(NASA-CR-149930) FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL). PHASE B: A SPACELAB MISSION PAYLOAD (TRW Systems Group) 198 p HC $7.50 CSCL 14B G3/14

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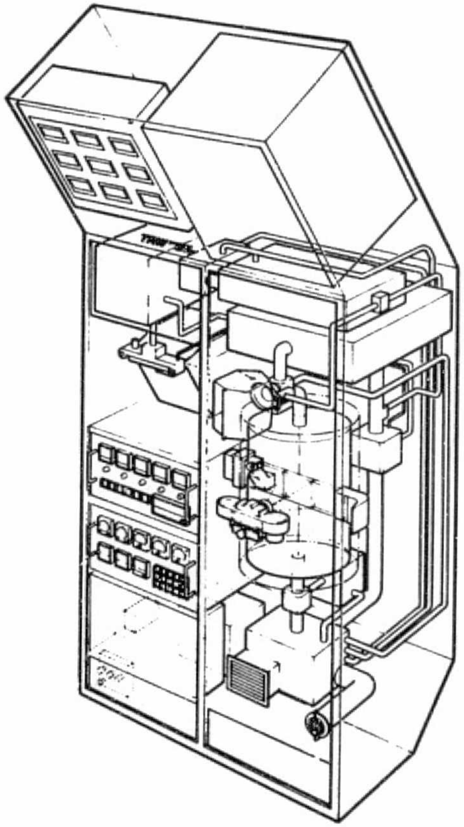
PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) - A Spacelab Mission Payload

CONCEPT REVIEW (DR-MA-03)



JUNE 30, 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

By
ACPL PROGRAM TEAM
O.W. Clausen, Program Manager

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

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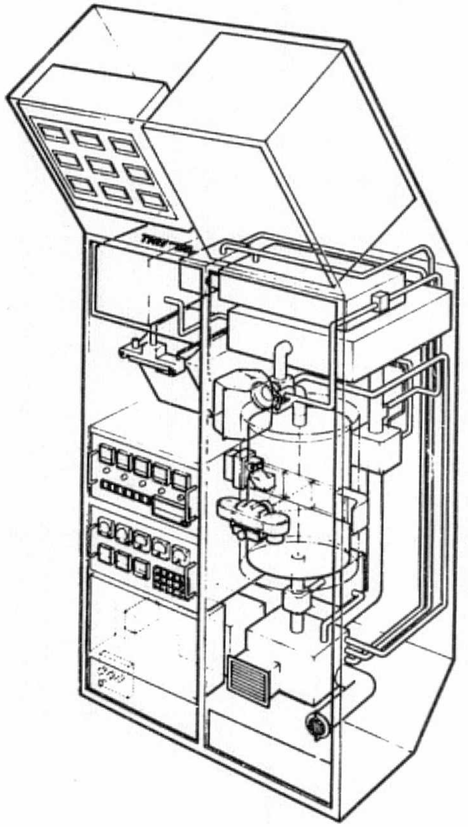

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AGENDA

NASA REMARKS

- SUMMARY – PROGRAM STATUS
- RECOMMENDED ACPL CONCEPT
- SCIENTIFIC REQUIREMENTS
- ENGINEERING ANALYSES AND TRADES
- SPACELAB INTERFACE

WRAP-UP

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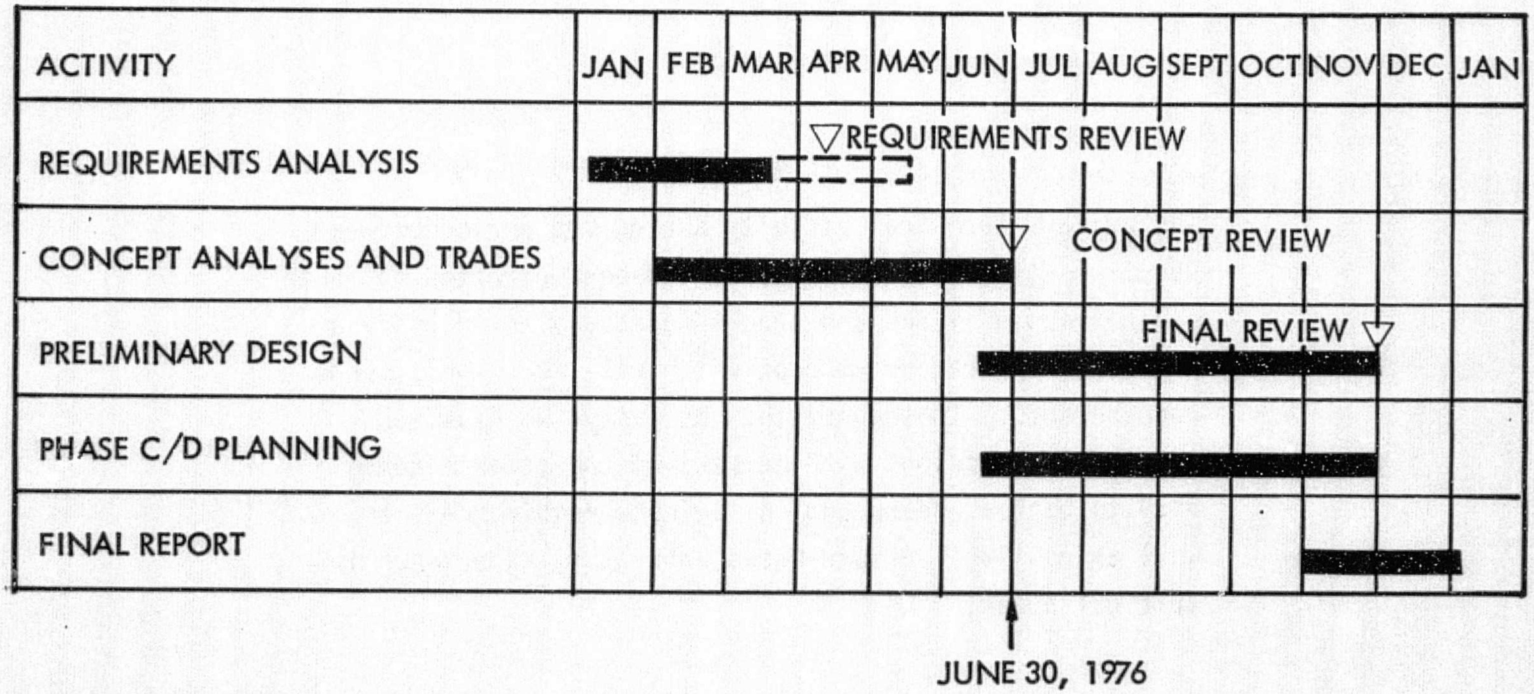
SUMMARY - PROGRAM STATUS

BILL CLAUSEN

The facing page presents an overview schedule for the ACPL Phase B Study. The effort has been underway approximately 25 weeks; there are only about 23 weeks left to the Final Review and 28 weeks left to contract completion. These times emphasize the need to agree on an ACPL concept at this meeting to be pursued into the Preliminary Design phase.

ACPL PROGRAM SCHEDULE



The primary technical activity during the period between Requirements and Concept Review has been directed to those engineering analyses and trades necessary to identify a preferred laboratory concept which will meet the science requirements. To support this activity, we have had numerous discussions with members of the science community to better understand the science requirements as well as available ground-based laboratory experience in critical areas.

MAJOR TECHNICAL ACTIVITIES

- EVALUATION OF LATEST SCIENTIFIC REQUIREMENTS.
- ENGINEERING ANALYSES AND TRADE STUDIES.
- SELECTION, WHERE POSSIBLE, OF RECOMMENDED ACPL SUBSYSTEM CONCEPTS. IDENTIFICATION OF CRITICAL COMPONENTS.
- DISCUSSION OF KEY SCIENCE DRIVERS WITH SCIENCE COMMUNITY.
- UPDATE OF SPACELAB INTERFACE DEFINITION.
- SEARCH FOR COMMERCIALLY AVAILABLE COMPONENTS.

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The Concept Review has been structured to present TRW's progress in this ACPL Final Definition and Preliminary Design Study, and to solicit comments on the work. The most pressing objective is to identify a laboratory concept which can, with confidence, be carried into preliminary design.

MEETING OBJECTIVES

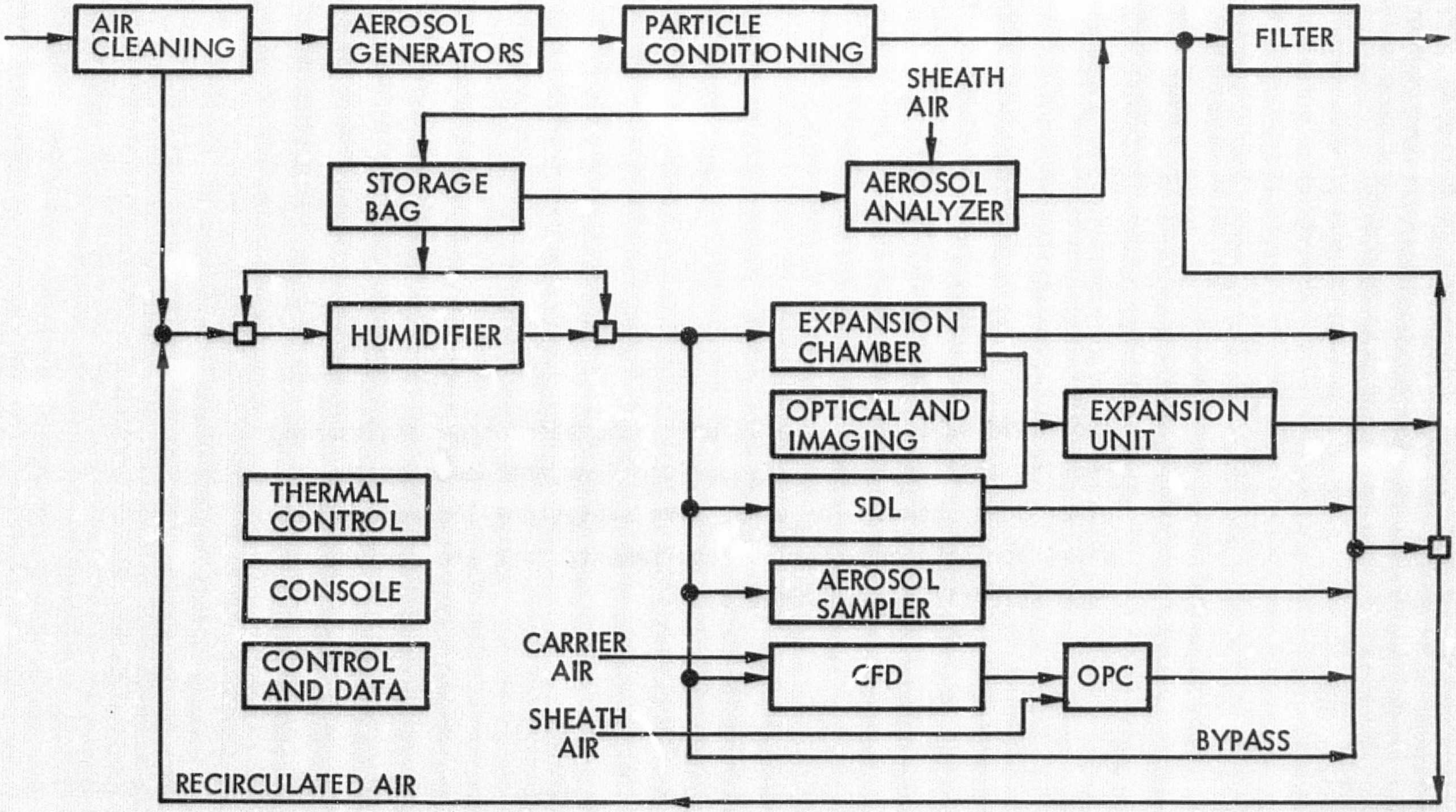
- TO DESCRIBE THE RESULTS OF THE ENGINEERING ANALYSES AND TRADES CONDUCTED TO DATE.
- TO PRESENT OUR RECOMMENDED ACPL CONCEPT.
- TO SOLICIT COMMENTS ON THE CONCEPT AND ALTERNATIVE CONCEPTS TO MEET SCIENCE REQUIREMENTS.
- TO IDENTIFY MAJOR SCIENCE REQUIREMENT DRIVERS.
- TO PROVIDE A FORUM FOR DISCUSSION OF SPECIFIC SCIENCE REQUIREMENTS.

RECOMMENDED ACPL CONCEPT

RALPH SCHILLING

The system block diagram identifies the major functional elements of the ACPL. The interrelationship of the elements is shown from the standpoint of the fluid system. The functions and components for each of the ACPL subsystems are summarized on the following pair of viewgraphs.

ACPL SYSTEM BLOCK DIAGRAM



The fluid subsystem is a support subsystem whose engineering requirements are primarily derived from the needs of the other subsystems. The other five subsystems listed on this viewgraph have engineering requirements that are derived from scientific requirements.

SUBSYSTEM FUNCTIONS AND MAJOR COMPONENTS

NO.	SUBSYSTEM	FUNCTION	MAJOR ELEMENTS
1.	FLUID	FLUID SUPPLY, FLOW/PRESSURE REGULATION, HUMIDIFICATION, FLOW/PRESSURE MEASUREMENT	PUMPS PRESSURE REGULATORS FLOW RESTRICTORS FLOW AND PRESSURE SENSORS, HUMIDITY SENSOR
	HUMIDIFIER	PROVIDES HUMIDIFIED AIR AT PRECISELY KNOWN VALUES OF STATE CONDITION	HUMIDIFICATION CHAMBER WITH SATURATION AND REHEAT ZONES WATER SUPPLY
2.	AIR CLEANING	INLET AND EXHAUST GAS CONDITIONING	DRYERS FILTERS HYDROCARBON TRAPS
3.	AEROSOL GENERATOR	PRODUCES, CONDITIONS, STORES AND DELIVERS PARTICLES OF VARIOUS TYPES, SIZES AND CONCENTRATIONS AS REQUIRED FOR EACH EXPERIMENT	NaCl GENERATOR H_2SO_4 GENERATOR DILUTION MIXERS AEROSOL NEUTRALIZER LARGE PARTICLE FILTER STORAGE BAG
4.	AEROSOL COUNTER	MEASURES NUMBER DENSITY AND SIZE DISTRIBUTION OF PARTICLES. COLLECTS AEROSOL SAMPLES FOR ANALYSIS.	OPTICAL PARTICLE COUNTER ELECTRICAL AEROSOL ANALYZER ELECTROSTATIC PRECIPITATOR
5.	CONTINUOUS FLOW DIFFUSION CHAMBER (CFD)	PROVIDES KNOWN SUPERSATURATION TO ACTIVATE CONDENSATION NUCLEI AND GROW RESULTING DROPLETS TO OPTICALLY OBSERVABLE SIZE	DIFFUSION CHAMBER WATER SUPPLY
6.	EXPANSION CHAMBER	PROVIDES PRESSURE AND TEMPERATURE CONTROLLED ENVIRONMENT FOR EXPERIMENTS. SIMULATES ATMOSPHERIC ADIABATIC COOLING PROCESSES.	CHAMBER WITH VARIABLE TEMPERATURE WALLS EXPANSION UNIT WINDOWS FOR VISUALIZATION, ILLUMINATION AND PHOTOGRAPHY

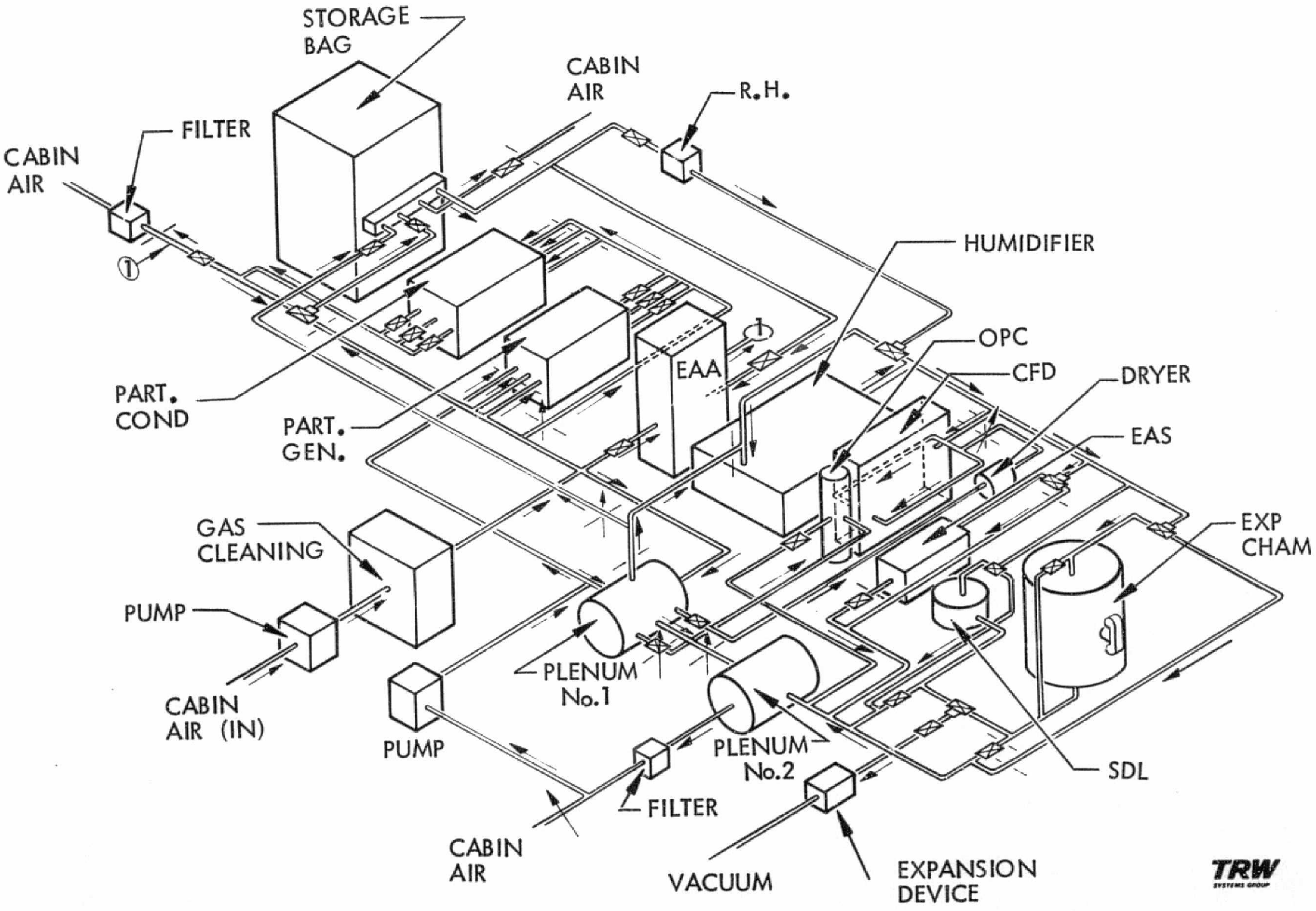
The SDL and Optical and Imaging Subsystems are science subsystems whose engineering requirements are derived from scientific requirements. The other three subsystems listed on this viewgraph are support subsystems with engineering requirements derived from the needs of the other subsystems.

SUBSYSTEM FUNCTIONS AND MAJOR COMPONENTS (CONT.)

NO.	SUBSYSTEM	FUNCTION	MAJOR ELEMENTS
7.	STATIC DIFFUSION CHAMBER - LIQUID (SDL)	PROVIDES KNOWN SUPERSATURATION TO ACTIVATE CONDENSATION NUCLEI AND GROW RESULTING DROPLETS TO OPTICALLY OBSERVABLE SIZE. FUNCTIONS AS AITKEN COUNTER WHEN USED WITH EXPANSION UNIT.	DIFFUSION CHAMBER WATER SUPPLY WINDOWS FOR VISUALIZATION, ILLUMINATION AND PHOTOGRAPHY THERMOELECTRIC COOLER
8.	THERMAL CONTROL	PROVIDES TEMPERATURE CONTROL FOR ACPL. PROVIDES THERMAL INTERFACE BETWEEN ACPL AND SPACELAB THERMAL SINK. TEMPERATURE MEASUREMENT.	FLOW LOOPS PUMPS THERMAL MIXING VALVES CHECK VALVES ACCUMULATORS TEM HEAT PUMP/REFRIGERATORS EVAPORATIVE COOLER LIQUID RESERVOIRS TEMPERATURE SENSORS
9.	CONTROL AND DATA	PROVIDES CONTROL OF FLOW, TEMPERATURE AND PRESSURE THROUGHOUT THE ACPL. CONTROLS THE ADIABATIC SIMULATION CYCLE IN THE EXPANSION CHAMBER AND THE SUPERSATURATION SEQUENCE IN THE CFD AND SDL. COLLECTS DATA FROM ALL SENSORS.	ELECTRONIC FEEDBACK CONTROL LOOPS SENSOR SIGNAL CONDITIONING CIRCUITRY SYSTEM CONTROLLER WITH OPERATOR'S PANEL INTERFACE CIRCUITRY FOR S/L RAU
10.	OPTICAL AND IMAGING	RECORDS NUMBER DENSITY OF OPTICALLY OBSERVABLE DROPLETS WITHIN SPECIFIC VOLUMES INSIDE EXPANSION CHAMBER AND SDL	CAMERAS WITH MOTORIZED FILM TRANSPORT FLASHLAMP ILLUMINATORS OPTICS ASSEMBLIES UV AND IR FILTERS
11.	CONSOLE	PROVIDES THE STRUCTURAL HARDWARE REQUIRED TO MOUNT THE ACPL COMPONENTS INTO SPACELAB RACKS. PROVIDES PROPERLY CONDITIONED ELECTRICAL POWER.	STRUCTURAL SUPPORTS POWER CONDITIONING AND DISTRIBUTION CIRCUITRY

The fluid system diagram depicts the interrelationship of the major ACPL equipment items with respect to the fluid flow and piping.

FLUID SYSTEM DIAGRAM



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The ACPL double rack packaging concept shows the relative locations selected for the major ACPL equipment items.

ACPL PACKAGING LAYOUT

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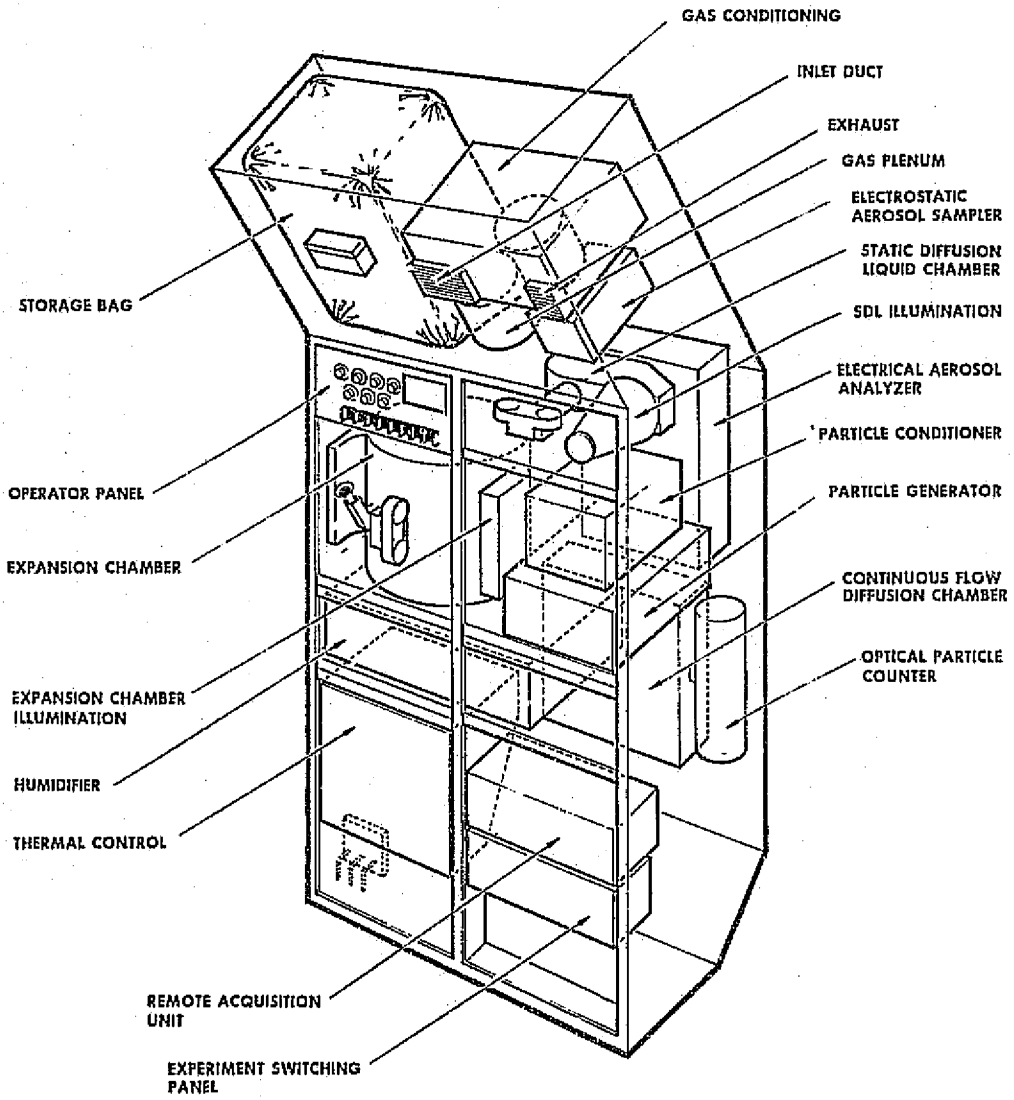
OF POOR QUALITY



SCIENTIFIC REQUIREMENTS

LARRY HARNETT

Considerations of diffusion and coagulation of stored aerosols led us to conclude that the aerosol loss rate during Expansion Chamber flushing and CFD characterizations may approach 4%. More results of the analysis are presented under Aerosol Generator Subsystem.

REQUIREMENTS FOR GENERATION AND STORAGE OF AEROSOLS

- NACL AEROSOL GENERATION

  CRITICAL SUPERSATURATION SPECTRUM: $N = CS^{k}$

  NUMBER DENSITY RANGE AFTER DILUTION: $\int_{.05\%}^{3\%} \frac{dN}{dS}\, dS = \left[\begin{array}{c} 100/CM^3 \\ TO \\ 1000\ CM^3 \end{array} \right.$

  $< .1/CM^3$ WITH RADIUS > 0.1 μm

- GENERATION OF OTHER AEROSOLS

  PROVISION MUST BE MADE FOR USE OF OTHER SPECIALIZED PARTICLE GENERATORS PROVIDED BY PRINCIPAL INVESTIGATORS

- STORAGE OF AEROSOLS

  MAXIMUM TOTAL PARTICLE LOSS WITHIN SIZE RANGE

  0.01 μm TO 0.1 μm RADIUS LESS THAN 4%

  DURING EXPANSION CHAMBER FLUSHING AND CFD CHARACTERIZATION

Aerosol size range and radius resolution for the size measurement are limited by the equipment available.

REQUIREMENTS FOR AEROSOL MEASUREMENT

•	RANGE OF PARTICLE DIAMETER MEASURED:	.0032 μm TO 1.0 μm
•	RESOLUTION OF PARTICLE DIAMETER:	.0032 μm TO .01 μm: 2 CHANNELS
		.010 μm TO 1.0 μm: 4 CHANNELS/ DECADE
•	ABSOLUTE ACCURACY OF NUMBER DENSITY MEASUREMENT IN EACH SIZE RANGE:	$\delta \log_{10} n < \pm .3$
•	MUST PROVIDE CAPABILITY FOR COLLECTION OF AEROSOL SAMPLES COMPATIBLE WITH ELECTRON MICROSCOPE ANALYSIS AFTER RETURN.	

REQUIREMENTS FOR AIR PREPARATION

AIR USED IN ACPL TEST CHAMBERS MUST BE CLEANED TO SATISFY THE FOLLOWING REQUIREMENTS:

ORGANIC COMPOUNDS:	< 0.1 PPM
PARTICLES:	$< 0.1/\text{CM}^3$ WITH RADIUS $> .1\ \mu m$ $< 100/\text{CM}^3$ AITKEN PARTICLES

PROVISION MUST BE MADE FOR VERIFICATION OF AIR CLEANLINESS USING A PHOTOCHEMICAL METHOD AND AN AITKEN COUNTER.

Water vapor mixing ratio is derived from the relative humidity, the pressure, and the temperature at the reference point. The absolute accuracy of the mixing ratio determination in the expansion chamber is limited by both the stability and absolute measurement accuracy of the pressure and temperature.

REQUIREMENTS FOR SATURATOR (HUMIDIFIER)

• DEGREE OF SATURATION	WITHIN 99.8% OF SATURATION AT REFERENCE TEMPERATURE AND PRESSURE.
• PRESSURE	
STABILITY:	± 0.5 mb FOR PERIODS ≤ 1000 SEC.
ABSOLUTE MEASUREMENT ACCURACY OF REFERENCE PRESSURE:	± 0.2 mb
CAPILLARITY:	EFFECTS OF CAPILLARITY ON VAPOR PRESSURE MUST NOT AFFECT OVER-ALL ACCURACY.
• TEMPERATURE	20°C TO 0.5°C
STABILITY:	± 0.02°C FOR PERIODS ≤ 1000 SEC.
ABSOLUTE MEASUREMENT ACCURACY OF REFERENCE TEMPERATURE	± 0.1°C
• AEROSOL INJECTION	PROVISION MUST BE MADE FOR INJECTION OF AEROSOLS UPSTREAM AND DOWNSTREAM OF THE HUMIDIFIER
• WATER FLOW	SATURATOR DESIGN MUST MINIMIZE CONTAMINATION OF WICKS WICKS MUST BE CLEANABLE BETWEEN FLIGHTS.

Expansion control in primary range uses a reversible pump for good pressure control. Secondary range bleeds air out of Expansion Chamber, but no return.

REQUIREMENTS FOR EXPANSION CHAMBER

- AT START OF EXPANSION

TEMPERATURE RANGE	0.5°C TO 25°C
PRESSURE RANGE	400 mb TO S/L AMBIENT
RELATIVE HUMIDITY RANGE	80% TO 95%
RESIDUAL VELOCITY	0.01 CM/SEC

- DURING EXPANSION

EXPANSION RATIO	$\frac{\Delta P}{P} \leq$ 5% (PRIMARY RANGE)
	$\Delta P < P_{initial}$ (SECONDARY RANGE)
EXPANSION RATE	$\frac{dT}{dt} <$ 6°C/MIN
	$T_{MIN} =$ 0°C

Temperature control during expansion may be preselected, but will not be based on CFD characterization of the aerosol or real time measurements of conditions inside the Expansion Chamber. Pressure control will be slaved to the measured temperature of the Expansion Chamber walls such that the gas pressure within the SEV follows either a dry adiabat or a wet adiabat, also selectable. This variation in gas pressure also acts as a temperature control on the gas within the SEV, and forces the gas temperature to track the wall temperature as long as the expansion can be accurately modeled by a dry or wet adiabat.

Temperature and pressure measurements in the Expansion Chamber, <u>relative to the conditions at the saturator reference condition</u>, permit accurate assessment of the relative humidity inside the chamber, up to the point where condensation becomes important.

REQUIREMENTS FOR EXPANSION CHAMBER (CONT.)

● DURING EXPANSION	
TEMPERATURE	
CONTROL WITHIN SEV	FOLLOWS ONE OF A PRESELECTED NUMBER OF CURVES OF THE FORM $T(t) = T_o + At + B\sin\left(\frac{\pi(t - t_o)}{\tau}\right)$ COEFFICIENTS ARE LIMITED TO THE FOLLOWING RANGES (A) < TBD °C/MIN (B) < TBD °C τ < TBD MIN DEVIATION OF T FROM DESIRED CURVE TO DEPEND UPON (A), (B), τ.
RELATIVE MEASUREMENT ACCURACY (RELATIVE TO SATURATOR REFERENCE TEMPERATURE)	± .02 °C
PRESSURE	
CONTROL WITHIN SEV	± TBD mb OF DRY ADIABAT BEFORE RH = 100% ± TBD mb OF $\left(\begin{matrix}\text{DRY}\\\text{WET}\end{matrix}\right)$ ADIABAT AFTER RH = 100%
RELATIVE MEASUREMENT ACCURACY (RELATIVE TO SATURATOR REFERENCE PRESSURE)	± .5 mb

Supersaturation within the SEV will be very uniform during the first part of the expansion, before wall-gas temperature differences begin to affect conditions in the center of the chamber, provided that initial conditions can be made sufficiently uniform.

REQUIREMENTS FOR EXPANSION CHAMBER

(CONTINUED)

• DURING EXPANSION	
UNIFORMITY IN SUPERSATURATION	10^{-4} (1% OF 1%) DURING FIRST 100 SECONDS OF EXPANSION
• STEADY STATE OPERATION (NO EXPANSION)	
PRESSURE AND TEMPERATURE ACCURACY	± 0.05 °C ± 0.5 mb
• OBSERVATION OF WATER DROPLET FORMATION	
PARTICLE DENSITY RANGE	100 TO 1000/CM^3
MAXIMUM FRAME RATE	10/SEC FOR 2 SECONDS 1/SEC FOR 50 SECONDS .1/SEC FOR 1000 SECONDS
ABSOLUTE ACCURACY OF NUMBER DENSITY DETERMINATION	± 3% FOR PARTICLES ABOVE MINIMUM DETECTABLE SIZE
MINIMUM DETECTABLE PARTICLE DIAMETER	5 µm AT 10 FR./SEC. 2 µm AT $<$ 10 FR./SEC.

REQUIREMENTS FOR EXPANSION CHAMBER (CONT.)

- GENERAL EXPANSION CHAMBER REQUIREMENTS

  CAPABILITY FOR VISUAL OBSERVATION OF EXPERIMENT IS REQUIRED

  A 2 CM DIAMETER PORT ALLOWING INSERTION OF SMALL PIECES OF HARDWARE IS REQUIRED

Entrance section to CFD preconditions carrier flow temperature distribution, but avoids development of supersaturations until sample is introduced, which occurs at the start of the wet hot plate.

REQUIREMENTS FOR CFD

- PRECONDITIONING OF CARRIER AND SAMPLE FLOWS

  TIME CARRIER FLOW MUST SPEND BETWEEN DRY HOT PLATE AND WET COLD PLATE OF CFD $\geq \frac{5h^2}{\pi^2 K_W}$.

  CARRIER AND SAMPLE FLOWS MUST BE CONDITIONED TO AVOID TRANSIENT SUPERSATURATIONS IN SAMPLE LAMINA

Because of diffusion, the sample may spread to fill the region where S $\sim$95% of S_{max}. The corresponding error in $n_c \sim CS^k$ is lower, however. Temperature measurement limits allow S_{max} to deviate by as much as 2% from the measured value for low supersaturations.

The sample must spend enough time between the wet plates to allow the supersaturation field to equilibrate, then enough additional time to allow the droplets to grow to measurable size.

REQUIREMENTS FOR CFD (CONT.)

- SUPERSATURATION FIELD

RANGE OF MAXIMUM SUPERSATURATION : 0.1% TO 3%

SPATIAL VARIATION OF S ACROSS SAMPLE : 5% OF S_{MAX}

ABSOLUTE ACCURACY OF MAXIMUM SUPERSATURATION : $\begin{cases} 1\% \text{ FOR } S_{MAX} > .005 \\ 2\% \text{ FOR } S_{MAX} = .001 \end{cases}$

SAMPLE MUST SPEND A TIME T BETWEEN WET HOT AND COLD PLATES WHERE

$$T = 7 \frac{h^2}{\pi^2 \quad K_W{}^2} + \begin{cases} 50 \text{ SEC AT } S_M = .0010 \\ 25 \text{ SEC AT } S_M = .0035 \\ 5 \text{ SEC AT } S_M = .0100 \\ 1 \text{ SEC AT } S_M = .0300 \end{cases}$$

DEPLETION OF WATER VAPOR DUE TO DROPLET GROWTH MUST BE MINIMIZED.

CFD MUST BE ISOLATED FROM TEMPERATURE DIFFERENTIALS AND EXPANSIONS GENERATING SUPERSATURATION EXCURSIONS > 0.001%.

REQUIREMENTS FOR CFD (CONT.)

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- ACTIVATED AEROSOL DENSITY MEASUREMENT

TOTAL NUMBER DENSITYOF DROPLETS:	10 TO 2000/CM^3
ACCURACY OF FLOW RATE TO CFD:	± 1%
SIZE RANGE OF DROPLETS COUNTED:	0.5 TO 5 μm DIA.

We have assumed that the primary objective of SDL design is to minimize the total error in $n_c = CS^k$ when the SDL is used as a spectrometer. Preliminary error analyses indicate that the accuracies in the table on the facing page are achievable.

REQUIREMENTS FOR SDL

- INJECTION OF SAMPLE AND STILLING OF RESIDUAL VELOCITIES

  MAXIMUM GAS VELOCITY AFTER STILLING COMPLETION: 0.01 cm/sec

- STEADY STATE OPERATION

  RANGE OF MAXIMUM SUPERSATURATION: 0.01% TO 10%
  MAXIMUM PERIOD OF STEADY STATE OPERATION: 1 HOUR
  ACCURACY OF MEASUREMENT OF $n_c = CS^k$ SHALL BE

S (%)	ERROR $\left(\frac{\delta n_c}{n_c}\right)$
.1	±20%
.3	±16%
1	±13%
3	±12%

WHEN THE NUMBER OF ACTIVATED PARTICLES AT $S = 3\%$ IS $1000/cm^3$, $K \leq 1$, AND THE NUMBER OF INDEPENDENT EXPERIMENTS REQUIRED TO PRODUCE THE REQUIRED ACCURACY IS ≤ 6.

The minimum detectable particle size is limited by the design of the optical system and the SEV volume definition error. In zero-g operation, particle residence times within the SEV permit large growth times and corresponding large minimum detectable particle sizes.

REQUIREMENTS FOR SDL (CONT.)

- OBSERVATION OF WATER DROPLET FORMATION
    - MAXIMUM FRAME RATE 1/SEC.
    - MINIMUM DETECTABLE PARTICLE RADIUS 2 μm.
- GENERAL SDL REQUIREMENTS
    - MUST BE USEABLE AS AN AITKEN COUNTER
    - MUST HAVE CAPABILITY TO ACHIEVE SUPERSATURATION EQUILIBRATION QUICKLY (~ 2 TO 3 SECONDS) AFTER INSERTION OF A SAMPLE
    - MUST HAVE CAPABILITY TO SET ΔT (S_{MAX}) IN A TIME CONSISTENT WITH USE AS A SPECTROMETER

ENGINEERING ANALYSES AND TRADES

- LARRY HARNETT
- BRUCE MARCUS
- RALPH SCHILLING
- RALPH WUERKER

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AEROSOL GENERATOR SUBSYSTEM

PRODUCES, CONDITIONS, STORES AND DELIVERS PARTICLES OF VARIOUS TYPES, SIZES AND CONCENTRATIONS AS REQUIRED FOR EACH EXPERIMENT.

The engineering requirements for the aerosol generator subsystem are derived from the science requirements presented on an earlier viewgraph. The recommended subsystem concept meets these engineering requirements.

AEROSOL GENERATOR SUBSYSTEM

SUMMARY OF ENGINEERING REQUIREMENTS

- AEROSOL GENERATION
  - $NaC\ell$
  - LOG-NORMAL SIZE DISTRIBUTION WITH MEDIAN RADIUS ~ 0.01 μM AND GEOMETRICAL STANDARD DEVIATION ~ 2
  - NUMBER DENSITY IN RANGE 0.01 TO 0.1 μM RADIUS AFTER DILUTION: 100 TO 1000 PER CM^3
- AEROSOL CONDITIONING
  - NUMBER DENSITY OF PARTICLES LARGER THAN 0.1 μM RADIUS: LESS THAN 0.1 PER CM^3
  - AEROSOL PARTICLES ELECTRICALLY NEUTRAL
- AEROSOL STORAGE
  - LESS THAN 4% REDUCTION IN NUMBER DENSITY FOR ANY PARTICLE SIZE IN THE RANGE 0.01 TO 0.1 μM RADIUS DURING THE EXPANSION CHAMBER FLUSHING AND CFD CHARACTERIZATION PERIOD

Several of the key activities leading to the selection of a subsystem concept are listed here. The results of these activities will be presented in the following viewgraphs.

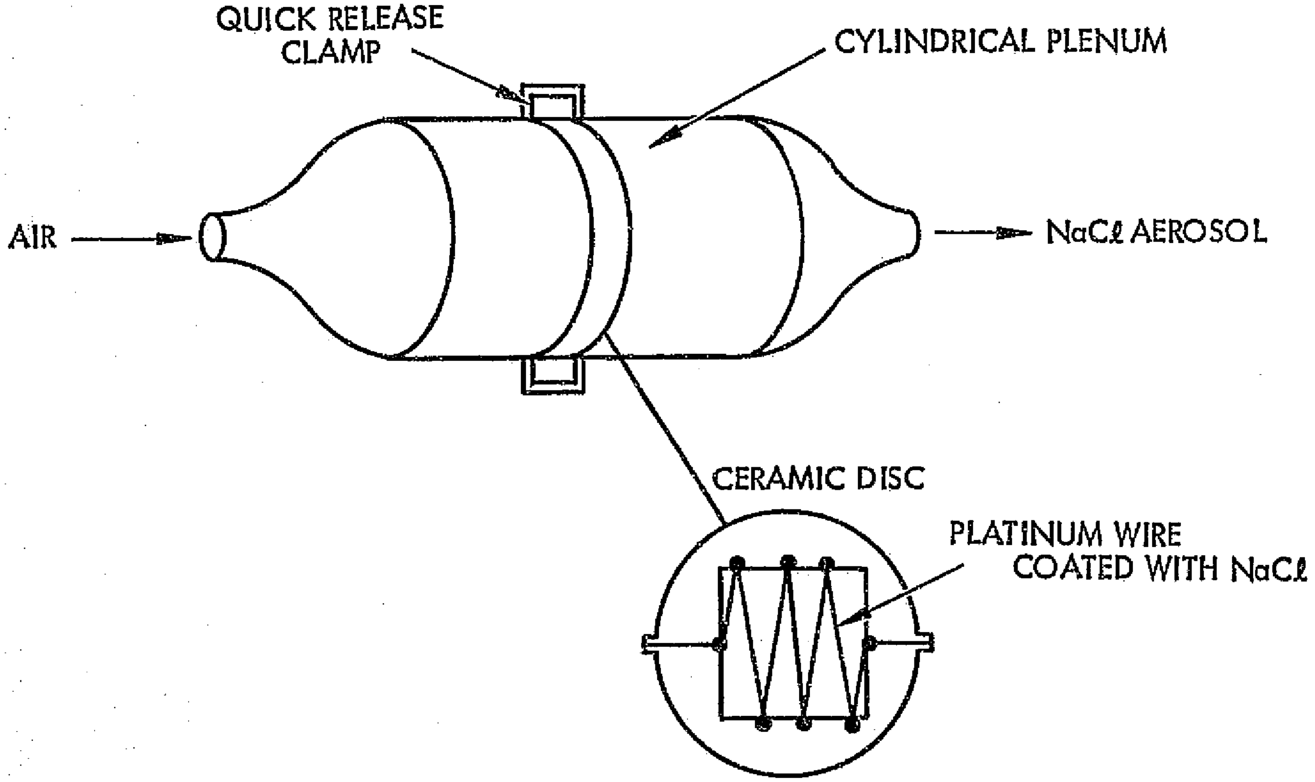
AEROSOL GENERATOR SUBSYSTEM

ANALYSES AND TRADES

- DETERMINATION OF ZERO-G SUITABILITY AND CHARACTERISTICS OF EXISTING LABORATORY TECHNIQUES FOR PARTICLE GENERATION LED TO SELECTION OF THREE CANDIDATES
  - EVAPORATION FROM NaCℓ COATED WIRE
  - COLLISON ATOMIZER WITH CONSTANT FEED NaCℓ SOLUTION
  - PHOTOCHEMICAL GENERATION OF H_2SO_4
- PARAMETRIC STUDY OF AEROSOL LOSSES IN A STORAGE BAG DUE TO COAGULATION AND DIFFUSION LED TO IDENTIFICATION OF THREE SEPARATE STABILITY CONDITIONS
  - AEROSOL DELIVERED TO EXPANSION CHAMBER AND CFD DURING FLUSHING AND CHARACTERIZATION
  - AEROSOL IN EXPANSION CHAMBER DURING STILLING
  - AEROSOL DELIVERED TO EXPERIMENTAL CHAMBERS FOR CONSECUTIVE EXPERIMENTS
- ANALYSIS OF STORAGE OF DELIQUESCED AEROSOL VERSUS DRY AEROSOL

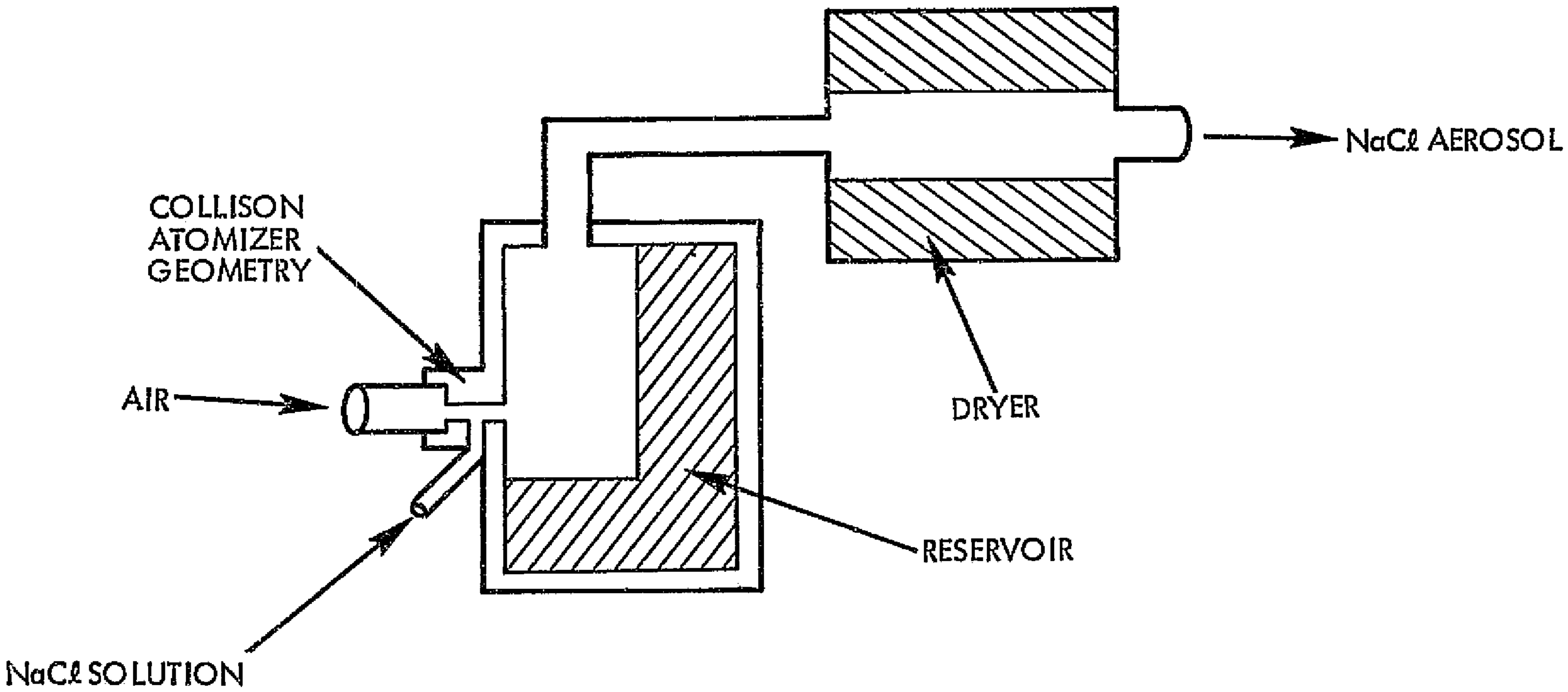
The evaporation-condensation aerosol generator is based on published laboratory work. Examples of the aerosol size distributions produced by this type of generator are shown in a subsequent viewgraph.

EVAPORATION-CONDENSATION AEROSOL GENERATOR



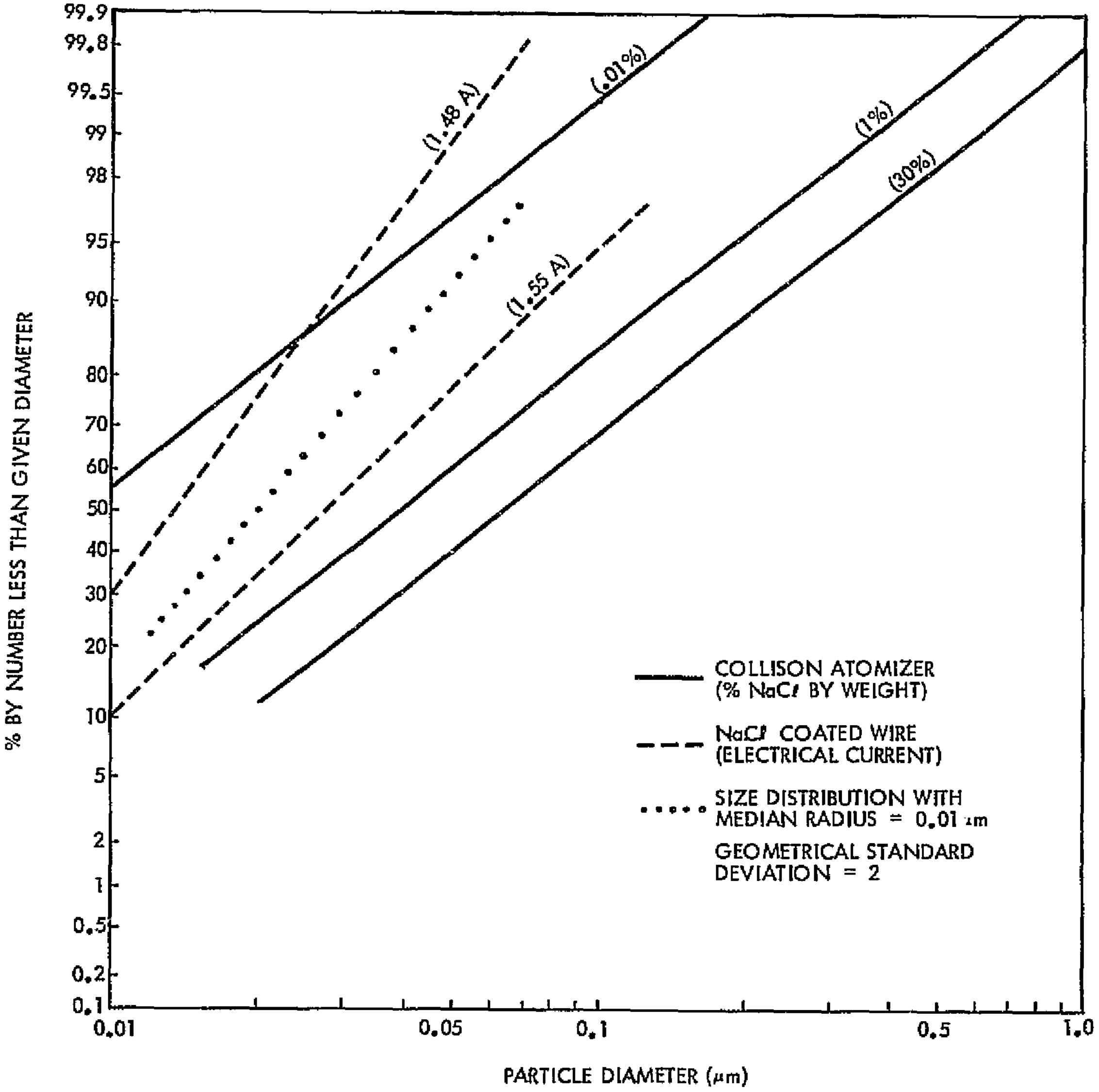
The constant feed Collison atomizer is based on published laboratory work. Examples of the aerosol size distributions produced by a standard Collison atomizer are shown in a subsequent viewgraph.

CONSTANT FEED COLLISON ATOMIZER



The size distributions shown are taken from published data for the respective aerosol generators. The constant feed Collison atomizer median aerosol diameter is reported to be on the order of 0.25 μm for a 0.1% solution and is thus somewhat larger than shown for a standard recirculating Collison atomizer.

SIZE DISTRIBUTION OF AEROSOL GENERATORS



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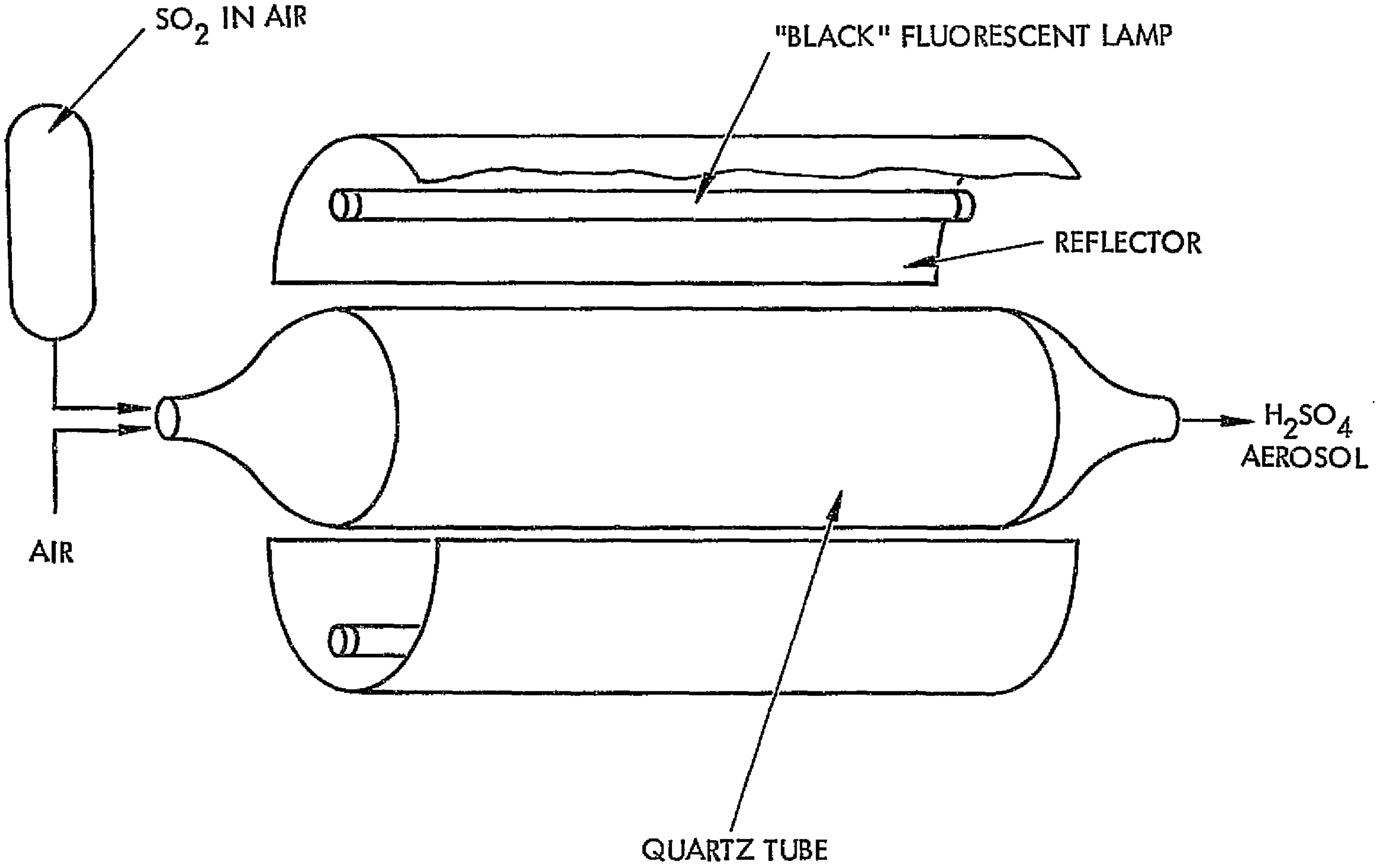
The photochemical aerosol generator is based on concepts discussed with Warren Kocmond.

PHOTOCHEMICAL AEROSOL GENERATOR



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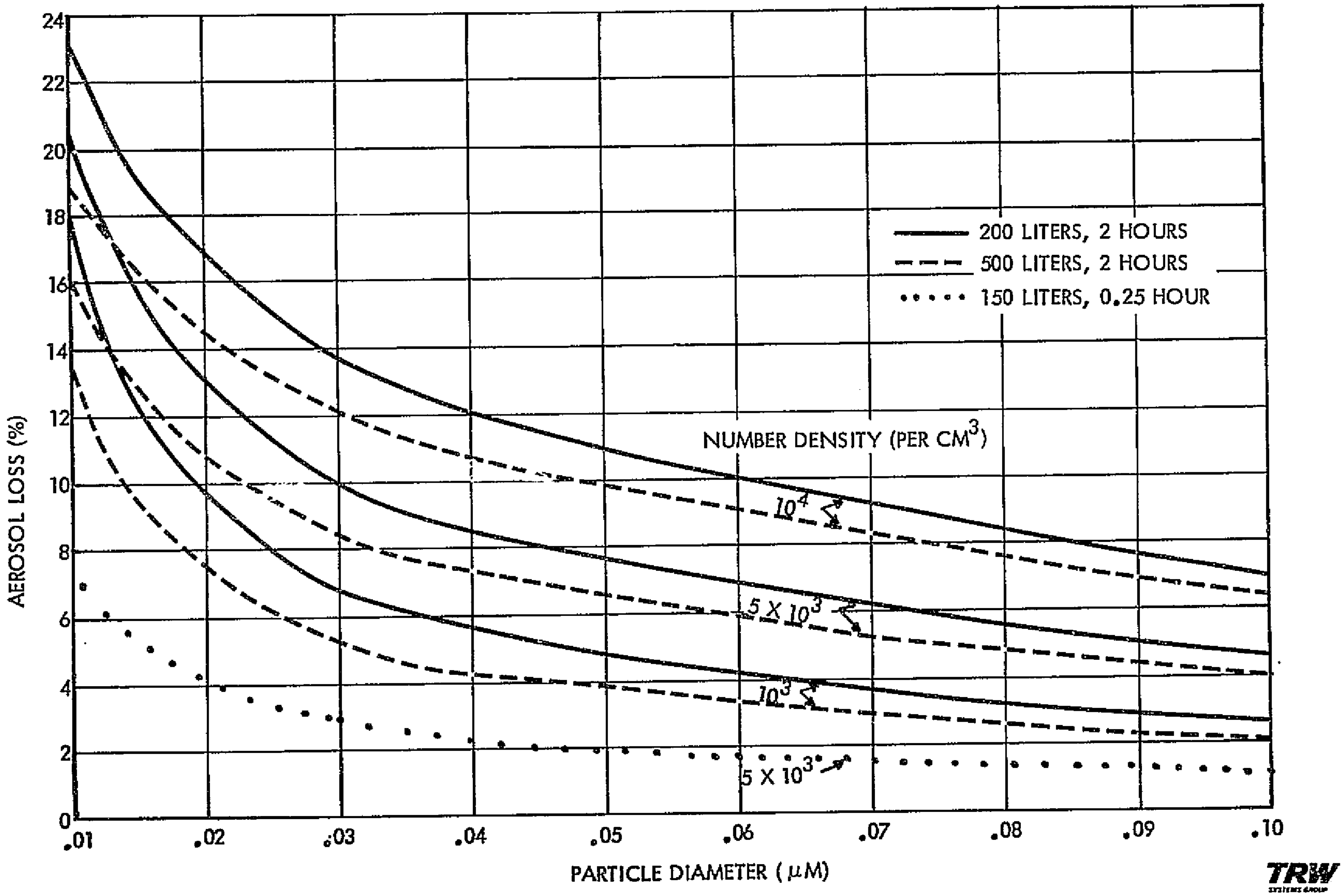
A parametric study of aerosol losses showed that even with a 500 liter storage bag, significant aerosol losses occur in the 0.01 μm to 0.1 μm radius aerosol size range over a two hour time period for consecutive experiments. The losses for a bag on the order of 200 liters, that could be much more readily accommodated in the ACPL double rack, are not significantly greater than for the 500 liter bag. A 150 liter bag provides a worst case loss of less than 4% for any aerosol size in the size range of interest over time periods required for flushing of the expansion chamber and characterization of the aerosol with the CFD.

ZERO-G DECAY OF MONODISPERSE AEROSOLS BY COAGULATION AND DIFFUSION



AEROSOL COUNTER SUBSYSTEM

MEASURES NUMBER DENSITY AND SIZE DISTRIBUTION OF PARTICLES. COLLECTS AEROSOL SAMPLES FOR ANALYSIS.

The engineering requirements for the aerosol counter subsystem are derived from the science requirements for aerosol measurement and collection of samples presented on an earlier viewgraph. The engineering requirements for the optical particle counter used with the CFD are assigned to this subsystem.

AEROSOL COUNTER SUBSYSTEM

SUMMARY OF ENGINEERING REQUIREMENTS

- AEROSOL SIZE DISTRIBUTION MEASUREMENT
  - RANGE OF PARTICLE RADIUS 0.0016 TO 0.5 μM
  - RESOLUTION TWO CHANNELS BETWEEN 0.0016 AND 0.005 μM
    FOUR CHANNELS PER DECADE ABOVE 0.005μM
- COLLECTION AND STORAGE OF SAMPLES
  - COMPATIBLE WITH ELECTRON MICROSCOPIC ANALYSIS ON EARTH
- CFD DROPLET NUMBER DENSITY MEASUREMENT
  - RANGE OF DROPLET DIAMETER 0.5 TO 5 μM
  - RESOLUTION FIVE CHANNELS
  - DROPLET COUNTING RATE 20 TO 400 PER SECOND

The engineering requirements for the aerosol counter subsystem are satisfied by three proven laboratory instruments. These instruments are commercially available and can be adapted for use in the ACPL with only minor modification to meet Spacelab environmental requirements.

AEROSOL COUNTER SUBSYSTEM

RECOMMENDED CONCEPT

- USE PROVEN LABORATORY INSTRUMENTS
  - SUITABLE FOR SPACELAB ENVIRONMENT WITH ONLY MINOR MODIFICATION
- ELECTRICAL AEROSOL SIZE ANALYZER
  - BASED ON ELECTRICAL CHARGING AND MOBILITY ANALYSIS TECHNIQUES DEMONSTRATED BY WHITBY
  - INSTRUMENT DEVELOPED AND EXTENSIVELY CHARACTERIZED BY LIU AND OTHERS
  - COMMERCIALLY AVAILABLE FROM TSI (MODEL 3030)
- ELECTROSTATIC AEROSOL SAMPLER
  - INSTRUMENT DEVELOPED BY LIU AND WHITBY
  - COMMERCIALLY AVAILABLE FROM TSI (MODEL 3100)
- OPTICAL PARTICLE COUNTER
  - LARGE NUMBER OF COMPETING INSTRUMENTS COMMERCIALLY AVAILABLE
  - EXTENSIVE LITERATURE BY LARGE NUMBER OF LABORATORY USERS
  - NO SINGLE UNIT IS CLEARLY SUPERIOR
  - ROYCO 225 HAS LONG HISTORY OF SUCCESSFUL USE WITH CFD'S AT DRI

HUMIDIFIER

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CAPABILITIES PROVIDED

- PROVIDES HUMIDIFIED AIR WITH PRECISELY KNOWN MIXING RATIO. AIR IS SATURATED IN FLOW OVER WET SURFACES AT KNOWN TEMPERATURE AND PRESSURE, AND THEN HEATED OVER DRY SURFACES TO LOWER R. H.

The engineering requirements for the humidifier (saturator/reheater) are provided by the Scientific Functional Requirements document.

ENGINEERING REQUIREMENTS: HUMIDIFIER

REQUIREMENT	SOURCE
FLOW RATE: ~1 LITER/SEC	SFR DOCUMENT
TEMPERATURE:	
MAGNITUDE: 0.5 - 20°C	SFR DOCUMENT; < S/L AMBIENT
STABILITY: ± 0.020°C	SFR DOCUMENT; ± 0.2% ACC. IN MIXING RATIO
PRESSURE:	
MAGNITUDE: ≥ S/L AMBIENT	FLUID SUBSYSTEM TRADE STUDIES
STABILITY: ± 0.5 mb	SFR DOCUMENT
ACCURACY: ± 0.2 mb	SFR DOCUMENT
WATER FLOW: NO STAGNATION NEAR REFERENCE REGION	SFR DOCUMENT; AVOID WICK CONTAMINATION EFFECTS
WICKS: CAPABILITY TO CLEAN OR REPLACE	SFR DOCUMENT
AEROSOL ADDITION: UPSTREAM OR DOWNSTREAM	SFR DOCUMENT

Three major analyses and trade studies have led to the selection of a humidifier concept which promises to meet the engineering requirements. An analysis was also performed to evaluate the implications of downstream aerosol injection.

ANALYSIS AND TRADES: HUMIDIFIER

ANALYSIS	RESULTS
FLOW GEOMETRY TRADE STUDY	PREFERRED APPROACH IS FLOW THROUGH HIGH ASPECT RATIO DUCTS
EVAPORATIVE LOAD VS. INLET R.H.	FLUID SUBSYSTEM MUST INCLUDE RECIRCULATION OF HUMID AIR TO INCREASE INLET R.H. AND LOWER HUMIDIFIER THERMAL LOAD AND WATER CONSUMPTION
THERMAL MODELING OF HUMIDIFIER PLATES	• BEST TEMPERATURE CONTROL OF REFERENCE REGION ACHIEVED WITH LOW CONDUCTIVITY PLATES AND CONTROL FLUID IN COUNTERFLOW. • CAN MEET UNIFORMITY REQUIREMENTS WITH 6 WATT EVAPORATIVE LOAD • CAN ISOLATE REHEAT SECTION WITH SHORT THERMAL INSULATORS.
EFFECT OF DOWNSTREAM INJECTION ON MIXING RATIO ACCURACY	MUST LIMIT AEROSOL FLOW TO $\leq$ 10% OF HUMIDIFIER FLOW TO ACHIEVE REQUIREMENTS

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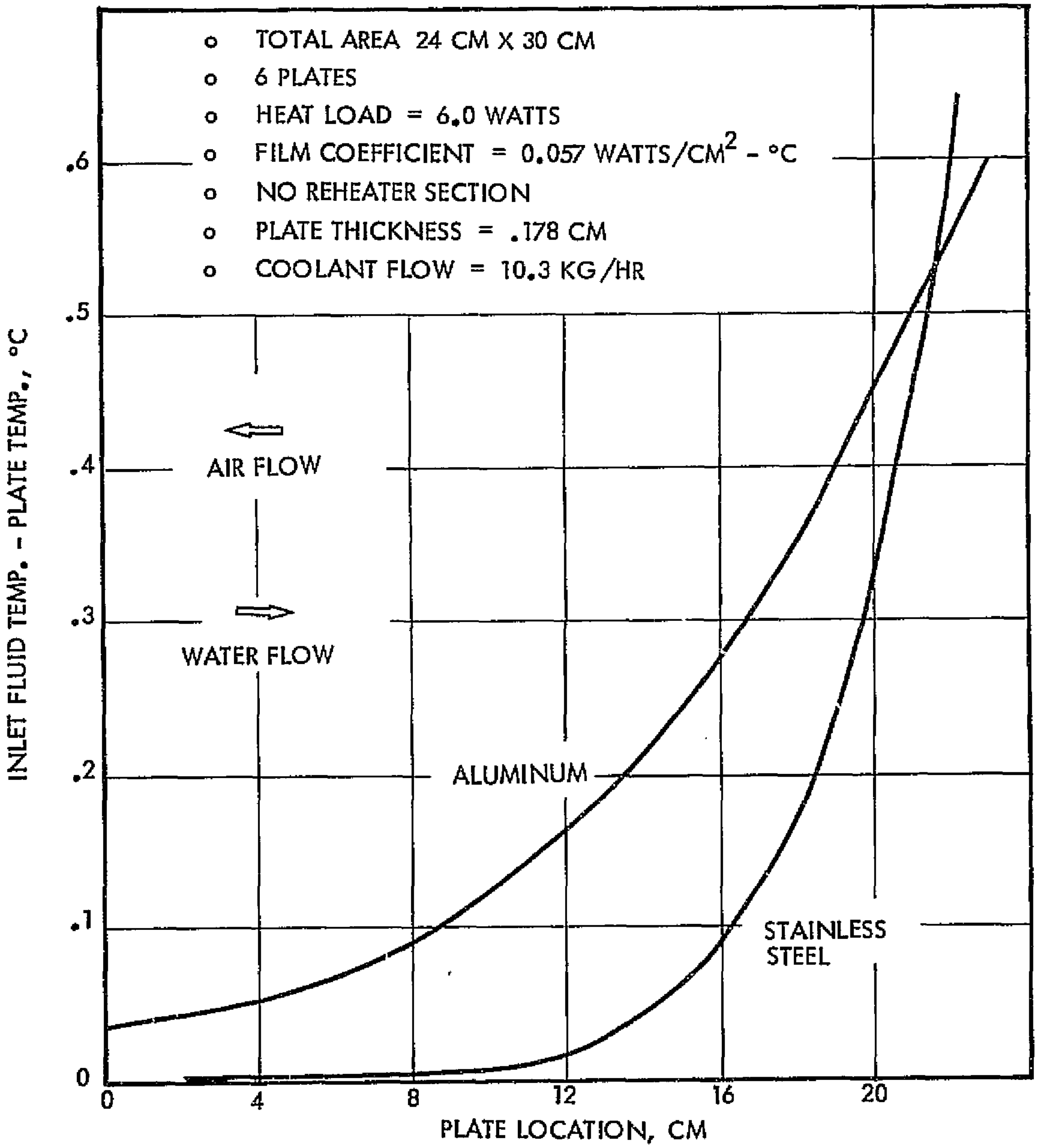
Thermal modeling of the humidifier plates indicates that maximum uniformity of the reference (downstream) region is achieved with low axial thermal conductivity plates. This serves to isolate the region of high evaporative load.

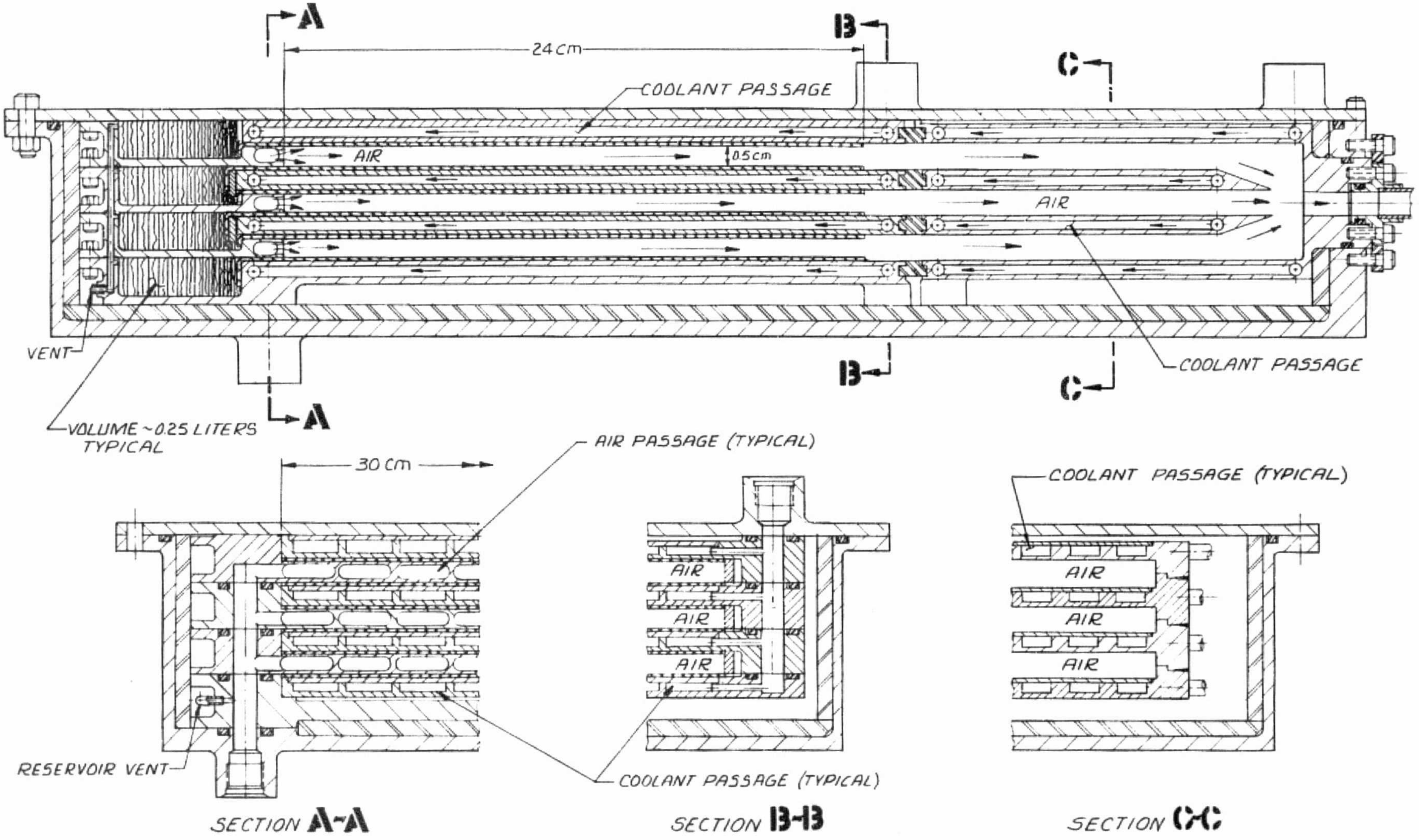
HUMIDIFIER PLATE TEMPERATURE PROFILE



The recommended humidifier concept features:

- air flow through three high aspect ratio rectangular ducts yielding >99.9% relative humidity
- capillary pumped water distribution system with self-contained storage reservoirs
- temperature control in critical region of low conductivity plates by pumped fluid in counterflow to air stream
- isolation of reheater and saturator sections with thermal insulators.

HUMIDIFIER CONCEPT



SECTION A-A

SECTION B-B

SECTION C-C

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The science requirements, a philosophy of making maximum use of proven laboratory technology and engineering analyses of feasibility combined to yield the engineering requirements shown.

KEY SCIENCE DRIVERS: HUMIDIFIER

TEMPERATURE STABILITY OF $\frac{\Delta T}{\Delta t} \leq \pm 0.020°C/_{1000\ SEC}$

PRESSURE STABILITY OF $\frac{\Delta P}{\Delta t} \leq \pm 0.5\ mb/_{1000\ SEC}$

CONTINUOUS FLOW DIFFUSION CHAMBER SUBSYSTEM

CAPABILITIES PROVIDED

- CAPABILITY OF EXPOSING CCN AEROSOL SAMPLES TO A KNOWN SUPERSATURATION FIELD FOR A KNOWN RESIDENCE TIME TO PERFORM GROWTH STUDIES (DE-EMPHASIZED FOR INITIAL ACPL)
- CAPABILITY OF EXPOSING A CCN AEROSOL SAMPLE TO VARIOUS SUPERSATURATIONS TO DETERMINE CRITICAL SUPERSATURATION SPECTRA (PRINCIPAL USE)

The requirements with maximum design and cost impact on the humidifier and supporting subsystems are the pressure and temperature stability specifications.

ENGINEERING REQUIREMENTS: CFD

REQUIREMENT	SOURCE
CHAMBER DIMENSIONS (REGION BETWEEN PLATES)	
PLATE SPACING: 1.3 CM	DRI PRACTICE: DIFFUSION τ VS. S PROFILE
SAMPLE WIDTH: 8 CM	DRI PRACTICE: UTILIZE MAX CAPACITY OF OPC
PLATE WIDTH: 30 CM	DRI PRACTICE: SIDE WALLS 8.5 h FROM SAMPLE
PLATE LENGTH: ~ 45 CM	ENG. ANALYSIS; RESIDENCE TIME REQUIREMENTS
SAMPLE FLOW CONDITIONS (DOWNSTREAM INJECTION)	
FLOW ACCURACY: 1%	SFR DOCUMENT
DEW POINT < MEAN PLATE TEMPERATURE	CONDENSATION IN ENTRY TUBE
CARRIER FLOW CONDITIONS	
FLOW RATE: $\overset{\sim}{>}$ 15 CM^3/SEC	OPC REQUIREMENT
DEW POINT < HOT PLATE TEMPERATURE	CONDENSATION ON DRY SURFACE
TEMPERATURE DIFFERENCE BETWEEN PLATES	
MAGNITUDE: 1 - 10°C	$0.001 \leq S_m \leq 0.03$
ACCURACY: ± 0.015°C	< 1% ERROR FOR $S_m \geq .005$, 2% FOR $S_m = .001$
ABSOLUTE PLATE TEMPERATURES:	
MAGNITUDE: 0.5 - 27°C	FUNCTION OF CLOUD FORMATION TEMP. ($\lesssim T_{SATURATOR}$)
ACCURACY: ± 0.1°C	SFR DOCUMENT
CHAMBER PRESSURE:	
MAGNITUDE: > S/L AMBIENT	FLUID SUBSYSTEM TRADE STUDIES
STABILITY: $\delta P/\delta t \leq 0.01$ mb/SEC	SFR DOCUMENT
VERTICAL OPERATION IN 1 - G	SFR DOCUMENT
CAPABILITY TO CLEAN OR REPLACE WICKS	SFR DOCUMENT

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A series of analyses and trade studies have been performed to evaluate the feasibility of meeting the science requirements for the CFD.

Key results indicate that a 1% accuracy in $n = Cs^k$ is impractical over the range $0.0005 < Sm < .03$.

ANALYSES AND TRADES: CFD

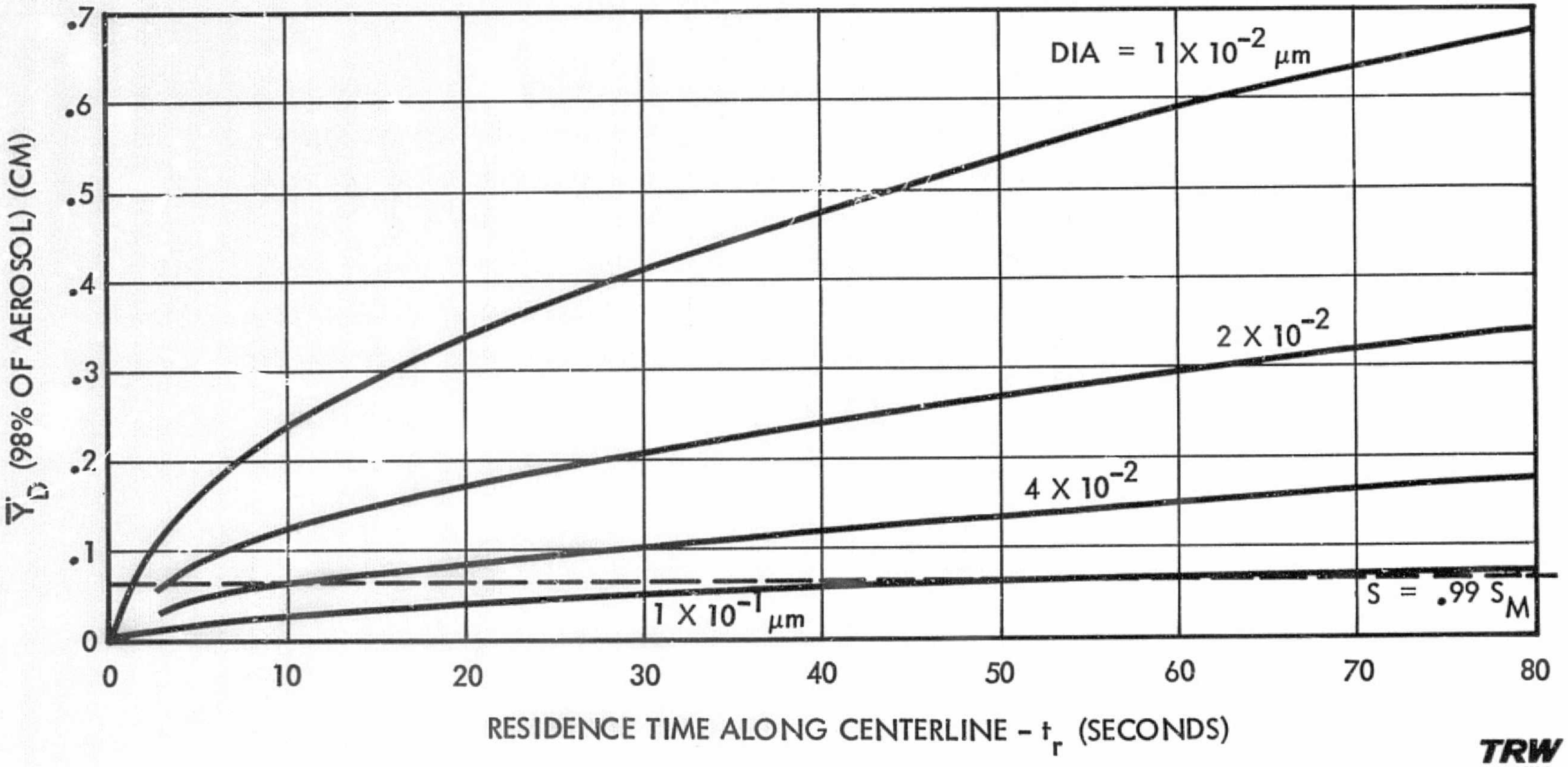
ANALYSIS	RESULT
MINIMUM PLATE LENGTH CONSISTENT WITH RESIDENCE TIME AND OPC FLOW REQUIREMENTS	LENGTH IS EXCESSIVE FOR $S_m < 0.001$
CONSTRAINING SAMPLE TO HUMIDITY CONTOUR WITHIN 99% OF THEORETICAL S_m • PHORETIC DISPLACEMENT • SAMPLE SPREADING BY DIFFUSION • SAMPLE SPREADING WITH STREAMLINES • DEPLETION OF WATER VAPOR	• DIFFUSION SPREADING IS SERIOUS PROBLEM. REQUIRES COMPENSATING PHORETIC DISPLACEMENT PLUS DOWNSTREAM INJECTION FOR HIGH ACCURACY. • LIMITING DEPLETION TO 1% OF S_m RESULTS IN VERY SMALL SAMPLE FLOW AT HIGH S_m. DIFFICULT TO MANAGE PLUS LONG COUNT TIMES. • 1% CFD APPEARS IMPRACTICAL OVER FULL RANGE IN S_m.
EVALUATION OF VERTICAL OPERATION IN 1-G:	
• WICK DESIGN	• FEASIBLE WITH NEGLIGIBLE DIFFERENCE IN 1-G VS. O-G OPERATION
• EFFECT OF WICKING STRESS ON P_V	• NEGLIGIBLE
THERMAL CONTROL OF PLATES	• CONTROL OF ΔT BEYOND ± 0.015°C APPEARS IMPRACTICAL WITHIN ACPL RESOURCE LIMITATIONS.

A major impediment to achieving high accuracy at high Sm is diffusive spreading of the very small aerosol particles with high Sc. The severity of this problem dictates a CFD design which minimizes the aerosol residence time prior to activation.

DIFFUSIVE SPREADING OF SAMPLE

$$\overline{Y}_D = \beta \sqrt{4 D t_r^*}$$

% OF SAMPLE WITHIN ± $\overline{Y}$	β
95	1.39
97	1.54
98	1.65
99	1.83



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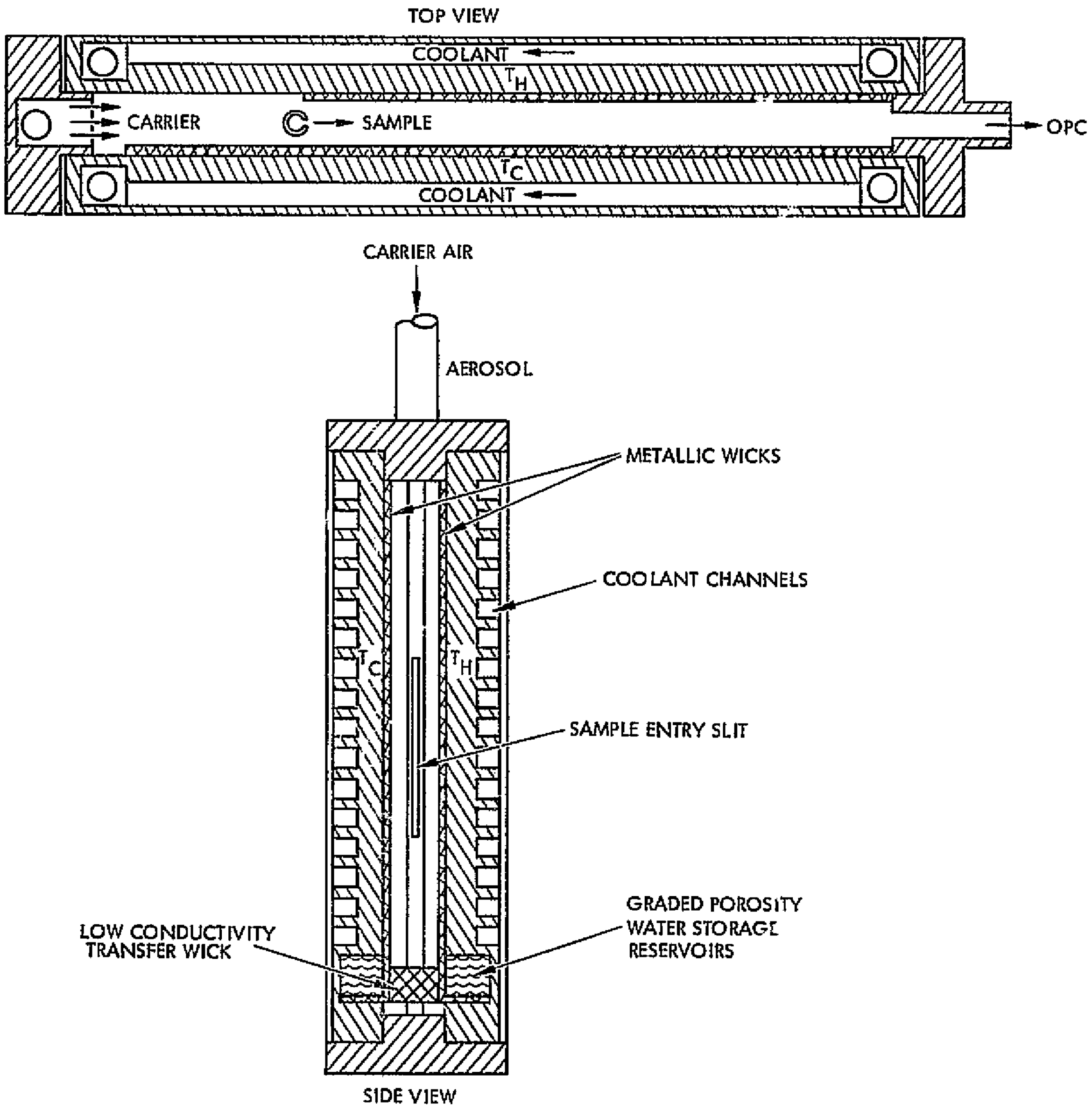
The CFD concept shown was evolved from the results of the analyses performed and several consultations with Dr. P. Squires. The key departure from current terrestrial practice is the downstream location of the sample entry slit to minimize diffusive spreading and phoretic displacement prior to activation. Additional concept features include the capillary water distribution system and counterflowing coolant temperature control scheme discussed in previous reviews.

CFD SCHEMATIC



The science drivers which have maximum influence on the complexity and cost of the CFD or its supporting subsystems are listed on the facing page.

KEY SCIENCE DRIVERS: CFD

MINIMUM VALUE OF S_m:	$S_m < .001$ REQUIRES EXCESSIVE LENGTH FOR DROPLET GROWTH
1% ACCURACY IN S_m:	REQUIRES EXTREME TEMPERATURE CONTROL FOR SMALL S_m. REQUIRES VERY SMALL SAMPLE FLOW RATES AT HIGH S_m TO CONTROL VAPOR DEPLETION
1% UNIFORMITY IN S_m OVER SAMPLE:	MAY BE UNACHIEVABLE DUE TO DIFFUSIVE SPREADING OF SMALL PARTICLES
MAXIMUM TRANSIENT SUPERSATURATIONS OF 0.00001:	LEADS TO EXTREME PRESSURE STABILITY REQUIREMENT OF $\frac{\delta P}{\delta t} \leq 0.01$ mb/SEC

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EXPANSION CHAMBER SUBSYSTEM

THE PURPOSE OF THE EXPANSION CHAMBER IS TO CREATE THE CONDITIONS SIMULATING THE ADIABATIC EXPANSION OF A MOIST AIR SAMPLE EMBEDDED IN A VERY LARGE EXPANSE OF MOIST AIR UNDERGOING THE SAME EXPANSION. THE SAMPLE WILL BE LADEN WITH AN AEROSOL OF A SPECIFIED NATURE.

The science requirements identified earlier translate into engineering requirements for the Expansion Chamber shown on the next two charts. Only those requirements associated with the warm cloud experiment (operation above 0°C) are identified.

EXPANSION CHAMBER ENGINEERING REQUIREMENTS

GENERAL

- MINIMUM VOLUME = 25 LITERS
- CONDENSATION PERMITTED ON 10% OR LESS OF SURFACE AREA
- PORT FOR INSERTION OF PROBE OR OTHER EXPERIMENTER PROVIDED DEVICE (2 CM DIAMETER - MINIMUM)
- OPEN AND CLOSE CHAMBER ON GROUND WITHIN 8 HOURS

INITIAL

- TEMPERATURE: 0.5°C TO 20°C
- PRESSURE: 400 MB TO SPACELAB AMBIENT (OPERATION DOWN TO 100 MB)
- WATER VAPOR MIXING RATIO:
  - WARM CLOUD: 0.1% (DESIRED), 0.2% (REQUIRED)
- FLUSHING
  - FLUSH CHAMBER WITH 10 VOLUMES OF SAMPLE AIR WITH SPECIFIC HUMIDITY KNOWN TO 0.2% AND CRITICAL SUPERSATURATION DISTRIBUTION KNOWN TO TBD%
- STILLING
  - RESIDUAL VELOCITY $\leq$ 0.1 MM/SEC (MUST BE CERTIFIED PRIOR TO EXPERIMENT)

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EXPANSION CHAMBER ENGINEERING REQUIREMENTS (CONT.)

ADIABATIC EXPANSION OF AIR SAMPLE

- TEMPERATURE:

dT/dt (°C/MIN)	=	6.0
TIME (MIN)	=	1
MIN. TEMP (°C)	=	0

- PRESSURE:
  - ΔP (PRIMARY) = 5%
  - ΔP (SECONDARY) = 500 MB
  - MEASURE dP/dt TO 1%
- UNIFORMITY IN SENSITIVE EXPERIMENT VOLUME
  - RELATIVE HUMIDITY $\lesssim$ 0.01% FOR 100 SECONDS: 0.10% AFTER
  - CORRESPONDS TO TEMPERATURE UNIFORMITY $\lesssim$ 0.001°C FOR 100 SECONDS: 0.010°C AFTER

Three major analyses and trades dominate the decisions associated with the concept definition of the Expansion Chamber Subsystem.

EXPANSION CHAMBER
MAJOR ANALYSES AND TRADES

THERMAL CONTROL CONCEPT

CONCLUSION: PUMPED LOOP TO EVAPORATIVE HEAT SINK (EXHAUST THROUGH SMALL EXPERIMENT VENT)

EXPANSION UNIT

CONCLUSION: OVERBOARD DUMP TO CHANGE PRESSURE LEVEL; PUMP FOR SMALL (~ 5%) EXPANSIONS

CHAMBER CONFIGURATION

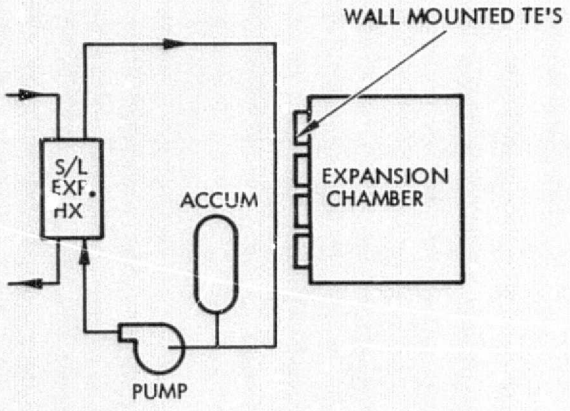
CONCLUSION: SIDE ILLUMINATION AND VIEWING

TOP INJECTION; TOP AND BOTTOM EXHAUST

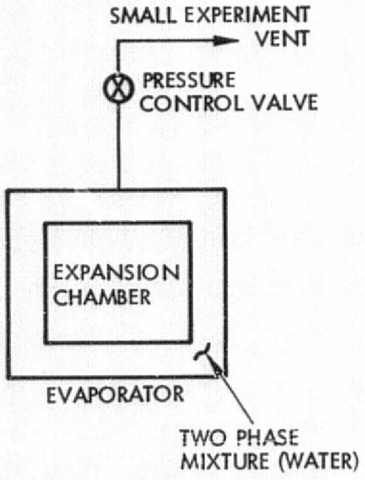
35 CM DIAMETER X 32 CM HIGH (30.8 LITERS)

The concepts considered for thermal control of the Expansion Chamber are shown here. While the specific hardware is part of the Thermal Control Subsystem, its selection is integral with design of the Expansion Chamber.

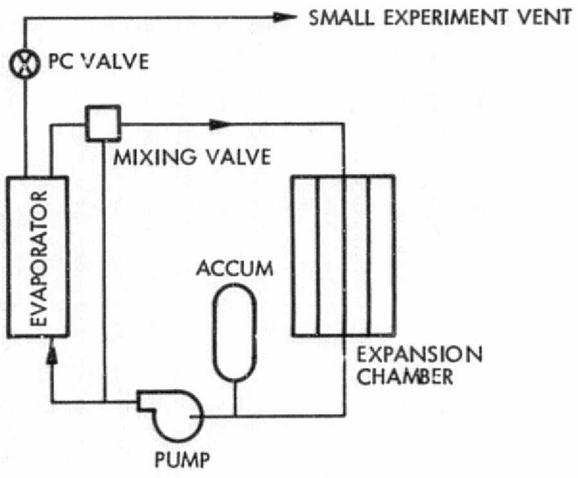
EXPANSION CHAMBER THERMAL CONTROL SYSTEM CONCEPTS



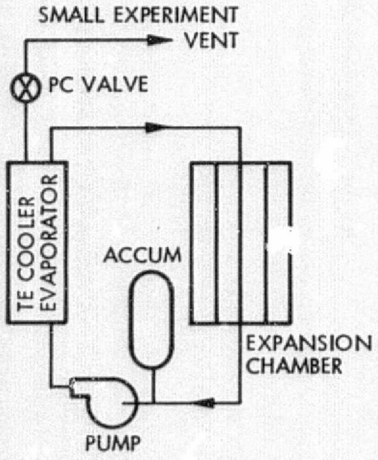
DIRECT MOUNTED THERMOELECTRICS



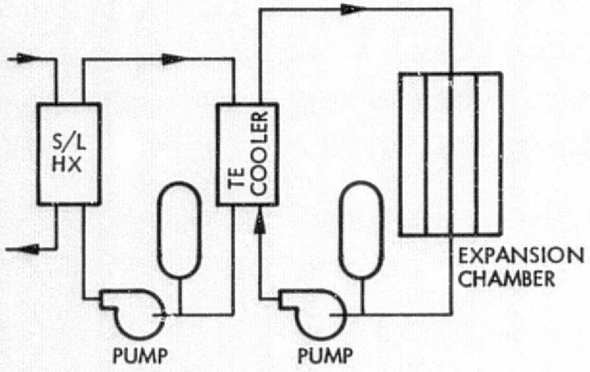
EVAPORATIVELY COOLED WALLS



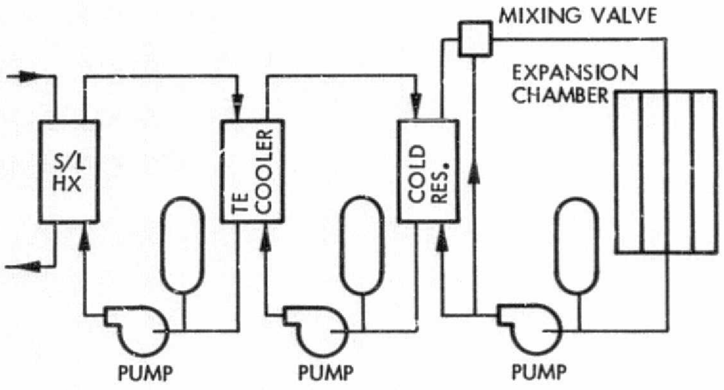
REMOTE EVAPORATIVE SINK



TE COOLER/EVAPORATIVE SINK



TE COOLER/S/L HEAT SINK



COLD RESERVOIR

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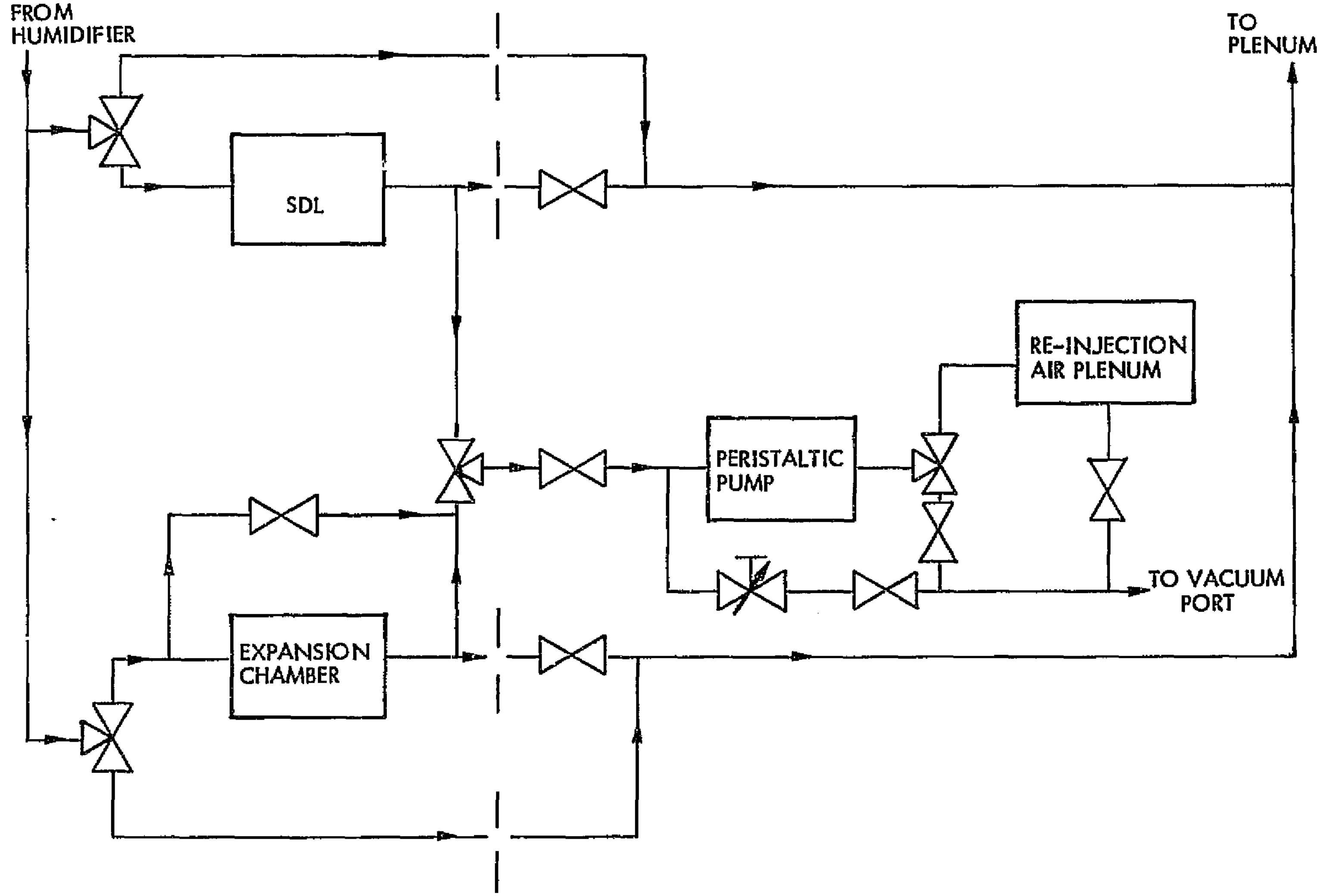
Primary expansion device components are a peristaltic pump and a manual metering valve, each of which will be connected to the small experiment vacuum port. The metering valve will be used to provide a slow bleed to the desired initial pressure in the expansion chamber. For slow expansions, the peristaltic pump (variable speed) will be computer-controlled to give the desired pressure/time excursion. A small tank is being shown downstream of the pump in the present concept to provide for reinjection if desired. For rapid expansion, it would be possible to use the metering valve and the peristaltic pump in parallel to provide the desired pressure curve. Anticipated flow rate through the expansion device will be less than 30 cm^3/sec., which is only a very small fraction of the vacuum port capacity.

C.2

EXPANSION MECHANISM SCHEMATIC



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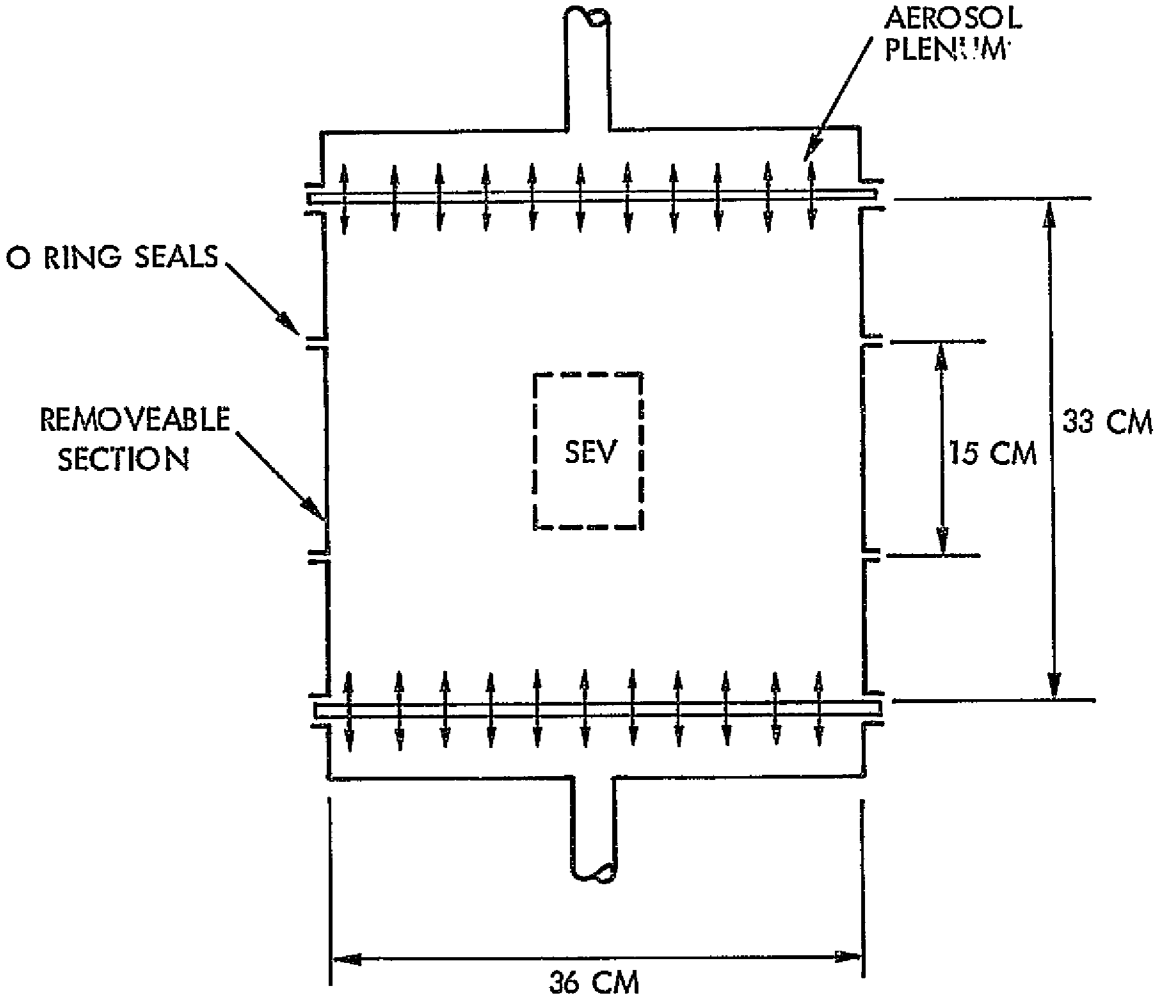
Shown schematically is the chamber geometry selected. The configuration selected has the following features:

- side illumination and viewing
- removable center section to meet a variety of experimental needs
- "O" ring seals for ease of disassembly
- multiple port sample introduction
- exhaust through both ends of the chamber
- counterflow fluid passages.

EXPANSION CHAMBER OVERALL CONFIGURATION



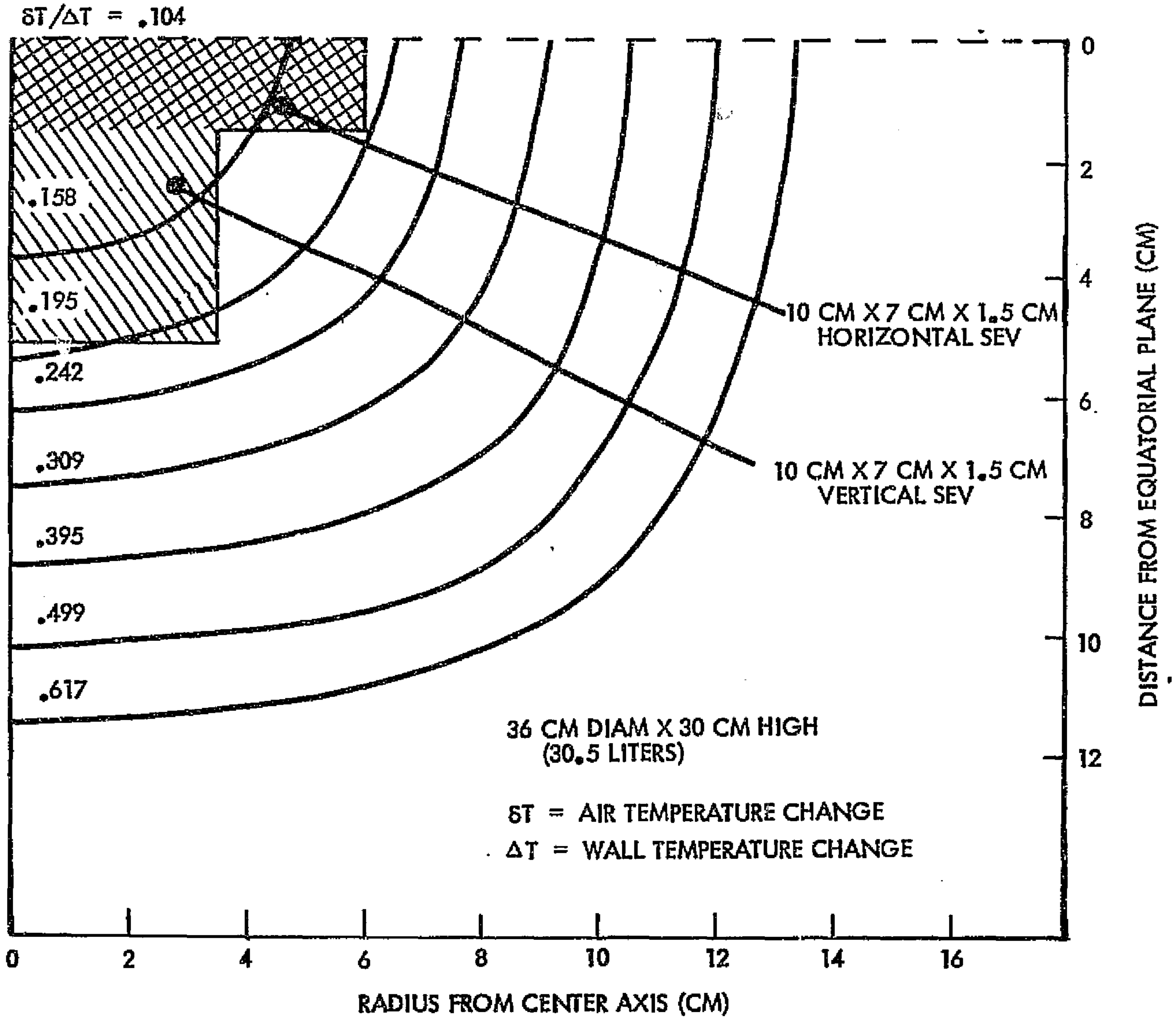
Primary considerations associated with selection of the Expansion Chamber configuration are summarized in the table on the facing page. Selected for preliminary design is the 36 cm diameter x 33 cm high geometry (∿14" diameter x 12" high).

COMPARISON OF EXPANSION CHAMBER GEOMETRY

	30 CM D X 46 CM	46 CM D X 30 CM	36 CM D X 30 CM
VOLUME (LITERS)	32.5	49.9	30.5
SURFACE AREA (CM^2)	5749	7659	5429
VOLUME AREA (CM)	5.65	6.52	5.62
$(\delta T/\Delta T)_{\text{℄}}$ AT 104 SECONDS	.158	.058	.104
$(\delta T_{SEV}/\Delta T)_{MAX}$ AT 104 SECONDS			
HORIZONTAL SEV	.084	.054	.090
VERTICAL SEV	.012	.086	.110
FLUSHING VOLUME FLOW (LITERS/SEC) (1 CM/SEC VELOCITY)	.707	1.662	1.018
ESTIMATED STILLING TIME (MIN) (0.01 CM/SEC)	9.8	23.0	14.1

Air temperature gradients due to our error in the Expansion Chamber wall temperature are shown for 104 seconds after initiation of the error. A flat (horizontal) SEV is compared to a vertical SEV.

AIR TEMPERATURE GRADIENTS IN FINITE CYLINDER AT 104 SECONDS



Those science "drivers" which have a large influence on the Expansion Chamber Subsystem are noted on the facing page.

EXPANSION CHAMBER
KEY SCIENCE "DRIVERS"

INITIAL PRESSURES DOWN TO 400 MB

CERTIFICATION OF RESIDUAL VELOCITIES (AFTER STILLING)

6°C /MINUTE MAXIMUM COOLING RATE

TEMPERATURE UNIFORMITY IN SEV

- .001°C FOR 100 SECONDS
- .010°C AFTER

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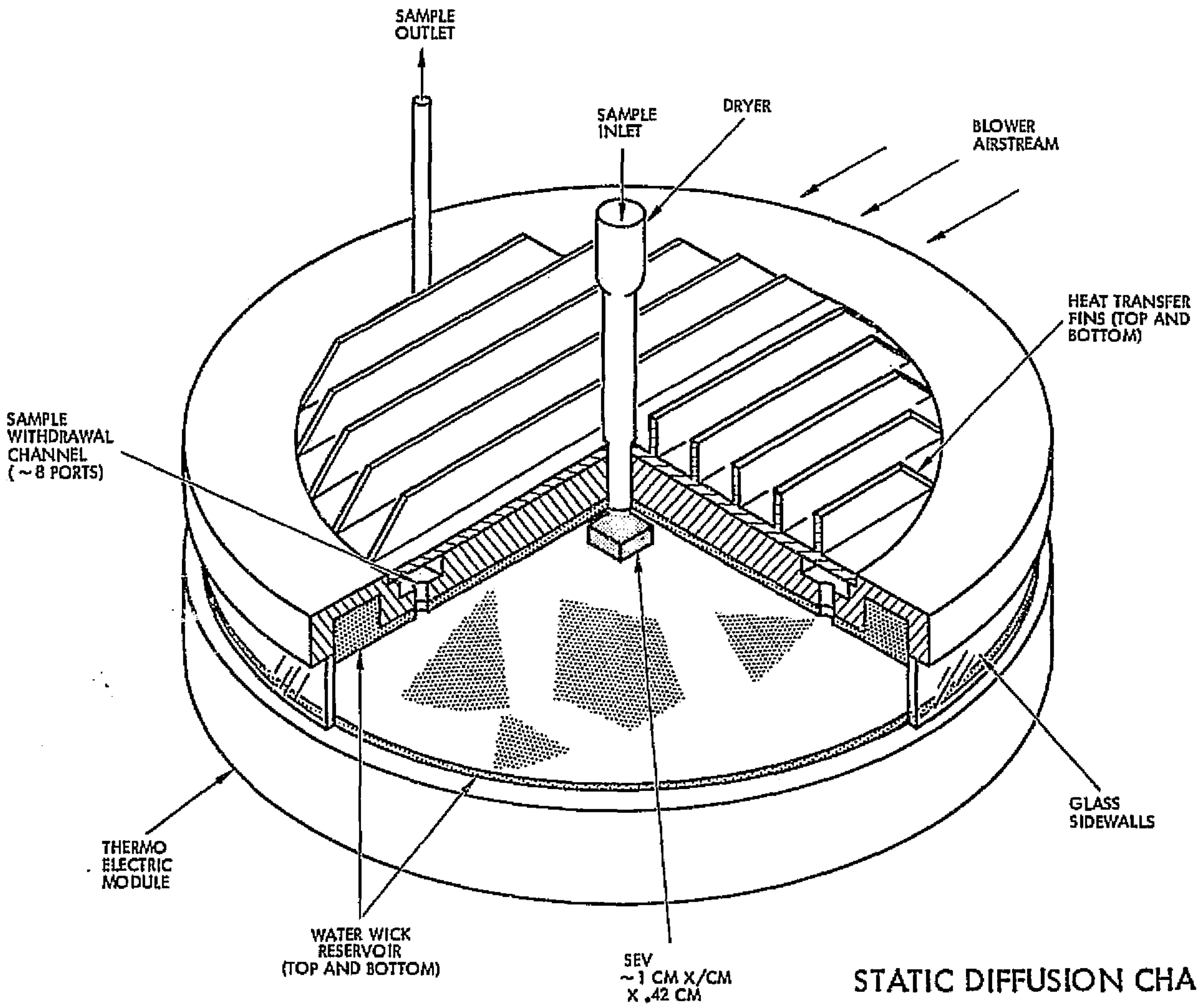
STATIC DIFFUSION CHAMBER (SDL)

- PROVIDE KNOWN SUPERSATURATION TO ACTIVATE CONDENSATION NUCLEI AND GROW RESULTING DROPLETS TO OPTICALLY OBSERVABLE SIZE.
- ACT TOGETHER WITH EXPANSION UNIT AS AITKEN COUNTER.

SDL design similar to laboratory designs in current use. Exceptions include a slightly larger aspect ratio (~10:1) to improve uniformity of supersaturation, and fluid reservoirs for the hot and cold plates, storing sufficient water for extended use.



STATIC DIFFUSION CHAMBER (LIQUID) CAPABILITIES

- PROVIDING AN ACCURATE SUPERSATURATION FIELD FOR DROPLET GROWTH STUDIES OR SUPERSATURATION SPECTRUM MEASUREMENTS
- PROVIDING AN AITKEN COUNTER

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SDL engineering requirements are derived from scientific requirements or concerns, as shown in the accompanying table. The most important requirement, controlling the dimensions of the SEV, is optimization of the overall experiment accuracy, defined as the error in the measured cumulative saturation spectrum ($n_c = CS^k$).

SDL ENGINEERING REQUIREMENTS

	SCIENCE REQUIREMENTS CONTROLLING DESIGN	ENGINEERING REQUIREMENTS	
1.	RAPID RESPONSE TIME FOR EQUILIBRATION OF SUPERSATURATION	CHAMBER HEIGHT $H \lesssim 1.5$ cm	
2.	OPTIMIZATION OF ERROR IN CUMULATIVE SUPERSATURATION SPECTRUM	CHAMBER HEIGHT	$H \simeq 1.5$ cm
		CHAMBER DIAMETER	$D \gtrsim 10H = 15$ cm
		SEV HEIGHT	$h \simeq .42$ cm
		SEV LENGTH	$l \simeq 1$ cm
		SEV WIDTH	$w \simeq 1$ cm
		UNIFORMITY OF ΔT	± .01°C
		STABILITY OF ΔT	± 04°C
		MINIMUM DETECTABLE PARTICLE DIAMETER	$r_{min} \simeq 4 \times 10^{-4}$ cm
3.	AVOIDANCE OF TRANSIENT SUPERSATURATION	DRYER IN SAMPLE INLET LINE	
4.	VARIATION OF SUPERSATURATION CONSISTENT WITH SPECTROMETER	ΔT ~ 16°C IN LESS THAN 10 MINUTES	

Preliminary analyses or trade studies shown in the accompanying table have been completed.

ANALYSES AND TRADE STUDIES

1. ESTIMATE OF OPTIMUM SEV DIMENSIONS
2. SELECTION OF ΔT VARIATION REQUIREMENT
3. MINIMUM DETECTABLE PARTICLE SIZE VS POWER TRADE-OFF
4. STILLING TIME FOR SAMPLE INJECTION
5. RESIDENCE TIMES FOR PARTICLES IN SEV
6. PRELIMINARY ERROR ANALYSIS

The optimum dimensions of the SEV are determined from consideration of the error in $n_c = CS^k$. An analysis of the error in S resulting from SDL side wall effects due to finite chamber aspect ratio is summarized on the facing page. The analysis was carried out at a fixed radius ($r \sim .6$ cm). Results suggest that the radius could be increased somewhat, but not greatly without introducing serious supersaturation errors. For this reason we have selected a 1 cm square ($h = 1 = 1$ cm $r_{max} \sim .7$ cm) SEV volume for preliminary optical design. Optical considerations (i.e., camera focal depth aperture size tradeoffs) also suggest that 1 cm is a reasonable upper bound on the size of the SEV.

ESTIMATE OF OPTIMUM SEV DIMENSIONS

S	$\frac{\delta S}{S_{\circ}}$
.01	9 %
. 1	3 %
1	1 %
10	.3 %

- WITH AN ASPECT RATIO $\left(\frac{D}{H}\right) \sim 10$, THE ERROR IN SUPERSATURATION AT A RADIUS OF 0.6 cm WILL BE

- THIS SUGGESTS THAT SEV WIDTH (w) AND LENGTH (l) BE APPROXIMATELY 1 cm EACH.

Preliminary selection of optimum SEV height (h) has been based on a direct consideration of errors in $n_c = CS^k$. The two error sources which depend directly on h are the statistical counting error and the effective error in n_c due to the variation in S across the SEV. These two error sources were summed and the sum minimized to find the optimum h. Note that h_{opt} is a weak function of dimensions l and w.

ESTIMATE OF OPTIMUM SEV DIMENSIONS (CONT.)

- HEIGHT (h) OF SEV CHOSEN TO MINIMIZE ERROR IN MEASUREMENT OF $n_c = CS^k$.

STATISTICAL COUNTING ERROR

$$\frac{\delta n_c}{n_c} = + \frac{1}{\sqrt{nNwlh}}$$

SUPERSATURATION ERROR DUE TO FINITE h

$$\frac{\delta n_c}{n_c} = - \frac{1}{3} k \frac{h^2}{H^2}$$

OPTIMUM h TO MINIMIZE SUM

$$h_{opt} = \left(\frac{9}{16} \frac{H^4}{Nnlwk^2} \right)^{1/5}$$

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SEV height (h) cannot be varied to minimize the error under all conditions. The dimension h we have selected gives minimum error for the conditions shown on the facing page.

ESTIMATE OF OPTIMUM SEV DIMENSIONS

- h MUST BE FIXED, CANNOT BE OPTIMIZED FOR DIFFERENT n, k, N
- h CHOSEN TO BE OPTIMUM FOR:

$$\left.\begin{array}{lcl} N & = & 6 \\ k & = & 1 \\ n & = & 33.3/CM^3 \\ S_c & = & .1\% \end{array}\right\} \text{ OR } \left\{\begin{array}{lcl} N & = & 6 \\ k & = & 1/2 \\ n & = & 144/CM^3 \\ S_c & = & .06\% \end{array}\right.$$

- $h_{opt} \sim .42$ CM

Results of other analyses and trade studies are shown on the facing page. ΔT variation is selected to make the resulting error in $n_c = CS^k$ small compared with the total error due to all error sources. The minimum detectable particle diameter -- power tradeoff is summarized in the optical subsystem section. The minimum particle size requirement for zero-g operation is really bounded only by the residence time available for particle growth, which can be extremely long. Stilling time estimates made by TRW aged substantially with analyses made elsewhere, indicating very short times to still the residual sample injection velocities to acceptable levels. Estimates of particle residence times in the SEV show very long times available for particle growth .

ANALYSES AND TRADE STUDIES (CONT.)

- SELECTION OF ΔT VARIATION REQUIREMENT
  $\Delta T \sim \pm .05°C$
- MINIMUM DETECTABLE PARTICLE SIZE/POWER TRADE-OFF
  RESULTS PRESENTED IN OPTICAL SUBSYSTEM SECTION
- STILLING TIME FOR SAMPLE INJECTION
  <1 SEC
- PARTICLE RESIDENCE TIMES IN SEV DUE TO PHORETIC FORCES AND BROWNIAN MOTION:

PHORESIS:

S	t
10%	22 SEC
1	110
.1	440
.01	1500

BROWNIAN MOTION:

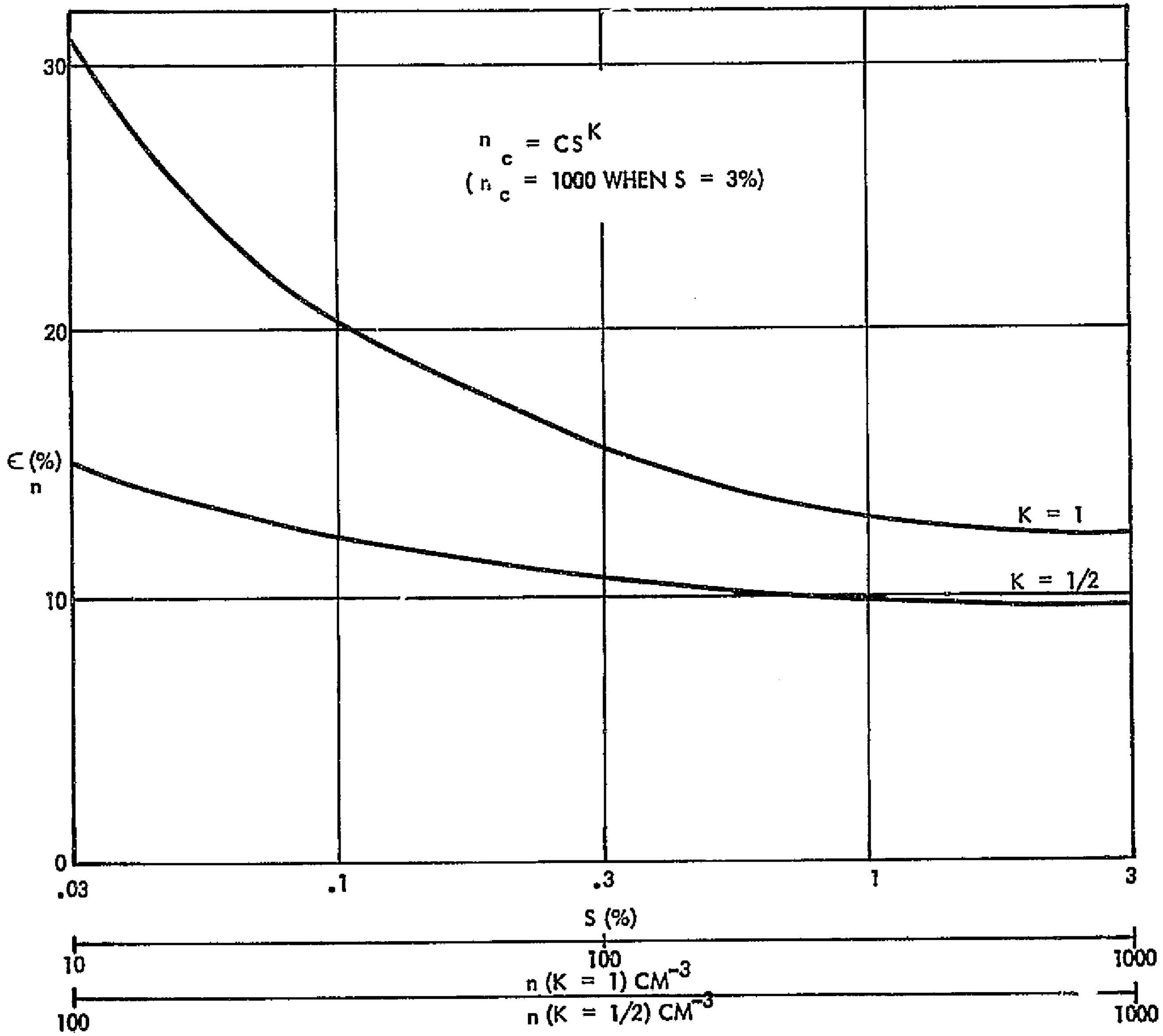
r	t
0.1μ	100 SEC
.1	1100
1	1.9×10^5

The preliminary error analysis shown here includes the following error sources:

- Statistical counting error (random)
- Temperature control error (ΔT, random)
- Error due to S variation with h (systematic)
- Error due to mean temperature variation (systematic)
- Error due to uncertainty in definition of SEV (systematic)

The error analysis does not include errors caused by depletion of the water vapor due to particle growth.

PRELIMINARY ERROR ANALYSIS



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OPTICAL AND IMAGING

DETERMINES DROPLET DENSITY IN BOTH THE EXPANSION AND SDL CHAMBERS.

Droplets within both the Expansion Chamber and the Static Diffusion Liquid Chamber (SDL) are to be recorded photographically. For the Expansion Chamber, the volume which must be photographed is determined by the droplet and ice crystal densities (p) and the required accuracy for measurement of particle density ($\delta p/p$). The error in particle density is related to the recorded number of particle (N) and the error in photographed volume by the following expression;

$$\frac{\delta p}{p} \simeq \sqrt{\left(\frac{\delta W}{N}\right)^2 + \left(\frac{\delta V}{V}\right)^2}$$

where $\delta N/N = 1/N$. The requirement for a 3% water droplet density accuracy leads to a recorded value size choice of 100 cm^3. A 1000 cm^3 volume is required to record the ice crystal density to 10% accuracy.

The error in recorded value is determined by the width of the illuminating beam (Δq) and the total member of particles recorded;

$$\frac{\delta p}{p} = \sqrt{\frac{1}{N} + \left[\frac{\delta(\Delta q)}{\Delta q}\right]^2}$$

N	$1/\sqrt{N}$
10	0.316
100	0.10
1,000	0.0316
10,000	0.01
100,000	0.003

Particle density accuracy for the SDL was not specified; however, preliminary estimates at TRW lead to the choice of a (1 x 1 x 0.42 cm) SDL volume as optimum.

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OPTICAL AND IMAGING SUBSYSTEM REQUIREMENTS

SCIENTIFIC REQUIREMENTS									ENGINEERING CONSEQUENCES							
APPARATUS	PARTICLE TYPE	MINIMUM RECORDED DIAMETER (MICRONS)	FRAME RATE FRAMES/SEC	NUMBER OF FRAMES FRAMES	PARTICLE DENSITY RANGE (N) PART/CM^3	ACCURACY $\frac{\delta N}{N}$ PERCENT	FORBIDDEN WAVELENGTHS		SIZE CM^3	DEPTH q CM	WIDTH (W) CM	HEIGHT (h) CM	35 MM FILM FORMAT PERCENT	NUMBER RECORDED #	COUNTING ERROR (PER PICTURE) PERCENT	MAXIMUM VOLUME ERROR
							IR	UV								
EXPANSION CHAMBER	WATER DROPS	4μ 4μ 10μ	0.1/SEC 1/SEC 10/SEC	100 50 ~20	10^2-10^3	3%	√	√	100	1.5	7	10.0	100%	10^4-10^5	1 - 0.3%	2.8 - 3.0%
	ICE XTALS	20μ	0.1/SEC 1/SEC 10/SEC	100 50 ~20	0.1-1	10%	√	√	1000	2.0	19	27	100%	10^2-10^3	10 - 3%	0 - 10%
SDL	WATER DROPS	2μ	1/SEC	N.S.	10^2-10^3	16 - 7% (NS)	NS		0.42	1.0	1.0	0.42	61%	42-420	15 - 5%	5% (N.S.)

N.S.; "NOT SPECIFIED"

TRW

Analytical expressions have been derived for the minimum particle sizes which can be recorded by the combination of a camera and a thermal xenon flashlamp. For the Expansion Chamber the output of a linear flashlamp is focused into the interior of the chamber by a cylinder lens. For the SDL a conventional lens is used.

The equations were used to predict the minimum particle sizes which could be recorded in terms of the volume error, flash duration, camera focal depth, and width of the recorded volume. The focal depth was made equal to the thickness of the illumination beam. The uncertainty in the recorded volume is due to the focusing of the thermal light source into the interior of the chamber, and the fact that as one moves away from this image, the boundaries become uncertain due to penumbra effects.

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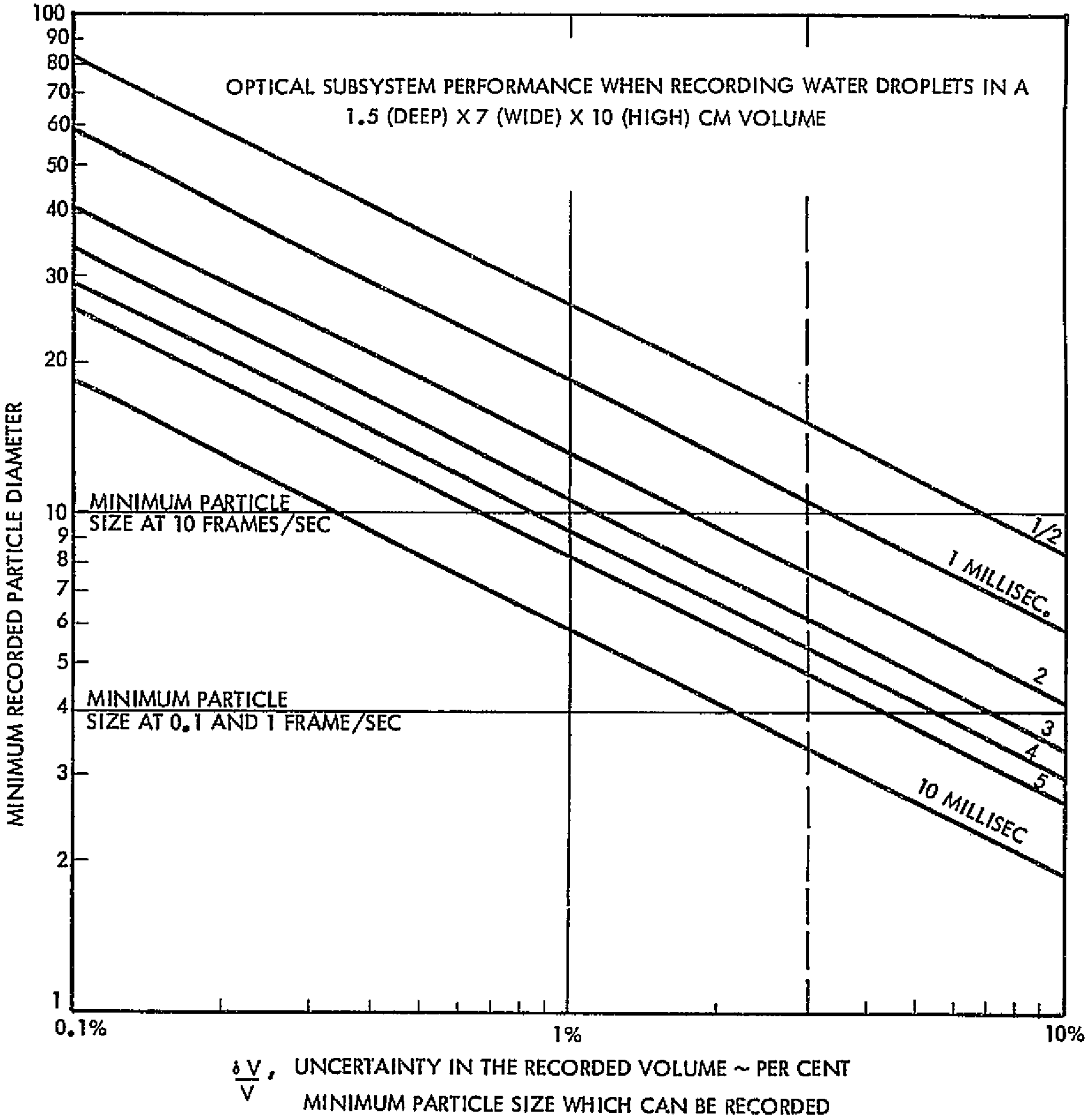
OPTICAL AND IMAGING SUBSYSTEM

TYPICAL ANALYSIS AND TRADES

APPARATUS	SCIENTIFIC REQUIREMENTS			ANALYTICAL RESULTS					ELECTRICAL NEEDS			
						CAMERA LENS					AVERAGE ELECT POWER	
	PARTICLE TYPE	MINIMUM RECORDED SIZE (RADIUS) MICRONS	FRAME RATE	FORMAT W (WIDTH) CM	SIZE H (HEIGHT) CM	Δq (FOCAL DEPTH) CM	FOCAL LENGTH MM	DISTANCE FROM CHAMB. CENTER CM	FLASH DURATION MILLISECONDS	ELECTRICAL ENERGY PER FLASH JOULES	REACTIVE CHARGING WATTS	RESISTIVE CHARGING
EXPANSION CHAMBER	WATER DROPLETS	2µ	0.1/SEC	7	10	1.5	47	18	7	26	4	5
		2µ	1/SEC						7	26	40	50
		5µ	10/SEC						1	4	65	80
	ICE XTALS	10µ	0.1/SEC	19	27	2.0	21	18	2	7	0.7	1.5
			1/SEC						2	7	7	14
			10/SEC						2	7	70	140
SDL	WATER DROPLETS	2µ	1/SEC	1.0	0.42	1.0	62	8	3	6	6	12

Functional dependence of the minimum recorded particle diameter versus volume accuracy, for the Expansion Chamber, is shown in the attached graph. Minimum particle size is determined by the flashlamp duration.

EXPANSION CHAMBER OPTICAL PERFORMANCE



MINIMUM PARTICLE SIZE WHICH CAN BE RECORDED
WITHIN A 7 CM WIDE VOLUME INSIDE THE EXPANSION
CHAMBER WHEN ILLUMINATED THROUGH AN 18 CM SIDE WINDOW

TRW

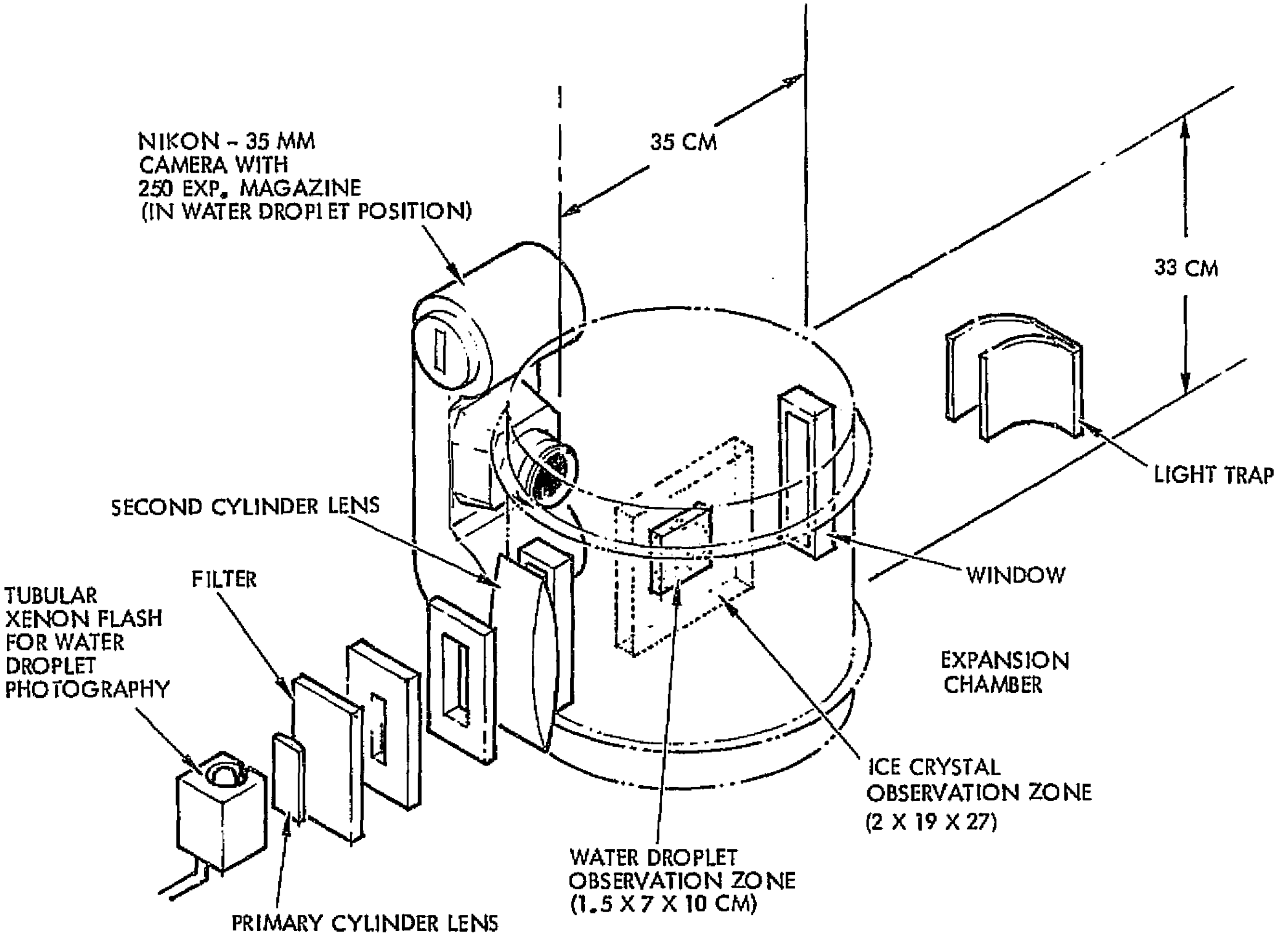
The optical subsystem for the Expansion Chamber is shown in the accompanying drawing. Particles inside the chamber are photographed by their own scattering of light from an external xenon flashlamp illuminator according to whether one is recording water droplets or ice crystals.

The illumination beam is formed into a rectangular pattern by a slit (principal slit) in the side of the lamp housing and by a cylinder lens. A dielectric mirror following the slit reflects IR and visible light back into the flash lamp. Light in the range of 0.6 - 0.4 microns passes in and out of the chamber through 2 x 18 cm windows on either side. Secondary slits shield other extraneous light.

For photographing water droplets, the width of the beam is 1.5 cm. This value or dimension also determines the focal depth (Δq) of the camera, and thus the camera aperture size or the lens f-number. As a result, all illuminated particles form equal in-focus images on the camera film. The width and height of the photographed volume was chosen to be 7 x 10 cm, to yield the required 100 cm^3 volume when recording droplets. The narrow horizontal dimension was chosen to minimize error uncertainty $\delta(\Delta q)/\Delta q$ due to the imaging of the principal slit onto the interior of the chamber.

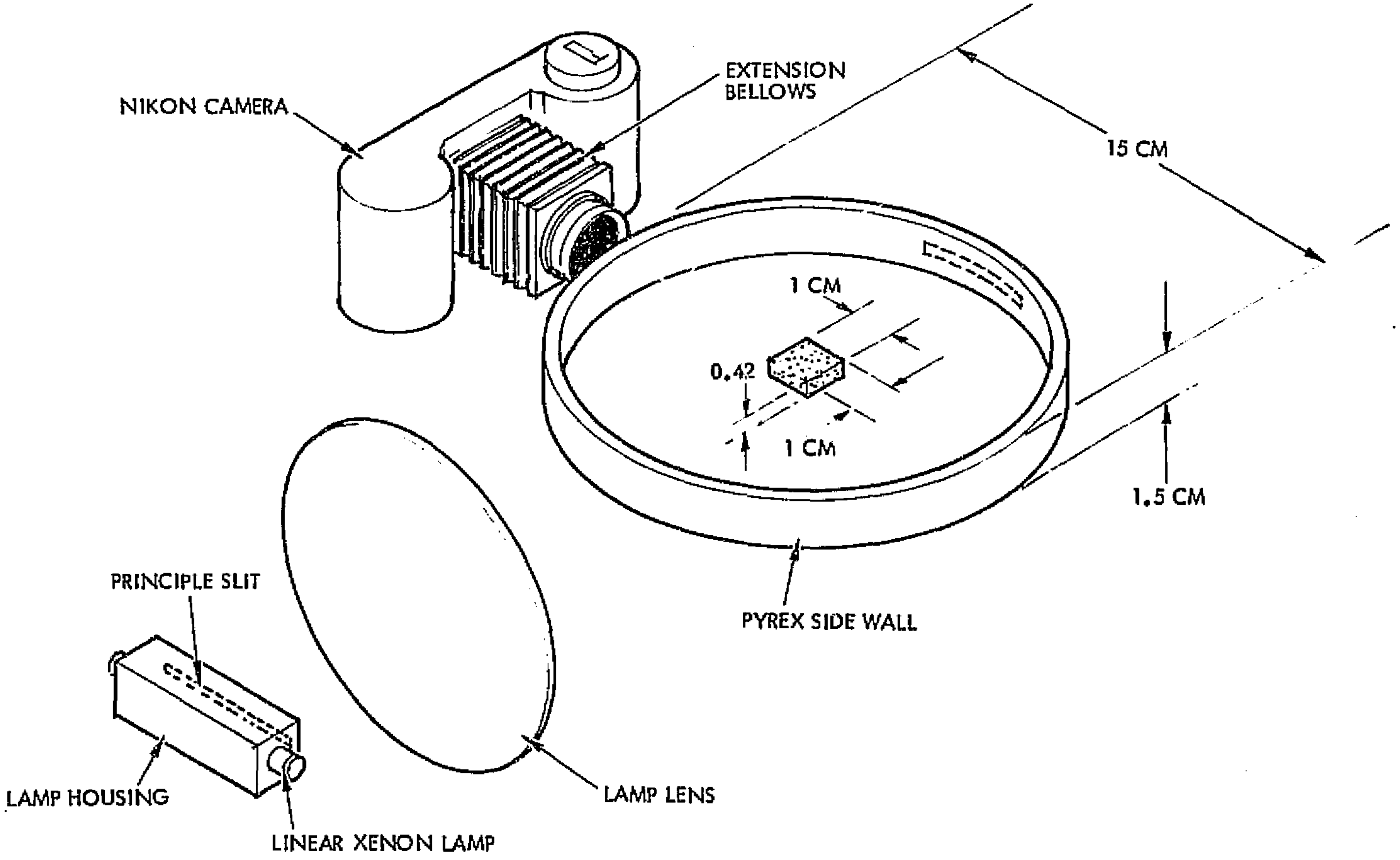
For future ice crystal formation studies, the recorded volume has to increase to 1000 cm to meet the photographically measured particle density. The illuminating beam thickness (Δq) will be increased to 2 cm, while width and height will be 27 x 19 cm, respectively.

EXPANSION CHAMBER OPTICS AND IMAGING APPROACH



The optical subsystem for the SDL is shown in the accompanying drawing. As with the Expansion Chamber, particles inside the SDL chamber are photographed by their own scattering of light from a xenon flashlamp. In this case, the illumination beam is focused into the chamber's interior by a conventional lens. As a result, the minimum particle size is more sensitive to error in the recorded volume due to penumbra effects.

The 1 cm thickness of the illumination beam is made equal to the camera's focal depth so that all illuminated particles form equal in-focus images on the camera film. The 1 cm width and 0.42 cm height were chosen to optimize the particle density measurement.



SDL OPTICS AND IMAGING APPROACH

TRW

Accuracy requirements on the SEV determine the minimum detectable particle size which can be photographically recorded by a thermal flash lamp system.

OPTICAL AND IMAGING KEY SCIENCE DRIVER

ACCURACY REQUIREMENTS OF THE SEV AND

MINIMUM DETECTABLE PARTICLE SIZE

FLUID SUBSYSTEM

PROVIDES:

- AIR SUPPLY TO ALL SUBSYSTEMS
- PRESSURE AND FLOW CONTROL
- HUMIDIFICATION (SEE HUMIDIFIER DISCUSSION)

The most critical part of the fluid system is the section between the humidifier inlet and the inlet to the experimental chambers. Good humidifier performance will be assured through active control of absolute pressure and flow rate at the humidifier inlet. Aerosol losses are to be minimized and condensation avoided downstream of the humidifier through the absence of significant pressure drops between the humidifier and the chambers and through the use of minimum lengths of appropriate diameter tubing.

Particle injection either up- or downstream of the humidifier will be accomplished through use of a calibrated manual control valve pre-set for each run. For aerosol injection downstream of the humidifier, the aerosol flow should not be more than 12% of the flow through the humidifier in order to insure that the relative humidity of the combined stream is known to ±.2%.

FLUID SUBSYSTEM

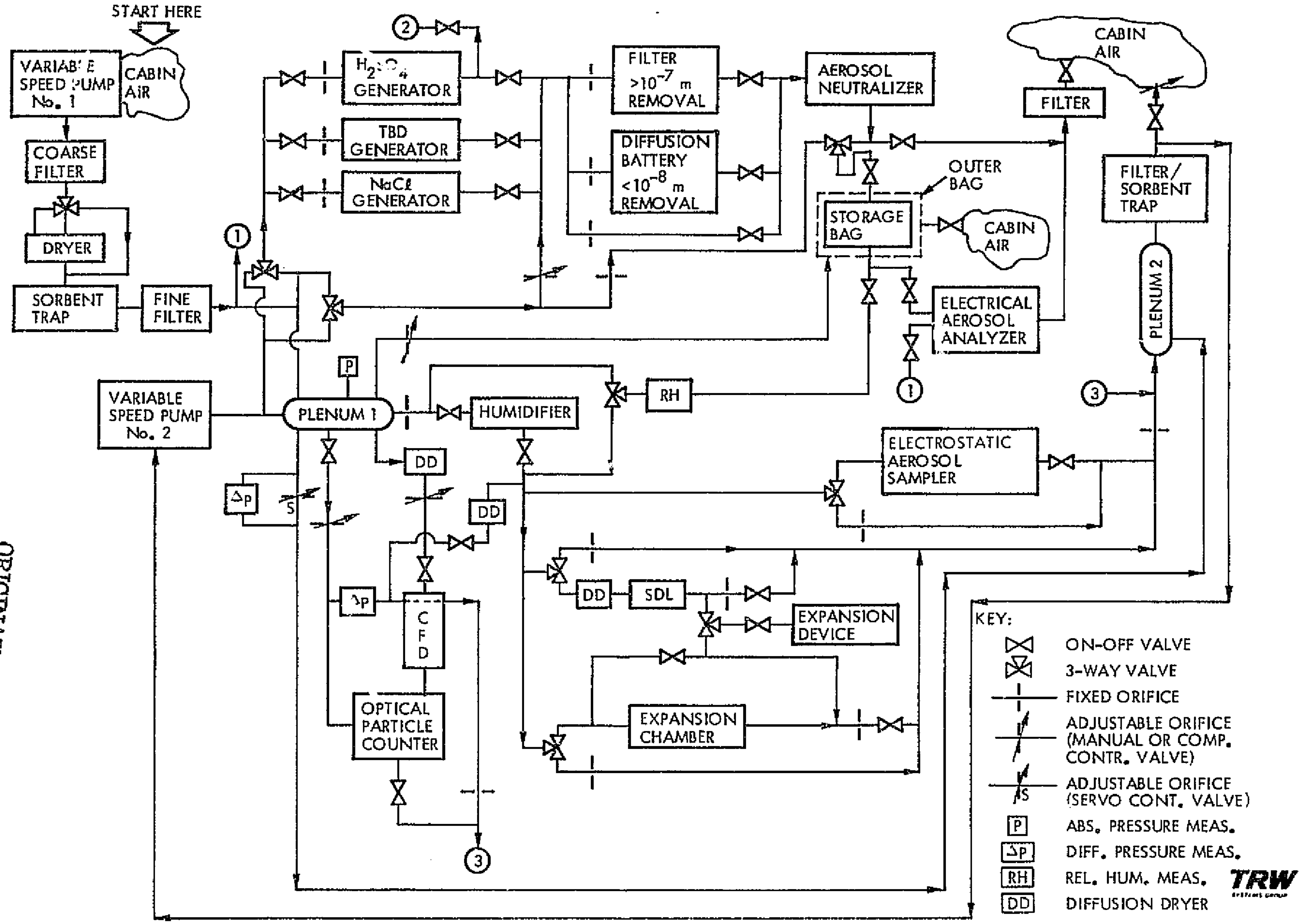
REQUIREMENTS SUMMARY

- THE FLUID SUBSYSTEM IS TO PROVIDE AIR AT THE PROPER FLOW RATE, HUMIDITY, AND PRESSURE TO THE INDIVIDUAL ACPL SYBSYSTEMS
- PRIMARY OPERATIONAL REQUIREMENTS ARE:
  - NOMINAL FLOW RATE OF 10^3 CC/SEC THROUGH HUMIDIFIER
  - PRESSURE STABILITIES OF ± .5 mb IN THE HUMIDIFIER AND ± .01 mb IN ONE SECOND IN THE CFD

The fluid system consists of two main branches -- the particle generation and conditioning section, and the experimental loop. The maximum flow capability through the generator branch is 8×10^{-4} m^3/sec., and through the recirculating experimental loop is 1.4×10^{-3} m^3/sec., of which 10^{-3} m^3/sec. passes through the humidifier. Pressure in the humidifier will be about .2 bar above cabin ambient pressure. In the experimental loop, most of the air will be recirculated to minimize the humidifier load. The recirculation air will also be available to the particle generators. Approximately 2×10^{-4} m^3/sec. of cabin air will be added to the recirculation stream, and a corresponding amount bled back to the cabin downstream of the experiment chambers.

The system has been designed specifically to avoid constrictions and significant pressure drops in all aerosol laden and/or high humidity lines upstream of the experimental chambers. A total of three line sizes is planned to minimize the size of valves and other flow components.

FLUID SUBSYSTEM SCHEMATIC



The fluid system must serve a large number of individual components,which could potentially lead to difficult control problems. Active controls have been held to a minimum, primarily through the use of matching fixed pressure drops accross parallel flow lines. Active controls will be driven by the outputs from pressure transducers, which in this application offer better flow control accuracy than flowmeters. The active elements will be a DC diaphragm pump, which is easily controlled, and flow control valves whose output will need to change by only a few per cent.

FLUID SUBSYSTEM

ANALYSES AND TRADES

ANALYSIS	RESULTS
PRESSURE DROP OPTIMIZATION	HIGH PRESSURE DIFFERENTIAL BETWEEN SYSTEM AND CABIN AMBIENT TO MINIMIZE EFFECT OF CABIN PRESSURE VARIATION; MINIMAL PRESSURE DROPS THROUGH SYSTEM TO KEEP POWER LOW AND AVOID CONDENSATION.
RECIRCULATION	RECIRCULATE MOST OF THE AIR TO THE HUMIDIFIER TO MINIMIZE HUMIDIFIER LOAD; SOME MAKE-UP AIR REQUIRED TO AVOID OVER-HUMIDIFYING STREAM.
CONTROLS	VARIABLE SPEED PUMPS WILL BE USED TO CONTROL TOTAL FLOW. PRESSURE MEASUREMENTS WILL BE USED TO CONTROL ABSOLUTE PRESSURE, PRESSURE STABILITY, AND FLOW RATES TO EXPERIMENTAL CHAMBERS.
HARDWARE SELECTION	SYSTEM IS DESIGNED TO MAKE USE OF COMMERCIAL PUMPS, VALVES, AND INSTRUMENTATION.
STABILITY	PLENUMS (PRESSURE TANKS) WILL BE PROVIDED UPSTREAM AND DOWNSTREAM OF CRITICAL COMPONENTS TO DAMP OUT PRESSURE FLUCTUATIONS AND PROVIDE REQUIRED STABILITY.

The fluid and air cleaning commercial equipment list is shown on the facing page. Specific sources have been identified for each component.

FLUID AND AIR CLEANING SUBSYSTEM

IDENTIFIED COMMERCIAL EQUIPMENT

- PUMPS, AIR - INLET AND RECIRCULATION, DIAPHRAGM
- FILTERS, MEMBRANE - COARSE AND FINE
- SORBENT TRAP, ACTIVATED CHARCOAL
- BULK DRYER, DESICCANT OR MOLECULAR SIEVE
- DIFFUSION DRYER, DESICCANT
- SOLENOID VALVES, TWO AND THREE WAY
- SERVO CONTROLLED METERING VALVE
- PRESSURE TRANSDUCERS, ABSOLUTE AND DIFFERENTIAL
- RELATIVE HUMIDITY SENSOR
- ADJUSTABLE ORIFICES, MANUAL CONTROLLED VALVES
- FIXED ORIFICES

These requirements have the greatest effect on system instrumentation and general system complexity, and are the source of active control requirements.

FLUID SUBSYSTEM

KEY SCIENCE DRIVERS

- PRESSURE STABILITY IN HUMIDIFIER AND CFD
- VARIABLE CARRIER AND SAMPLE FLOW RATES TO CFD
- AEROSOL INJECTION DOWNSTREAM OF HUMIDIFIER

AIR CLEANING SUBSYSTEM

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PROVIDES INLET, EXHAUST, AND IN-LINE GAS CONDITIONING

The air cleaning subsystem appears to be the least complex one in the laboratory. There will be few components, and each of these is expected to be a passive device. Commercially available hardware has been identified for each of the subsystem components.

The air purity check is to be accomplished through use of the UV light source in the H_2SO_4 generator to produce aerosols from vapor in the air, and subsequent use of the SDL as an Aitken counter. The inlet and recirculation streams can be checked independently to help isolate the source of any contamination.

AIR CLEANING SUBSYSTEM

REQUIREMENTS SUMMARY

- CONDITIONED CABIN AIR MUST CONTAIN:
  - LESS THAN .1 PPM CARBON (EXCLUDING CO_2)
  - LESS THAN .1 PARTICLES/CC LARGER THAN .1 μm
  - LESS THAN 100 PARTICLES/CC SMALLER THAN .01 μm
- A CAPABILITY MUST BE PROVIDED TO PERFORM AN IN-ORBIT VERIFICATION OF AIR PURITY
- THE HUMIDITY OF THE AIR DRAWN FROM THE CABIN MUST BE REDUCED FOR LOW DEW POINT EXPERIMENTS
- SUBSYSTEM COMPONENT PRESSURE DROPS MUST BE COMPATIBLE WITH PUMPING CAPABILITIES.

KEY SCIENCE DRIVER

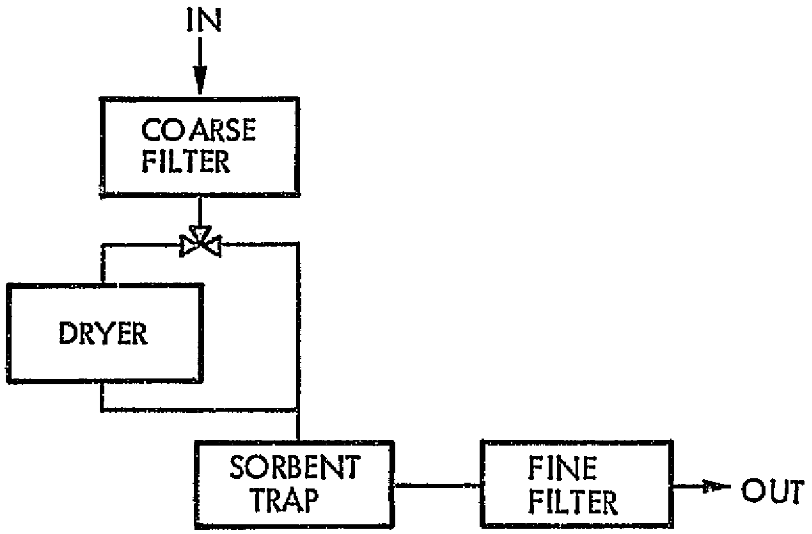
- REQUIREMENT TO VERIFY AIR PURITY.

Standard cartridge-type elements have been found for this application. For gas drying, silica gel or molecular sieve type dryers will be selected, depending upon the extent of drying required. High surface area folded cartridges will be used for particle filtration and activated charcoal (e.g., from peach pits) will be used for vapor removal.

AIR CLEANING SUBSYSTEM

BLOCK DIAGRAM

INLET CONDITIONING:



OTHER COMPONENTS:

- FINE FILTER FOR PARTICLE GENERATOR CABIN EXHAUST
- FINE FILTER/SORBENT TRAP IN RECIRCULATION LINE
- DIFFUSION DRYERS AHEAD OF CFD AND SDL INLETS

AIR PURITY CHECK TO BE PERFORMED BY PASSING INLET AIR AND RECIRCULATION AIR INTO H_2SO_4 GENERATOR, EXPOSING IT TO UV RADIATION, AND INJECTING IT INTO THE SDL TO DETECT THE PRESENCE OF SMALL PARTICLES. ABSENCE OF LARGE PARTICLES CAN BE VERIFIED WITH ELECTRIC AEROSOL ANALYZER OR OPTICAL PARTICLE COUNTER.

THERMAL CONTROL SUBSYSTEM

CAPABILITIES PROVIDED:

- TEMPERATURE CONTROL OF ALL SUBSYSTEMS
- THERMAL INTERFACE BETWEEN ALL SUBSYSTEMS AND SPACELAB HEAT SINKS
- TEMPERATURE MEASUREMENT THROUGHOUT ACPL

The engineering requirements for the thermal control subsystem are determined by those of the critical science subsystems. Stringent temperature uniformity and stability requirements as well as the need for rapid temperature changes in several cases are primary factors influencing the TCS design.

THERMAL CONTROL SUBSYSTEM

TEMPERATURE CONTROL REQUIREMENTS OF KEY COMPONENTS

	HUMIDIFIER	CFD	SDL	EXPANSION CHAMBER	
				SEV	WALLS
TEMPERATURE UNIFORMITY	0.010°C(1)	0.010°C(1)	0.010°C(1)	0.001°C(2) 0.010°C(3)	TBD(2) TBD(3)
TEMPERATURE STABILITY	±0.020°C	±0.010°C	±0.040°C(4)	0.001°C	TBD
RAPID TEMPERATURE CHANGES	NO REQ.	2°C/MIN	NO REQ.	≤6°C/MIN	
TEMPERATURE RANGE	0.5 - 20°C(5) (-25) - 20°C (ICE)	0.5 - 28°C(5)	$(T_{AMB} - 16) - T_{AMB}$ °C	5 - 20°C (INITIAL) (-25) - 20°C (ICE)	

NOTES:

(1) UNIFORMITY REQUIRED IN CRITICAL REGIONS ONLY

(2) REQUIRED AT START AND FIRST 100 SECONDS OF EXPANSION

(3) REQUIRED AFTER FIRST 100 SECONDS OF EXPANSION

(4) STABILITY OF ΔT; LOWER PLATE CONTROLLED W.R.T. UPPER PLATE

(5) MEAN CFD TEMPERATURE MUST BE CLOSE TO SATURATOR TEMPERATURE

A series of analyses and trade studies were performed to establish a Thermal Control Subsystem concept which meets the requirements consistent with available Spacelab resources.

ANALYSES AND TRADE STUDIES: TCS

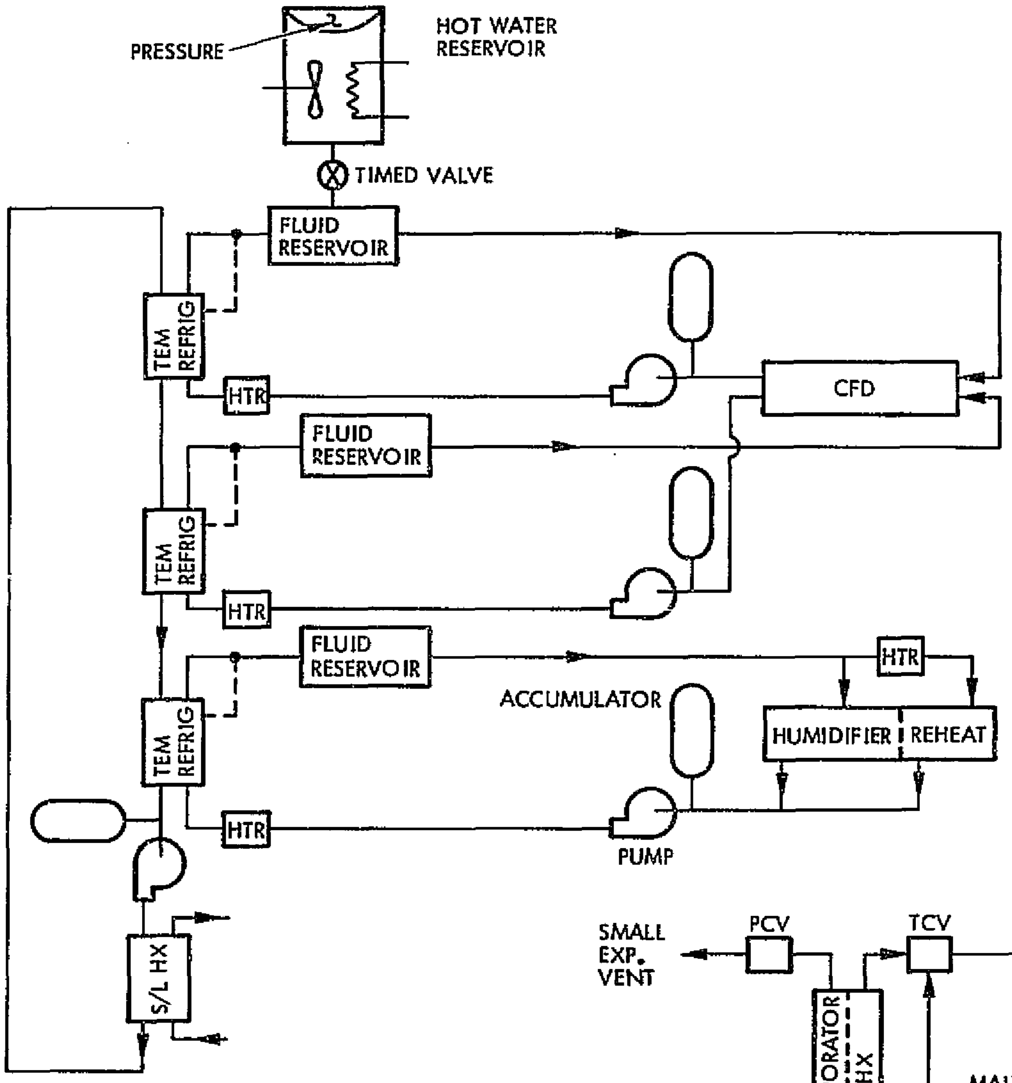
ANALYSIS	RESULTS
THERMAL LOADS OF SUBSYSTEMS	• PRELIMINARY VALUES ESTABLISHED FOR SUBSYSTEM HEAT REJECTION (OR SUPPLY) REQUIREMENTS
ANALYSES OF TEMPERATURE CONTROL REQUIREMENTS AND TECHNIQUES	• PUMPED FLUID LOOPS SELECTED FOR HIGH HEAT LOADS OR VERY PRECISE CONTROL OF LARGE AREAS AS APPROACH WITH MINIMUM RESOURCE REQUIREMENTS • CABIN OR AVIONICS AIR COOLING FOR LESS STRINGENT REQUIREMENTS
EVALUATION OF HEAT TRANSPORT FLUIDS	• WATER IS FLUID OF CHOICE ABOVE 0° C; ETHYLENE GLYCOL-WATER SOLUTION BELOW 0°C.
SEARCH FOR REFRIGERATION SOURCES	• VORTEX TUBES AND AIR CYCLE REFRIGERATORS TOO INEFFICIENT • VAPOR-CYCLE REFRIGERATORS NOT STATE-OF-ART FOR O - G • THERMOELECTRIC HEAT PUMPS SELECTED FOR LOW CAPACITY REQUIREMENTS • EVAPORATIVE HEAT EXCHANGER SELECTED FOR HIGH CAPACITY EXPANSION CHAMBER REQUIREMENT
TRADE STUDIES BETWEEN REFRIGERATOR CAPACITIES, LOOP FLOW RATES, FLUID RESERVOIR SIZES, ETC. IDENTIFICATION OF COMPONENTS.	• ESTIMATES OF RESOURCE REQUIREMENTS

The facing page shows a block diagram of the Thermal Control Subsystem concept. Key features of this concept include:

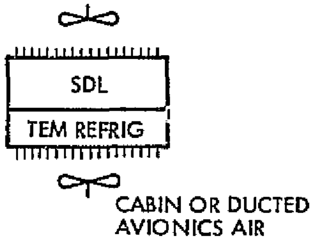
- Thermal control of the Expansion Chamber by controlled mixing of hot and cold streams in a pumped loop. High refrigeration capacity is provided by evaporation of an expendable fluid, supplementing S/L resources.
- Precision temperature control of the CFD and Humidifier with pumped loops incorporating thermoelectric refrigerators. Heat loads are accommodated with S/L Experiment Heat Exchanger.
- Rapid temperature changes in CFD hot plate temperature are provided for with a hot water reservoir in order to time-average the electrical load.

THERMAL CONTROL SUBSYSTEM

CFD AND HUMIDIFIER

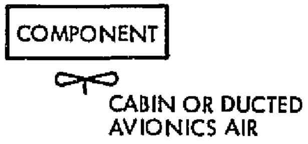


SDL

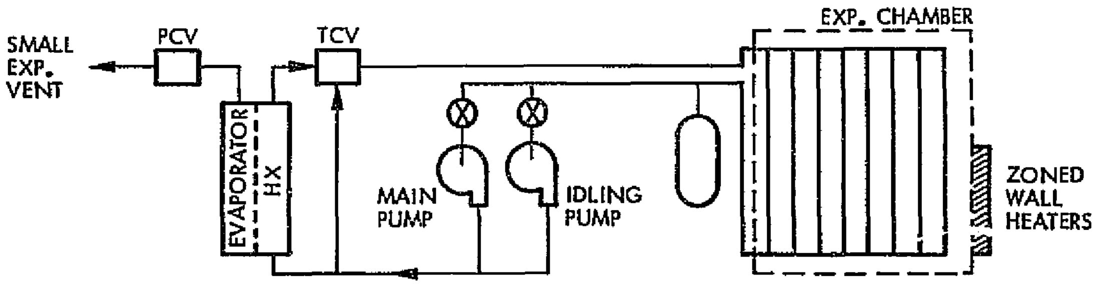


MISCELLANEOUS

- FLASHLAMPS
- PARTICLE GENERATORS
- PUMPS



EXPANSION CHAMBER



The science requirements with greatest engineering and cost impact on the ACPL are 1) the extreme temperature stability needed for critical science subsystems, and 2) the large thermal loads associated with rapid temperature changes in the CFD and Expansion Chamber.

THERMAL CONTROL
KEY SCIENCE DRIVERS

- TEMPERATURE STABILITY REQUIREMENTS FOR KEY COMPONENTS
- PEAK THERMAL LOADS DURING RAPID TEMPERATURE CHANGES

Many of the components needed for the Thermal Control Subsystem are available as commercial hardware. Specific sources have been identified for those listed on the facing page.

THERMAL CONTROL SUBSYSTEM

IDENTIFIED COMMERCIAL EQUIPMENT

- PUMPS, LIQUID
- ACCUMULATORS, BLADDER OR PISTON
- THERMAL CONTROL VALVE AND CONTROLLER
- PRESSURE CONTROL VALVE AND CONTROLLER
- TEM POWER SUPPLY AND CONTROLLER
- SOLENOID VALVES, TIMED CONTROL
- VALVES, MANUAL - ON/OFF AND REGULATING
- TEMPERATURE SENSORS
- HEATERS

CONTROL AND DATA SUBSYSTEM

PROVIDES CONTROL OF FLOW, TEMPERATURE AND PRESSURE THROUGHOUT THE ACPL AND COLLECTS DATA FROM ALL SENSORS. CONTROLS THE ADIABATIC SIMULATION CYCLE IN THE EXPANSION CHAMBER AND THE SUPERSATURATION CONDITIONS IN THE CFD AND SDL.

The engineering requirements for the control and data subsystem are not derived directly from science requirements. Instead, they arise primarily from support requirements for the other subsystems and from operational and interface considerations.

CONTROL AND DATA SUBSYSTEM

SUMMARY OF ENGINEERING REQUIREMENTS

- PROVIDE SUPPORT FOR ACPL SCIENCE SUBSYSTEMS
  - SIGNAL CONDITIONING AND DIGITIZATION FOR SENSORS (PRESSURE, TEMPERATURE, AND FLOW)
  - SERVO CONTROL OF EQUIPMENT (PRESSURE, TEMPERATURE, AND FLOW)
  - DISCRETE CONTROL OF EQUIPMENT (PARTICLE GENERATORS, PARTICLE COUNTERS, CAMERAS, AND FLASH LAMPS)
  - ACQUISITION OF DATA FROM EQUIPMENT (PARTICLE COUNTERS)
- PROVIDE LIMITED, STAND-ALONE, INTERACTION OF CREW WITH ACPL
  - MANUAL CONTROL AND DISPLAY PANEL
- PROVIDE INTERFACE OF ACPL WITH CDMS
  - CONNECTION TO RAU
- IMPLEMENT GENERAL ACPL GUIDELINES
  - EVOLUTIONARY GROWTH CAPABILITY
  - MAXIMUM UTILIZATION OF EXISTING SPACELAB SUBSYSTEM CAPABILITY

The selection of the recommended concept was primarily based on the more general, program considerations . The specific support requirements will be a major consideration in the preliminary design of this subsystem, but do not significantly affect the selection of the concept.

CONTROL AND DATA SUBSYSTEM

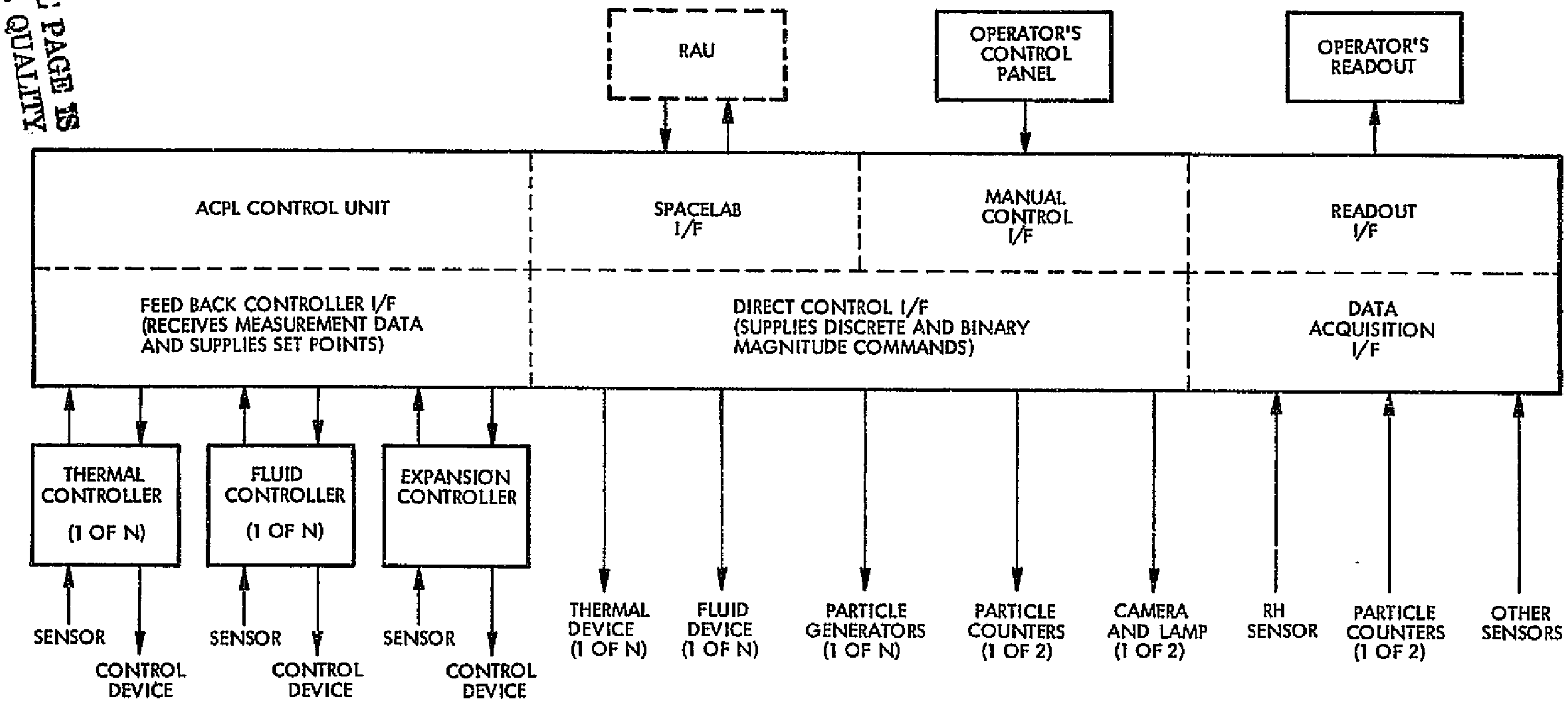
REQUIREMENTS ANALYSIS

- SUPPORT REQUIREMENTS PRIMARILY IMPACT PRELIMINARY DESIGN ACTIVITY (SPECIFIC NUMBERS AND TYPES OF SENSORS, SERVO LOOPS, DISCRETE CONTROL AND DATA ACQUISITION FUNCTIONS REQUIRED)
- BROADER, MORE GENERAL, PROGRAM CONSIDERATIONS ARE MAJOR DRIVERS FOR SELECTION OF CONCEPT
  - MODULAR ELECTRONICS PARTITIONED ON A FUNCTIONAL BASIS FACILITIES EVOLUTIONARY GROWTH
  - DATA BUS ARCHITECTURE FOR MODULE INTERCONNECTS FACILITATES USE WITH MANY DIFFERENT TYPES OF CENTRAL PROCESSOR UNITS
- RECOMMENDED CONCEPT
  - BUILD ALL ACPL ELECTRONICS IN A MODULAR, CPU-INDEPENDENT FORM
  - USE CAMAC AND OTHER COMMERCIALLY AVAILABLE ELECTRONIC MODULES WHERE APPLICABLE; MODIFY AS REQUIRED TO MEET SPACELAB ENVIRONMENT

TRW
SYSTEMS GROUP

The block diagram indicates the major functional elements of the control and data subsystem. These functions will be built in the form of individual modular elements and will communicate by way of a data bus architecture.

CONTROL AND DATA SUBSYSTEM BLOCK DIAGRAM



Pressure and temperature control for the adiabatic expansion process in the Expansion Chamber is one of the key requirements placed on the control and data subsystem. Our recommended concept utilizes the Spacelab experiment computer in a manner similar to the minicomputer control used for the cooled wall Expansion Chamber at the University of Missouri - Rolla.

CONTROL AND DATA SUBSYSTEM

CONTROL OF ADIABATIC EXPANSION

- CONTROL PRESSURE AND WALL TEMPERATURE AS FUNCTION OF TIME AND/OR ACCORDING TO ADIABATIC EXPANSION RELATIONSHIP
- FOUR BASIC APPROACHES TO DETERMINE P AND T SET POINTS
  - INDEPENDENT LINEAR APPROXIMATION
  - STORED TABLES
  - REAL-TIME CALCULATION BASED ON RESULTS OF CLOUD MODEL
  - REAL-TIME CALCULATION USING CLOUD MODEL DIRECTLY
- GREATEST FLEXIBILITY AND LOWEST HARDWARE COST ARISES FROM USE OF SPACELAB EXPERIMENT COMPUTER FOR REAL-TIME CALCULATION
  - CLOUD MODEL COMPUTING REQUIREMENTS TOO EXTENSIVE FOR ON-BOARD USE
  - RESULTS OF OFF-LINE CLOUD MODEL CALCULATIONS USED AT UMR AND RECOMMENDED FOR ACPL

TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

PROVIDES THE STRUCTURAL HARDWARE REQUIRED TO MOUNT THE ACPL COMPONENTS INTO THE SPACELAB DOUBLE RACK AND DISTRIBUTES ELECTRICAL POWER.

The engineering requirements for the console subsystem arise primarily from support requirements for the other subsystems and from interface considerations.

CONSOLE SUBSYSTEM

SUMMARY OF ENGINEERING REQUIREMENTS

- PROVIDE SUPPORT FOR ACPL SCIENCE SUBSYSTEMS AND OTHER SUPPORT SUBSYSTEMS
  - MECHANICAL MOUNTING
  - ELECTRICAL POWER DISTRIBUTION
- PROVIDE INTERFACE OF ACPL WITH SPACELAB
  - STRUCTURE
  - ELECTRICAL POWER AND DISTRIBUTION SUBSYSTEM
- IMPLEMENT GENERAL ACPL GUIDELINES
  - EVOLUTIONARY GROWTH CAPABILITY
  - MAXIMUM UTILIZATION OF EXISTING SPACELAB SUBSYSTEM CAPABILITY

The recommended concept for the console subsystem has been selected to meet a number of operational and interface requirements. Some of the features that meet specific requirements are listed here.

CONSOLE SUBSYSTEM

FEATURES OF RECOMMENDED CONCEPT

- LINE LENGTHS BETWEEN KEY EQUIPMENT MINIMIZED TO REDUCE AEROSOL LOSSES
- EQUIPMENT REQUIRING OBSERVATION (EXPANSION CHAMBER, SDL, OPERATOR PANEL) LOCATED AT EYE LEVEL
- IN ORBIT ACCESS PROVIDED TO COMPONENTS REQUIRING OPERATOR ATTENTION (CAMERAS AND AEROSOL GENERATOR FILAMENT) AND POTENTIALLY REQUIRING MAINTENANCE (ILLUMINATION AND PARTICLE COUNTER LAMPS)
- HEAVIER COMPONENTS LOCATED IN BOTTOM SECTION OF RACK
- SPACE ALLOWED FOR COMPONENT GROWTH, MOUNTING HARDWARE, AND FLUID AND ELECTRICAL ROUTING
- ELECTRICAL POWER INTERFACE USES SPACELAB MISSION DEPENDENT SUBSYSTEM EQUIPMENT

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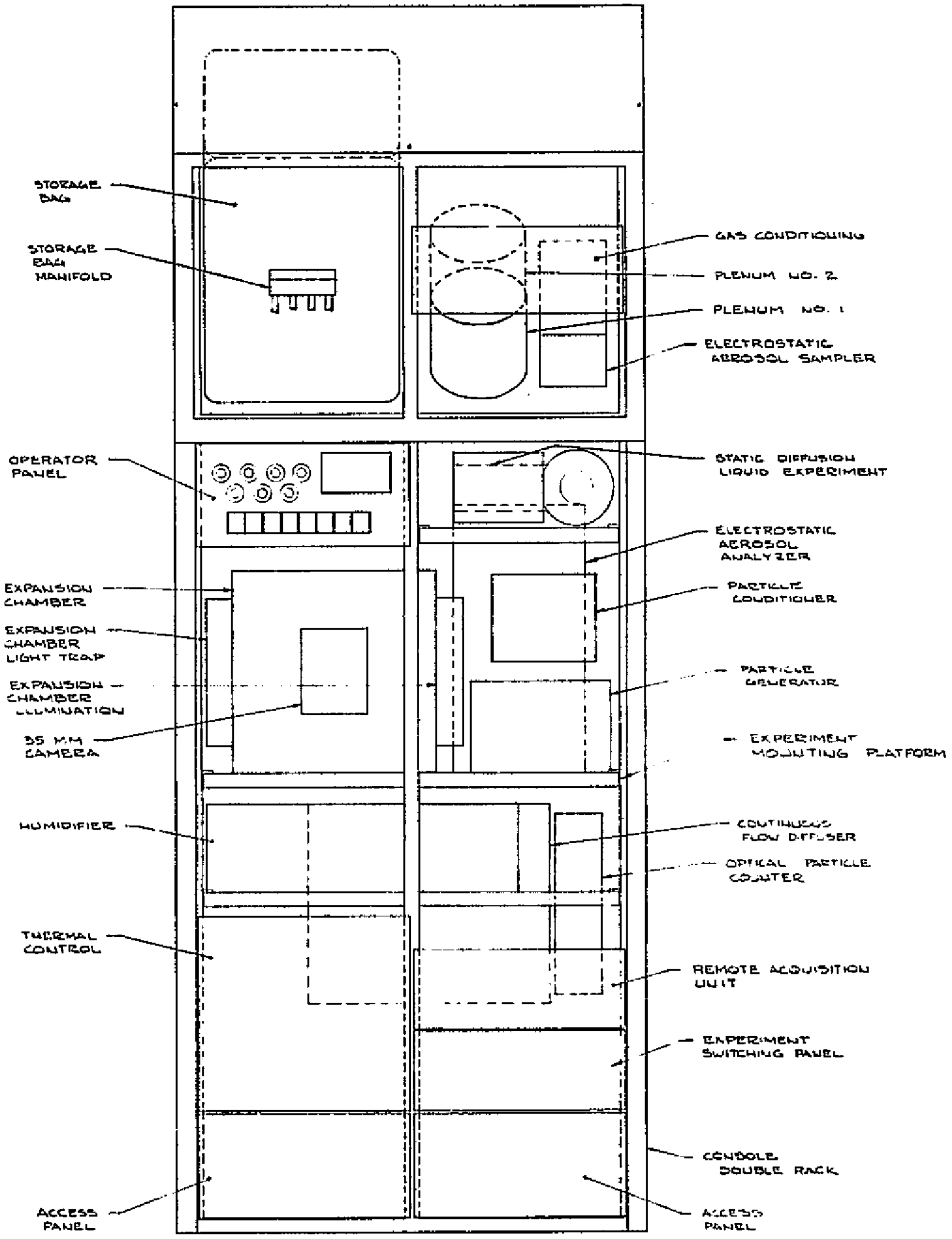
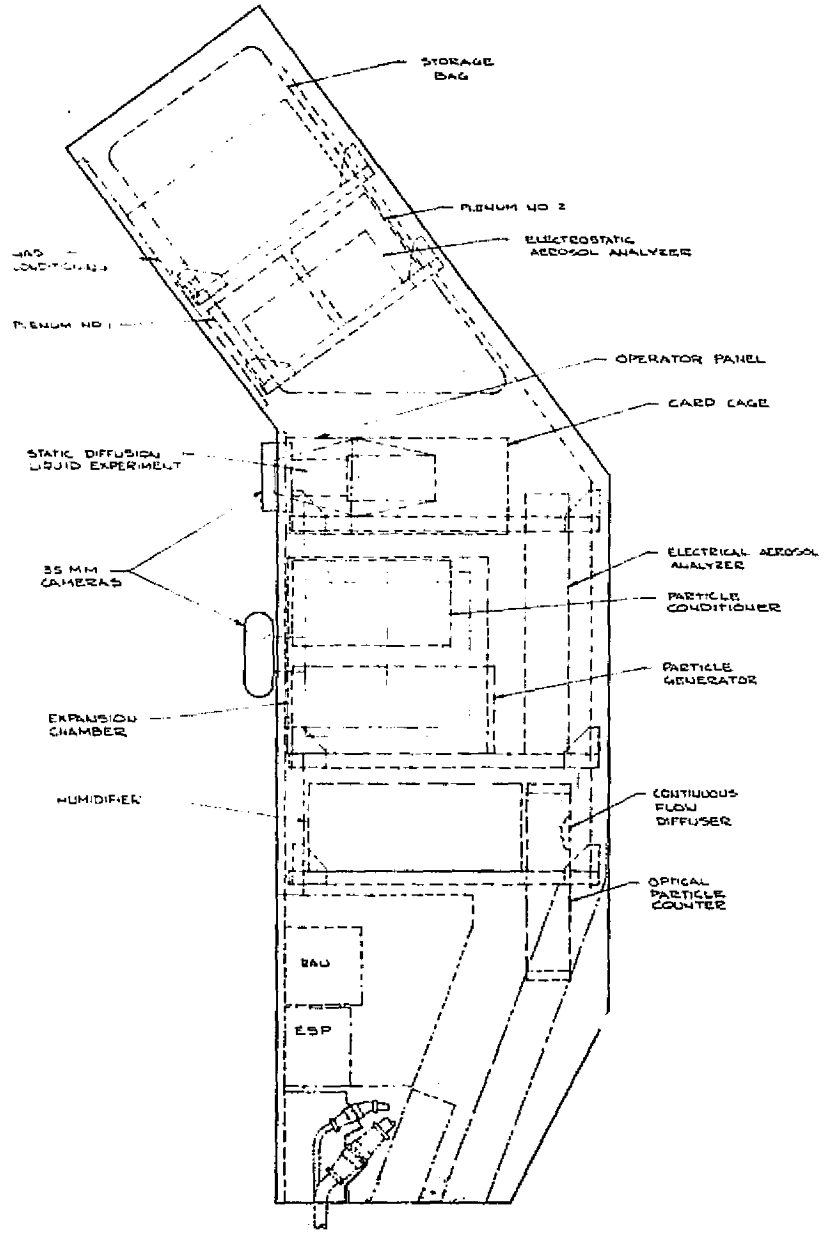
The console subsystem mechanical layout shows the relative locations of the ACPL major equipment items in the Spacelab double rack.

ACPL FRONT VIEW



ACPL SIDE VIEW



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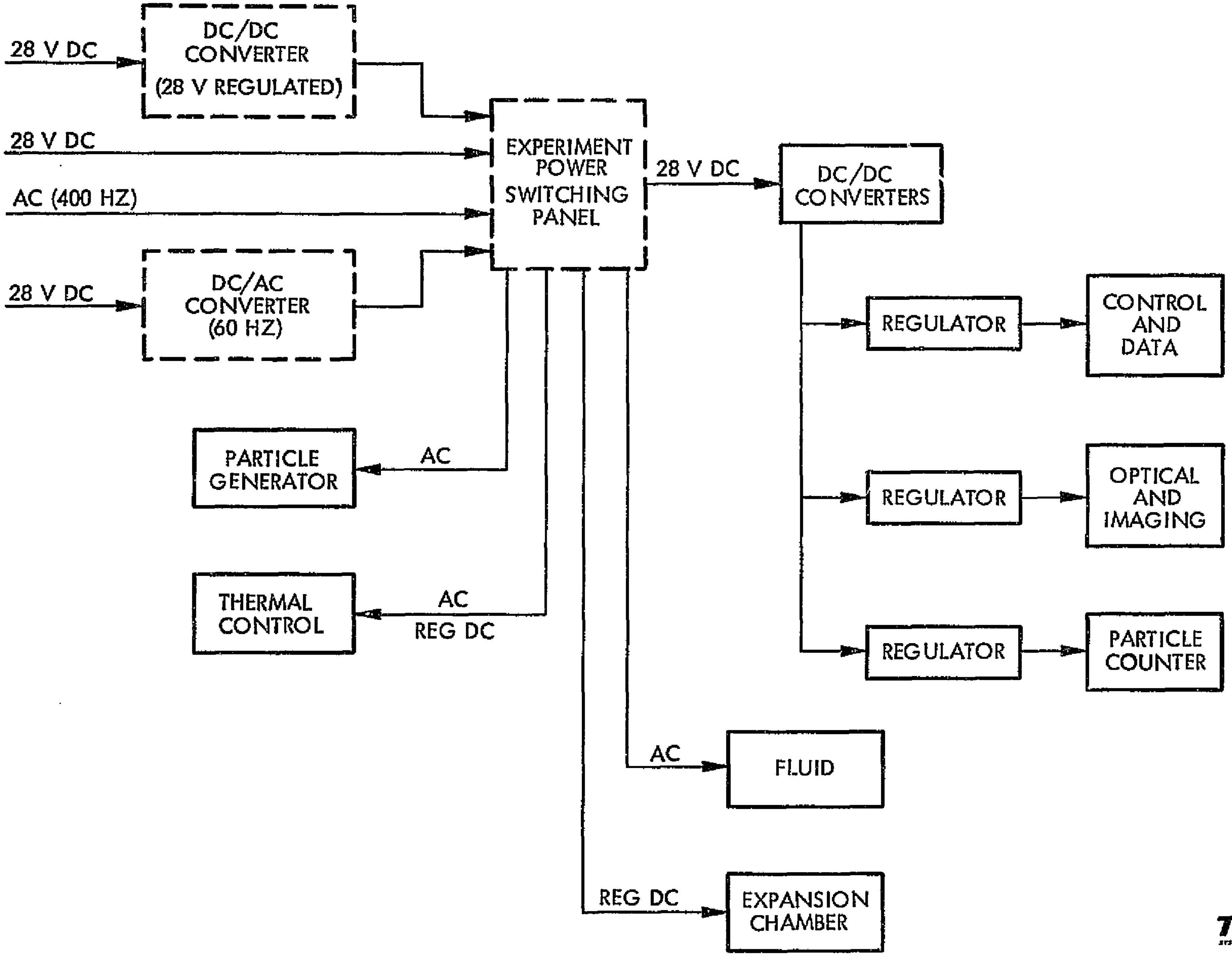
The console subsystem electrical power block diagram depicts the distribution of electrical power from several Spacelab sources (dashed boxes) to various ACPL subsystems .

ELECTRICAL POWER SUBSYSTEM BLOCK DIAGRAM



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SPACELAB INTERFACE

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The interfaces between the ACPL and the Spacelab subsystems are summarized here. For each subsystem, the specific Spacelab elements providing the interface to ACPL are identified. Engineering details of individual interfaces were included in the preceding description of the associated ACPL subsystems.

SPACELAB SUBSYSTEM INTERFACE SUMMARY

- STRUCTURE
    - STANDARD DOUBLE RACK
- ELECTRICAL POWER AND DISTRIBUTION SUBSYSTEM
    - EXPERIMENT POWER SWITCHING PANEL
- ENVIRONMENTAL CONTROL SUBSYSTEM
    - CABIN AIR LOOP
    - AVIONICS AIR LOOP
    - EXPERIMENT HEAT EXCHANGER
    - SMALL EXPERIMENT VENT ASSEMBLY
- COMMAND AND DATA MANAGEMENT SUBSYSTEM
    - REMOTE ACQUISITION UNIT
    - EXPERIMENT COMPUTER
- SOFTWARE
    - CDMS COMPUTER OPERATING SYSTEM
- COMMON PAYLOAD SUPPORT SYSTEM
    - FILM VAULT

The MSFC Low G Study for the Third Spacelab indicates that typical accelerations due to orbital maneuvers and vigorous crew activity are on the order of 10^{-4} G or less. The Study assumes a requirement of 10^{-5} G for ACPL. However, considerations of convective motions in the Expansion Chamber led Squires (Preliminary Notes Concerning a Cloud Forming Experiment in Zero-G) to conclude that accelerations on the order of 10^{-4} G or less would be acceptable.

ACCELERATION LEVELS

ACPL REQUIREMENTS AND SPACELAB ENVIRONMENT

- CONVECTIVE MOTION OF AIR IN EXPANSION CHAMBER SHOULD BE NEGLIGIBLE IF ACCELERATION IS $\sim 10^{-4}$ G OR LESS.
- ORBITAL OPERATIONS, INCLUDING USE OF 25 POUND THRUSTERS, PRODUCE ACCELERATIONS LESS THAN 1.3×10^{-4} G AT DISTANCES OF FOUR METERS OR LESS FROM AXIS OF ROTATION.
- ONLY VIGOROUS CREW MOTIONS, SUCH AS COUGHING, SNEEZING OR ARM FLAPPING, PRODUCE ACCELERATIONS ON THE ORDER OF 10^{-4} G.

Although appropriate packing factors have been included in the allocations for each piece of equipment, the contingency remaining (about 10%) is not large considering the possible estimating errors at this stage of ACPL design. This budget will be carefully monitored during the upcoming preliminary design activities.

ACPL RESOURCE BUDGET

VOLUME (m^3)

1)	FLUID	.174
2)	AIR CLEANING	.360
3)	AEROSOL GENERATOR	.230
4)	AEROSOL COUNTER	.162
5)	CONTINUOUS FLOW DIFFUSION CHAMBER	.033
6)	EXPANSION CHAMBER	.180
7)	STATIC DIFFUSION LIQUID CHAMBER	.013
8)	THERMAL CONTROL	.204
9)	CONTROL AND DATA	.056
10)	OPTICAL AND IMAGING	.012
11)	CONSOLE	.039
	TOTAL	1.463
	DOUBLE RACK LIMITATION	1.6

The mass budget has a comfortable contingency at present. Because the May 1976 Spacelab resource limitations allow a density of about 360 kg/m^3 (22 lb/ft^3), it is likely that the volume budget would become tight before the mass budget.

ACPL RESOURCE BUDGET

MASS (KG)

1)	FLUID	78
2)	AIR CLEANING	16
3)	AEROSOL GENERATOR	16
4)	AEROSOL COUNTER	61
5)	CONTINUOUS FLOW DIFFUSION CHAMBER	25
6)	EXPANSION CHAMBER	33
7)	STATIC DIFFUSION LIQUID CHAMBER	12
8)	THERMAL CONTROL	134
9)	CONTROL AND DATA	25
10)	OPTICAL AND IMAGING	18
11)	CONSOLE	26
	TOTAL	444
	DOUBLE RACK LIMITATION	580

The power requirement for the ACPL looks reasonable compared to the average power available from Spacelab for all payload experiment equipment combined. The peak power in each case includes the standby power. The worst case peak power requirement occurs when the fluid, thermal control and control and data subsystems are operating in a mode that provides maximum cooling to the CFD and humidifier in order to shift their operating temperatures down at the rate of 12°C per hour. All other subsystems can be turned off during this cool down period.

ACPL RESOURCE BUDGET

ELECTRICAL POWER (WATTS)

		STANDBY	PEAK	
1.	FLUID	160	185	
2.	AIR CLEANING	0	0	
3.	AEROSOL GENERATOR	0	16	
4.	AEROSOL COUNTER	0	68	
5.	CONTINUOUS FLOW DIFFUSION CHAMBER	0	0	
6.	EXPANSION CHAMBER	0	80	
7.	STATIC DIFFUSION LIQUID CHAMBER	0	10	
8.	THERMAL CONTROL	176	482	
9.	CONTROL AND DATA	84	84	
10.	OPTICAL AND IMAGING	0	80	
11.	CONSOLE	0	0	
	TOTAL REQUIRED	420	726	WORST CASE
	AVAILABLE FROM SPACELAB	~ 3000		

The thermal load budget is significantly reduced because of the use of an evaporator to cool down the expansion chamber. The evaporator augments the existing Spacelab heat rejection capability by accommodating an 1100-watt peak load that does not appear in this budget.

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ACPL RESOURCE BUDGET

THERMAL LOAD (WATTS)

		STANDBY	PEAK	
1.	FLUID	160	185	
2.	AIR CLEANING	0	0	
3.	AEROSOL GENERATOR	0	16	
4.	AEROSOL COUNTER	0	68	
5.	CONTINUOUS FLOW DIFFUSION CHAMBER	0	0	
6.	EXPANSION CHAMBER	0	80	
7.	STATIC DIFFUSION LIQUID CHAMBER	0	10	
8.	THERMAL CONTROL	176	642	
9.	CONTROL AND DATA	84	84	
10.	OPTICAL AND IMAGING	0	80	
11.	CONSOLE	0	0	
	TOTAL REQUIRED	420	886	WORST CASE
	AVAILABLE FROM SPACELAB	~ 3400		

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WRAPUP

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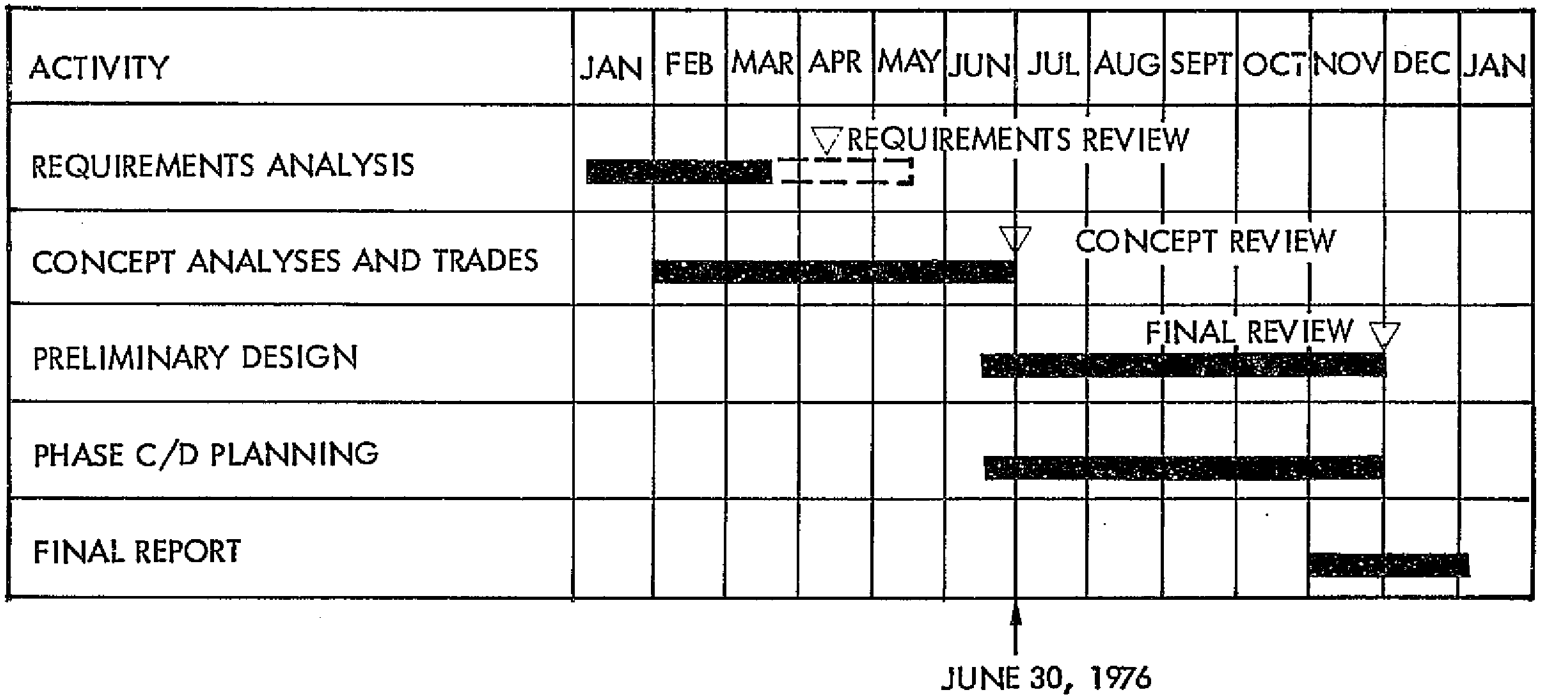
ACPL PROGRAM SCHEDULE



PLANNED ACTIVITIES

- ACPL PRELIMINARY DESIGN
- ACPL FULL SCALE MOCKUP
- PREPARATION OF CEI SPECIFICATIONS AND INTERFACE CONTROL DOCUMENTS
- PHASE C/D PROGRAM PLANNING
- PHASE C/D PROGRAM COSTING

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