA

Purpose:

Demonstrate the human factors associated with helium resupply handling transfer line

Operating coupling

Interface with control/data system

Demonstrate EVA coupling and transfer line

Measure thermal performance before and after coupling operation

Measure flow impedance before and after coupling operation

Procedure:

Launch with coupler mated

Perform several transfer operations

Demate then mate coupling

Perform several more transfer operations
EVA coupler concept
Data/Command System

Approach:

Process control core
Real time data acquisition

Real time control
Manual control
Pre-packaged routines

Growth to full automation

Expert system shell
Fault diagnosis
Valves, sensors, pumps

Growth potential to full up expert system with fault work arounds

OAST Technologies

Storage technologies

PODS
Support materials
Design tools and options

Active coolers

Pulse tubes
Sub-kelvin coolers
  He-3
  ADR
  Dilution
2 Kelvin cooler
Passive Orbital Disconnect Struts (PODS)

Variable strength variable thermoconductance Dewar support system

- High strength on launch
- Low conductance on orbit
- Extensive ground testing (flight ready - chosen for GP-B)

Best suited for missions where orbital frequency requirement < launch frequency requirement

Two versions developed

**PODS-III:** best thermoconductance to strength ratio

Suited for moderated sized systems

**PODS-IV:** best side load resistance

Suited for system with many/heavy shields
DEWAR SUPPORT WITH PASSIVE ORBITAL DISCONNECT (PODS)

PODS III
- HIGH LAUNCH STRENGTH
- LOW ORBITAL CONDUCTANCE
- FLIGHT READY

PODS IV
- INCREASED SIDE LOAD CAPACITY
Support Materials

New materials can improve both strap type and PODS type supports

Want greater strength (ultimate, buckling, fatigue, etc.) to conductance ratio

**Glass - Epoxy:** Used in IRAS and COBE

**Graphite - Epoxy:** Better below 30 Kelvin (used in PODS)

**Alumina - Epoxy:** Under development by various groups

- Conductance similar to glass above 30 K
- Conductance similar to graphite below 30 K
- Ultimate strength similar to glass
- Stiffness similar to graphite

**Alumina - PEEK (a polymerized ketone) Ames/NBS program**

Promises to be better than epoxy (also less permeable to helium diffusion)

**Pulse Tubes**

**Motivation:**
Need for low cost, highly reliable, high efficiency coolers (15-100 K)

**Pulse tubes:**
- One moving part (a room temperature compressor with a room temperature seal)

Uses existing G-M and Stirling cryocooler technology
- compressor, regenerator

No cold displacer
- Phase shift between pressure and velocity waves is supplied by balast volume and orifice

Heat pumping occurs within empty (except for working gas) tube

Heating/cooling is the result of discontinuity of enthalpy flow at ends of tube

**Breadboard single stage:**
- 60K min., 16W @ 100K, 50-90% efficient (tube only)

Overall efficiency approaches that of Stirling cycle

**Model:**
- Math model being developed to study optimization of cycle cooling power scales with volume of pulse tube

**Future work:**
- Build demonstration unit

- Measure performance at lower temperatures (a second stage)
Pulse tube refrigerator

- Compressor
- Regenerator
- Ballast volume
- Orifice
- Warm heat exchanger
- Pulse tube
- Cold heat exchanger
Sub-Kelvin Coolers

Dilution Refrigeration (300-5 mK)

- Uses a $^3\text{He}/^4\text{He}$ mixture
- Has become the refrigerator of choice in most ground based applications

Approach

- Develop $^3\text{He}$ circulating type circulating type
- 20 years of commercial experience to draw upon
- Requires the control of 3 fluid interfaces
- Use surface tension devices to control fluid interfaces
- (JPL is trying electrostatic control)
- (MSFC is trying $^4\text{He}$ circulating type)
Dilution refrigerator

check valves

compressor

heater

heat switches

10K

condenser

pre-cooler

still

mixing chamber

surface tension control device

film flow limiter
Sub-Kelvin Coolers

Adiabatic demagnetization refrigerator (<0.1 Kelvin)
Simplest (gravity independent), closest to being flight ready of all sub-kelvin coolers

Ames has developed two working ADR's with excellent performance
14 μK stability at 100 mK for 12 hr
Achieves temperatures down to 50 mK
90% duty cycle

Operating principal:
Magnetization of paramagnetic material (a solid) at 2 Kelvin with 6 Tesla field
Adiabatic demagnetization to operating temperature
Isothermal demagnetization to maintain temperature under feedback control
Repeat

Current activities:
Efficiency improvement
Improved refrigerants (ones without water of hydration)
Adiabatic Demagnetization Cooler
2 Kelvin Cooler

Stored cryogens may not meet requirements of long life (<2 years)
Large heat load (>1 W @ 2 K) missions such as LDR

Goal:
- Develop a final stage to work off coolers being developed in other NASA/DOD programs

Possible approaches:
- Reverse turbo Brayton
- Magnetic cycles
- Use of \(^3\)He as working fluid

2K Cooling Stage
I have a question about your pressure drop. On the straight tube, your pressure drop for helium correlates well with the prediction, however, in the bellows section, the pressure drop was 50 percent greater than predicted. Is this 50 percent over the entire range of flow you tested or only at the higher Reynolds numbers?

Kittel:

We've only made those measurements at the higher Reynolds numbers.

Hasan:

So, you had this inconsistency only at the higher Reynolds numbers; what was the system pressure?

Kittel:

It was near saturation; it was above, but not very much above.