LOW-G PROPELLANT GAGING

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ABSTRACT

This presentation describes a program to develop and demonstrate technology for low-g propellant gaging on future geostationary satellites. The work was performed by McDonnell Douglas Corporation under a contract with the International Telecommunications Satellite Organization (INTELSAT). Although the work pertained to storable propellants, the results can also be applied to cryogenic systems.

Evaluations were performed to select four gaging concepts for ground tests and low-g tests in the NASA KC-135 aircraft. The selected concepts were (1) an ultrasonic point sensor system, (2) a nucleonic gaging system, (3) an ultrasonic torsional wave guide, and (4) an ultrasonic flowmeter. The first three systems provide a direct measurement of propellant quantity remaining, while the fourth system integrates (totalizes) the propellant flow to the engines and infers propellant remaining based on a known initial propellant load. As a result of successful ground and KC-135 tests, two concepts (the ultrasonic point sensor and nucleonic systems) were selected for orbital test in a shuttle Get-Away-Special experiment. These systems offer high end of life accuracy potential and are non-intrusive (external to the tanks and feedlines). The shuttle experiment has been assembled and passed flight certification testing in April 1986. The detailed results from this program are presented in Reference 1.

Eighteen gaging concepts were screened to select the four concepts identified in Figure 1. Ultrasonic point sensors operate by transmitting a pulse through the liquid. The time for the pulse to reflect off the liquid gas interface and return to the sensor provides a measure of liquid depth. By using a surface tension vane device to hold the liquid in a wall-bound orientation, ultrasonic point sensors offer the potential for measuring wall-bound liquid depth in low-g (ultrasonic holography).

A nucleonic gaging system is currently being flown on a satellite to measure the quantity of hydrazine remaining in the propellant tanks. The system employs a Krypton-85 gas radiation source with Geiger-Mueller detectors to measure radiation attenuation across the tank. The amount of radiation attenuation is proportional to the mass of propellant remaining.

The ultrasonic flowmeter consists of two transducers which alternately transmit and receive sonic pulses across the feedline in both an upstream and downstream direction. The flow velocity is calculated as a function of the pulse transit times.

The torsional wave guide is installed inside the tank with a high frequency exciter attached to the end of the wave guide, outside the tank. The exciter transmits an ultrasonic torsional wave, which travels along the wave guide. Since the transit time for the wave is proportional to the integral of wetted length times liquid density (Reference 2), the wave guide provides a measure of settled liquid depth.

GAGING CONCEPTS SELECTED FOR TEST

- **ULTRASONIC POINT SENSORS**
- **NUCLEONIC GAGING**
- **ULTRASONIC FLOWMETER**
- **TORSIONAL WAVE GUIDE**

FIGURE 1

ORIGINAL PAGE IS
OF POOR QUALITY

All four gaging concepts of Figure 1 were evaluated on the ground and in zero- and low-g tests on the NASA KC-135 aircraft. For the zero-g tests, the test article (Figure 2) was free-floated in the cabin of the KC-135. For low-g outflow tests, the test article was strapped to the floor of the aircraft.

Three different surface tension devices were evaluated in the test tank: (1) a radial vane device designed to position liquid in a wall-bound orientation in zero-g; (2) a petal vane device designed to hold liquid in the center and bottom of the tank in zero-g; and (3) an internal bulkhead device designed to hold liquid in the aft end of the tank in zero-g.

KC-135 FREE FLOAT TEST

FIGURE 2

The tests demonstrated successful operation of all four gaging systems. The ability of the ultrasonic point sensors to measure settled liquid depth is shown in Figure 3. Time zero corresponds to the main pulse which causes high amplitude ringing of the sensor. The reflection at 320 microseconds is a measure of the round trip time of the pulse. This value is divided by 2 and multiplied by the speed of sound in the liquid to obtain a measure of liquid depth. For this test, the measured liquid depth was 9 inches (TH-Dimer).

BOTTOM MOUNTED POINT SENSOR TRACE

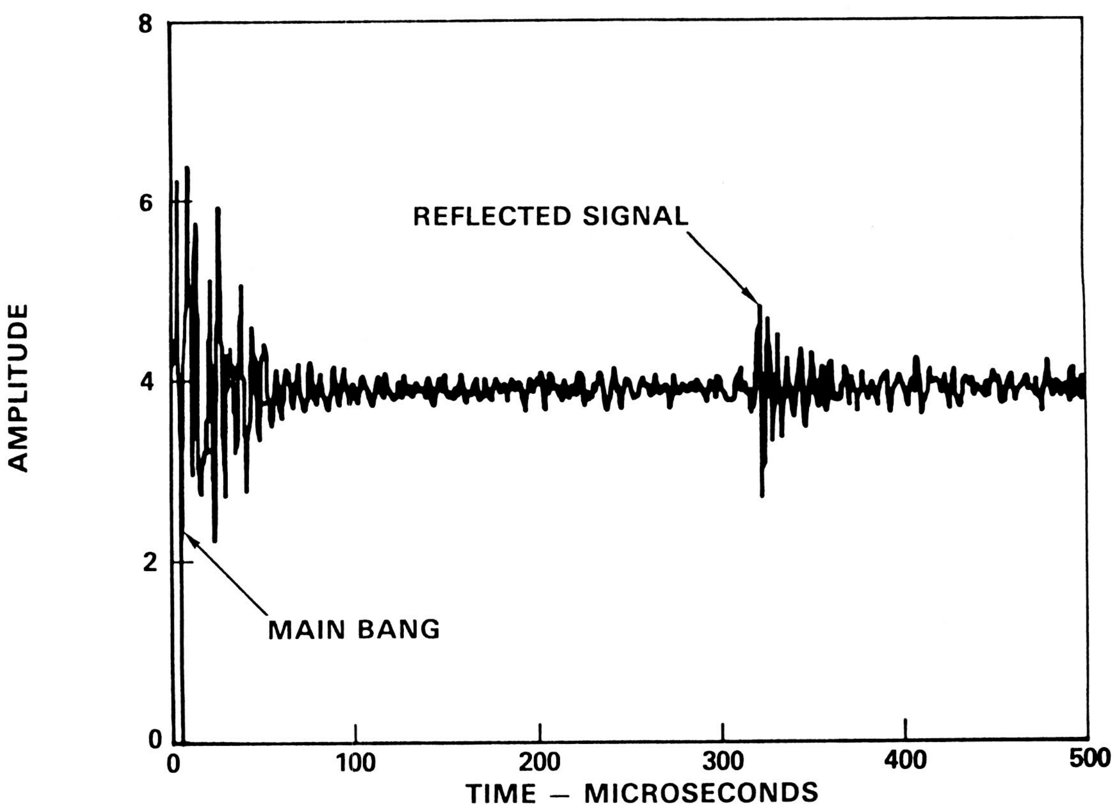

FIGURE 3

Figure 4 shows example traces for two point sensors mounted to the tank side walls. These sensors were used to measure the wall-bound liquid depth during the stable zero-g portion of the parabola, as observed from the flight films. The two reflections at 26.2 microseconds (from sensors 180 degrees apart) correspond to a wall-bound liquid depth of 0.7 inches.

SIDE MOUNTED POINT SENSOR TRACES

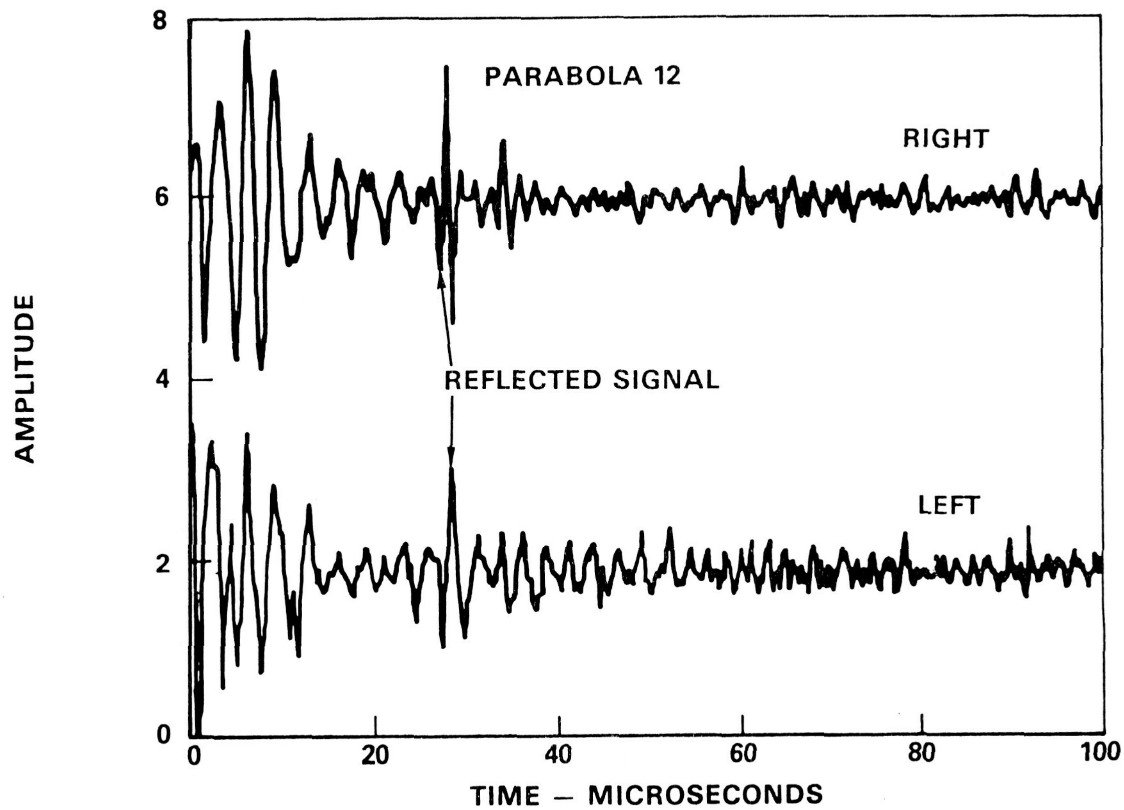

FIGURE 4

Example traces for the nucleonic gaging system using Krypton-85 radiation sources and Geiger-Mueller detectors are shown in Figure 5. The same amount of liquid (TH-Dimer) was loaded for each parabola, however, parabola 2 employed the radial vane device, while parabola 8 employed the petal vane device. The average detector output voltage (3.85 volts) was the same for each parabola, indicating that nucleonic gaging system response was insensitive to the type of propellant acquisition device employed.

The oscillation in the voltage traces is the result of radiation source reflections from the walls and ceiling of the aircraft as the test article is free-floated. In operational usage, reflected radiation would be constant, and these oscillations would not occur.

NUCLEONIC SYSTEM TRACES

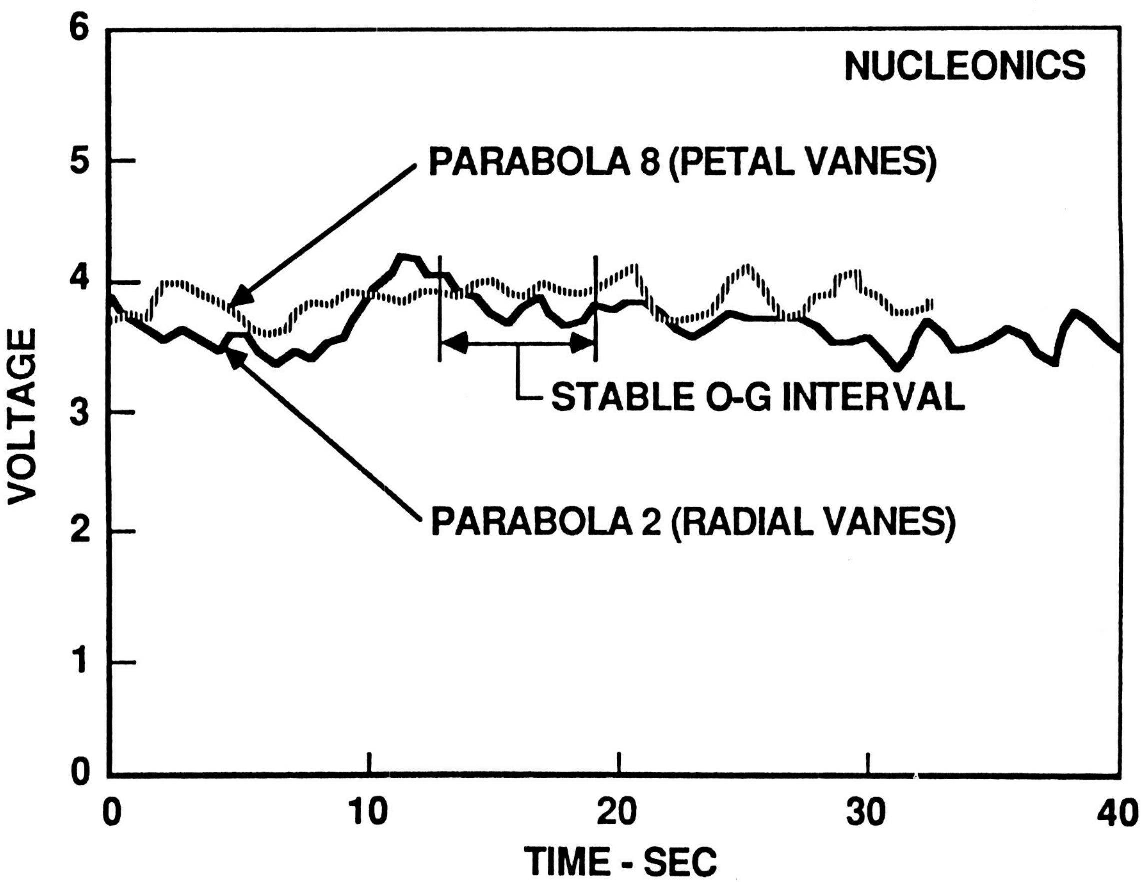

FIGURE 5

Results of low-g outflow tests to compare response of the wave guide, nucleonic, and ultrasonic flowmeter gaging systems are shown in Figure 6. These tests were performed at 0.15g using two outflow rates. As shown in Figure 6, the totalized outflow readings were nearly the same for all gaging systems.

TOTALIZED FLOW READINGS FROM LOW-G TESTS

PARABOLA	GAGING SYSTEM	TOTALIZED FLOW, LBM
1	WAVE GUIDE	4.2
	NUCLEONIC	4.0
	ULTRASONIC FLOWMETER	3.9
	TURBINE FLOWMETER	4.2
2	WAVE GUIDE	4.1
	NUCLEONIC	4.2
	ULTRASONIC FLOWMETER	4.1
	TURBINE FLOWMETER	4.1
3	WAVE GUIDE	1.0
	NUCLEONIC	1.2
	ULTRASONIC FLOWMETER	1.1
	TURBINE FLOWMETER	1.0
4	WAVE GUIDE	1.4
	NUCLEONIC	1.2
	ULTRASONIC FLOWMETER	1.3
	TURBINE FLOWMETER	1.4

FIGURE 6

The conclusions derived from the KC-135 tests are presented in Figure 7. Because of their good performance, and because they are non-intrusive and measure propellant quantity directly, the ultrasonic point sensor and nucleonic gaging systems were selected for further evaluation in a shuttle Get-Away-Special experiment.

KC-135 TEST CONCLUSIONS

NUCLEONIC SYSTEM

- GOOD RESULTS AT ZERO & LOW-G
- INSENSITIVE TO TYPE OF PROPELLANT ACQUISITION DEVICE

ULTRASOINC POINT SENSORS

- SUCCESSFUL MEASUREMENT OF WALL-BOUND LIQUID DEPTH IN ZERO-G

TORSIONAL WAVE GUIDE

- ACCURATE READINGS WITH SETTLED LIQUID
- ZERO-G READINGS INCONSISTENT DUE TO LIQUID HANG-UP

ULTRASONIC FLOWMETER

- ACCURATE TOTALIZED FLOW READINGS

FIGURE 7

The purpose of the shuttle experiment (Figure 8) is to provide an orbital test of both the ultrasonic point sensor and nucleonic gaging systems. The experiment consists of the following elements:

- Plexiglas test tank with ultrasonic and nucleonic gaging systems
- Two-liquid supply (positive displacement) accumulators with associated valving and plumbing
- Support structure
- Power supply
- Control electronics and data acquisition system
- Movie camera and lighting

The overall experiment weighs 145 pounds and will be contained within a standard 5-cubic-foot GAS canister.

SHUTTLE EXPERIMENT

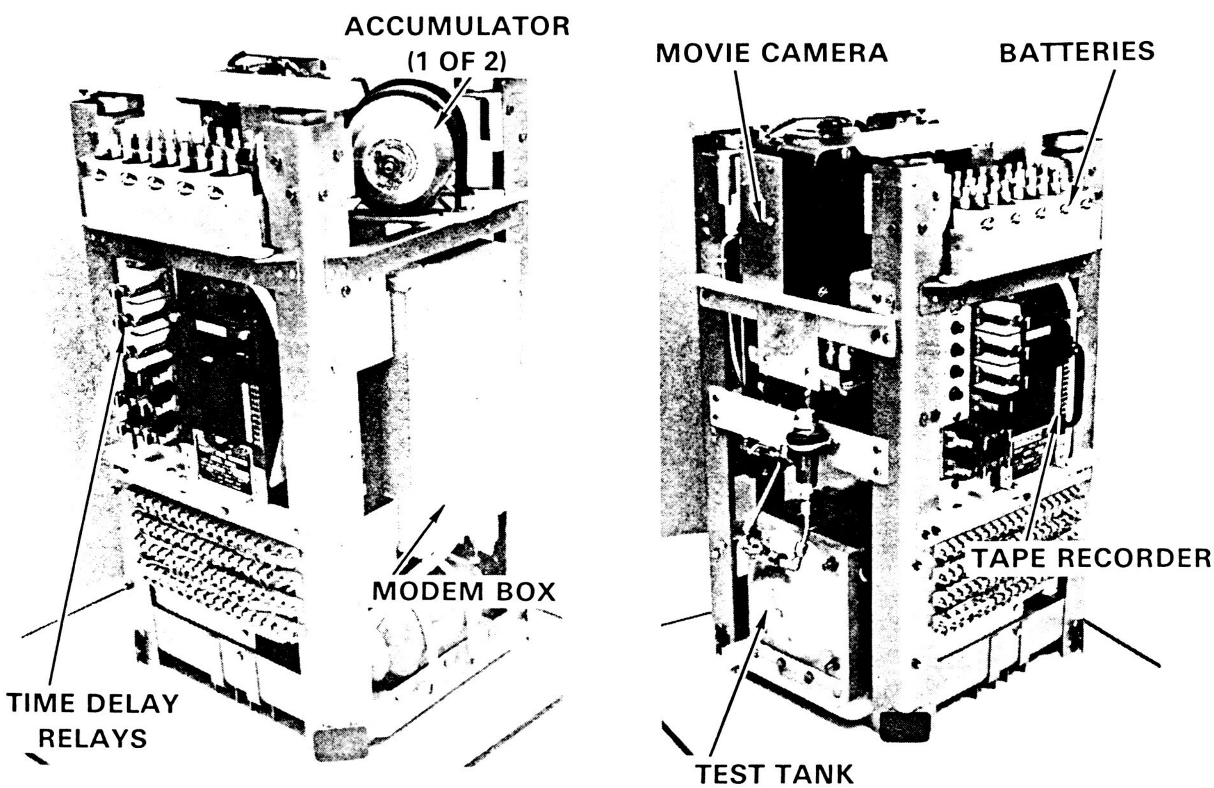

FIGURE 8

To provide calibration data for interpreting the results of the shuttle experiment, additional KC-135 tests were performed using the test article shown in Figure 9. These tests employed the same size tanks to be used in the shuttle experiment and evaluated both the nucleonic and point sensor gaging systems. Calibration data were developed for two test fluids: Freon 113 to simulate nitrogen tetroxide and TH-Dimer to simulate monomethyl hydrazine.

GAGING SYSTEM CALIBRATION TESTS

FIGURE 9

Results of the calibration tests for the nucleonic gaging system are shown in Figure 10. For the same liquid volume, detector output voltage is lower for Freon 113 than TH-Dimer. This is because a greater amount cf radiation is absorbed by the higher density Freon.

NUCLEONIC SYSTEM CALIBRATION DATA

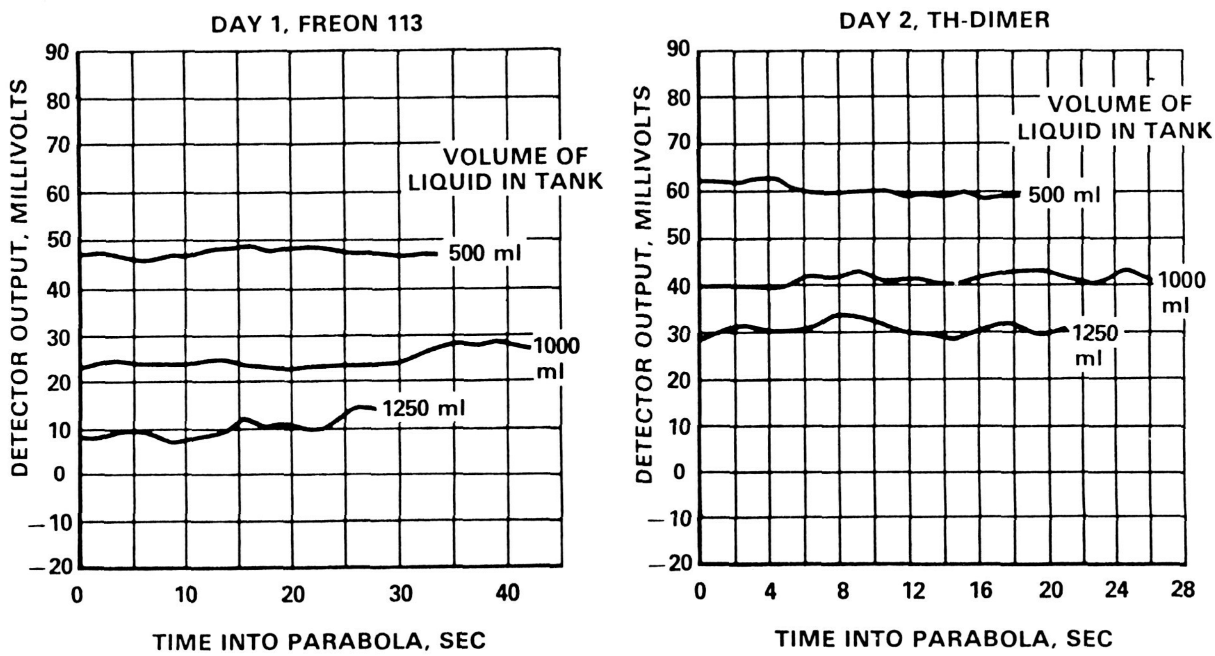

FIGURE 10

Results of calibration tests for the ultrasonic point sensor system are shown in Figure 11. Flight certification testing of the experiment was completed in April 1986, and the experiment is now in storage awaiting a flight assignment.

POINT SENSOR CALIBRATION DATA

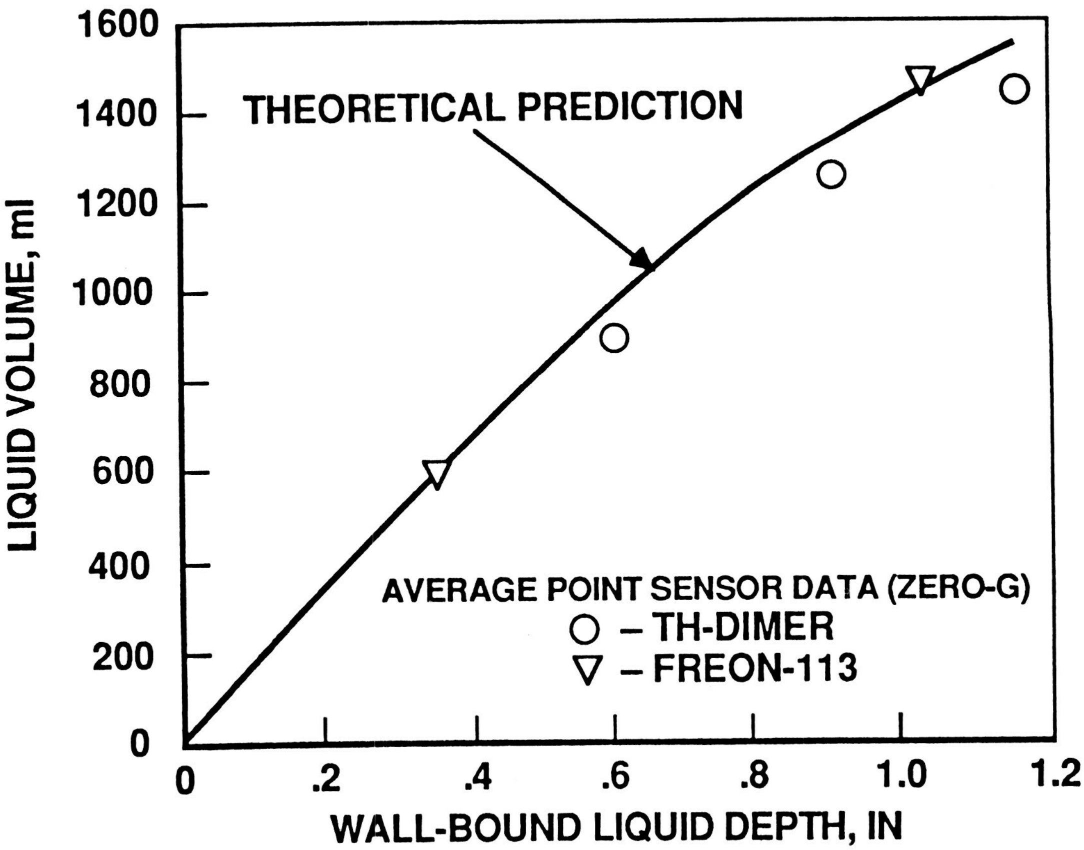

FIGURE 11

SUMMARY

This program has expanded the technology base for direct, non-intrusive gaging systems--nucleonic and ultrasonic point sensors--that are high value candidates for future propulsion systems. The nucleonic system provides a direct measurement of propellant mass remaining and affords high end-of-life accuracy potential. For large diameter tanks employing high density oxidizers (nitrogen tetroxide or oxygen) more energetic radiation sources such as Cobolt 60 would be required. The ultrasonic point sensors measure wall-bound liquid depth and require a geometric algorithm to convert the readings to liquid volume remaining. Tank ultrasonic point sensors could be used in a dual system to provide updates to integrating ultrasonic flowmeters.

1. **LOW-G KC-135 TESTS HAVE DEMONSTRATED FEASIBILITY OF NUCLEONIC & ULTRASONIC PROPELLANT GAGING SYSTEMS**

2. **SHUTTLE FLIGHT EXPERIMENT HAS BEEN BUILT TO PROVIDE ORBITAL DEMONSTRATION**

3. **TECHNOLOGY FOR NUCLEONIC & ULTRASONIC GAGING CAN BE EXTENDED TO CYROGENIC SYSTEMS**

References

1. Orazietti, A. J.; Orton, G. F.; and Schreib, R.: Propellant Gaging for Geostationary Satellites. AIAA Paper 86-1716, June 1986.

2. Bau, H. H.: Torsional Wave Sensor - A Theory. Journal of Applied Mechanics, Vol. 108, December 1986.

SPEAKER: GEORGE ORTON/MCDONNELL DOUGLAS ASTRONAUTICS

Walter Swift/Creare, Inc.:

I have two questions about the nucleonic process. A couple of years ago, we did some density measurements in water, steam-water environments, with a gammadensitometer that we built. The biggest problem we had was the calibration; the fact that you had to use pure vapor and then pure liquid in order to get reasonable sensitivity out of the instrument. As I recall, what happened was the detectors drifted on a day-to-day basis, so you could get good measurements and good accuracy as long as you could calibrate within any 8-hour period. Have you considered that in trying to extend this technique to a 6 or 10-foot diameter tank?

Orton:

No, we haven't made any attempt to extend it to a very large diameter tank. All the applications we've considered have been to tanks probably no more than three feet in diameter and specifically geared to the Intelsat application.

Swift:

I recall that the Nuclear Regulatory Commission has done a lot of work trying to use nuclear gauging systems for reactors; they were trying to deduce what two-phase behavior exists inside the reactor cores. They find they have to lump detectors but not many sources, necessarily, to try to figure out where the gas and liquids are to get a reasonable integrated response. You might also consider that when determining the kind of accuracy you might need in zero-g where the vapor phase could be distributed in funny ways.

Gracio Fabris/Jet Propulsion Laboratory:

Did you consider during the application of the nucleonic system that the flight tanks would not be made out of that material you are using for the demonstration but would be metallic? The ultrasonic system worked well in your test tank, but how would it perform in very complex tank configurations?

Orton:

There is a satellite tank currently flying that has a 6AL4V titanium tank wall, and I don't think that the tank wall materials would have a significant impact on the nucleonic system. It would be a very thin wall tank for flight systems. With regard to the ultrasonic system, how you orientate the liquid in the tank is very critical so you would need an acquisition device for the spherical tank that would hold the liquid in a wall-bound orientation, and that's one big disadvantage of the ultrasonic system if you want to use it for zero-g gauging.

Peter Mason/Jet Propulsion Laboratory:

Did you do experiments over a wide range of ullage volumes? It seems to me that when you are very full or very empty, the liquid distribution might be hard to interpret.

Orton:

We did test down to two-tenths, or 20 percent, and up to 90 percent, in the KC-135 test.

Mason:

Did you get satisfactory results?

Orton:

Yes.

Hugh Arif/Lewis Research Center:

Have you considered the reduction in radioactive power from radio isotopes during long term usage?

Orton:

The Crypton 85 sources that were used in these tests had very very low levels of radiation. In fact we were required to wear dosimeters during the test to measure the amount of radiation received during flight. We took those dosimeters home with us at night, and we got more radiation from watching TV in the room than we did from the Crypton 85. Cobalt 60 is a much more energetic source, but the people at General Nucleonics, who developed this system, say that they handle that routinely and that should not be something that would keep you from using the system in a flight environment.

Arif:

My concern is that over a period of time radioisotopes lose their radioactive power. For long-term cryogenic storage, do you see that that has to be considered?

Orton:

I certainly do. If you want a 10 to 15-year lifetime on your satellite that would be a real consideration.