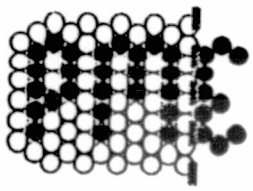
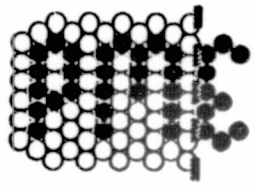


NASA In-STEP

Permeable Membrane Experiment

Presented at
NASA/DoD
Flight Experiment Technical Interchange Meeting
Monterey, CA
October 8, 1992

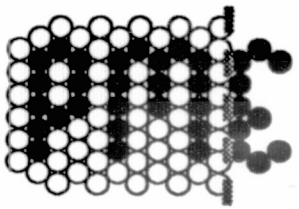
Boeing Defense and Space Group
Kent Washington



Agenda

BOEING

- Experiment Overview
- Membrane Phase Separation Experiment
- Membrane Diffusion Interference Experiment
- Membrane Wetting Experiment
- Summary and Conclusions

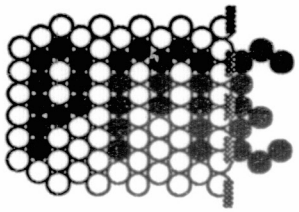


Experiment Background

BOEING

History

Announcement of opportunity	11/89
Submittal of proposal	12/89
Notification of award	5/90
Contract negotiations begun	3/91
Contract start date (Phase B)	9/91
Phase B completion	5/92
Phase B extension start date	9/92
Phase B extension expected completion date	11/92



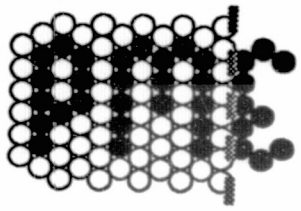
Experiment Design

Experiment Project

BOEING

Problem Statement

- There is a need for compact, reliable, and efficient technologies.
  - Advanced life support
  - Life sciences facilities
- Membrane technology meets this need in the following areas:
  - Phase separation
  - Fluid degassing
  - Particulate removal (including micro-organisms)
  - Ion transfer
- Membrane performance may be compromised by multiple phases.
  - Gas/liquid/membrane interface
  - Effect on phase separation and ion transfer efficiency
  - Area of greatest influence by presence of gravity



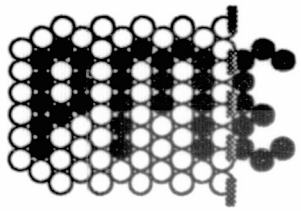
Experiment Design

Experiment Project

BOEING

Project Objectives

- Primary
  - Determine influence of different phases at membrane surface
  - Provide information on performance and possible problems
  - Study three areas of critical membrane design concern:
    - Phase separation.
    - Diffusion.
    - Wetting.
  - Use these data and provide data to other design engineers
- Secondary
  - Provide a reusable membrane experiment package



Experiment Design

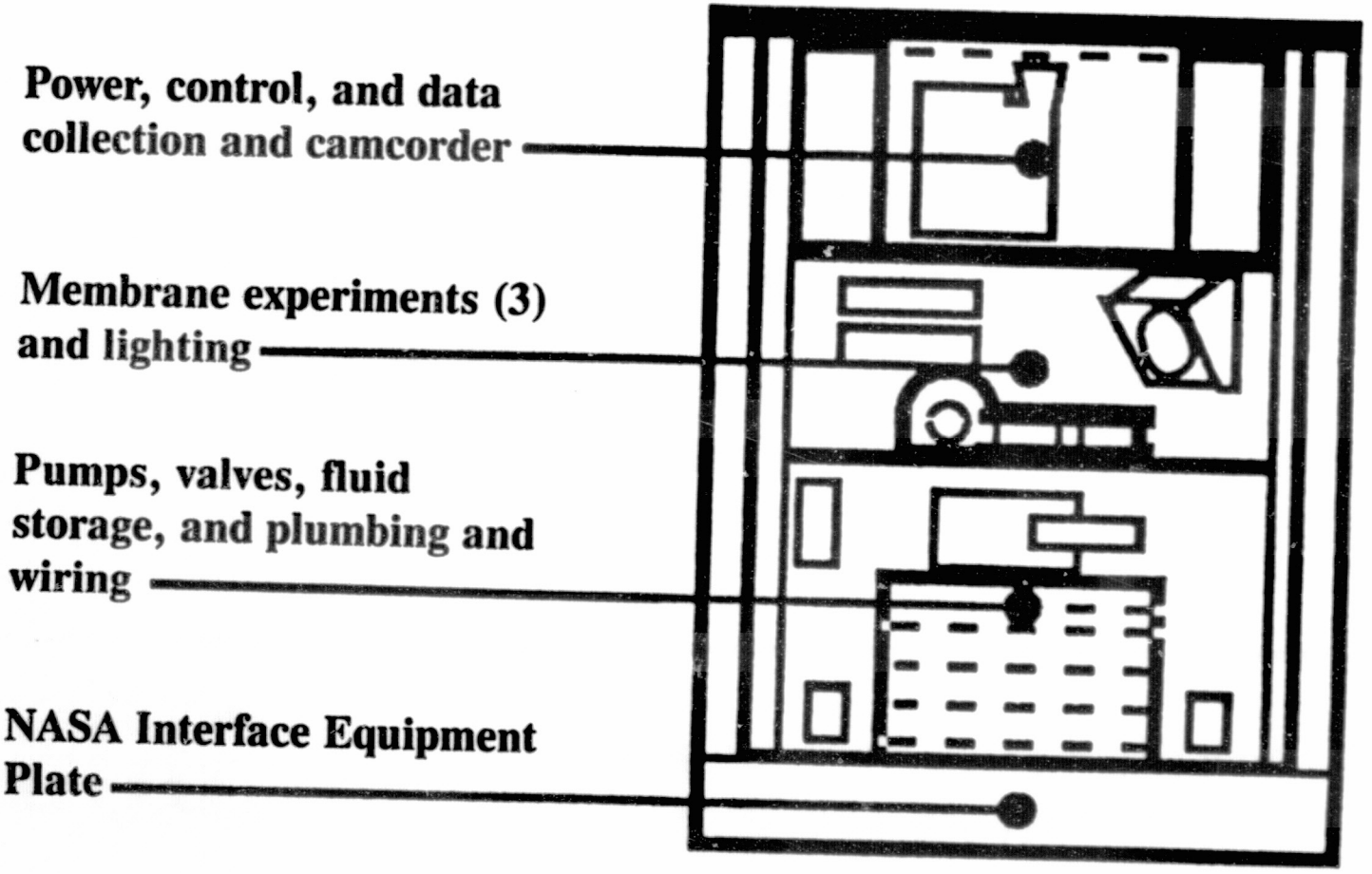
Experiment Project

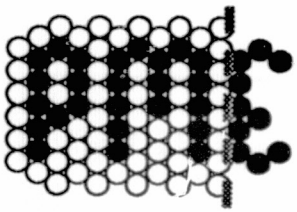
BOEING

Experiment Description

- Three experiments packaged within a single shuttle CAP canister:
  - Dual-membrane gas/liquid phase separator
  - Membrane diffusion interference by gas bubbles
  - Membrane fluid wetting behavior
- Standalone Complex Autonomous Payload (CAP) carrier
  - Battery power
  - Passive thermal control
  - Embedded data acquisition and control
  - 8-mm video camcorder for visual record
  - Experiment package initialized from aft flight deck

Experiment Package – CAP Canister Section





Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Problem Statement

- Free-gas contamination of liquid systems
- Gas interference with transport processes
- Difficulty of gas elimination in microgravity
- Drawbacks of existing approaches
  - EMU gas trap
  - Shuttle fan/separator

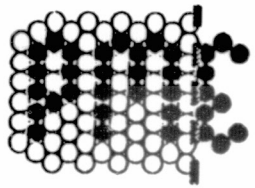
Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Objectives

- Evaluate ability to completely separate gas and liquid.
- Evaluate separation over a range of free-gas conditions.
- Eliminate the effects of gravity.



Experiment Design

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Experiment Description

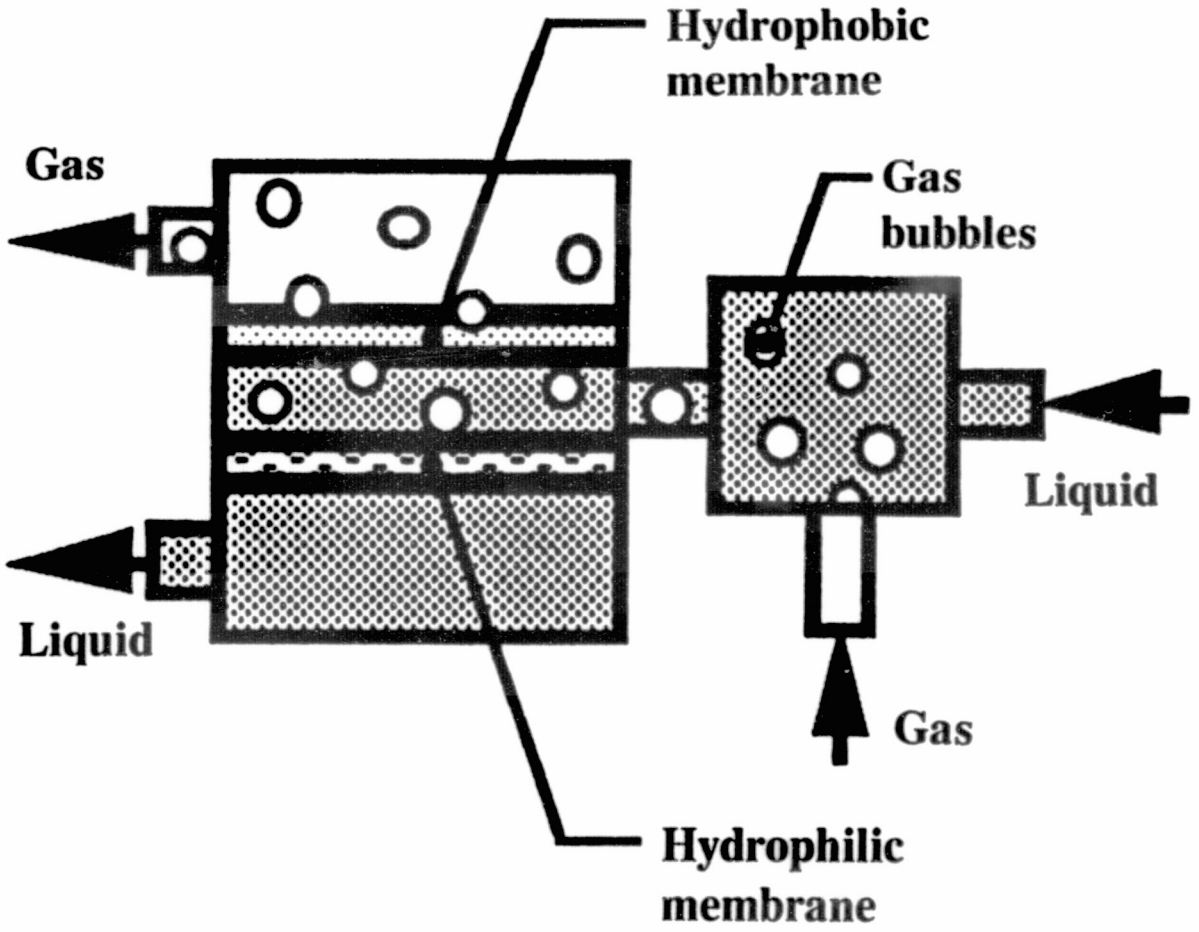
- Three-chamber test cell with two membranes
  - Hydrophilic for water passage
  - Hydrophobic for gas passage
- Fixed liquid flow with varying gas flow - mixed
- Video recording of tubing and test cell chambers
- Record of --
  - Flow rates (fluid and gas)
  - Separation effectiveness (visual)
  - Inter-chamber gas bubble behavior (visual)
  - Time, pressure and temperature
  - Shuttle acceleration environment

Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Test Configuration



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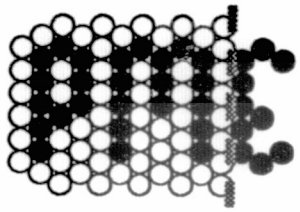


Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Parameters To Be Tested

- Complete separation of gas from gas/liquid stream
- Performance envelope for dual-membrane separator
  - Gas loading
  - Liquid flow rate
  - Pressure

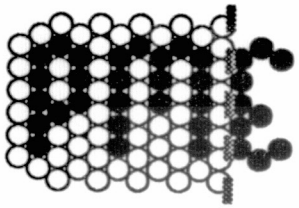
Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Microgravity Testing Requirement

- Performance depends on gas-to-membrane contact.
- Gravity strongly influences contact based on orientation.
- There is an unknown attraction of hydrophilic membrane for bubbles.
- Time periods greater than 50 sec are required.



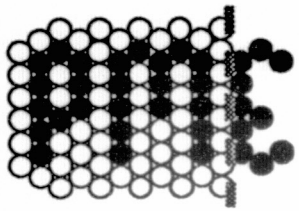
Experiment Description

No. 1 Dual-Membrane Gas/Liquid Phase Separator

BOEING

Benefits

- Definition of operating parameters
  - Pressure
  - Flow rate
  - Gas loading
- Improvements in microgravity phase separation
  - Reduced complexity, mass, volume, and power
  - Increased reliability
- Applications
  - Humidity condensate removal
  - Urine collection
  - Hand wash and shower water recovery
  - Fluid (liquid) system degassing



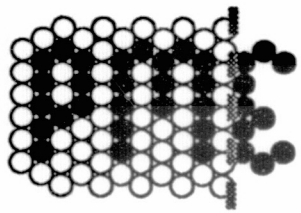
Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Problem Statement

- Entrained gas bubbles potentially adhere to hydrophilic membranes in microgravity.
- Adhered gas bubbles reduce effective transfer surfaces for material diffusion.



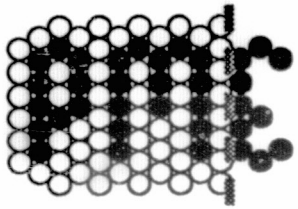
Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Objectives

- Determine to what degree entrained gas bubbles adhere to hydrophilic membranes.
- Determine the interference of adhered gas bubbles to diffusion.



Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Experiment Description

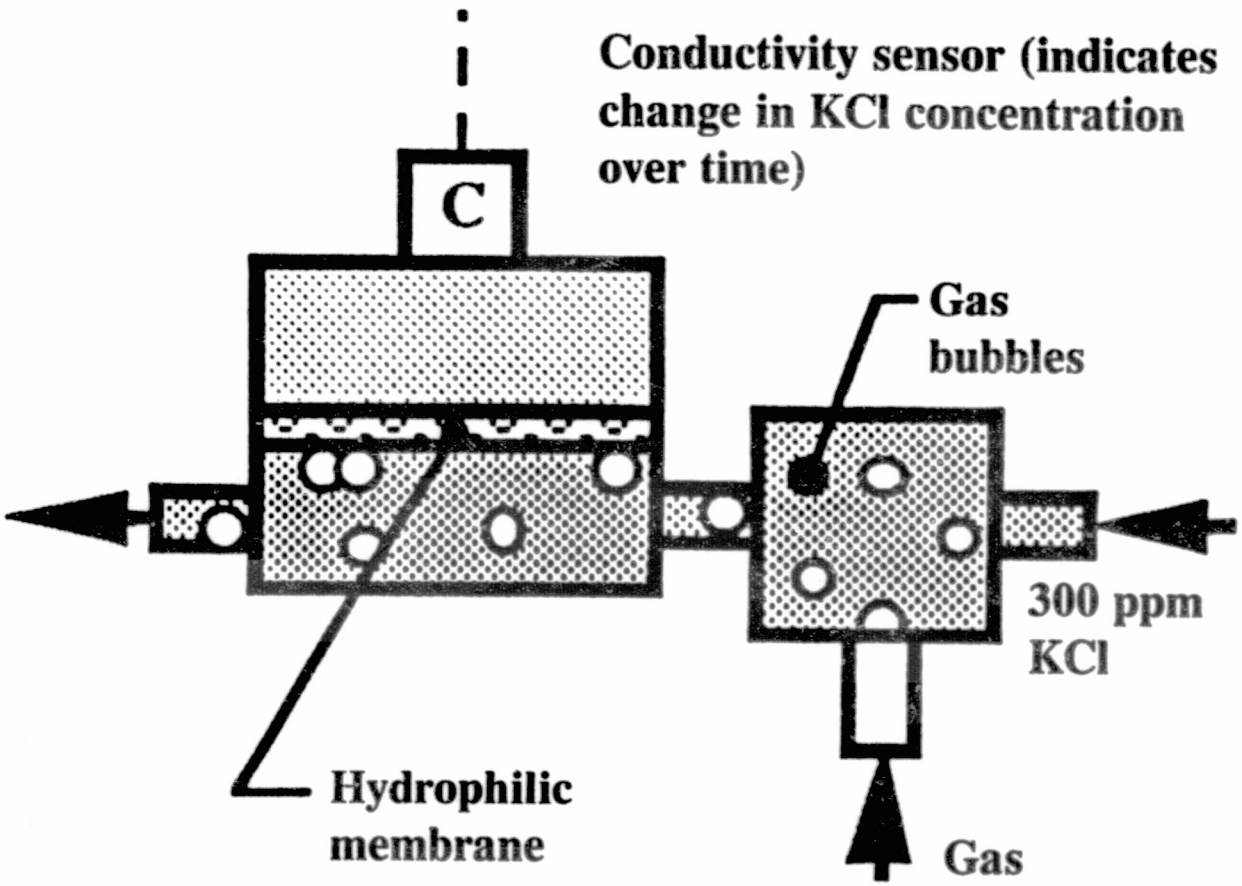
- Two test cells used—control and induced-gas entrainment.
- Each cell is composed of two compartments separated by a hydrophilic membrane.
- Each cell contains test fluid, which is pumped through one compartment (feed), and deionized water, which is stagnant in the other compartment (permeate).
- A variable gas flow rate is added to the feed of the induced-gas test cell.
- The adhesion of entrained gas bubbles on the membrane surface is video-recorded for later analysis.
- The difference in diffusion between the two cells is demonstrated by the difference in the rate of change in measured conductivity of the permeates of both test cells.

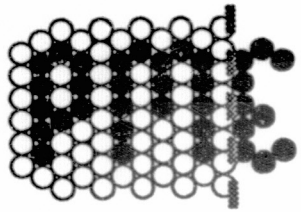
Experiment Description

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Test Configuration





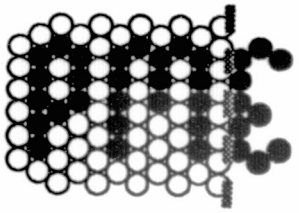
Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Parameters To Be Tested

- The adhesion of entrained gas bubbles to a hydrophilic membrane surface
- The interference of adhered gas bubbles to the material diffusion through membranes



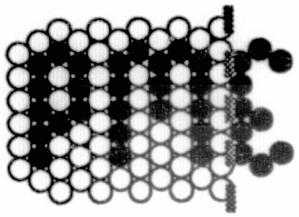
Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Microgravity Testing Requirements

- Buoyancy of gas bubbles in 1g dominates bubble behavior in liquid.
- KC-135 cannot provide stable low gravity for the required 20 min.



Experiment Design

No. 2 Membrane Diffusion Interference by Gas Bubbles

BOEING

Benefits

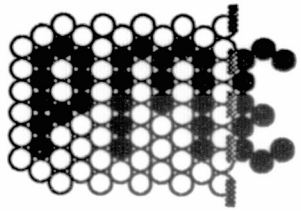
- Design effective plant nutrient delivery systems.
- Provide information to predict gas-bubble adhesion on hydrophilic surfaces such as metal pipes and tubes.
- Provide information to determine whether gas bubbles adhere to the hydrophilic membrane of the phase separator under low-flow conditions.

Experiment Design
No. 3 Membrane Wetting Experiment

BOEING

Problem Statement

- Certain membranes are sensitive to wetting (conditioning) for proper operation.
- Preconditioning membranes—
  - Add weight.
  - Create waste water for flushing.
  - Require special packaging.
- Wetting dried membranes in microgravity may not be feasible depending on fluid behavior.



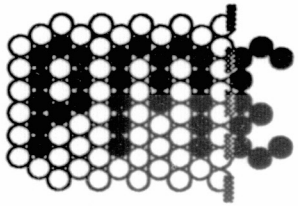
Experiment Design

No. 3 Membrane Wetting Experiment

BOEING

Objective

- **Investigate fluid behavior on a dried membrane surface as the fluid permeates the membrane.**



Experiment Design

No. 3 Membrane Wetting Experiment

BOEING

Experiment Description

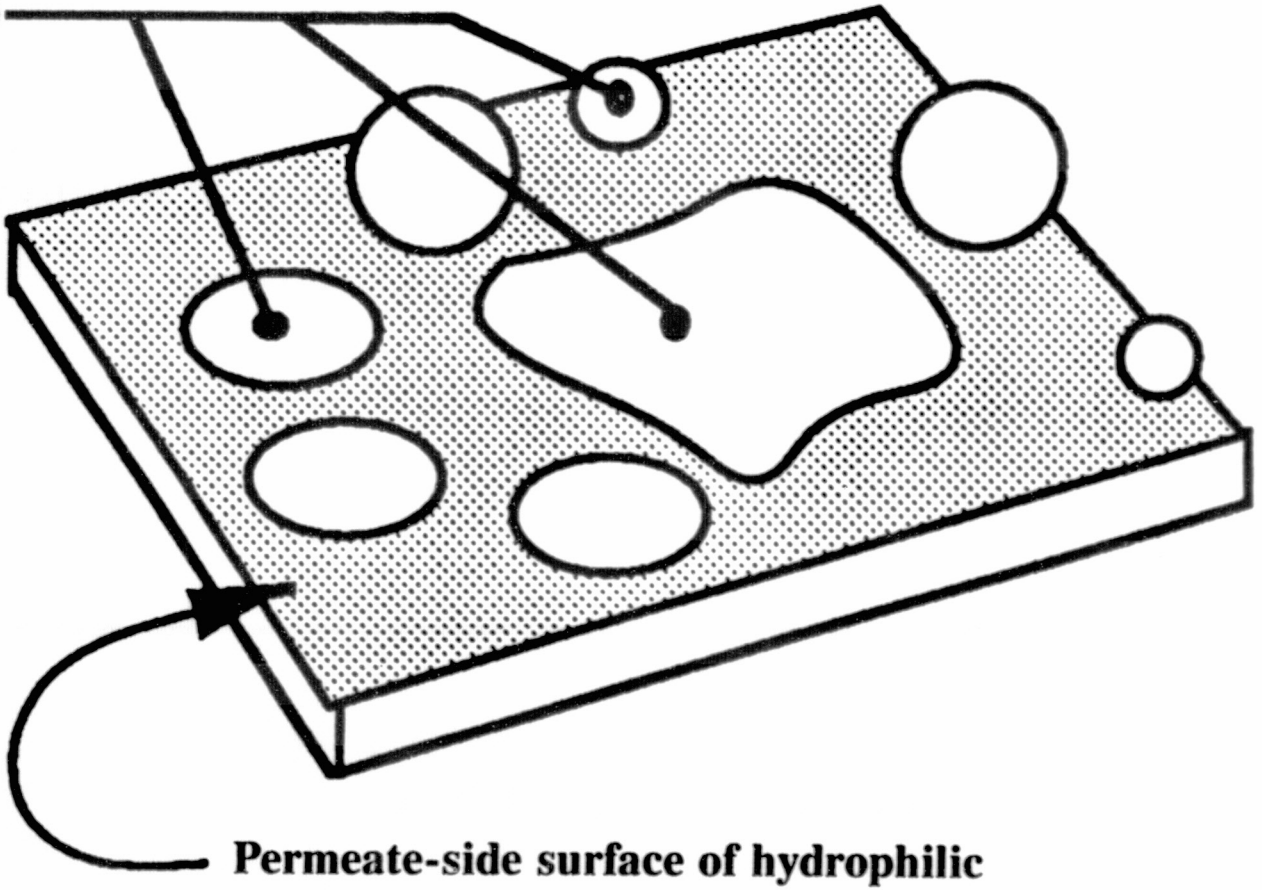
- Two-chamber test cell is separated by a hydrophilic membrane.
- Liquid flows through one chamber and permeates the membrane.
- Droplet or film formation on the permeate side of the membrane surface is recorded on video.

Experiment Description
No. 3 Membrane Fluid Wetting Behavior

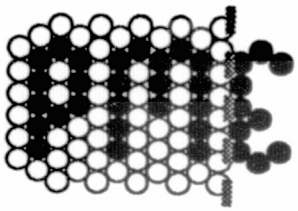
BOEING

Test Configuration

Possible patterns of fluid formation (to be determined)



Permeate-side surface of hydrophilic membrane under test



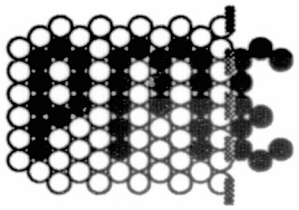
Experiment Design

No. 3 Membrane Wetting Experiment

BOEING

Parameters To Be Tested

- **Fluid behavior on permeate side of membrane surface is observed.**



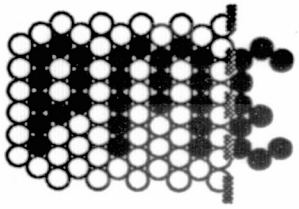
Experiment Design

No. 3 Membrane Wetting Experiment

BOEING

Microgravity Testing Requirements

- Gravity dominates fluid behavior in 1g.
- Surface tension forces dominate in microgravity.
- Testing requires 20 min of stable microgravity.



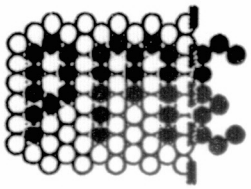
Experiment Design

No. 3 Membrane Wetting Experiment

BOEING

Benefits

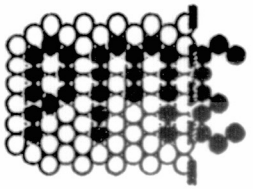
- Visual data is obtained to determine whether membranes can be conditioned in microgravity.
- Droplet formation data on membrane surfaces can be applied to condensate recovery on cold surfaces.



Summary and Conclusions

BOEING

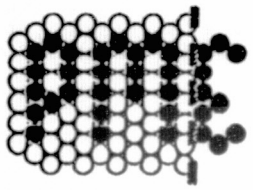
- **Phase separation is an important issue for microgravity life support systems**
  - **Improvements could be made over the existing rotary separation technology**
  - **Membranes over a compact, passive and highly efficient means for gas/liquid separation**
  - **Membrane separation in microgravity is highly dependent upon surface tension forces and therefore requires testing in microgravity where these forces predominate.**



Summary and Conclusions

BOEING

- **Many life support processes depend upon transport (heat or material) across boundaries, such as for heat exchange, filtration, sensing, and water purification.**
  - **Membrane technology can be applied especially well for filtration, sensing and purification**
  - **Laboratory testing has shown that bubble adhesion on a membrane surface impedes the rate of transport across the membrane**
  - **The predominance of surface forces in microgravity requires testing for the susceptibility of membranes to bubble adhesion and the affects of that adhesion on transport**



Summary and Conclusions

BOEING

- **Some membrane applications (especially for water purification) require the membrane to be "wetted"**
  - **Wetting replacement membranes on-orbit as opposed to shipping them pre-wetted can result in weight, and labor savings**
  - **Information on how a wetting fluid forms across a membrane surface is needed to give an indication if dry membranes can be "wetted" after replacement**
  - **The predominance of surface forces in microgravity requires testing for membrane wetting in a microgravity environment**