NASA TM- 83117

NASA Technical Memorandum 83117

NASA-TM-83117 19810016818

EVALUATION OF SEVERAL ULTRASONIC FLOWMETER TRANSDUCERS IN CRYOGENIC ENVIRONMENT

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APRIL 1981

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NF00380

EVALUATION OF SEVERAL ULTRASONIC FLOWMETER

TRANSDUCERS IN CRYOGENIC ENVIRONMENT

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SUMMARY

In Langley Research Center's National Transonic Facility, the flow of large quantities of liquid nitrogen (450 $Kg\text{-}sec^{-1}$) will be measured using an ultrasonic flowmeter. The sensing mechanism employed uses piezoelectric transducers which cause an interaction of acoustic waves with the moving fluid to measure fluid velocity (ref. 1). This paper summarizes the result of thermal cycle tests (295 K to 77 K) performed on various ultrasonic flowmeter transducers from four manufacturers to determine their suitability and reliability for this critical measurement. The tests were performed at a pathlength of 66 cm which simulates that of the NTF flowmeter. Although one Millis Research transducer failed after 51 thermal cycles, test results disclose that all transducers tested have the potential for meeting NTF requirements. However, the epoxied-lead metaniobate displayed the strongest signals and the least signal loss per thermal cycle.

INTRODUCTION

Ultrasonic flowmeters are completely nonintrusive and therefore offer no impedance to fluid flow, have no moving parts, and cover a wide flow range of 100:1 or greater. They are an ideal device for liquid flow measurements. When first used to measure cryogenic fluids however, they proved to be somewhat unreliable because of the inability of the piezoelectric sensors to withstand, for practical periods, the rigors of repeated extreme temperature cycling (295 K to 77 K). This problem was first experienced by Langley researchers in the development of the Shuttle pogo flowmeter and only after concentrated efforts by American and French engineers was the ultrasonic flowmeter rendered useful in the measurement of lox and LN_2. Because of its desirable features the ultrasonic flowmeter was selected for measuring and controlling the NTF LN_2 flow. To assure its suitability for this application, laboratory durability tests were conducted using 18 ultrasonic transducers, all candidates for the NTF flowmeter (fig. 1). The purpose of this paper is to report the results of these laboratory tests which included several different type transducers (American and French), under simulated NTF flow conditions in order to determine their long-term reliability. Identification of commercial products in this report is used to adequately describe the model. The identification of these commercial products does not constitute official endorsement, expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

Test Apparatus

Test apparatus included an open-top rectangular tank constructed of 3-mm-thick aluminum plate 135-cm long, 33-cm deep, and 33-cm wide (fig. 2). A smaller tank was also constructed 120-cm long, 22-cm deep, and 17-cm wide and this was placed inside the larger tank with 8 cm of insulation separating the two tanks (figs. 2 and 3). The small inner tank was the actual test chamber and both tanks were filled with liquid nitrogen. A polyvinylchloride (PVC) adaptor was constructed for holding the transducers. The transmission pathlength was approximately 66 cm. A pulse-echo device (fig. 3) was used to excite the transducer and measure the return signal in order to determine the active life of the crystal and its ability to generate adequate flow sensitive signals without distortion or ringing. All signals were monitored and measured on a dual-beam oscilloscope. Transducer A was tested first and then connections C1 and C2 were switched and transducer B was tested.

PROCEDURE

Eighteen candidate ultrasonic transducers were selected from the following manufacturers: Panametrics, Millis, ONERA, and MAPCO, Inc. Each transducer was installed (in pairs) in an adapter with a transmission pathlength (66 cm) equal to that of the NTF flowmeter. This adapter was then lowered into a styrofoam insulated tank and filled with LN_2. After reaching 77 K, the transducers were then excited with a pulse-echo device and the signal strength measured on a dual beam oscilloscope. After allowing transducers to soak for from 1 to 4 hours, the signal strength was measured again. The adaptor was then removed and allowed to come to ambient temperature. This procedure was repeated a number of times (Table 1) until the testing was completed.

RESULTS

Panametrics Transducers

Two 15-cm-long transducers, 1 MHz epoxied PZT crystal (lead-zirconate-titanate) were thermally cycled. No. 1 was cycled 82 times and No. 2, 58 times. After all tests, both transducers remained active although the signal level was about 20 dB down from 1.5 Vpp. The attenuated signals were nevertheless of sufficient strength to trigger established electronic processing circuits. Two 5-cm-long transducers, 2 MHz epoxied K-81 crystal (lead metaniobate), were also thermally cycled. No. 3 was cycled 77 times and No. 4, 67 times. After all tests, signals were strong at approximately 2 to 2.5 Vpp.

Two other 5-cm-long transducers, 2 MHz soldered PZT crystals (lead metaniobate), were then thermally cycled. No. 5 was cycled 54 times and No. 6, 58 times. After all tests signals were strong at approximately 1 to 2.5 Vpp. (See Table 1.)

All six transducers remained active after all thermal cycle tests.

Millis Research Transducers

The Millis Research Transducers are unique in that the crystal is bonded to a graphite damping material and the stainless steel transducer tip by a thermal diffusion method which was developed by Millis Research Corp. This technique involves tinning both sides of the crystal, the transducer tip, and the damping material with a special solder mixture (proprietary) and producing the bond in a high temperature welding machine.

Initially six 15-cm long, 1 MHz, PZT soldered transducers were thermally cycled. No. 1 and No. 2 were each cycled 60 times and retained strong output signals between 0.9 and 1.2 Vpp. No. 3 was thermally cycled 51 times and retained strong transmission signals between 1.0 and 1.5 Vpp. During testing, No. 4 suffered a separated crystal at the transducer tip. The stainless steel cover (transducer tip) oil canned and separated from the crystal which blocked acoustic transmission although the crystal itself remained active. No. 5 and No. 6 were cycled 59 times and retained a strong signal between 0.7 Vpp and 1.1 Vpp. (See Table 1.)

ONERA Transducers

Four ONERA transducers (Office Nationale D'Etudes et des Recherches Aerospatiales of France), 2 MHz PZT (lead-zirconate-titanate), electron beam welded tips, were all thermally cycled 35 times and none showed any degradation of the signal between 2 Vpp and 3 Vpp. These transducers were a later generation than those used in the Shuttle pogo flowmeters designed by ONERA to investigate pogo-induced flow oscillation in the Shuttle lox feed lines. (See Table 1.)

MAPCO

The MAPCO transducers were thermal cycled 10 times and maintained clean output signals of 1.5 Vpp throughout testing (Table 1).

It is interesting to note that these (same) transducers were originally in a (prototype) ultrasonic flowmeter being tested with LN_2 at the National Bureau of Standards, Boulder, Colorado. During testing (June 1978) the electronics failed and had to be returned to the manufacturer for redesign. This took over 1 year. Meanwhile, the flowmeter body (with transducers) was left in the line at NBS while other testing continued. A meter was connected to the transducers to monitor their activity. During this period the transducers were thermal cycled over 150 times with no loss of signal.

CONCLUSION

Eighteen ultrasonic flow transducers were thermally cycled between 295 kelvin and 77 kelvin repeatedly and their signal strength measured at simulated NTF conditions. The data show that the transducers performed satisfactorily and would be suitable for NTF cryogenic measurements. Since the NTF flowmeter will be occasionally subjected to thermal cycling these tests were performed to determine the endurance and reliability of the transducers when subjected to extreme temperature differences. Because of these favorable test performances it is felt that the problem of transducer reliability in cryogenic ultrasonic flowmeters has been virtually eliminated.

REFERENCE

1. Carpini, T. D. and Monteith, J. H.: "An Ultrasonic Flowmeter for Measuring Dynamic Liquid Flow, NASA TM 78798, October 1978.

APPENDIX A

TRANSDUCER MANUFACTURERS

Panametrics--Panametrics, Inc., Waltham, MA

Millis--Millis Research Laboratory, Boston, MA

ONERA--Office National D'Etudes et des Recherches Aerospatiales, Chalillion, France

MAPCO--Mid-American Pipeline Company, Tulsa, OK

TRANSDUCER IDENTIFICATION									TEST RESULTS		
		MATERIAL					SIZE		OUTPUT IN VOLTS (pp)		
MANUFACTURER	S/N	BONDING TECHNIQUE	CRYSTAL	DAMPING	HOUSING	TRANSMIT FREQUENCY	LENGTH	DIAMETER	NUMBER THERMAL CYCLES	FIRST TEST	FINAL TEST
Millis	1	Thermal Diffusion	*LZT	Graphite	Stainless Steel	1 MHZ	15 cm	20 mm	60	1.2	1.0
Millis	2	Thermal Diffusion	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	60	1.0	.90
Millis	3	Thermal Diffusion	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	51	1.5	1.0
Millis	4	Thermal Diffusion	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	51	Separated Crystal	NA
Millis	5	Thermal Diffusion	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	59	1.1	0.6
Millis	6	Thermal Diffusion	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	59	1.0	0.7
Panametrics	1	Epoxied	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	82	1.5	1.35
Panametrics	2	Epoxied	LZT	Graphite	St. Steel	1 MHZ	15 cm	20 mm	58	1.5	1.35
Panametrics	3	Epoxied	**LM	Graphite	St. Steel	2 MHZ	5 cm	20 mm	77	2.6	2.5
Panametrics	4	Epoxied	LM	Graphite	St. Steel	2 MHZ	5 cm	20 mm	67	2.1	2.0
Panametrics	5	Soldered	LM	Graphite	St. Steel	2 MHZ	5 cm	20 mm	54	1.2	1.0
Panametrics	6	Soldered	LM	Graphite	St. Steel	2 MHZ	5 cm	20 mm	58	2.5	2.5
ONERA	1	Adhesive Methacrylate	LZT	Lucite	St. Steel	2 MHZ	7 cm	10 mm	35	2.0	2.0
ONERA	2	Adhes. Meth.	LZT	Lucite	St. Steel	2 MHZ	7 cm	10 mm	35	2.7	2.7
ONERA	3	Adhes. Meth.	LZT	Lucite	St. Steel	2 MHZ	7 cm	10 mm	35	2.6	2.6
ONERA	4	Ester Anerobic Glue	LZT	Lucite	St. Steel	2 MHZ	7 cm	10 mm	35	2.2	2.1
MAPCO	1	Oil Seal	Unknown	Oil Seal	Teflon	1.5 MHZ	12 cm	27 mm	10	1.5	1.5
MAPCO	2	Oil Seal	Unknown	Oil Seal	Teflon	1.5 MHZ	12 cm	27 mm	10	1.6	1.5

* Lead Zirconate Titanate
** Lead Metaniobate

Table 1. Specification and Test Results for 18 Ultrasonic Transducers Tested for the National Transonic Facility Flowmeter.

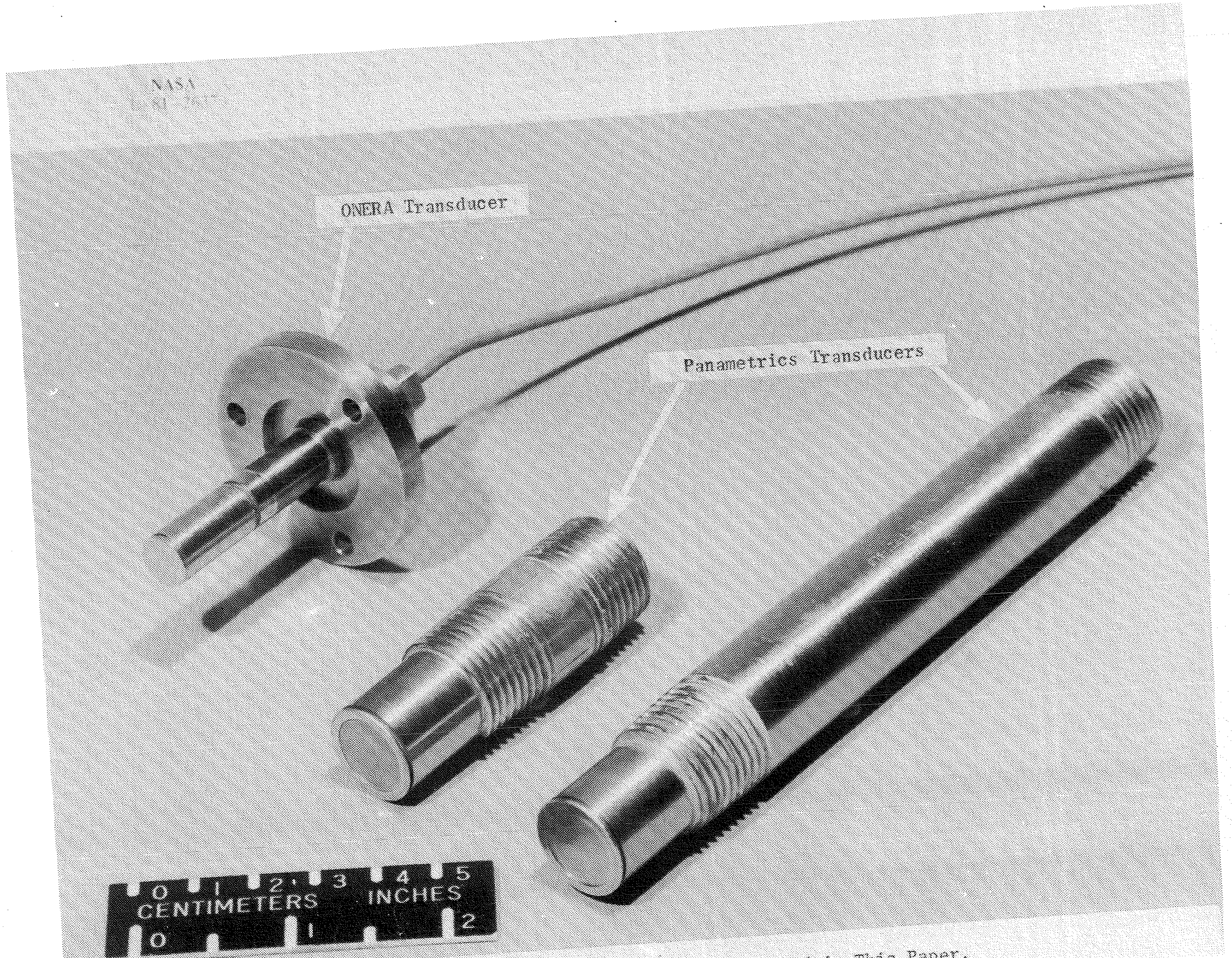

Figure 1. Types of Ultrasonic Flow Transducers Evaluated in This Paper.

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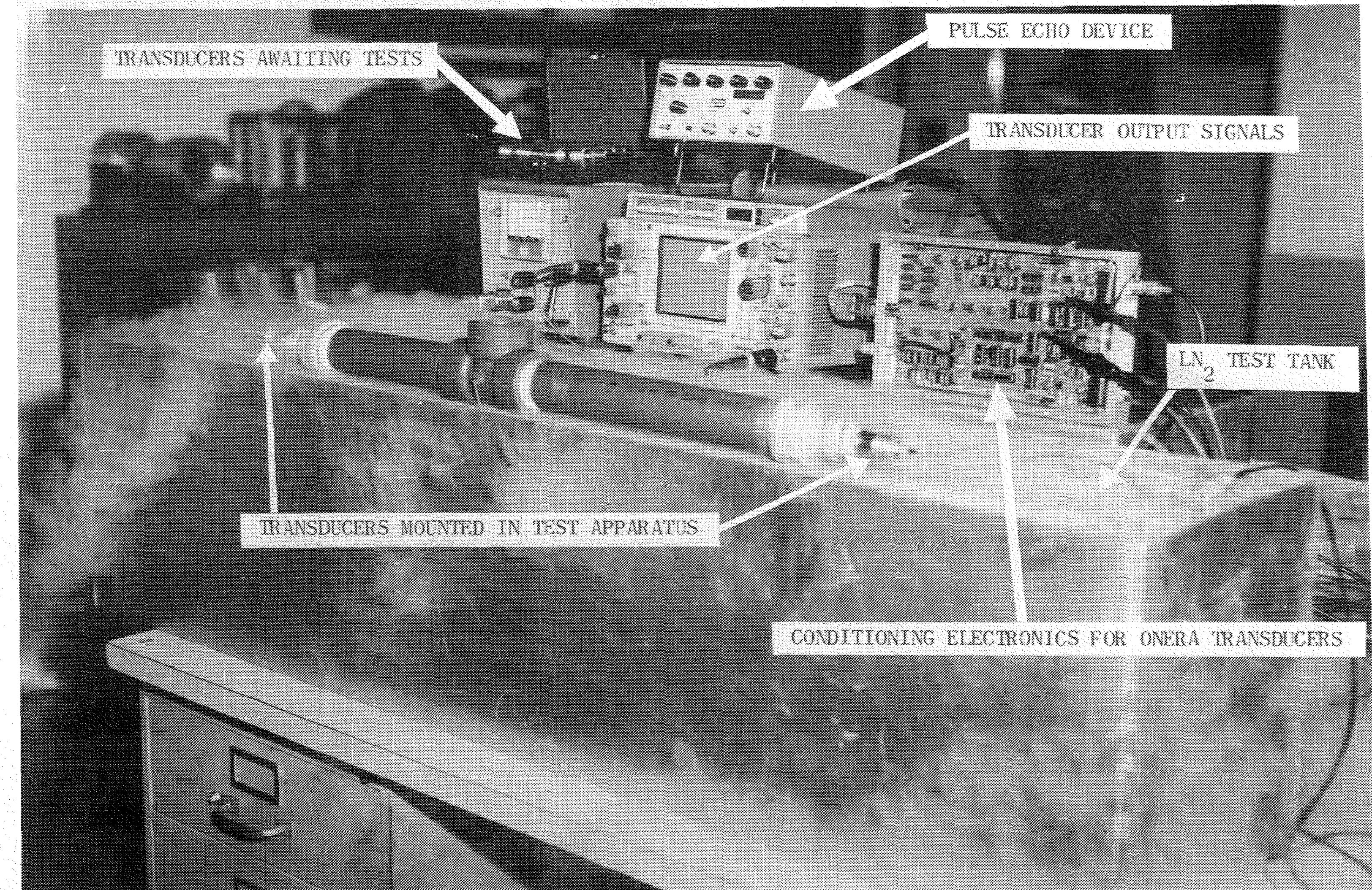

Figure 2. Test Apparatus for the Evaluation of Several Ultrasonic Flowmeter Transducers.

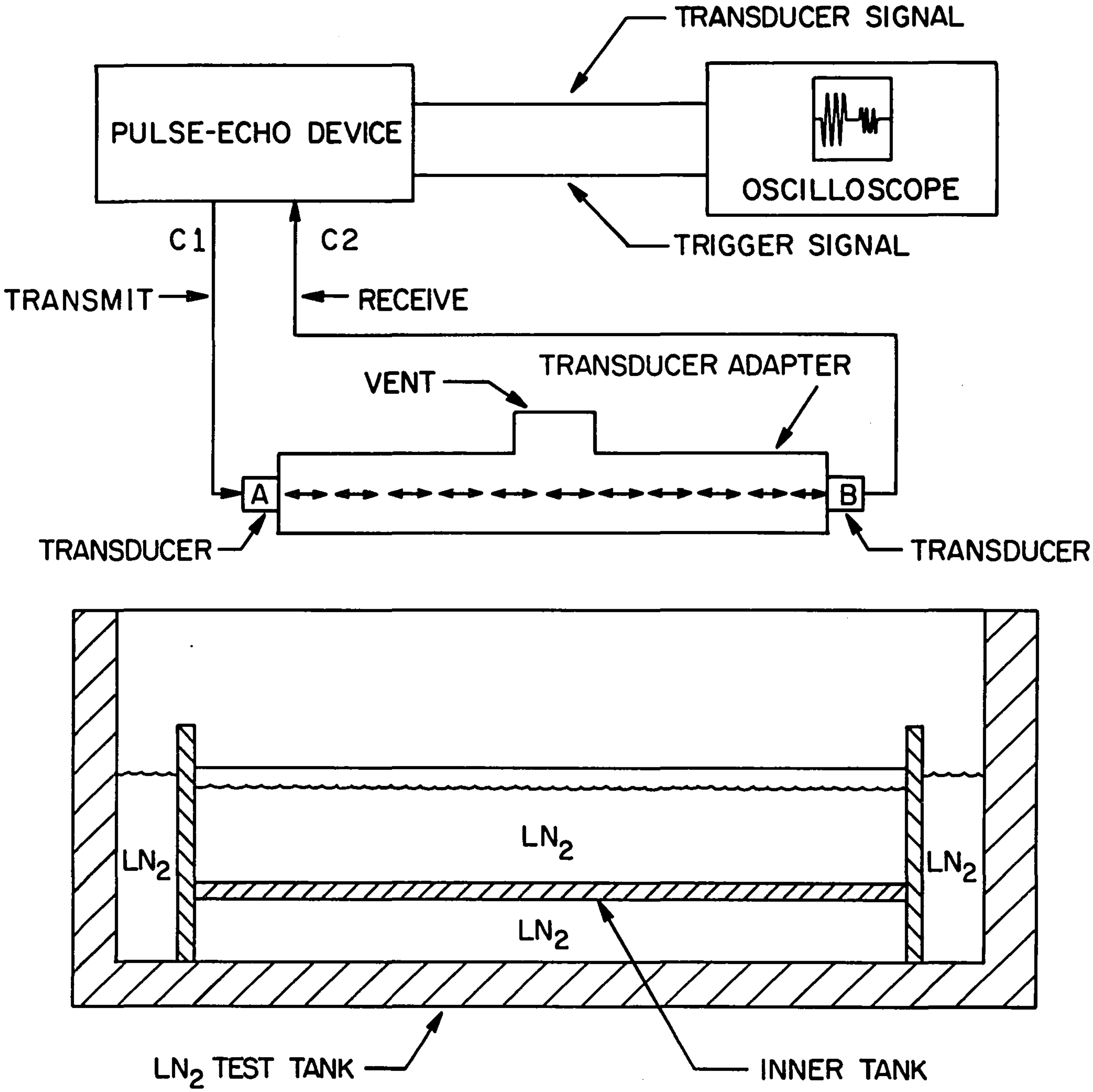

FIGURE 3 - BLOCK DIAGRAM OF THE ULTRASONIC FLOW TRANSDUCER TEST APPARATUS.

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