NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center

PROJECT PLAN

FOR A
SPACE FLIGHT EXPERIMENT
ENTITLED

INVESTIGATION CONTINUATION OF

CRITICAL VISCOSITY OF XENON (CVX-2)

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I. INTRODUCTION

A. Experiment Justification

Earth-bound measurements on critical fluids are constrained by the compressibility of these special fluids. The divergence of the compressibility as the temperature approaches the critical temperature, T_c , causes the fluid to stratify leaving an ever decreasing layer of fluid at critical density. This limitation has restricted earth-bound measurements to temperatures ~15 mK above the critical temperature. Unfortunately, it is within this final temperature range that the divergence of several interesting physical parameters (such as viscosity, density fluctuations, and heat capacity) occurs at the most intriguing rates. Decreasing the stratification by conducting the experiment in orbit offers the promise of significant improvement of the experimental data in the region of most interest for test of existing theory.

B. Objectives of Flight Experiment

The overall objective of the experiment is to measure the viscosity of a pure fluid (xenon) near its liquid-vapor critical point. The thermodynamic path will be an approach to the critical temperature, T_c = ~16.7°C, on an isochoric path at the critical density from the one phase (vapor) region. The second flight of the experiment will explore the shear rate dependance of the sample at temperatures very near T_c.

A continuous scan of temperature will approach and pass the T_c to enable both precise location of T_c and measurement of viscosity at many temperatures around T_c. The low gravity environment will enable T_c to be approached 100 times closer in reduced temperature than on Earth before stratification begins to diminish the quality of the measurements. A programmable viscomert capability (adjustable in frequencey and amplitude) will permit selective probing of the shear rate dependence at many temperatures in the region of most interest.

To provide data comparable to the best laboratory data, it is required that viscosity be measured with a precision of ~0.2% and the viscosity exponent be determined with an accuracy of 1.0%.

C. Project Implementation

The CVX instrument and payload operated successfully during the first flight and is available for the proposed experimental program. The required modifications are well understood and will be implemented by a small project team centered at the Lewis Research Center, Cleveland, OH and at the National Institute for Science and Technology (NIST), Gaithersburg, MD. The project will be managed by Susan Motil, 6728/Fluids Flight Projects Branch, Microgravity Science Division of the Lewis Research Center with ongoing support from Dr. Richard W. Lauver, 6724/ISS Facility Projects Branch. The science team will include Principal Investigator, Dr. Robert F. Berg, and Co-Investigator, Dr. Michael R. Moldover of NIST with oversight by NASA Project Scientist, Dr. Greg A. Zimmerli, a resident contractor at the National Center for Microgravity Research.

Hardware design and development and operations support will be accomplished by Dynacs Engineering Company, Inc. with James Myers as the contractor task manager. All acceptance testing will be conducted at Lewis. The proposed carrier (Hitch-hiker G or M) is managed by Goddard Space Flight Center (GSFC). Integration with the carrier and final checkouts will occur at GSFC.

Flight operations will occur at the GSFC operations center and will be conducted by a CVX project team of scientists and engineers.

D. Cost and Manpower Requirements

The flight instrument is available and flight worthy. A significant amount of development and laboratory demonstration has occurred during the four months prior to the May 1998 requirements review to address of feasibility issues. This level of hardware readiness and experience is a major factor in keeping the remaining timeline relatively short and the cost estimate relatively low. It is estimated that, from approval to proceed, the project will require approximately 6 to 9 months to modify and ready a tested flight instrument and a total of approximately 2 years (dependent on flight opportunities) to carry the project to completion.

This project will strive to maintain a small, dedicated team to encourage commitment and understanding of project objectives. The maximum estimated personnel requirement at each participating organization is ~1 person for science at NIST, ~3.5 persons at Dynacs for engineering support, 0.5 person for management at LeRC, and ~1.5 persons at LeRC for science, SR&QA and miscellaneous support.

The total cumulative project cost for CVX-1 was $4.19M. This effort spanned approximately 13 years of science preparation and viscometer development prior to flight hardware development and flight operations which spanned approximately 3 years.

The estimated costs to complete the CVX-2 project (from approval to proceed) are approximately $0.54M for hardware development, integration, test, and operations costs, plus $0.10M contingency. This totals approximately $0.64M for projected development and operations costs. Science support ($0.15M) will be separately tracked.

The project team has been challenged during the initial flight development by the science investigators to minimize the hardware costs to produce the required flight data. The project team met the cost goals for CVX-1 and will continually strive to reduce run out costs for CVX-2 where possible.

E. Project Schedule

This flight experiment does not, at this time, have a firm flight manifest. The primary (proposed) mission opportunity is assumed to be on STS-107 which is currently planned for approximately November, 2000. Because the CVX hardware is configured for standard Hitchhiker integration as a secondary payload, we propose to continue to seek earlier flight opportunities which meet the requirements for the experiment (such opportunities may exist in late 1999 and beyond but have not been defined).

The proposed baseline schedule is presented in Section VI (assuming a 7/1/98 start-up). The development effort is planned for approximately 9 months from authority to proceed. This will make the instrument ready for turnover for mission integration in approximately April, 1999. With typical turnover ~3 to 6 months prior to flight on a Hitchhiker carrier, this could provide for a flight as early as August, 1999 if an opportunity were to appear. To accommodate the later flight manifest, we assume low level support (~.3) for up to 3 contractor team members followed by an additional functional test cycle to demonstrate readiness prior to delivery.

The extended history of project activity to this point has produced a substantial experience base and a very mature design which enhances the likelihood for successful modification, test, and operation of the flight instrument. We see no schedular risk to this effort.

II. SCIENCE SUMMARY

A. History and Related Work

The investigation of critical fluids has spanned more than a century and the potential of utilizing a low-gravity environment to extend the measurements was proposed over twenty years ago (J. V. Sengers, "Transport Properties near the Critical Point", Tech. Report 71-074 on ONR Contract N00014-67-A-0239-0014 (1970)). However, the research in both theory and earth-bound measurements on critical fluids did not peak until the decades of 1960-70 and it became obvious that many measurements were limited by the stratification of the sample due to the divergence of the fluid's compressibility and the presence of gravitational loading. The potential and desirability of conducting precision physical measurements of critical fluids in microgravity has been a topic of discussion for more than a decade. A much referenced paper ("Gravity Effects in Fluids Near the Gas-Liquid Critical Point", M. R. Moldover, J. V. Sengers, R. W. Gammon, and R. J. Hocken; Rev. Modern Physics, **51**(1), 1979) described the primary constraints caused by gravitational compression of these very "soft" fluids. The subject experiment evolves from a successful proposal by Moldover in 1983 to the NASA Physics and Chem-istry Experiments (PACE) program which led to a most successful microgravity experiment in August, 1997. A second proposal by R. Gammon led to a microgravity experiment called Zeno (flown 3/94) which measured the turbidity and correlation length of critical xenon by dynamic light scattering. The combined data sets from Zeno and the subject viscometry experiment will enable a desirable test of the mode coupling theory of dynamic critical phenomena.

The measurement of viscosity is particularly limited on Earth because the observed divergence near T_c is not as dramatic as other observable properties (in particular, turbidity) and the volume of fluid typically required to perform a precise measurement is relatively large which makes it more susceptible to the effects of stratification. The most precise measure-ments of the critical exponent of viscosity and the closest approach to T_c have been pro-duced by Berg and Moldover ("Critical Exponent for the Viscosity of Four Binary Liquids", J. Chem. Phys. 89, 3694 (1988) and "Critical Exponent for the Viscosity of Carbon Dioxide and Xenon", Phys. Rev. **A 42**, 7183 (1990)) in preparation for the initial flight experiment. They demonstrated that the previous theoretical value of the critical exponent (y = 0.032) was in error and experimentally deter-mined the exponent ($y = 0.042 \pm 0.002$) for a diverse set of pure fluids and binary mixtures. A unique torsion oscillator viscometer was employed in these measurements to maintain the necessary low frequency (~1 Hz) and low shear rate ($\gamma = 1\ s^{-1}$). The torsion viscometer was determined to be too sensitive to background mechanical noise (g-jitter) to use for the flight experiment and subsequently a more robust, moving screen viscometer was developed. The new viscometer has been demonstrated to be less sensitive to background vibration and adequately robust to survive qualification-level test vibrations. The successful micro-gravity experiment (CVX-1) confirmed the sensitivity and precision of the viscometer and ex-tended the viscosity measurements to reduced temperatures near 10^{-7} as planned and pro-vided insight into the interesting shear rate phenomena which prompted the CVX-2 proposal.

B. Justification as a Microgravity Experiment

In general, Earth-bound measurements on critical fluids are constrained by the compress-ibility of these special fluids. The divergence of the compressibility as the temperature approaches

T_c causes the fluid to stratify leaving an ever decreasing layer of fluid at critical density. This limitation has restricted laboratory measurements to temperatures ~15 mK (reduced temperature, $t = (T-T_c)/T_c = \sim 5 \times 10^{-5}$) above the critical temperature. Unfortunate-ly, it is within this final temperature range that the divergence of several interesting physical parameters (such as viscosity, density fluctuations, and heat capacity) occurs at the most intriguing rates. Decreasing the stratification by conducting the experiment in orbit offers the promise of significant improvement of the experimental data in the region of most interest for test of existing theory. In particular, the shear rate phenomena to be studied in CVX-2 are predominantly accessible at temperatures very near T_c and, therefore, are most accessible in the microgravity environment.

C. Science Requirements

The objective of the experiment is to precisely measure the viscosity and its shear rate dependence in a pure fluid (xenon) near its liquid-vapor critical point. The thermodynamic path will be an approach to the critical temperature, $T_c = \sim 16.7$°C, on an isochoric path at the critical density from the one phase (vapor) region. The low gravity environment will enable T_c to be approached 100 times closer in reduced temperature than on earth before stratification begins to diminish the quality of the measurements.

To provide data comparable to the best laboratory data, it is required that the viscosity be measured with a precision of 0.18% and the viscosity exponent be determined with an accuracy of 1.0%.

To achieve this precision it has been determined that:

- the sample density must be within 0.3% of the critical density,
- the temperature gradient within the sample must be less than 0.22 μK/cm,
- the sample temperature must remain stable within 29 μK during a measurement,
- the error in relative T_c location must be less than 0.1 mK, and
- the resolution of the sample temperature measurements must be 29 μK.

These capabilities exist in the available flight system. The viscometer developed by the Berg and Moldover has been demonstrated to be capable of meeting the measurement requirements and operates:

- at a frequency of viscometer oscillations of .032 - 12.5 Hz (in the CVX-1 configuration and at selectable frequencies in that range for CVX-2),
- with the required precision in a temperature range of viscometry relative to T_c of 60 mK < ΔT < 600 μK (or at reduced temperatures of $2 \times 10^{-4} < t < 2 \times 10^{-6}$)
- with a shear rate less than 15 s^{-1} (in the CVX-1 configuration) and at selectable shear rates (viscometer amplitudes) up to 30x larger for CVX-2.

To ensure that the final results are not perturbed by external mechanical excitations which could couple to the fluid or to the viscometer, the environment must be monitored and the experiment will be timelined to minimize potential g-jitter interference during measurements very near T_c. It has been experimentally determined that the viscometer system is affected by quasi static accelerations larger than 2.4×10^{-4} g in the viscosity measurement regime and by vibrations greater than 8×10^{-5} g√Hz. Therefore, the background "g-jitter" environment must remain less than $8x10^{-5}$ g√Hz over at least 3% of the frequency bandwidth during the periods of viscosity measurement. Data points can be selectively excluded if accelerometry data indicate excessive disturbances may have contaminated the data. The acceptability of data gathered throughout many dynamic environments during flight 1 demonstrated the viability of the CVX strategy.

D. Proposed Experiment Sequence

The experiment will operate for as long as power is available on orbit. The detailed timeline for CVX-2 has not been defined, but it will be comparable to that used for CVX-1. Four principal operations occur during the course of the mission (Figure 1.) Initialization will stabilize the instrument at the required operating temperature and briefly checkout instrument functionality. The heat up operation conditions the sample at a temperature above T_c (never higher than 27°C) in preparation for a scan through the critical temperature as viscosity measurements are made. Four principal cycles (each typically requiring heat up and a temperature ramp) will be programmed for autonomous operation:

- The first action of the experiment will be to establish the location of T_c within ~3 mK. This will be accomplished with a series of viscosity measurements during a (relatively) fast temperature ramp starting at 1 K above T_c (as established by ground calibration) and continuing below T_c. This temperature ramp should take about 12 hours. This operation will validate viscometer response as compared to CVX-1 results.
- The primary viscosity data will be acquired during a series of measurements at a single viscometer operating frequency and two different viscometer amplitudes (1x and 30x the amplitude of CVX-1) at each of 10 temperatures logarithmically distributed from 0.3 mK to 30 mK above T_c. The strategy for this experiment protocol has not been finalized but it will require several days.
- A third data set will repeat the measurements at two significantly different viscometer amplitudes.
- A fourth data set will repeat the measurements at two additional viscometer frequencies.

If mission time permits, additional measurements will be performed by interactive control through preapproved commands.

INITIALIZE -------->	**HEAT UP**	4 Cycles ----------> <---------	**RAMP TO Tc** --------------->	**SHUT DOWN**
2 Stage Turn-on	Energize Heaters		Control Temperature	Increase Temperature
Lid Heaters On	Check for Start Temp		Set Viscometer Frequency/Amplitude	Activate Descent
Monitor Temp	Check Error Flags		Read/Log Viscometry Data	Heater Relay
Electronics On	Read/Log Temperatures		Read/Log Temperatures	Deactivate
Initialize Boards	Read/Log Health Data		Read/Log Health Data	
System Check			Read/Log Accelerometer Data	
			Check Error Flags	
			Temp Bridge Gain Settings	
			Process Uplink Commands	
			Downlink Data	

Figure 1. CVX Flight Experiment Sequence (Approximate)

During the shut down operation (as late as feasible during the mission), the cell temperature will be raised and the battery powered descent heater will be activated to ensure that the sample does not cool to below T_c in the time between instrument power down and Shuttle landing. This interval is expected to be about 6 hours.

III. TECHNICAL PLAN

A. Hardware Objectives

These objectives provide broad direction for the hardware development and verification effort. Detailed hardware requirements are contained in the Flight Instrument Specification, doc XXXXX, as amended to accommodate CVX-2 requirements.

1) Meet Primary Science Requirements
   - Of the science requirements listed in section II.C., density accuracy is determined by the Principal Investigator's sample cell design and fill/measurement technique and are not a part of the hardware development effort, though care must be taken to interface correctly with the PI's design. It is intended to utilize the CVX-1 sample if posible. This will require verification of key cell parameters.
   - The required acceleration levels are provided by the carrier such that vibration isolation is not required. Acceleration will be monitored and recorded.
   - Viscometry precision, viscometer operating conditions, temperature stability, temperature resolution, and temperature gradient are the major drivers in the hardware design. The thermomechanical design must provide an acceptable thermal environment in order to control the sample adequately at the critical temperature of ~16.7 °C, to keep the electronics stable at a reasonable operating temperature, and to prevent excess gradients on the sample cell. The electrical design must make low noise viscosity and temperature measurements and provide stable temperature control.
   - Uplink and downlink communications must be provided during the flight in order to monitor and control the progress of the experiment.
   - Viscometry data will be stored in raw form on orbit within the instrument.
   - Viscometry must be performed (approximately) from +3 C° to -1 C° relative to T_c on orbit with temperature control resolution at 5% of the reduced temperature.
   - The temperature control software must be able to accommodate selected ramp rates, the slowest of which requires sample cell temperature steps of 70 µK every 2446 seconds.
   - Continuously monitor accelerations and log when the threshold of $8x10^{-5}$ g√Hz is exceeded.
   - The experiment must be capable of operating autonomously for the duration of the mission (10 to 16 days).

2) Meet Requirements for Space Flight
   - Verify that safety, environmental, and functional requirements have been met.
   - Meet the interface requirements of the Hitchhiker carrier, including power, mechanical, and communications.

3) Meet Programmatic Requirements
   - Accommodate any hard schedule constraints which arise.
   - Stay within the established budget.
   - Ensure an acceptable level of reliability.

B. Hardware Description

CARRIER - Hitchhiker (HH) is the carrier of choice. We have maintained compatibility with both the HH-M or HH-G configurations to enhance the number of flight opportunities in this secondary payload scenario. HH-M is a Multipurpose Experiment Support Structure (MPESS) providing mechanical support for multiple experiments. HH-G consists of a side mounted plate support. Figures 2 and 3 show typical HH assemblies.

Figure 2. Hitchhiker-G Configuration

Figure 3. Hitchhiker-M Configuration

STRUCTURE/THERMAL - CVX consists of two packages, the Experiment Package (EP) and the Avionics Package (AP), which are contained in standard 5 ft^3 Hitchhiker canisters. The mechanical and thermal design was verified during the first mision and no changes have been made to the basic design for CVX-2.

The thermal environment will be analyzed carefully since a warm environment can compromise the experiment. Each canister is radiatively cooled through an uninsulated lid that is controlled through bucking heaters. These heaters have a dedicated analog controller with a programmable setpoint and will control the temperature to better than 0.5 K full swing. Thermal analysis must show that the EP can maintain a temperature below Tc for thermostat temperature control for most shuttle attitudes, including the most common bay-to-earth attitude. Experience during the first flight demonstrated that the design performs within the required margins.

The EP contains the sample cell and thermostat and the sensitive electronics for the temperature and viscosity measurements. The main assemblies are the eurocard rack, bridge box, and the thermostat. These items are conductively cooled. Alternate card slots of the eurocard rack contains a black anodized aluminum card for improved heat transfer and electronics shielding. Figures 4 and 5 show the mechanical layout of the Experiment Package. The EP contents weigh approximately 140 lb.

The AP contains the majority of the electronics to isolate these major heat sources and potential noise sources from the sensitive subsystems in the EP. The main assemblies are two STD card racks and a Space Acceleration Measurement System (SAMS) head. Because more heat is generated in this canister, a more robust design is used to enhance heat transfer. Forced air cooling is employed on the STD card cages and the primary support rails are solid (the EP rails are U-shaped for convenient wire routing). Figures 6 and 7 show the layout of the Avionics Package. The AP contents weigh approximately 130 lb.

Figure 4. CVX Experiment Package (side view)

Figure 5. CVX Avionics Package (side view)

THERMOSTAT - The design of the thermostat is driven by the need to prevent gradients of greater than 0.22 μK/cm from occurring over the sample volume. To meet this, three aluminum shells are layered over the copper sample cell to smooth out the gradient as seen by the outer shell. The shells and sample cell are decoupled by an air gap and the supporting

Ultem™ plastic spacers. The mechanical design permits con-venient removal of the cell from the thermostat without complete disassembly. Figure 6 shows the nested shells.

Figure 6. CVX Thermostat (cross section)

Figure 7. CVX Sample Cell and Viscometer Subsystem (cut away)

SAMPLE CELL - Xenon, at 58 atmosphere pressure, is contained within the sample cell. The cell has a copper body, one brass endplate with electrical feedthrus, and one sapphire window for observation during the cell fill procedure. Inside the cell the oscillating screen viscometer element is supported between two pairs of electrodes that both excite and detect screen motion. The cell end closures are sealed to the cell body using o-ring seals. Figure 7 shows a cut away view of the cell assembly. The cell performed well for CVX-1 and it is planned to use the same cell and sample will be used for CVX-2. The required changes in viscometry do not affect the cell structure but alter the frequency and field strengths applied at the electrodes.

TEMPERATURE ELECTRONICS - Temperature measurement on the thermostat shells rely on Wheatstone bridge circuitry. The outer two shell bridges are excited by a DC voltage compatible with the moderate resolution requirements. However, the inner shell and cell bridges are excited by AC voltages (frequencies less than 1 kHz). The voltage levels applied to the thermistors must be small to avoid unacceptable thermal gradients on the cell due to heat losses. A fixed bridge technology, pre-nulled near T_c, is used for the AC bridges. This implementation is unique for such sensitive measurements and greatly simplifies the bridge circuitry. Because adjustable bridge balancing is not used, a careful choice of precision resistors must be made to pre-null the bridge. The bridge box temperature is stabilized to at least ±0.3 K to avoid unacceptable drift of the resistors. The bridge output gain must be reduced as the bridge error signal increases at temperatures far from T_c.

The AC bridges use commercial Ithaco lock-in amplifiers (eurocard configuration) on the bridge output while the DC bridges use a standard instrumentation amplifier. The output signals are fed into the main processor via a 16-bit A/D card. Temperature control is performed in software, with the control signal being fed through the 12 or 16-bit D/A to the controllable heater power supply. The temperatures of the outer two shells of the thermostat are measured/controlled to about 0.5 mK, while those of inner shell and cell are measured/controlled to better than 16 µK (the cell is measured but not controlled). Successively less power is applied to shells closer to the cell in order to minimize thermal gradients due to the heaters. A constant temperature offset between shells is maintained during the temperature scans as all shells are adjusted in an appropriate series of small steps to produce the chosen rate of change.

VISCOMETRY ELECTRONICS - The viscometry electronics excite the oscillating screen viscometer and detect its motion. For CVX-1, the screen was excited using a "chirp" signal (a complex mixture of many frequencies) generated in the AP using a digitally recorded waveform stored in EPROM. The "chirp" signal is passed through a square root circuit that applies a DC offset, takes the square root, and divides the signal into two channels of opposite phase and polarity. The output signals are two 10 Vp-p "chirps" riding on + and - 30 V DC offsets. This excitation signal then goes to the EP where it is added to the 1 Vrms 10 kHz lock-in carrier signal and applied to the viscometer electrodes. For CVX-2, circuitry will be added to permit, selectively, operation at single frequencies and, more importantly, to operate the viscometer with larger voltage offsets which drive the oscillating screen to larger displacements (producing the required higher shear rates).

The oscillating screen is used as one side of a capacitance bridge. The bridge is nulled using a controllable 9-bit inductive voltage divider on the 10 kHz signal. This bridge output goes to an Ithaco lock-in amplifier card and is returned to the AP for A/D conversion. The output signals of this circuit (the viscometer input waveform) and of the lock-in amplifier (the viscometer output waveform) are filtered and sampled at 512 Hz and stored. Samples must be no more than ~14 µs apart and a sample and hold circuit is necessary to sustain this sampling rate. The ratio of these two viscometer signals is subsequently used to calculate viscosity of the sample.

ACCELEROMETRY - Real time acceleration measurement is desired to ensure that any exceedence of the acceleration threshold is recorded. A SAMS triaxial accelerometer sensor head and a custom filter card is used with a 10 Hz bandwidth. The filter card resides, with a dedicated processor, on an STD bus along with a 12-bit A/D card. Minimal data storage is required due to planned data reduction. For each 32 sec. chirp interval, the reduced acceleration data exhibits one number for the percentage of the bandwidth in which the threshold was exceeded and a second number for the vibrational energy over that bandwidth. These data are stored and sent to the communications processor for storage and downlink.

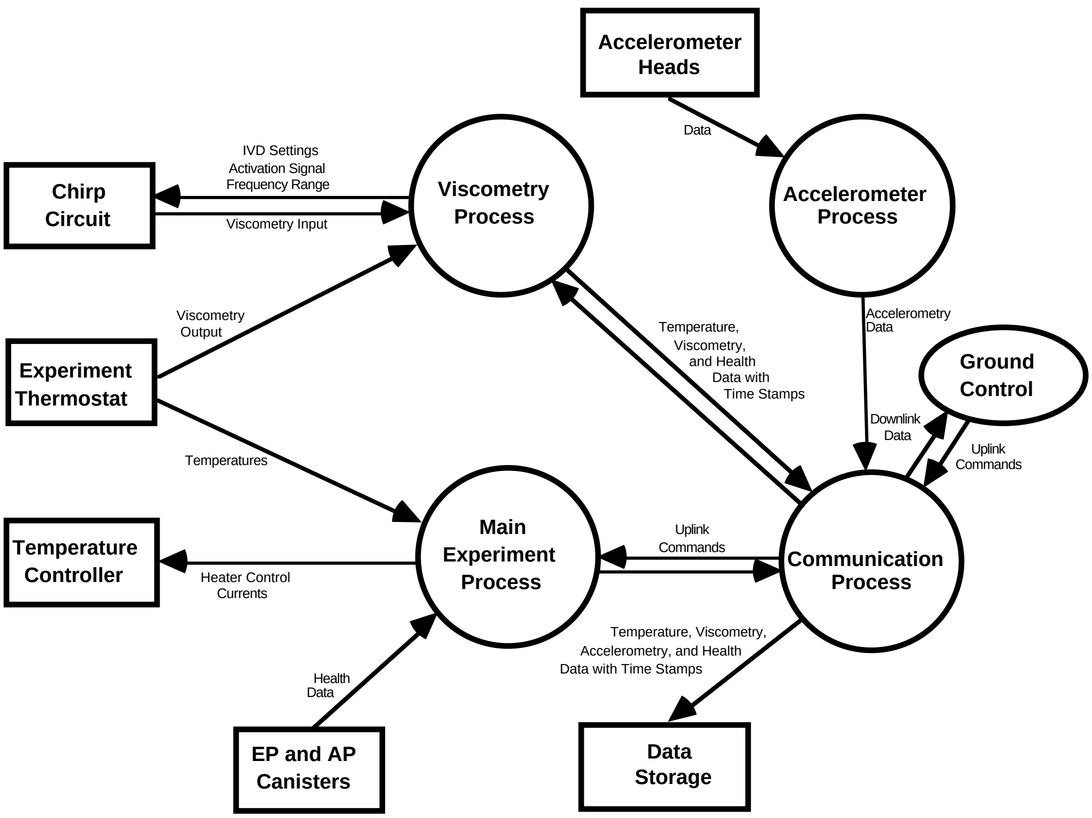

Figure 8. Data Acquisition/Control Data Flow

DATA AQUISITION AND CONTROL HARDWARE - The digital acquisition and control system (DACS) resides in the AP and includes 4 independent computers with each operating DOS on a STD bus. The major elements include:

1) A main processor for experiment control and temperature monitoring;
2) A second procesor handling viscosity measurements and data reduction;

3) A third processor to handle communications. The communications processor will accept and store data from the accelerometry, viscometry and main processors, and must operate as an asynchronous interface with the Shuttle computers;
4) A fourth processor to handle accelerometer measurement and analysis.

Internal commanding to the lock-in amplifier (gain settings), and to the viscometer (null setting) is performed using digital lines with a decoder at the receiving end. Data transfer to the down link processor uses RS-232 lines.

SOFTWARE - The only manual switching of this instrument occurs when the instrument is activated and deactivated by the Hitchhiker ground control station. After initial power up, the cannister heaters becomes operational. When the temperature is in the operating range, the electronics are activated and all subsequent functions of the instrument are controlled by the flight software. Data flow in the multiprocessor system is shown in Figure 8.

Both flight and ground software is written in the C language. It is organized into the following processes:

temperature control	experiment control	viscometry
accelerometry	uplink/downlink	simulation & test
flight operations		

These tasks are prioritized and timed with care; however, with the primary data gathering tasks (trigger chirp, null bridge, and control temperature) controlled on independent processors, no conflicts with lower priority tasks are expected. Data which are time-stamped and downlinked include:

viscometry data	cell temperature	shell temperatures
canister temperatures	canister pressures	shell heater currents
health data	accelerometry data	T_c value

Commands to be uplinked include:

Instrument Pause	Instrument Resume	Instrument Reset
Retrieve data file	Set new Ramp Sequence	Accelerometer on/off
Set canister temperature	Set sample temperature	Set ramp rate
Descent heater on/off	Initiate noise check	Set IVD ratio
Set chirp mode	Set viscometer offset	

Operations software for the experiment ground support computers employs a commercial graphics environment to plot and display flight data. The operations environment was demonstrated to be reliable and efficient during flight 1.

POWER - All power to the instrument enters through the AP, which then routes power to the EP. The instrument interfaces with shuttle power via an EMI filter. There is also be an EMI filter in the EP to interface with the AP power. Commercial power converter modules are used to convert the shuttle's 28±4 Vdc into voltages suitable for the instrument subsystems. DC voltage levels required are: 12 V for the SAMS head, 5 V and ± 15 V for system electronics, + and - 48 V for the square root circuit, 24 V for selected heaters, and 28 V for canister heaters.

An independent battery powered heater is incorporated to maintain the sample cell temperature above T_c prior to descent. Below T_c, the sample fluid separates into two phases (liquid and vapor) and there is a concern that sloshing of the liquid during re-entry and landing might damage the oscillating screen. Maintaining the fluid in a single phase ($T > T_c$) eliminates this issue.

SUPPORT EQUIPMENT - The following items will be employed as support equipment:

Item	***CVX-1***	***CVX-2***
2 flight assembly buildup carts	purchase	available
Wooden EMI test cart	fabricate	available
Instrument lifting equipment	borrow from TES	available
Thermal chamber	purchase	available
Heater/chiller	borrow	available
Tools	borrow or purchase	available
Shipping containers	borrow or fabricate	available
GAS canisters	obtain from GSFC	same
Flight operations computers	purchase	~available
Vibration test fixtures	borrow/fabricate	available

C. Hardware Development Approach

It is stressed that the <u>costs will be minimized</u> and, therefore, any activities not necessary for the accomplishment of the primary mission will be identified and eliminated unless significant benefits can be demonstrated.

During hardware modifications, the emphasis will be on placed on purchase of proven commercial components and subsystems, keeping the project team as small as is practical, and maintaining communications with the PI to ensure that science requirements are being met. Confidence in the hardware's functionality, reliability, and safety will be established through successful system-level testing as opposed to extensive analysis, custom design, and aerospace quality parts. Selected analysis and testing will be performed on subsystems and components as necessary to minimize the impact of failures at the higher levels of integration but emphasis will be on end-to-end testing.

The engineering model of the instrument is available for selected test and evaluation; however, it is expected that most testing will be carried out on the modified flight instrument.

The instrument will be requalified for a single flight as a secondary payload. Reflight is considered a contingency option with several likely opportunities available (particularly for HH-G berths).

D. Metrication Approach

The project recognizes the importance of transitioning to metrically dimensioned designs. However, this project has utilized existing designs and commercial hardware to a large extent and no change in this approach is expected.

E. Facilities

Activities during development and test requiring special facilities include selected fabrication, functional testing, vibration testing, thermal cycle testing, and electromagnetic interference (EMI) testing.

All facilities required for modification and bench test of the flight instrument are available at the Lewis Research Center and/or at the NYMA building. Most functional test support equipment will be supplied within the project. Facilities for vibration testing are available at the Lewis Research Center and at the Goddard Space Flight Center. Existing capabilities for EMI testing will be employed at Lewis and a final test will be conducted at GSFC. No constraints are envisioned for these facilities.

F. Mission Operations

Mission operations for Hitchhiker payloads are conducted at the Goddard Space Flight Center. The primary CVX-2 team will be resident at GSFC for the duration of the mission. Auxiliary support could be implemented through the Lewis Telescience Operations Facility, if required. Flight operations will include instrument monitoring, near real time data logging/analysis, and instrument commanding to reset parameters and adjust the timeline for the experiment.

Update and implementation of experiment ground support equipment (hardware and software) for ground and flight operations and personnel to support operations is a part of this plan.

G. Analysis of Mission Results

Analysis will be the responsibility of the investigator team. No issues are envisioned rel-ative to data analysis. An analysis plan will be prepared for project use and will define the primary activities and approximate schedule for flight data analysis. The primary activities are screening and correction of data for known external factors (instrumental contributions such as remaining transfer function nonlinearities and fluid physics contributions such as stratification and thermal gradients) and data fitting to models permitting extraction of the critical temperature and separation of gravitational effects from critical divergence.

H. Payload Classification

The payload has been identified as "Class D" per OSSA Policy for Classifying Payloads (5/92) and NASA NMI 8010.1A. This classification is consistent with the low-cost and rapid development schedule goals of this project. The secondary payload status typical of Hitch-hiker instruments and the related decrease in interface complexity and documentation were key factors in attaining the desired lower cost of the project dor the first flight and such status will be maintained for CVX- 2.

I. Reliability, Quality Assurance, and Safety

A Product Assurance program was implemented as described by Lewis Product Assurance Manual (PAM), and Lewis Standard Assurance Requirements and Guidelines (SARGE, January 1993). The same plan and procedures will be employed for CVX-2.

The reliability goal for flight 1 was to demonstrate failure free operation for 300 hours of burn-in and test prior to shipment. This translates (per MIL-STD-781D) as no failures during 100 hours of flight operation with a 95% confidence factor. A detailed parts reliability analysis *was not and will not be performed*. Performance of the instrument during flight 1 and during ground testing has exhibited exceptional reliability. The primary element of potential concern is the single dynamic mechanical component in the hardware: the suspension of the viscometer screen. Based on prior analysis, we have reason for confidence in its life however, we will conduct analyses at the new operating conditions while accounting for prior cycle life.

A detailed failure mode and effects analysis *will not be performed* for this hardware. Selected specific concerns were analyzed within the design process. These included:

1. Protection from shorts (both internal and external to the instrument) in the power subsystem;
2. Handling of communications drop out; and
3. Handling of command data errors.

Approved parts lists, material and assembly procedures, and test procedures were implemented during development and will be employed during upgrade for flight 2. Commercial quality electronic circuit boards will be used extensively. Detailed inspection and test procedures were implemented to ensure reproducible quality for such components. A formal verification plan was implemented that is consistent with the Class D designation of the instrument and in full compliance with Shuttle and carrier equirements. As logical, the same verification plan will be employed for flight 2. An 'ALERT' scan will be repeated for the parts contained within this payload to assure awareness of any recent concerns flagged in that system.

No safety issues are envisioned. The instrument is fully contained in flight proven containers. The generic hazards associated with similar flight instruments cover all aspects of the system. Full compliance with NASA safety policy was demonstrated by the test and analysis verification program for flight 1 and no changes are envisioned for flight 2.

TABLE 1. CVX Major Documents (**CVX-2 Updates**)

GENERAL REQUIREMENTS	
Science Requirements Document (SRD)	Product Assurance Plan (PAP)
Data Analysis Plan	Configuration Mngmt Plan (CMP)
Project Plan (PP)	Contamination Control Plan (CCP)
Customer Payload Rqmts Document (CPR)	Receiving/Inspection Plan (R/IP)
Flight and Ground Safety Packages	EEE Parts Control Plan
GSFC, KSC, and Misc Procedures	
HARDWARE DESIGN	
Flight Instrument Specification (FIS)	Hardware Drawings
Materials Ident and Usage List (MIUL)	Interface Control Document (ICD)
Technical Notes	
SOFTWARE	
Software Requirements Document (SWRD)	**Software code**
Software Implementation Document (SID)	Software Test Plan (STP)
Software Procedures Document (SPD)	**Software Test Report** (STR)

HARDWARE TEST & VERIFICATION	
Integration and Test Plan (ITP)	Random Vibration Test Plan**
Functional Acceptance Plan (FAP)	Thermal Test Plan**
Verification Plan (VP)*	EMI Test Plan**
Fracture Control Implementation Plan**	
HARDWARE TEST REPORTS	
Functional Acceptance Test Report (FATR)	Stress Analysis Report**
Verification Report (VR)	Thermal Analysis Report**
Random Vibration Test Report**	**EMI Test Report****
Thermal Test Report**	Mass Properties Report**

* Analysis plans (thermal, stress, mass properties, pressure profile) are included in the Verification Plan
** Sections of the Verification Plan or the Verification Report

J. Configuration and Data Management

A configuration and data management plan was defined and successfully implemented for flight 1 that ensured that the following objectives were met:

1. The identification and documentation of the CVX flight instrument unit technical requirements which specify flight hardware and software.
2. The establishment and implementation of a control system which documents and controls the configuration baseline and its changes.
3. The establishment and implementation of a configuration accounting system which records and reports the information required to maintain an accurate status of the established baseline and all approved changes.
4. The baseline configuration is in agreement with interface and safety requirements.

The same system of controls will be used for flight 2.

Configuration control for flight 1 employed the Space Experiments Division Configuration Control System (SEDCCS). The following categories of CVX documents exist:

DOC: Project Plans and documents, such as the CMP, PAP, SWRD.
RPT: Reports such as analysis reports and test reports.
TAP: Test and assembly procedures and processes.
TST: Test Plans.
TEC: Technical notes to answer/address specific questions.
PJM: Project team memos with a lasting impact, covering various topics.
COR: Correspondence with procurement/vendors.
SOW: Statement of work to vendors

In addition, hardware drawings and software code were entered into SEDCCS using a numbering system consistent with the Space Experiments Division OI 6700-3. The project number for CVX-1 was 60009. The Table 1 lists the major CVX documents. The same system will be used for CVX-2 (if it remains viable) and a contiguous numbering system will be employed for documents and drawings. If SEDCCS is not available, the paper/filing version of all documents and controls will be expanded.

Note that the test and verification program is covered by the Functional Acceptance Plan (FAP) for functional and science requirements and the VP for environmental requirements.

FAP items for verification are listed in the FIS and derived from science requirements, while VP items for verification are derived from the HH CARS document and from Lewis policies. As possible, these key documents will be used (with only required modifications) for CVX-2.

IV. MANAGEMENT PLAN

A. Management Structure

The CVX-2 project team organizational structure is in Figures 9. This flight project will be implemented by the Fluids Flight Projects Branch of the Microgravity Science Division of the Lewis Research Center.

B. Organizational Roles and Responsibilities

The Microgravity Science and Applications Division (NASA HQ Code UG) has primary program management responsibility and direct financial support for the project. The Code UG Enterprise Scientist for Fundamental Physics provides HQ oversight for this project. Implementation of the flight program is managed by the Microgravity Research Program Office (MRPO) of MSFC with delegation of responsibility for 'fundamental physics' experiments to the Fundamental Physics Program management team at the Jet Propulsion Laboratory. MSAD has approved the experiment for development on the basis of a non-advocate review (CVX Investigation Continuation Review, May 21, 1998) and directed MRPO to support development and flight of the CVX instrument within the limits of science requirements and cost/schedules plans identified in this project plan. The MRPO will provide annual budget authorizations to sustain the approved plans for all science, engineering, and operations called out in this plan.

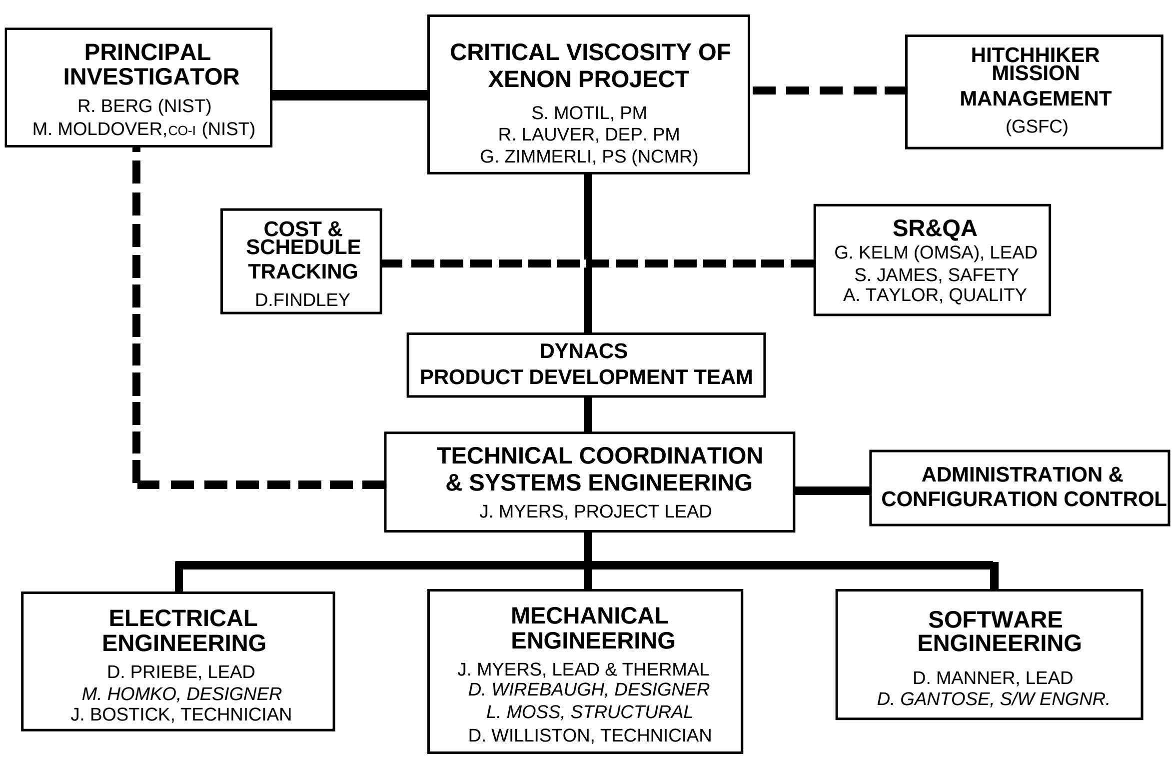

Figure 9. CVX Project Organization

The Principal Investigator (PI) for the project has finalized the science requirements and will provide ongoing support to facilitate efficient and valid implementation of those requirements into the flight instrument. The PI will assemble and fill flight sample cells (if required), support instrument development as required, support test and review activities as required, and complete analysis and reporting of flight data as defined in an approved Data Analysis Plan.

The Microgravity Science Division (LeRC 6700) has technical and science management responsibility for the project. This organization will provide the ongoing oversight and support to sustain the proposed commitment of people and support services called out in this plan and monitor/report progress relative to this plan.

Instrument development and direct project management is the responsibility of the Project Manager who resides in the Fluids Flight Projects Branch (LeRC 6722). The CVX Project Manager plans and coordinates the technical and administrative details of the project and reports status to HQ, MRPO, and LeRC management. The CVX instrument is provided by Dynacs Engineering Company, Inc. under Contract NAS3-98008, Task #069. The Dynacs team is directed by the Dynacs Task Manager with direct responsibility for implementation and day to day operations of the CVX engineering team.

Project science oversight is the responsibility of the NASA Project Scientist who resides in the National Center for Microgravity Science and reports to the Microgravity Fluids Branch (LeRC 6712). The Project Scientist provides direct coordination with the Principal Investigator and has joint responsibility for monitoring the implementation and validity of science requirements for the flight experiment.

C. Management Reporting and Reviews

The Critical Viscosity of Xenon (CVX-2) experiment team desires to maintain a very aggressive schedule in order to minimize development costs and time to flight. We feel that the traditional engineering milestones are not compatible with the rapid and highly parallel approach to design and fabrication currently being implemented. The proposed approach will utilize two stages of review:

(1) A design review process conducted, as possible, informally and culminating in concurrence of acceptable design and analysis of the modifications to the instrument. This process was initiated during the ICR preparation when system level plans and functions, electrical design and performance, and selected asurance tasks were presented and discussed with the Engineering Review Panel.

(2) A System Integration Review (SIR) which will occur prior to final integration and test of the flight system to assure compliance with flight level handling and test requirements and appropriate preparation for flight acceptance testing.

At completion of this two stage process, all requirements of SED 6700-1 will have been met.

A formal Preship Review will be conducted to confirm closure of all verification requirements and readiness to ship and perform flight operations.

Formal status reports will be submitted monthly to LeRC and MRPO management. Monthly management status reviews will be presented to MSD management.

Weekly team meetings will be held to guarantee communication of status and issues to project management. Technical status will be tracked within the project in on-going daily interactions with the Team Coordinator. The project technical team is co-located for efficient interaction and communication.

V. PROCUREMENT PLAN

A. Personnel Services

This hardware development plan will be implemented via contract with Dynacs (NAS3-98008, Task #0069). The task order includes flight hardware development and flight operations support. It is expected that the effort would continue with the same team if the contractor should change during the life of this task.

The science activities will be implemented through a contract with the National Institute for Standards and Technology (NIST) as Inter-agency Agreement C-32001-K.

B. Hardware Acquisition

The development plans call for selective design and fabrication of custom hardware and electronics and an emphasis on purchase of commercial hardware. All purchases of materials and hardware are within the scope of the NYMA task order and/or LeRC purchase authority.

Long lead items will be identified for special consideration in the development plan, but none is envisioned at this time. The only items of potential concern (at this time) would be flight quality connectors (~6 month lead if required). No other items are believed to require lead times greater than six weeks.

VI. COST AND SCHEDULE PLAN

A. Work Breakdown Structure

The hardware Work Breakdown Structure is attached (Figure 10).

B. Budget

The summary of the planned budget is attached (Figure 11).

C. Schedule

The planned top-level development schedule is attached (Figure 12).

D. Staffing

The planned staffing plan is attached (Figure 13).

E. Cost Control Plan

The unique (and successful) cost control guideline for this project is an explicit challenge by the PI team to minimize the hardware costs and still provide an exemplary and optimal evolution of the experiment. The PI team believes that minimal cost for acceptable data will enhance the quality and credibility of the flight experiment in the eyes of the physics community.

Cost Control Guidelines - To maintain a cost plan appropriate for a NASA sponsored flight project and acceptable by the PI team, we propose the following guidelines:

a. Project costs for Phase C/D should not exceed $0.6 M (this indicates our desire to avoid the costing of contingency, if at all possible).

b. The primary control for increased design and development costs will be deletion of "low priority" hardware capabilities that are deemed "very desirable but not absolutely essential" to meeting the primary science requirements. Because the effort is quite limited in scope, further reduction will be very challenging. At this time, two items would be considered for possible deletion/decrease: 1) implementation of desired improvements in cannister thermal heater designs capabilities and, 2) need for full flight operations team.

c. Contingency held within the project will be visible to the total project and will be applied only with concurrence of PI team. It will be used to offset costs due to internal technical problems on science critical project elements, project approved design changes, and unforeseen cost growth in materials and fabrication costs or labor costs. Changes in program scope due to external circumstances such as change in launch date or change of carrier, changes in NASA requirements (integration/interface or acceptance requirements, product assurance requirements), or NASA driven changes in science requirements will be implemented, as required, but will be identified as special cases of cost growth and adjustment of the baseline budget will be recommended to accommodate such cost elements.

Figure 15. CVX Work Breakdown Structure

Figure 16. CVX Project Budget to Completion

Figure 17. CVX Top Level Schedule to Completion

Figure 18. CVX Personnel Distribution to Completion

Cost Reporting and Control Structure - Progress relative to scheduled work and initial budget will be analyzed weekly within the project. These status data will be used as the basis for reporting to the Microgravity Science Division (monthly management review) and to Code MRPO (monthly program review).

Cost Control Strategy - Monthly monitoring and quarterly reporting of budget status toward this total cost will be monitored by PI team as well as NASA project team. This will insure the PI team that every effort has been made to avoid cost growth as well as demonstrate to the NASA management team that the project is operating within planned budgets.