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Two-Phase Flow Research Using the DC–9/KC–135 Apparatus

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SUMMARY

Low-gravity gas-liquid flow research can be conducted aboard the NASA Lewis Research Center DC–9 or the Johnson Space Center KC–135. Air and water solutions serve as the test liquids in cylindrical test sections with constant or variable inner diameters of approximately 2.54 cm and lengths of up to 3.0 m. Superficial velocities range from 0.1 to 1.1 m/sec for liquids and from 0.1 to 25 m/sec for air. Flow rate, differential pressure, void fraction, film thickness, wall shear stress, and acceleration data are measured and recorded at data rates of up to 1000 Hz throughout the 20-sec duration of the experiment. Flow is visualized with a high-speed video system. In addition, the apparatus has a heat-transfer capability whereby sensible heat is transferred between the test-section wall and a *subcooled* liquid phase so that the heat-transfer characteristics of gas-liquid two-phase flows can be determined.

INTRODUCTION

NASA Lewis Research Center has been conducting low-gravity gas-liquid flow research since 1986 using an apparatus designed to fly in the NASA Lewis Learjet 25 (ref. 1). Based on the design of and experiences with this apparatus, a larger apparatus was designed, built, and tested. The larger apparatus, the DC–9/KC–135 Two-Phase Flow Apparatus shown in figure 1, mixes air with a water solution in metered quantities and measures basic, two-phase flow phenomena. The capabilities and operation of the apparatus are detailed in this report.

Flying an aircraft through a Keplerian trajectory produces a low-gravity environment (refs. 2 and 3) in which researchers can conduct experiments. Such experiments can be conducted in a near-weightless environment (on the order of 10^{-2} g) or at partial gravity levels ranging from 0.05 to 0.75 g. Periods of low gravity are approximately 18 to 20 sec long; therefore, depending on the flight profile and fuel load, at least 40 trajectories can be completed in a single flight of either the DC–9 or the KC–135.

The apparatus provides two-component, two-phase flow. The first component and phase is air. The other component and phase is a water solution, usually distilled water mixed with a minute amount of salt. However, a 50-wt % glycerin and water solution has also been used—to study the effects of increased liquid viscosity on flow phenomena. And a 0.5-wt % solution of Zonyl FSP (a fluorosurfactant made by DuPont) in water has been used to study the effects of decreased surface tension.

The apparatus has a data-acquisition system that obtains gas and liquid flow rates from various sensors and records these measurements. It also records acceleration levels measured from a triaxial acceleration head, and various two-phase flow characteristics, such as differential pressure, void fraction, liquid-film thickness, and wall shear stress, at acquisition rates up to 1000 Hz. The flow pattern can be visualized at either 250 or 500 images/sec with high-speed cinematography.

One series of tests with this apparatus focused on determining heat-transfer coefficients (ref. 4). For these tests, heaters and thermistors were strategically located along the length of the test section to measure the axial temperature distribution as a two-phase mixture consisting of air and a *subcooled* liquid phase entered the heated region. In changing from the liquid to the gas or vapor phase, the mixture exhibited no significant mass transport as is encountered in boiling.

APPARATUS LAYOUT

The Two-Phase Flow Apparatus is composed of three distinct structures called racks (see fig. 1). All three racks have plumbing and electrical connections for power, control, and data-acquisition systems.

The first rack, or flow-metering rack, primarily contains the liquid-supply tank, the gas and liquid flow loops, the two-phase mixer and flow development (or entry) length, and the thermocouple amplifier electronics. The rack is approximately 90 cm wide by 120 cm long by 120 cm high. In addition to the liquid-supply tank, which is a large Plexiglas cylinder with anodized aluminum end plates, it holds the flow-rate setting devices, such as metering valves and pressure regulators, and flow-rate measurement devices, such as pressure transducers and turbine flow meters. The mixer housing is made of aluminum and can use either stainless steel or Teflon inserts. After the mixer, there is a short entry length with a diverging cross section in which the flow is expanded to the test-section diameter. The entry length is made of Plexiglas and is contained within a transparent box filled with water. This arrangement reduces the optical distortion caused by refraction near the test-section walls. A camera may be mounted on the top shelf of the rack for imaging the diverging region and the adjacent length of test section. Also in the rack are an operator interface panel with a light emitting diode (LED) display, toggle switches, and thumbwheels. A video monitor on the top shelf has a "wipe" unit that is used with the high-speed video system to govern the percentage of data which is recorded from each of the two video cameras. A three-axis accelerometer records residual g-levels.

The second rack, which is approximately 60 cm wide by 60 cm long by 120 cm high, is primarily used as a midspan support of the test section. It also houses the video tape recorder and the power and control units for the strobe lights.

The third rack, which is the same size as the first rack, houses the two-phase collector/separator tank, back-pressure regulator, recirculation pump, data-acquisition system, and the signal conditioning boxes for several transducers and probes.

All three racks are mounted to Unistrut channels that are attached to the mounting points within the aircraft. The channels provide a capability for adjusting the spacing between racks, whereas the 51-cm hole patterns in the aircraft floor (ref. 2) do not. Plywood mounted between the channel and the aircraft floor helps distribute the load and prevent damage to the floor padding.

An additional rack, supplied by aircraft support personnel, is the gas-bottle rack, which holds either two or four K-bottles and is mounted near the first rack.

FLOW SYSTEM DESIGN

The flow system is illustrated schematically in figure 2. It has four parts: the gas system, the liquid system, the two-phase portion, and the liquid recirculation system. An itemized listing of the individual components comprising this system is given in appendix A.

Gas is supplied as compressed air from two standard K-size bottles manifolded together. A pressure regulator mounted to the manifold at the gas-bottle rack is used to set the pressure to 5170 kPa (700 psi). A high-pressure flexible hose connects the regulator to the gas inlet line on the first rack. From this point on the first rack, the gas-supply line is split into two parallel lines. Each line has its own pressure regulator and transducer. The first line supplies gas to the test section, and the second line supplies gas to pressurize the liquid-supply tank.

Beyond the pressure regulator in the gas flow line are three parallel gas-metering flow legs. Each leg has its own solenoid valve and square-edged orifice. Beyond the orifice, the legs are recombined. Pressure and temperature are measured upstream of each orifice as well as in the common line after the orifice. If the absolute pressure upstream is at least 2 times greater than the pressure downstream, the gas flow through that particular orifice is choked. The mass flow rate can be determined from the following relationship (ref. 5):

$$\dot{m} = Ca\phi_i^*\left(\frac{\phi^*}{\phi_i^*}\right)\frac{P_{1t}}{\sqrt{T_{1t}}}$$

where $\dot{m}$ is the mass flow rate; C is the orifice discharge coefficient; a is the throat area of the orifice; ϕ_i^* is the sonic flow function of an ideal gas; ϕ^*/ϕ_i^* is the ratio of the real-to-ideal gas sonic flow functions; P_{1t} is the inlet stagnation pressure; and T_{1t} is the inlet stagnation temperature.

Each orifice has a different diameter: 0.381, 1.079, and 3.048 mm. For the same pressure range, a turndown ratio (maximum-to-minimum flow rate) of greater than 250 to 1 is obtained. The superficial velocity at atmospheric pressure for flow through the small orifice can range from 0.1 to 1.0 m/sec; through the medium orifice, from 1.5 to 9.0 m/sec; and through the large orifice, from 10.0 to 25.0 m/sec. The gas flows through a check valve in the common leg to minimize the backflow of the liquid phase into the gas-supply system. A small gas-sample cylinder is connected to the gas line through a ball valve. This sample cylinder has approximately the same volume as does the gas line between the critically choked orifices and the mixer. By opening and shutting the ball valve, it is possible to ascertain the effect of the gas line capacitance on the flow. From the check valve, the flow enters the two-phase mixer.

The liquid-supply tank holds 45 L of liquid. Gas pressure is supplied from the gas-supply cylinder through a regulator on the first rack. The gas passes through a three-way solenoid valve that permits the liquid-supply tank to be pressurized when the valve is powered and that vents the pressure from the liquid-supply tank when the solenoid valve is de-energized. Gas is introduced into the top of the tank above a piston that travels down a shaft in the center of the tank. The gas pushes the piston downward to force out the liquid while maintaining positive phase separation. Liquid exits from the bottom of the liquid-supply tank and splits into two paths: test flow and purge flow.

The test flow path has a pair of hand valves connected in parallel. These valves have indicators on the handle showing the number of turns that the valve has been opened, thereby allowing the flow settings to be easily reproduced. One of the parallel flow legs has a solenoid valve as well.

First, the flow passes through an electrically actuated solenoid valve and then into the parallel legs with the hand valves, where it is metered with a turbine flow meter. The flow continues past a check valve and through a conductivity reference cell. This cell, which is made of Plexiglas, contains two parallel thin wires with which it measures the baseline liquid conductivity. The baseline is used as a reference for correcting the temperature and salt concentration differences in the liquid conductivity data. After the conductivity reference cell, the liquid flow enters the two-phase mixer.

The purge flow path is used to flush any gas bubbles trapped in the differential pressure measurement system. On this route, the flow goes through a valve that essentially sets the flow rate; then the path splits into three parallel lines before entering the test section. Each parallel line contains a metering valve to minimize the pressure drop during purging and a solenoid valve to turn the flow on and off. Exiting the three parallel lines, the flow passes through a chamber containing the pressure transducer diaphragm and then enters the test section.

The gas and liquid phases are introduced at the Plexiglas mixer. The gas flow is injected axially down the center of the tube. The liquid phase is injected perpendicular to the test-section axis and the gas flow direction. If desired, the inlet lines for the gas and liquid phases can be reversed. Two schemes have been used to mix the liquid with the gas, as depicted in figure 3. In the first arrangement (fig. 3(a)), the liquid is injected directly into the mixer through several small holes (diam = 3.18 mm) around the circumference of the mixer. This approach promotes turbulence and mixing. In the second arrangement (fig. 3(b)), the liquid is injected into an annular region and flows in the same direction as the gas before the two flows come into contact. This approach establishes the annular liquid film more quickly in the slug and annular flow regimes and reduces the amount of liquid droplet entrainment in the annular flow.

Flow is allowed to develop along an entry length made of transparent Plexiglas tubing, where the flow from the mixer expands to the test-section diameter. Various configurations of straight conduit test sections, each with a different combination and placement of sensors, have been utilized for measuring the flow phenomena. Sensors include differential pressure transducers, conductivity probes, and hot-film anemometers. Currently, two Druck PCDR 820 transducers with a full-scale range of 6.9 kPa (1.0 psid) are being used. These transducers have a flush fitting and are mounted in a special receptacle affixed to the test-section tube, as illustrated in figure 4. A small-diameter connection between the receptacle and the test section permits pressure measurement.

The Druck transducers measure differential pressures; however, the reference port of the transducer must be exposed to a dry, noncorrosive gas. To meet this requirement, the references from both transducers are connected and exposed to the pressure at the test-section outlet via a pitot tube device. The opening in the pitot tube is pointed downstream to minimize liquid infiltration into this line. To further minimize liquid contamination, a small separator chamber containing a hydrophobic porous material and a chamber containing a calcium carbonate desiccant are located between the ports and the collector tank. An absolute pressure transducer is connected to this reference pressure to measure the pressure within the test section so that the mass flow rate can be converted to a superficial gas velocity.

The Druck pressure transducers can tolerate pressures higher than their rating; their output signal is linear up to 68.9 kPa (10 psid). Consequently, signal-conditioning electronics were developed to utilize the full range of input voltages in the data-acquisition system and to permit measurement of several pressure ranges: from 0 to 4.1, to 13.8, and to 41.4 kPa (0.6, 2.0, and 6.0 psid).

Void fraction and liquid-film-thickness measurements are made with thin-wire conductivity probes (ref. 6). Two parallel wires stretched across the diameter of the test section measure these parameters as a function of the area between the wires when they are immersed in liquid. The wires, which are 0.0762 mm (0.003 in.) in diameter, are 87 wt % platinum and 13 wt % rhodium. To enhance the conductivity of the liquid, a small amount of sodium chloride, typically about 1 g per liter of solution, is dissolved in the liquid. The liquid-film-thickness probes are coated along one-half of their length with a nonconductive enamel. Calibration of the void fraction and liquid-film-thickness probes is discussed in reference 6.

Wall shear stress measurements are made with a hot-film anemometer. This probe is made on a polyimide film, has a nickel hot-film sensor, and has a built-in compensator to correct for the temperature of the liquid film. Such probes are calibrated under annular flow conditions in which waves in the liquid film are suppressed (ref. 6).

In the flow visualization section, a rectangular box surrounds the cylindrical test section. The box is filled with water to minimize refraction. High-speed, S-VHS video cameras, with strobe lighting that gives an effective shutter speed of 10^{-6} sec, record the flow pattern at 250 full images/sec or 500 half images/sec. The dual camera system permits the output from two cameras to be recorded simultaneously; however, the total amount of data recorded does not vary, whether the system is operated with a single camera or two cameras.

The heated test section that was used for the heat-transfer tests was built by the University of Houston. The test section consists of a 56-cm nickel-plated copper tube wrapped with etched-foil heaters. Resistance temperature elements (RTD's) were positioned between the heaters and the external tube wall to estimate the internal wall temperature. A thin-film thermocouple, capable of response times as short as 1 to 3 msec, was mounted inside the tube near the exit. A film-thickness probe just beyond the exit was used to correlate the temperature fluctuations with waves or slugs. Additional signal-conditioning electronics for the thermistors was developed; it is similar to the electronics currently being used for the differential pressure transducers.

After exiting the test section, the flow enters the two-phase collector/separator tank (see fig. 5). This tank is a large, aluminum tank designed to retain the liquid and vent the air through a backpressure regulator into the aircraft cabin (ref. 7). The two-phase flow enters into a plenum and then is injected tangentially into an internal Plexiglas cylinder. Here, a centrifugal field is established and the two phases separate. The gas is vented through a woven-mesh outlet at the center of the internal cylinder, and the liquid exits the internal cylinder, via holes in the cylinder wall, into the outer tank. A coarse fiber mesh retains the liquid in the outer tank. During the pullout at the end of the trajectory, the liquid phase falls to the bottom of the outer tank, from which it can be pumped back to the liquid-supply tank.

Between trajectories, when gravity is restored to normal levels, liquid is pumped from the collector/separator tank back to the liquid-supply tank through a recirculation line. The liquid recirculation line has a filter to remove any impurities or organic growth that is in the liquid. A solenoid valve opens between the two tanks, and another solenoid valve vents the pressurized air from the top of the liquid-supply tank. A small centrifugal pump is used to transfer the liquid. Air that has been vented into the cabin is not recovered.

All nonstandard fluid devices (e.g., the liquid tank, the collector/separator tank, and the test section) are hydrostatically tested at 1.5 times the maximum working pressure differential to satisfy safety standards. The lower pressure on this differential is about 27.6 kPa to account for the possibility of the aircraft suddenly losing cabin pressurization.

ELECTRICAL POWER AND CONTROL SYSTEMS

Three types of power are supplied by the aircraft: 28-V dc; 110-V, 60-Hz; and 110-V, 400-Hz. Aircraft power is fed to a power distribution strip attached to the back of the first rack. Power connections between the experiment and the power distribution strip are made in accordance with aircraft standards (ref. 2). The 28-V dc source powers most of the solenoid valves. The 110-V, 60-Hz source powers one of the gas flow solenoid valves; the data-acquisition and control system; the recirculation pump; the high-speed video system; the heaters; and the signal-conditioning equipment for the conductivity probes, hot-film anemometers, differential pressure transducers, and thermistors. Power to the absolute pressure transducers is supplied via an alternating-to-direct-current power converter.

The data-acquisition and control system is a card cage standard (STD) bus computer system. The central processing unit is a 486-chip rated at 20 MHz. A170-MB hard drive and a 1.44-MB floppy drive offer 4 MB of random access memory and storage capacity.

Three cards are used for data acquisition. Each has 12-bit resolution and accepts either 16 channels of differential input signal or 32 channels of single-ended input. They can be configured to accept input voltage ranges of either ±10 V, or 0 to 10 V dc. At least 25 msec is required to digitize an input signal.

A digital input/output board controls and monitors the operator panel and the timing and sequencing of the valves, camera, and other devices. The digital input/output board can output a 0- or 5-V-dc timing signal to other data-acquisition systems.

The operator panel consists of a display, an ENTER button, thumbwheels, an emergency STOP button, and several toggle switches. The display is 4 lines by 20 characters. Pressing the emergency STOP button turns power off to all solenoid valves, the camera, lights, heater, pressure transducers, and signal conditioning. However, the data-acquisition and control system is unaffected because it is powered through an uninterruptible power supply.

SOFTWARE FOR DATA ACQUISITION AND DATA REDUCTION

Two types of software are used: data-acquisition and control system software, and data plotting and transmission software. The data-acquisition and control system software was written in C and relies heavily on a DOS extender to maximize the use of the upper memory. This software initializes the apparatus, monitors various data channels, acquires data and controls the experiment during testing, and transfers data from the hard drive to the floppy disk.

During the experiment, the software monitors several data channels and records the outputs. Scientific measurements (i.e., the acceleration levels, the differential pressure, the void fraction, film thickness, and wall shear stress) are recorded as voltages. Data from other sensors are recorded in appropriate units: from the thermocouples as degrees Fahrenheit; from the absolute pressure transducers as absolute pounds per square inch; and from the turbine flow meter as gallons per minute. The data-acquisition system also calculates and records the gas and liquid flow rates as superficial velocities in meters per second.

A diagnostic routine has the ability to read switch and thumbwheel positions on the control panel via the digital input lines and to individually control the solenoid valves and pump via the digital output lines.

Data plotting routines have been written to plot data on either Hewlett-Packard graphics language (HPGL) or PostScript devices, such as Hewlett-Packard plotters, PaintJet XL printers, and laser printers.

INSTALLATION AND TEST PROCEDURES

Installation

In order to accommodate the floor loading limitations of the aircraft, the rig is mounted with a Unistrut channel and plywood arrangement. The plywood is placed on the floor, and the Unistrut channels are placed on the plywood and bolted through the plywood to the aircraft floor. (The hole pattern for the attachment points is specified in the KC–135 and DC–9 users guide (refs. 2 and 3)). Next, the attachment bolts on rack 1 are tightened.

After the racks have been installed in the aircraft, the test section is installed, starting with rack 1. As the test-section installation proceeds, the positions of racks 2 and 3 are adjusted by sliding the racks along the Unistrut-channel. There is some tolerance incorporated within rack 3 to slide the test-section outlet port approximately 2 cm without having to reposition the entire rack. The test section is held in place on racks 2 and 3 by top and bottom Teflon mounting brackets that encircle the test-section diameter and mount to fixtures on the racks.

After the test section has been installed, the plumbing and electrical connections are made. The plumbing connections are (a) the liquid return line that runs between racks 1 and 3; (b) the differential pressure transducer flush lines that are parallel connections between rack 1 and the differential pressure transducer ports on the test section (these lines may have intermediate connections on racks 2 and 3); and (c) the differential pressure transducer reference lines that are also parallel connections between the reference pressure source at the rack-3 test section and the reference ports on the Druck PCDR 820 pressure transducers (these lines may also have intermediate connections on rack 2).

There are four types of electrical connections:

(a) Power. Most of the power connections run from the aircraft to rack 1. From rack 1, parallel connections are then made to racks 2 and 3.

(b) Control. The control connections run from rack 3, where the data-acquisition and control systems are located, to rack 2 for the high-speed video system and to rack 1 for both the control panel and solenoid valves. An additional cable between racks 1 and 3 enables one to control the LED operator interface panel and utilize the serial port on the STD bus.

(c) Data. The data-acquisition connections run from racks 1 and 2 and also along the test-section length to rack 3.

(d) Video. For the videocassette recorder (VCR) mounted on rack 2, which is part of the high-speed video system, there are connections between the monitor and "wipe" unit on rack 1 and the VCR on rack 2. Although the two cameras and strobe lights can be placed on either rack 1 or 3, they need to be connected to the strobe light power supply units and the VCR on rack 2.

Preflight Tasks

After the rig has been mounted and the proper electrical and plumbing connections have been made, a functional test of the rig is conducted. A typical function test plan or checklist is included in appendix B.

Prior to each flight, the following tasks must be completed:

(a) Fill the liquid supply. If there is a change from the previous flight's test liquid, the new test liquid must be recirculated through the entire flow loop, including the purge lines, prior to the flight. The liquid supply tank is filled and completely emptied at least twice to ensure that gas trapped in the liquid test flow and purge flow lines has been purged.

(b) Adjust the zero offset of the absolute pressure transducers. The ambient pressure is measured with each transducer, and then the local barometric pressure is entered. The software compares the measured value with the barometric pressure and adjusts the zero offsets. This is done by depressing the NO-FLOW button on the control panel, following the directions on the LED display, and entering the barometric pressure on the Flight Number and Trajectory Number thumbwheels on the control panel on rack 1.

(c) Check the gas supply. At least two K-size bottles of compressed air are required per flight. They should have similar pressures of at least 1500 psi.

(d) Pack a supply of floppy disks to transfer data from the data-acquisition system for data analysis.

(e) Load the high-speed video system with a fresh S-VHS videotape.

Inflight Duties

Four operators are required for conducting tests. Checklists for the first and second operators are included in appendixes C and D, respectively.

The first operator, stationed at the control panel on rack 1, controls the data-acquisition software and video system and sets the gas and liquid flow rates. After the aircraft is airborne, operator 1 turns on the power to the rig, opens the gas-supply valves, and adjusts the gas regulator to obtain the proper pressures. In addition, this operator adjusts the thumbwheels on the control panel to configure the data-acquisition system for several parameters, including the following:

(a) Data-acquisition rates for the high-speed data, such as the acceleration, differential pressures, and conductivity measurements. Rates of 100, 250, 500, and 1000 Hz are possible, but typically 1000 Hz is selected.

(b) Data-acquisition rates for the low-speed data, which are primarily gas and liquid flow rate measurements required to determine the gas and liquid flow rates. Rates of 1, 2, 5, and 10 Hz are available; however, 1 Hz is typically selected.

After the aircraft is airborne, the second operator turns on power to the data-acquisition system, video system, and signal-conditioning electronics for the conductivity probes, differential pressure transducers, and any other probes. Operator 2 also configures the two-phase separator tank's valves on rack 3 and configures the settings for the high-speed video system. Operator 2 then assists the first operator, primarily by reading the test matrix and checklist, during the experiments.

The third operator, positioned at the back of rack 3 with the secondary two-phase separator, monitors the performance of that separator, which is governed by the performance of the primary separator. The secondary separator is transparent, so it is possible to track the passage of any liquid into and out of the separator. If it appears that the secondary separator will eject liquid into the aircraft cabin, operator 3 depresses the large red emergency STOP button to shut off the flow.

The fourth operator serves as a backup and a spare set of hands to the other three operators. Operator 4 also monitors the performance of the primary gas-liquid separator through its transparent lid and observes the gas-liquid flow within the test section.

Test Procedures

For each test, the first operator configures the control panel's thumbwheels and toggle switches. The thumbwheels are used to input the following information:

- Flight number
- Trajectory number
- Liquid type
- Differential pressure transducer range
- Test-section diameter
- Gravity level
- Test duration
- Preflow duration

At lower gas and liquid velocities, the two-phase mixture takes a significant amount of time to traverse the full test-section length. Establishing a liquid flow during the high-gravity portion of the trajectory ensures having sufficient liquid to wet the test-section walls earlier during the trajectory.

The first operator sets the desired superficial velocity of the gas by adjusting regulator A06, and then sets the liquid flow rate with the handles on the two liquid flow valves. The handles have scales that indicate how far the valve is opened, which ensures repeatability in setting the liquid flow rates.

After the gas and liquid flow rates have been set, the data-acquisition and control software waits for the operator to signal the start of the experiment. On receiving the command to proceed, the software acquires the zero offsets for the differential pressure transducers by turning off power to the purge solenoid valves and acquires differential pressure data and accelerometer data for 0.5 sec. After power is reestablished to the purge solenoid valves, the zero offsets for the differential pressure transducers are measured and corrected for residual hydrostatic forces. Next, the liquid solenoid valves are opened for the amount of time prescribed by the Preflow thumbwheels; then the experiment begins.

Both the appropriate gas and liquid solenoid valves are opened. The high-speed video system starts recording the flow pattern, and the data-acquisition system records the transducer and probe outputs. After the two-phase mixture has entered the test section and covered the last port to the differential pressure transducers, the ENTER button on the control panel is depressed, thereby shutting off the liquid flow through the purge lines. During the low-gravity period, the first operator monitors the apparatus for any leaks or air bubbles in the Plexiglas sense chamber for the differential pressure transducers, and notes the position of any air bubbles in the liquid supply tank that might be ingested into the liquid feed system. If necessary, the first operator may press the large red emergency STOP button on the control panel to close all solenoid valves and stop all flow. Meanwhile, the camera and data-acquisition system continue to operate.

After the low-gravity period has ended, the first operator toggles the pump switch on and monitors the liquid level in the supply tank. When the piston is near the top, the operator turns the switch off. The first and second operators, working together, configure the rig for the next set of tests.

After all data have been taken, they are transferred to floppy disks. These data are analyzed to see whether the desired flow rates were obtained, whether the data were out of the range of the differential pressure transducers, and if electronic noise interfered with the differential pressure transducers and conductivity probes. Some scientific results are presented in reference 6.

CONCLUDING REMARKS

The KC–135/DC–9 Two-Phase Flow Apparatus has provided excellent data and photographs of low-gravity two-phase flow. It has demonstrated this ability over a wide range of flow conditions while exhibiting excellent capability for time resolution of electronic data and providing splendid images.

REFERENCES

1. McQuillen, J.B.; and Neumann, E.S.: Two-Phase Flow Research Using the Learjet Apparatus. NASA TM–106814, 1995.
2. Yaniec, J.S.: Users Guide for NASA Lewis Research Center DC–9 Reduced-Gravity Aircraft Program. NASA TM–106755, 1995.
3. White, L.G.: JSC Reduced Gravity Program User's Guide. JSC–22803, NASA Lyndon B. Johnson Space Center, 1991.
4. Witte, L.C.; Boosman, W.S.; and Fore, L.B: Studies of Two-Phase Flow Dynamics and Heat Transfer at Reduced Gravity Conditions. NASA CR–198459, 1996.
5. Bean, H.S., ed.: Fluid Meters: Their Theory and Application. ASME, New York, 1971.
6. Bousman, W.S.: Studies of Two-Phase Gas-Liquid Flow in Microgravity. NASA CR–195434, 1995.
7. Schrage, D.S.; and Shoemaker, J.M.: Operational Characteristics of a Two-Phase Free-Vortex Separator for Micro-Gravity Environments. Proceedings of the 30th 1995 National Heat Transfer Conference. ASME HTD–Vol. 307, 1995, pp. 97-104.

APPENDIX A

TPFE PIPING SCHEMATIC PARTS LISTING

Item	Description	Manufacturer	Model No.	Connection Size	Working Pressure	Notes
A01	GAS-SUPPLY CYLINDERS			CGA 346	2,200 PSIG	K BOTTLE
A02	PRESSURE GAUGE	US GAUGE	P500-46994	1/4" NPTF	3,000	0-3000 PSIG
A03	PLUG VALVE	NUPRO	SS-8P6Y	1/2" SWAGELOK	3,000	$C_v = 4.0$
A04	RELIEF VALVE	NUPRO	SS-4R3A5-E	1/4" NPTM	6,000	ADJUSTS 2250-3000 PSI, $C_v = .41$
A05	BALL VALVE	MCF	SRS66HP	1/2" NPTF	4,000	$C_v = 8.0$
A06	PRESSURE REGULATOR	TESCOM	44-1316-2122	3/4" NPTF	3,750	$C_v = 2.0$
A07	SOLENOID VALVE	ASCO	8223G3	1/2" NPTF	1,500	$C_v = 3.2$, 110 VAC, NORM. CLOSED
A08	SOLENOID VALVE	SKINNER	R2H6DL21001	1/4" NPTF	1,000	$C_v = .76$, 24 VDC, NORM. CLOSED
A09	SOLENOID VALVE	SKINNER	R2H6DL21001	1/4" NPTF	1,000	$C_v = .76$, 24 VDC, NORM. CLOSED
A10	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	1,250	0-1000 PSIA, 24 VDC
A11	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	1,250	0-1000 PSIA, 24 VDC
A12	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	1,250	0-1000 PSIA, 24 VDC
A13	SQUARE EDGE ORIFICE	NASA		1/2" AN		ORIFICE DIA .0150
A14	SQUARE EDGE ORIFICE	NASA		1/2" AN		ORIFICE DIA .0425
A15	SQUARE EDGE ORIFICE	NASA		1" AN		ORIFICE DIA .1200
A16	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	150	0-100 PSIA, 24 VDC
A17	CHECK VALVE	NUPRO	SS-16C-1	1" SWAGELOK	2,000	$C_v = 4.68$, 1 PSI CRACKING
A18	RELIEF VALVE	NUPRO	SS-8CPA2-3	1/2" NPTM	3,000	$C_v = 1.2$, ADJUSTS 3-50 PSI
A19	MIXER	NASA		3/4" NPTF	65	HYDRO TESTED 100 PSIG
A20	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	150	0-100 PSIA, 24 VDC
A21	TEST SECTION	NASA			65	HYDRO TESTED 100 PSIG
A22	RELIEF VALVE	NUPRO	SS-8CPA2-2	1/2" NPTM	3,000	$C_v = 1.2$, ADJUSTS 3-50 PSI
A23	COLLECTOR TANK	NASA			35	HYDRO TESTED 45 PSIG
A24	BACKPRESSURE REGULATOR	CASH-ACME	FR-10	2" NPTF	250	0-10 PSI RANGE
A25	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	1,250	0-1000 PSIA, 24 VDC
A26	RELIEF VALVE	NUPRO	SS-4R3A5-C	1/4" NPTF	6,000	ADJUSTS 750-15-- PSI, $C_v = .41$
A27	PLUG VALVE	NUPRO	SS-8P6T	1/2" SWAGELOK	3,000	
A28	SAMPLE CYLINDER	HOKE	6HD500TL	3/8" NPTF	1,800	$C_v = .73$
A29	FILTER	NUPRO	SS-8FT-140	1/2" SWAGELOK	3,000	$C_v = 2.0$
A30	CYLINDER REGULATOR	TESCOM	44-1316-2122-005	1/4" NPTF	3,750	HYDRO TESTED 100 PSIG
A31	FLEX-HOSE	PARKER	881-16	1-5/16-12	250	
A32	FLEX-HOSE	PARKER	550-H-4	1/4" AN	3,000	$C_v = .08$, OUTPUT 2-150 PSI
W01	PRESSURE REGULATOR	TESCOM	26-1631-26	3/8" NPTF	5,000	0-250 PSIA, 24 VDC
W02	PRESSURE TRANSDUCER	SETRA	205-2	1/4" NPTF	375	0-250 PSIA, 24 VDC
W03	BALL VALVE	NUPRO	SS-6P6T	3/8" SWAGELOK	3,000	$C_v = 7.0$
W04	RELIEF VALVE	NUPRO	SS-RL3M4-F4	1/4" NPTM	1,500	$C_v = .6$, ADJUSTS 0-225 PSI
W05	WATER SUPPLY TANK	NASA			65	HYDRO TESTED 100 PSIG
W06	BALL VALVE	DYNAQUIP	1/2 VPB1-AO	1/2" NPTF	3,000	$C_v = 8.3$
W07	SOLENOID VALVE	ASCO	8210D89	1" NPTF	100	$C_v = 13.0$, 24 VDC, NORM CLOSED
W08	TURBINE FLOW METER	FLOW TECH	FMC-75-16M	1" AN	5,000	.40-45 GPM
W09	SOLENOID VALVE	ASCO	8210D89	1" NPTF	100	$C_v = 13.0$, 24 VDC, NORM. CLOSED
W10	NEEDLE VALVE	ENGINEERED CONTROLS	FFG2008SSTA	1" NPTF	10,000	$C_v = 5.22$
W11	NEEDLE VALVE	ENGINEERED CONTROLS	FFG2006SSTA	1" NPTF	10,000	$C_v = 5.22$
W12	CHECK VALVE	NUPRO	SS-16C-1	1" SWAGELOK	2,000	$C_v = 4.68$
W13	CHECK VALVE	NUPRO	SS-16C-1	1" SWAGELOK	2,000	$C_v = 4.68$
W14	BALL VALVE	DYNAQUIP	1/2 VPB1-AO	1/2" NPTF	3,000	$C_v = 8.3$
W15	PUMP	MARCH	AC-5C-MD	1F, 1/2 MPT	50	17 GPM OR 27 FT HEAD MAX
W16	SOLENOID VALVE	ASCO	8210G87	1/2" NPTF	40	$C_v = 4.0$, 24 VDC, NORM. CLOSED
W17	BALL VALVE	DYNAQUIP	1/2 VPB1-A0	1/2" NPTF	3,000	$C_v = 8.3$
W18	SIGHT GAUGE	NASA		3/4" SWAGELOK	65	HYDROTESTED 100 PSIG
W19	3-WAY SOLENOID VALVE	ASCO	8300D76G	1/2" NPTF	75 PSID	$C_v = 1.0$, 120 VAC
W20	METERING VALVE	NUPRO	SS-4MG	1/4" SWAGELOK	1,000 PSIG	$C_v = .03$
W21	METERING VALVE	NUPRO	SS-2MG-MH	1/9" SWAGELOK	3,000	$C_v = .03$
W22	METERING VALVE	NUPRO	SS-2MG-MH	1/8" SWAGELOK	3,000	$C_v = .03$
W23	METERING VALVE	NUPRO	SS-2MG-MH	1/8" SWAGELOK	3,000	$C_v = .03$
W24	PRESSURE TRANSDUCER	DRUCK	PDCR 820	M14 X 1.5	10	0-1 PSIG, 10 VDC
W25	METERING VALVE	NUPRO	SS-2MG-MH	1/8" SWAGELOK	3,000	$C_v = .03$
W26	SOLENOID VALVE	SKINNER	B2DA1175	1/8" NPTF	175 PSID	$C_v = .065$, 24 VDC, NORM. CLOSED
W27	SOLENOID VALVE	SKINNER	B2DA1175	1/8" NPTF	175	v = .065, 24 VDC, NORM. CLOSED
W28	SOLENOID VALVE	SKINNER	B2DA1175	1/8" NPTF	175	$C_v = .065$, 24 VDC, NORM. CLOSED
W29	PRESSURE TRANSDUCER	DRUCK	PDCR 820	M14 X 1.5	10 PSIG	0-1 PSIG, 10 VDC
W30	PRESSURE TRANSDUCER	DRUCK	PDCR 820	M14 X 1.5	10	0-1 PSIG, 10 VDC
W31	FILTER	FACET	569412	3/4" AN	3,000	
W32	FLEX-HOSE			1" AN		HYDRO TESTED 100 PSIG
W33	CHECK VALVE	NUPRO	SS-CH16S16-1/3	1" SWAGELOK	5,000	$C_v = 4.7$ MAX
W34	DESICCATOR	NASA		1/8" SWAGELOK	20	

APPENDIX B
FUNCTIONAL TEST PLAN

1.0 INTRODUCTION

A functional test shall be performed to determine system operational integrity. The test will confirm that all systems are functional, all cables and wiring are connected as required, and all sensors exhibit acceptable noise immunity.

2.0 OBJECTIVE

The objective of the test is to verify the operation of the system. The test will be considered successful if all the sections of this test are performed and passed. If certain sections and/or parts of sections are not required for a certain flight configuration, they may be omitted.

3.0 TEST SETUP

Connect all interconnecting cables as shown in the applicable KC–135 drawings. Connect the 120-V-ac plug to the facility power. Connect the 28-V-dc lines to the power supply.

4.0 POWER–UP PROCEDURE

(1) Verify that all switches are in the OFF position.

(2) Turn on the 28-V-dc Power Supply switch and verify that it is set to 28 V dc.

(3) Turn the 120-V-ac, 60-Hz Power switch on rack 1 to ON. The LED should light up.

(4) Turn the 28-V dc Power switch on rack 1 to ON. The LED should light up.

(5) Turn on the Uninterruptible Power Source (UPS) on rack 3. The UPS will begin to beep.

(6) Press the Control Power switch (LPB1) located on the Control Panel.

(7) Turn ON the Anemometer Power supplies (the green lights should light up), the Conductivity Box, and the STD bus.

(8) Turn the High-Speed Video (HSV), Strobe Light Power Supply, and TV monitor ON.

(9) Set up the HSV.

(10) Set Scene Code to 001 and Press ENTER.

(11) Set switches as follows:

Input: CAM; Mode COLOR
Start Cue: ON
Strobe: OFF
Repeat Rec: OFF
Picture Size: HALF
Freeze: OFF
Freeze Display: OFF

(12) Verify that the LCD display is on. The display should indicate that the software is operating.

5.0 TEST PROCEDURE—SYSTEM DIAGNOSTICS

(1) Set the Program Options (PO) switch (SW23) on the Control Panel (CP) to 0. Press the ENTER button on the CP two times. Set the PO switch to 6 and press ENTER. Set the PO switch to 1 and press ENTER. This enters the Digital Output test.

(2) Disconnect the BNC cables labeled Anemometer Probe (A and B) going to the two Anemometer Signal Conditioners located at the back of rack 2.

(3) Set the G-Level thumbwheel switch (SW20) on the CP to the values listed in the following table and verify that each device turns on correctly. Press the Clock Reset switch (SW16) on the CP to energize the device. The solenoids, which are labeled, will make an audible click if they are energized, and the LED's on the Anemometer Power Box located on rack 3 should light up when the ENABLE switches are ON. Release the Clock Reset switch and the device is de-energized.

G-Level SW20	Device tested	Location	Result–pass/fail
120	Solenoid A07	Rack 1	
[a]122	Recirc. pump W15 3-way valve W19	Rack 3	
129	Anemometer	Rack 3	
132	Solenoid A08	Rack 1	
133	Solenoid A09	Rack 1	
135	Solenoid W09	Rack 1	
136	Purge Solenoid	Racks 1, 2, and 3	
143	Solenoid W07	Rack 1	

[a]Turn the Liquid Recirculation switch (SW29) to ON; W16, W19, and W15 will be energized. Press SW16 and release; W16, W19, and W15 will be de-energized. Turn SW29 OFF.

(4) Next, test the Digital Input lines: Press the ENTER button. Set the PO switch to 2 and press ENTER. Set the G-Level thumbwheel switch (SW20) on the CP to the values listed in the table and verify that each switch functions correctly by noting that the LCD display shows the switch toggling ON and OFF.

G-Level SW20	Switch	Pass/Fail
77	Recirculation switch SW29	
79	ENTER pushbutton SW30	
80	Clock Reset pushbutton SW16	
81	Noflow pushbutton SW12	
82	Autostart pushbutton SW13	
83	Test flow switch FORCE SW11	
84	Test flow switch ARM SW11	
85	Preflow switch FORCE SW10	
86	Preflow switch ARM SW10	
91	W09 switch ARM SW5	
92	W07 switch ARM SW4	
93	A09 switch ARM SW3	
94	A08 switch ARM SW2	
95	A07 switch ARM SW1	

Next test the thumbwheels:

Press the ENTER button. Set the PO switch to 6 and press ENTER.

Set all the thumbwheel switches (SW17 to SW23) to 0. Cycle through each switch section individually and verify that the LCD display displays the same number.

Set the PO switch to 0 and press ENTER until the main menu appears on the LCD display. The top line will read "Two-Phase Flow."

Press the Clock Reset switch and verify that all the 99-sec timers start counting up. Release the switch and verify that the timers return to 0.

Reconnect the BNC cables disconnected in Step 2 in section 5.0.

6.0 TEST PROCEDURE—SENSOR TEST

(1) Press the ENTER button three times. Set the PO switch to 5 and press ENTER. This enters the monitor mode.

(2) Set the PO switch to 2 and press ENTER. This enters the display of the absolute pressure transducers.

(3) Verify that all pressure sensor readings are at ambient pressure, approximately 14.7±1.5 psia.

(4) Press the ENTER button. Set the PO switch to 3 and press ENTER. This enters the display of the thermocouples.

(5) Verify that all temperature readings are at ambient temperature, nominally 70 °F.

(6) Press the ENTER button. Set the PO switch to 7 and press ENTER. This enters the display of the accelerometers.

(7) Verify that the X- and Y-axes are less than ±1 V. Verify that the Z-axis is approximately 9.5±0.5 V.

(8) Remove the BNC cable from the Conductivity Box channel-1 input, located on Rack 3. Connect the test resistor of 5 kΩ to the input.

(9) Press the ENTER button. Set the PO switch to 5 and press ENTER. This enters the display of the Conductivity cells.

(10) Verify that the value of P02 is 4.90±0.5 V

(11) Repeat steps 8 through 10 for channels 2 through 4, for P03 through P05, respectively, and channel 5 for P01.

(12) Press the ENTER button. Set the PO switch to 0 and press ENTER three times.

(13) Fill the accumulator tank to the required level with water.

(14) Toggle the Liquid Recirculation switch (SW29) to ON. The Recirculation Motor (W15) turns on and solenoid valves W19 and W16 open. After several minutes verify that the water starts filling into the supply tank. Once the water level reaches the desired level, about 6 in. from the top, toggle the Liquid Recirculation switch OFF. The supply tank will stop filling.

(15) Press the ENTER button. Set the PO switch to 1 and press ENTER.

(16) Using the LCD display to read the pressures, set WSP to 20 psia using regulator W01.

(17) Press the ENTER button. Set the PO switch to 3 and press ENTER. This enters the display of the liquid flow rate.

(18) Press the C button on W04, the Flow Meter Display. This should display the flow rate of 0.

(19) Toggle the Liquid Flow switch, W07, to FORCE. Verify that water begins to flow through the test section. Compare the values displayed on the flow display and the LCD display and verify that the values are within 0.5 gal/min. Toggle the Liquid Flow switch, W07, to OFF.

(20) Press the ENTER button. Set the PO switch to 9 and press ENTER. This enters the display of the Anemometers.

(21) Disconnect the BNC cables from the test section labeled AN1 and AN2. This is a total of four cables.

(22) Connect the Anemometer Simulator to the cables labeled AN1.

(23) Switch the Computer Override and the Enable switches on the Anemometer Power Box located on rack 3 to ON. Turn on the Simulator and verify that a voltage is displayed on the LCD display for Anemometer 1.

(24) Turn OFF the Simulator and move the switches to OFF. Repeat Steps 21 and 22 for AN2.

(25) Turn the Computer Override and the Enable switches on the Anemometer Power Box located on rack 3 to OFF.

(26) Reconnect the BNC cables disconnected in Step 21.

(27) Press the ENTER button. Set the PO switch to 0 and press ENTER. Set the PO switch to 5 and press ENTER. Set the PO switch to 1 and press ENTER. This displays the readings in volts.

(28) Set the PO switch to 0 and press ENTER three times.

7.0 TEST PROCEDURE—RECIRCULATION AND FLOW

(1) Press the RESET button on the STD BUS CPU Card. Repeat Step 18 of Section 6.0.

(2) Set the following switches to ARM:

SW3	Small Gas Orifice A09
SW4	Liquid Flow W07
SW6	Photo Lights switch
SW7	Camera 1 switch
SW10	Preflow switch
SW11	Test Flow switch

(3) Set the Preflow Time thumbwheel switch (SW21) to 05.

(4) Set the Test Flow Time thumbwheel switch (SW22) to 15.

(5) Set the PO switch to 0 and press ENTER until the main menu appears on the LCD display. The top line will read "Two-Phase Flow."

(6) Press the Autostart switch (SW13). Using the LCD display to read the pressures, set W02 to 25 psia using regulator W01, and A25 to 35 psia using regulator A06.

(7) Press the ENTER button twice. This will enable Preflow for 5 sec and then automatically enable Test Flow for 15 sec. When preflow starts, verify that A09 and W07 are opened, by viewing the test section for liquid with bubbles, and that the high-speed video (HSV) starts recording, at which time the strobe lights will turn on.

(8) Verify after 20 sec has elapsed that the HSV stops recording, the strobe lights turn off, and solenoids A09 and W07 close.

(9) Verify that the LCD display reports saving data to disk. The file names will be the Flight Number (AA) and the Trajectory Number (BB) thumbwheels with several extensions (XXX) as follows: AABB.XXX.

8.0 POWERDOWN PROCEDURE AND EMERGENCY POWERDOWN TEST

(1) Toggle the Anemometer Power supply, Conductivity Box power, TV Monitor, Strobe Light Power Supply, and High-Speed Video switches to OFF.

(2) Press the Control Power switch (SW25) located on the Control Panel. This de-energizes the distribution of 120 V ac and 28 V dc to the entire system. Verify that the UPS begins to beep, signifying that power was lost.

(3) Press the Control Power switch (LPB1). This will distribute power to the system.

(4) Press the Emergency Power switch on rack 2 (the red mushroom-head pushbutton). This de-energizes the distribution of 120 V ac and 28 V dc to the entire system. Verify that the UPS begins to beep, signifying that power was lost.

(5) Repeat Steps 2 and 3 for the Emergency Power switch on rack 3.

(6) Verify that the UPS is functioning. The UPS should be beeping and the rack computer, along with the LCD display, should continue to function. Turn off the UPS.

(7) Turn the 120-V-ac Heater Power switch on rack 1 to OFF. The LED should turn off.

(8) Turn the 28-V-dc Power switch on rack 1 to OFF. The LED should turn off.

(9) Turn the 120-V-ac Power switch on rack 1 to OFF. The LED should turn off.

(10) Turn the 28-V-dc Power supply switch to OFF.

APPENDIX C
CHECKLIST FOR OPERATOR 1 AT RACK 1

1.0 AFTER TAKEOFF

(1) Power up rig
- 120 V ac, 60 Hz
- 120-V-ac heater power
- 28 V dc
- Push Control Power ON button
- Turn ON the HSV system
- Strobe Power supply
- TV Monitor

(2) Set up HSV
- Set Scene Code to 001 and press ENTER
- Verify switches
- Input: CAM
- Mode: COLOR
- Start cue: ON
- Strobe: OFF
- Repeat rec: OFF
- Picture size: HALF
- Freeze: OFF
- Freeze Display: OFF

(3) Set gas pressure
- Shut gas vent valve, A03 (green handle)
- Open K-bottles and pressurize to 1000 psi
- Open gas line and shut off valve, A05 (blue handle)

(4) Set liquid tank pressure
- Close liquid tank vent valve, W03 (green handle)
- Push ENTER on Control Panel (CP)
- Dial 5 on Program Option thumbwheel (POT), SW23
- Push ENTER on CP
- Dial 2 on POT, SW23
- Push ENTER on CP
- Adjust Liquid Pressure Regulator, W01, until WSP reads 25±0.2 psi
- Dial 0 on POT, SW23
- Shut valve, A27, for gas capacitance test
- Press ENTER on CP five times

(5) Set low-resolution collection frequency
- Dial 2 on POT, SW23
- Push ENTER on the CP
- For 1 Hz, dial 1 on POT, SW23
- Push ENTER on the CP

(6) Set high-resolution collection frequency
- Dial 3 on POT, SW23
- Push ENTER on the CP

For 1000 Hz, dial 4 on POT, SW23
Push ENTER on the CP
Dial 0 on the POT, SW23
Push ENTER two times

(7) Initialize liquid flowmeter
Push C button on Flowmeter Monitor, W04

2.0 BEFORE EACH TRAJECTORY

(1) Record scene number on monitor

(2) Set liquid flow rate
Dial Liquid Metering valve, front W10, to Setting
Dial Liquid Metering valve, back W11, to Setting

(3) Verify thumbwheels
Verify Flight Number
Verify SW20 hundreds place set for correct G-level
Verify SW20 tens place set to 0
Verify SW20 ones place set for correct tube diameter
Dial in Preflow and Flow Duration
Dial in Trajectory Number

(4) Set delta pressure range
Dial 0 on POT, SW23
Push ENTER on the CP
Dial 9 on POT, SW23
Push ENTER on the CP
Select range of ÄP with POT, SW23
Push ENTER on the CP
Dial 0 on POT, SW23
Press ENTER on the CP three times

(5) Configure switches
SW1, SW2, SW3 for Gas Flow
SW4, SW5 for Liquid Flow
SW10 for Preflow
SW11 for Test Flow

(6) Check liquid supply volume

(7) Check K-bottle pressure

(8) Notify operator 2 that configuration is complete

(9) Push Autostart, SW13, on CP

(10) Set gas flow rate
Toggle appropriate Gas Orifice switch (SW1, SW2, SW3) from ARM to FORCE
Adjust superficial gas velocity using Gas Regulator, A06 (brass body), from test list ±10 percent
Toggle switch to ARM

3.0 DURING TRAJECTORY

(1) Push ENTER on CP two times to start flow

(2) Push ENTER to turn off purge valves on signal from operator 2, when liquid covers last pressure tap

(3) Monitor flow regime

(4) Use red emergency STOP button if a leak occurs

APPENDIX D
CHECKLIST FOR OPERATOR 2 AT RACK 3

1.0 AFTER TAKEOFF

(1) Close backpressure regulator bypass valve, W17 (orange handle)

(2) Check local switches
- Uninterruptible Power Supply
- STD bus
- Differential Pressure Box
- Conductivity Box —Top of Power SW is IN
  - Range switch to 3
  - Channel switch to 8
- Shear Stress Box
  - Power modules (green light ON)
  - Computer override OFF
  - S2 and S3 Enable ON
- Delta-P Box
  - All switches are OFF

2.0 DURING TRAJECTORY

(1) Notify operator 1 when liquid covers last tap

(2) Monitor flow regime

(3) Monitor pilot tube reference pressure line for liquid and desiccant color

(4) Use red emergency STOP button if a leak occurs

3.0 AFTER EACH TRAJECTORY

(1) Operator 1 will check if liquid is available, and operator 2 will check if collector tank is full. Recirculate if required.

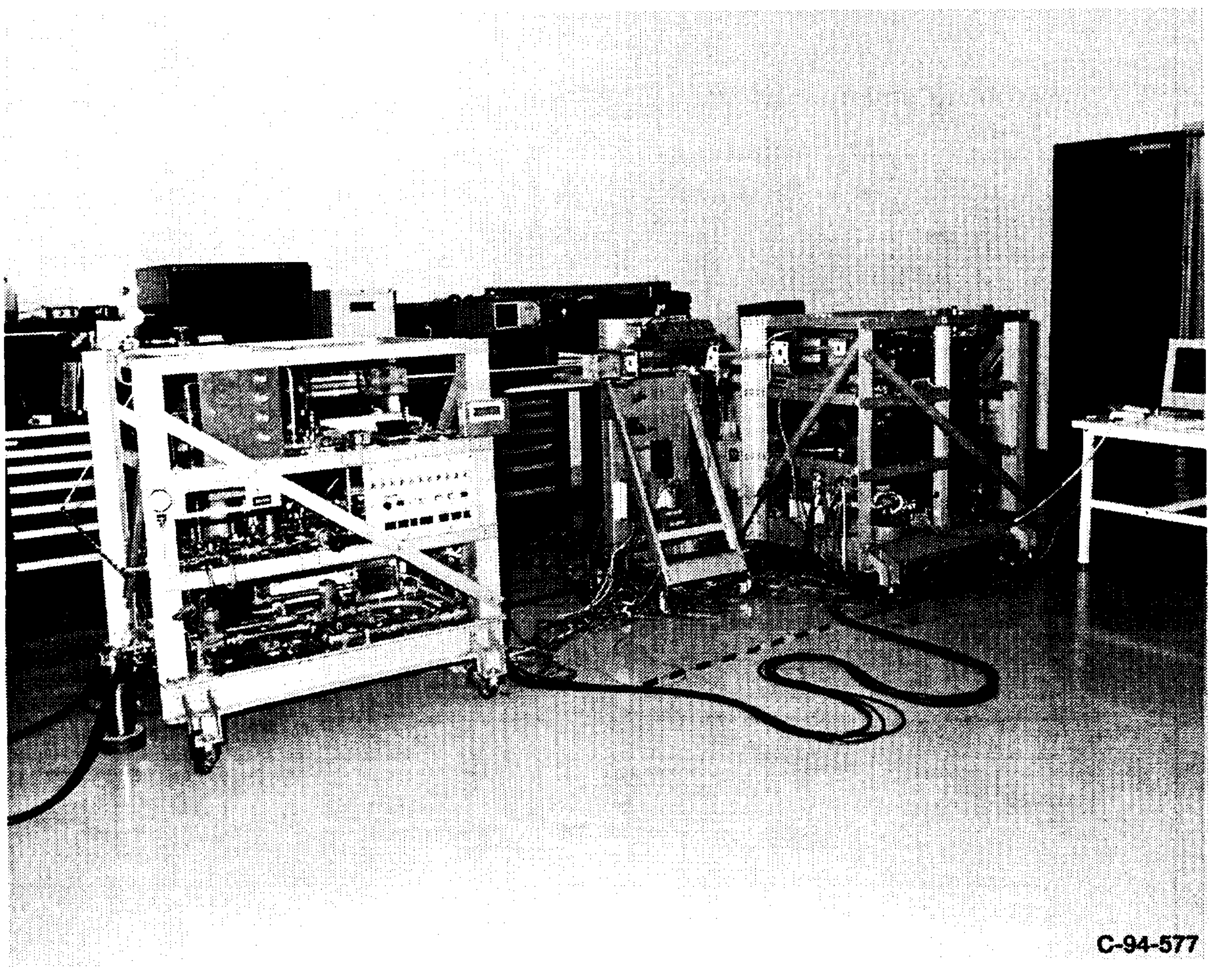

Figure 1.—DC–9/KC–135 Two-Phase Flow Apparatus.

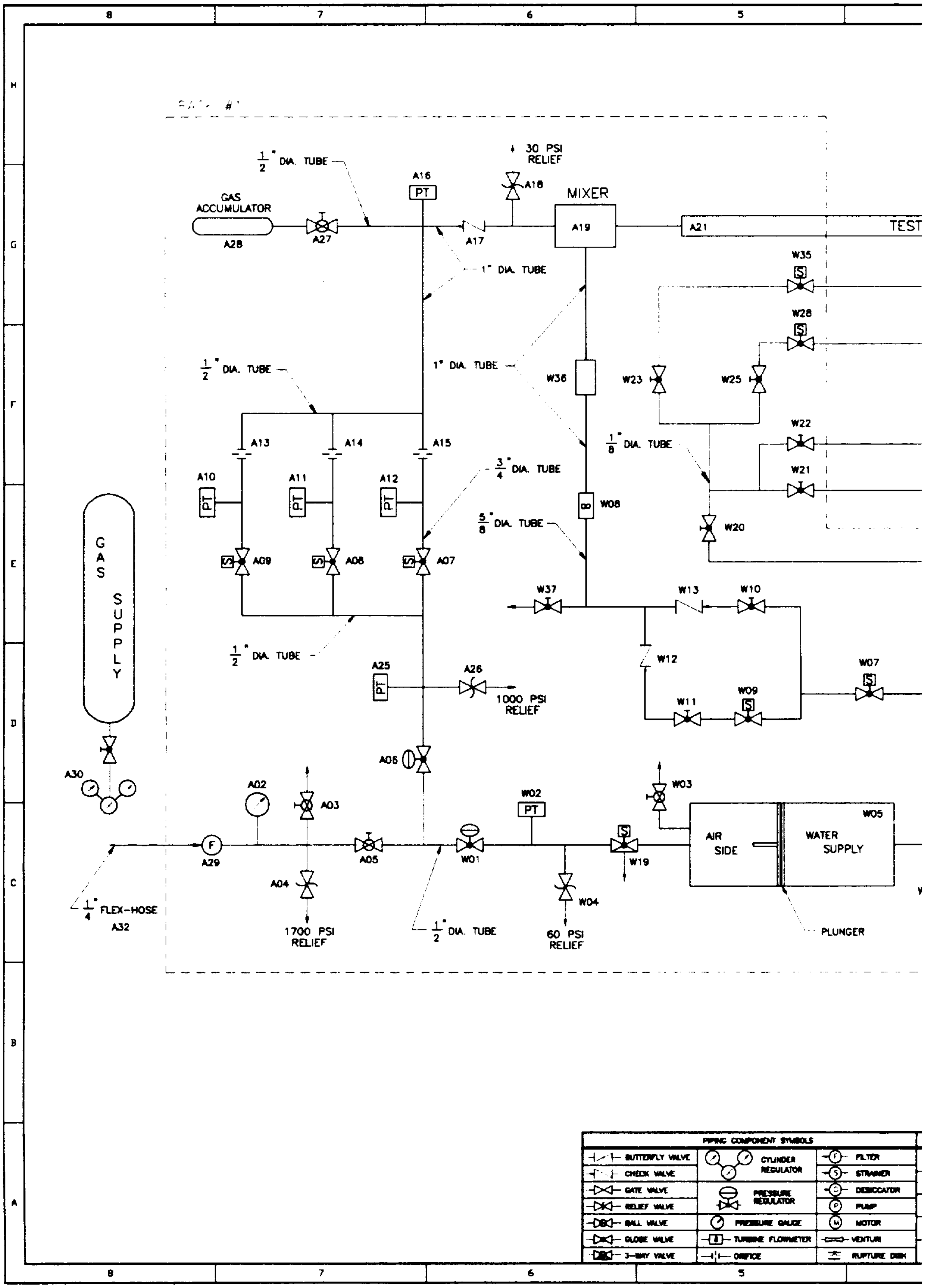

Figure 2.—Two-phase flow experiment piping schematic.

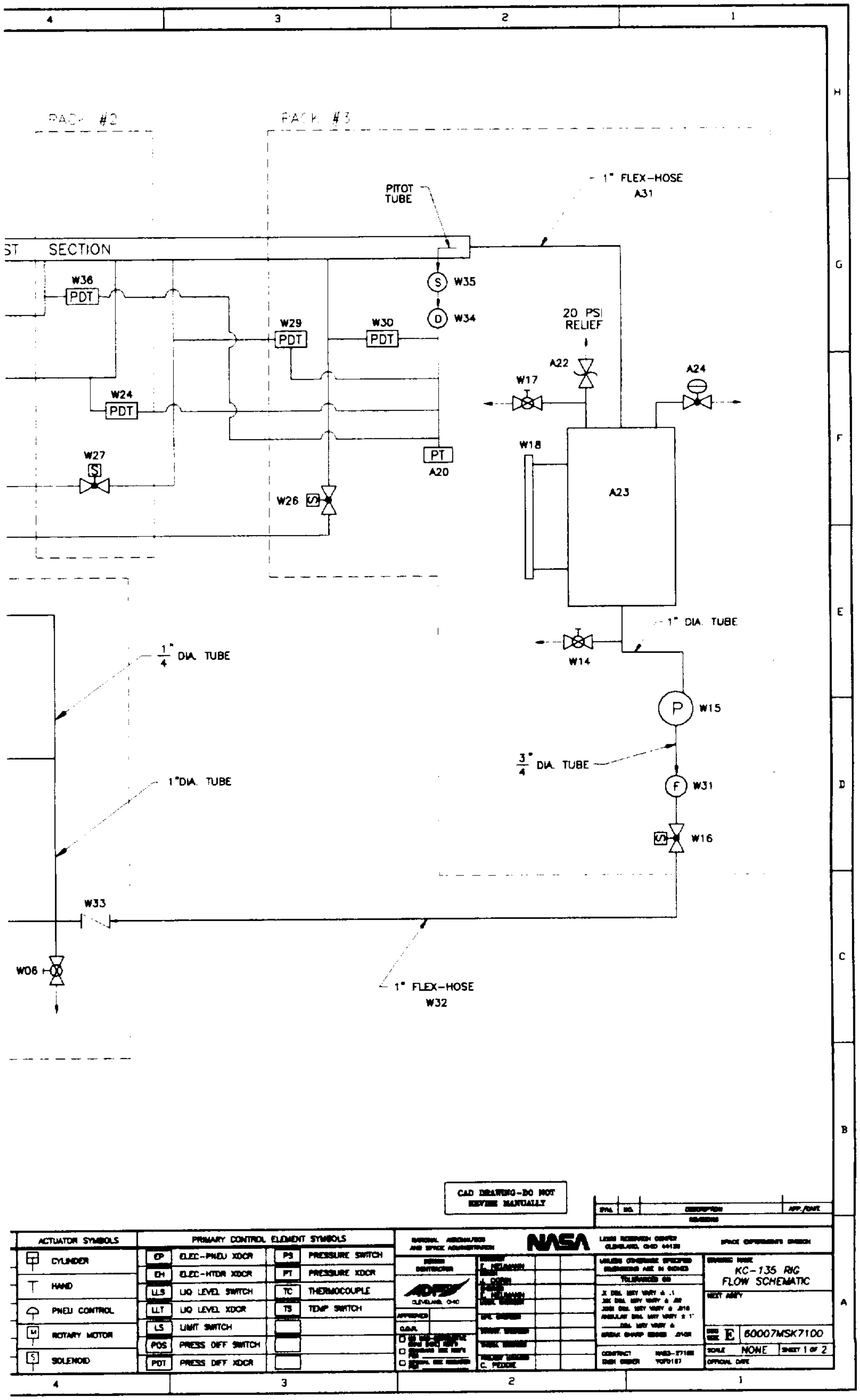

Figure 2.—Concluded.

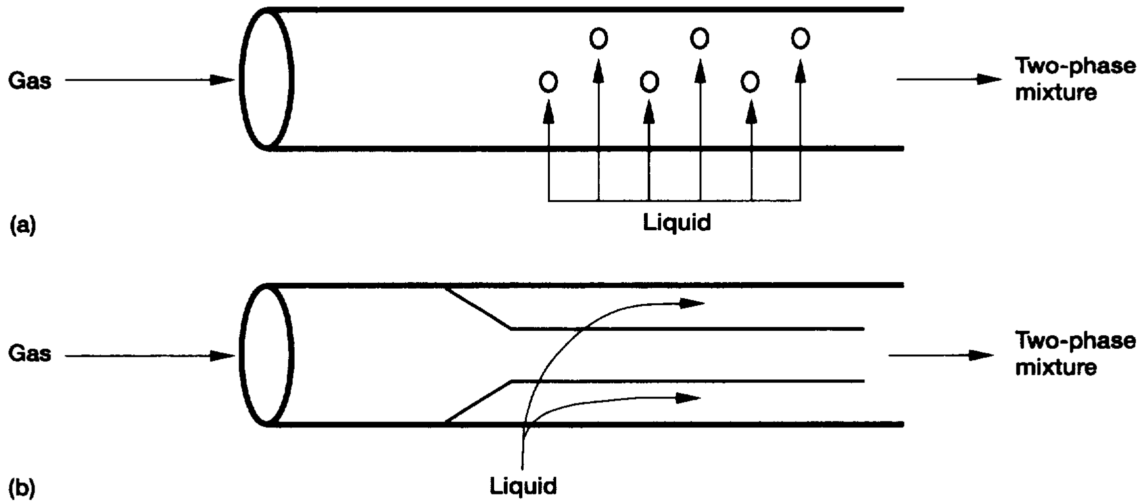

Figure 3.—Two-phase flow mixer configurations. (a) Radial. (b) Annular.

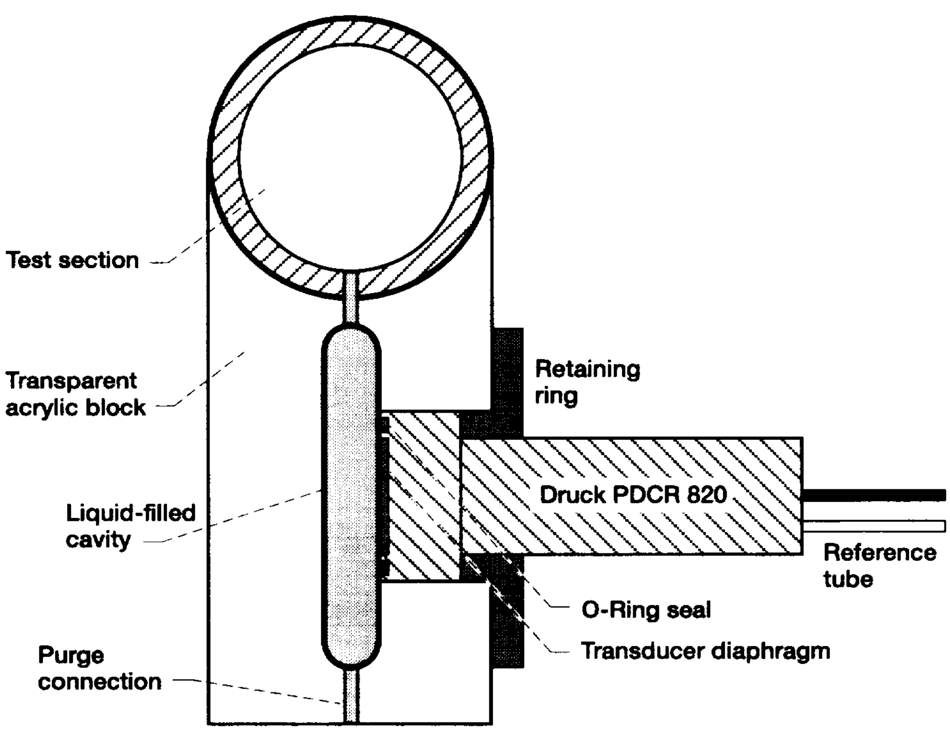

Figure 4.—Differential pressure transducer mounting

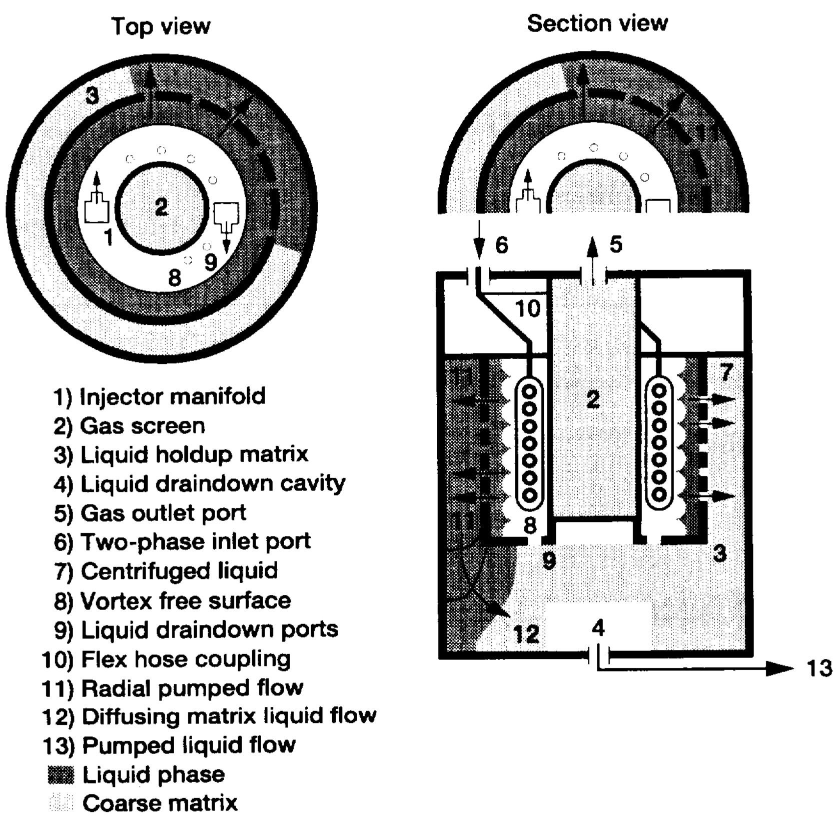

Figure 5.—Illustration of two-phase collector/separator tank.

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13. ABSTRACT ***(Maximum 200 words)***

Low-gravity gas-liquid flow research can be conducted aboard the NASA Lewis Research Center DC–9 or the Johnson Space Center KC–135. Air and water solutions serve as the test liquids in cylindrical test sections with constant or variable inner diameters of approximately 2.54 cm and lengths of up to 3.0 m. Superficial velocities range from 0.1 to 1.1 m/sec for liquids and from 0.1 to 25 m/sec for air. Flow rate, differential pressure, void fraction, film thickness, wall shear stress, and acceleration data are measured and recorded at data rates of up to 1000 Hz throughout the 20-sec duration of the experiment. Flow is visualized with a high-speed video system. In addition, the apparatus has a heat-transfer capability whereby sensible heat is transferred between the test-section wall and a *subcooled* liquid phase so that the heat-transfer characteristics of gas-liquid two-phase flows can be determined.

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