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EXPOSURE TO ULTRASONIC CLEANER NOISE IN THE CANADIAN FORCES

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ABSTRACT

The high-frequency noise produced by ultrasonic cleaning devices at CFB North Bay and CFB Trenton is sufficiently intense to produce effects such as nausea, headaches, tinnitus and fatigue among exposed personnel. Although the 20-kHz one-third octave-band sound pressure levels observed close to these units are well under 140 dB (the level below which damage to the human ear is thought not to occur), they nevertheless exceed the levels recommended for hearing conservation (105 dB at an operator's position, 95 dB within 15 feet of an operator). The most effective means of reducing the noise radiated from these cleaners is to contain each unit in an appropriately ventilated enclosure or room. Personnel operating or working close to units not enclosed should wear hearing protection.

INTRODUCTION

Ultrasound (the sound produced by an ultrasonic source) is defined as sound occuring at frequencies above the audible range of man (typically above 16 or 17 kHz). Human exposure to intense levels of ultrasound has become relatively common since the introduction of jet engines into military and civilian aircraft operations. The ultrasonic energy in close proximity to these engines can be as intense as the audible-frequency components of the engine's noise (Macpherson and Thrasher, 1959; Parrack, 1966). The effects that result from exposure to such levels of ultrasonic energy were first observed on a large scale in personnel working around military jet aircraft. Termed 'ultrasonic sickness', these effects include headaches, vertigo, nausea and excessive fatigue. Acton and Carson (1967) have reported that these subjective effects do not occur unless an individual's hearing extends to at least 17 kHz and the sound pressure level in the 17-kHz region exceeds 78 dB. They have noted that women experience adverse symptoms more often than men, and young men more often than old, presumably due to differences in high-frequency hearing acuity rather than sex or age.

Ultrasonic devices have now found wide application in industrial processes such as drilling, cleaning and welding. The Canadian Forces employ ultrasonic cleaning systems (e.g., Lewis Ultrasonic Cleaner Model L/C 136H manufactured by the Lewis Corporation (Figures 1 and 2); Hyper-Intense Proximinal Scanning Ultrasonic Cleaner (HIPS) Model AC 2858-IX, manufactured by Cavitron Ultrasonics Inc. (Figures 3 and 4)) for aircraft maintenance purposes, and personnel working near these cleaners have reported symptoms of 'ultrasonic sickness'.

Because the units operating these devices (the Aircraft Maintenance Development Unit (AMDU), CFB Trenton, and the Aircraft Maintenance Control and Records Office (AMCRO), CFB North Bay) did not have the equipment required to measure ultrasound, the Sonics Section of DCIEM was requested to take the following action:

1. Determine the levels of ultrasound being produced by the cleaning units.

2. Provide information on the hazards associated with exposure to ultrasound.

3. Measure the effectiveness of the enclosure fabricated at CFB North Bay and the Cleaning Rooms at CFB Trenton in reducing the amount of ultrasound being radiated.

4. Recommend procedures and/or exposure limits in order to minimize the effects of ultrasound upon personnel.

PROCEDURE

The sound fields produced by one HIPS and three Lewis ultrasonic cleaners (in the AMCRO section (CFB North Bay), the AMDU section and No. 3 Hangar (CFB Trenton)) (see Figures 4, 5 and 6) were measured (overall and octave-band sound pressure levels) using a Bruel and Kjaer type 2209 Sound Level Meter. For certain conditions, the sound was also recorded on a Nagra type IV-SJ Tape Recorder for subsequent one-third octave-band analysis.

RESULTS AND DISCUSSION

The results of the overall and octave-band noise measurements are given in Table I to V for various conditions and locations around the cleaners. It can be seen that the most intense noise produced by the cleaners occurs in the 16-kHz octave band. A narrow-band analysis of this noise shows, in fact, that its peak occurs in the 20-kHz one-third octave-band, the operating frequency of the HIPS and Lewis Ultrasonic cleaners (see Tables VI to IX). It is noted that the noise produced by Lewis Generator No. 688 (Table VII) peaks at 16 kHz due to the inadvertent misadjustment of the machine's operating frequency during maintenance. Note also that considerable noise is generated below 20 kHz due to cavitation in the cleaning solutions. Minute bubbles are formed in the liquid and grow until they reach a resonant size, at which time they oscillate with increasing amplitudes until implosion occurs (Hughes, 1965).

The first question to be answered is whether these levels are sufficiently intense to cause tinnitus and the feelings of nausea and fatigue reported by personnel working in the vicinity of the cleaners. It is noted that the noise levels (in the 1.25- plus 16-kHz one-third octave bands) produced by the ultrasonic cleaners (when not enclosed) range from 82 to 97 dB (see Tables VI to IX, last line), thus exceeding the 78-dB criterion of Acton and Carson (1967), and are therefore intense enough to produce the reported symptoms. One of the authors (RBC) himself experienced extraordinary fatigue and an 'unnatural sensation' in his ears after a two-hour exposure (without hearing protection) in the ultrasonic room at CFB Trenton.

A second question is whether the noise levels reported above are hazardous to hearing. Parrack (1966) has concluded that ultrasonic fields should not be harmful to the human ear until the octave-band or one-third octave-band sound pressure levels approach

140 dB.

At the same time, it is recognized that a hazard may exist due to subharmonic energy accidentally generated by ultrasonic equipment. As a result Parrack has recommended that the 20-kHz one-third octave-band sound pressure level, measured at the ear of an operator of ultrasonic generating equipment, should not exceed 105 dB. Likewise, the 25-, 31.5- and 40-kHz one-third octave-band sound pressure levels should not exceed 110, 115 and 115 dB respectively. Further, the sound pressure level in the 20-kHz one-third octave band should not exceed 95 dB for general advetitious exposures of people within 15 feet of the operator's position (Guignard, 1973). Although the 20-kHz one-third octave-band sound pressure levels observed around the unenclosed ultrasonic cleaners at CFB North Bay and CFB Trenton are well below the 140-dB limit thought to be non-injurious to hearing, the levels do exceed the 105-dB criterion suggested by Parrack.

The enclosure fabricated at CFB North Bay, constructed from 3/4 inch plywood, lined with one-inch styrofoam, and fitted with a top lid and front panel which are hinged with piano-type hinges, (Figures 8, 9 and 10) is effective in attenuating the noise produced by their ultrasonic cleaner. At the operator's position (with the cleaner lid closed), the enclosure reduces the cleaner noise from 94 to 65 dBA, and in the 12.5- plus 16-kHz one-third octave bands, from 85 to 55 dB.

It is observed that a vertical force of approximately 30 pounds is required to lift the top lid on this enclosure. The addition of a mechanical assist and a small access panel to provide access to the cleaner controls would reduce much of the inconvenience that has resulted from the use of the enclosure.

The rooms constructed in No. 3 Hanger (Figure 6) and in the AMDU (Figure 7) at CFB Trenton[1] effectively reduce the sound produced by the ultrasonic cleaners in other areas of these buildings. In No. 3 Hanger, the sound pressure level at the operator's position is 94 dBA; outside the room at the Silting Index Bench and

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[1] The room in the AMDU is constructed using 1/2" gypsum board on both sides of 2" x 4" studs. The room in No. 3 Hanger has walls with 1/4" plywood on one side and 1/4" plywood and 1/2" tentest on the other side of 2" x 4" studs, with the space between filled with fibreglass. No attempt has been made to seal the doors in either room, and in fact, there are at least 1/2" air spaces under the doors.

at the Filter Bench, the levels are 54 and 51 dBA respectively. In the 12.5- plus 16-kHz one-third octave bands, the sound pressure levels inside the room (with the ultrasonic cleaner lid open) are 91 and 60 dB respectively.

Likewise, the sound pressure levels inside the cleaner room in the AMDU are 79 to 95 dBA (depending upon operating conditions (Table II)); outside the room it is 50 dBA.

Placing plastic absorbers on the surface of the ultrasonic cleaner fluid has about the same effect on sound radiation as does closing the lid of the cleaner. Without absorbers on the surface, for example, the sound radiated from the cleaner in the 12.5- plus 16-kHz one-third octave band drops from 90 to 88 dB when the lid is closed. Leaving the lid open and placing absorbers on the surface of the cleaner fluid reduces the radiated sound from 90 to 87 dB. Closing the cleaner lid and placing absorbers on the surface of the fluid does not result in additional noise reduction, due presumably to the fact that other modes of radiation become dominant.

CONCLUSIONS

The high-frequency noise produced by ultrasonic cleaning devices at CFB North Bay and CFB Trenton is sufficiently intense to produce effects such as nausea, headaches, tinnitus, fatigue etc., among exposed personnel.

Although the 20-kHz one-third octave-band sound pressure levels observed close to these units are well under 140 dB (the level below which damage to the human ear is thought not to occur), they nevertheless exceed the levels recommended for hearing conservation (105 dB at an operator's postion, 95 dB within 15 feet of an operator).

The enclosure fabricated at CFB North Bay reduces the noise produced by the ultrasonic cleaner in the AMCRO below the level where the above effects begin to occur. The addition of a mechanical device to assist in lifting the enclosure lid, and a small access panel to provide access to the cleaner controls, would make the cleaner more convenient to use.

The rooms constructed in No. 3 Hanger and in the AMDU at CFB Trenton effectively reduce the sound produced by the ultrasonic cleaners from propagating to other areas of these buildings. Of course, personnel required to work inside these rooms receive no protection from the generated noise.

The plastic absorbers on the surface of the cleaning fluid inside the ultrasonic tanks have about the same effect on reducing radiated sound (by 2 to 3 dB) as does closing the cleaner lid. It has been suggested that a greater reduction might be achieved (perhaps 10 dB on the A-weighted scale) by isolating the ultrasonic tank (Figure 2) from the remainder of the cleaner unit. It would appear, however, that this rather complex modification is not warranted since the resulting reduction in noise level would not be sufficient to completely alleviate the above exposure effects.

The most effective means of reducing the noise radiated from ultrasonic cleaners is to contain each unit in an appropriately ventilated room or enclosure. An enclosure should include an easy-to-operate lid and convenient access to the cleaner controls.

RECOMMENDATIONS

1. Ultrasonic cleans should be enclosed to minimize the effects of ultrasonic exposure upon operators and personnel working in proximity with the devices.

2. Personnel who operated ultrasonic cleaners that are not effectively enclosed, or who work in environments where the noise radiated from such cleaners produces effects such as nausea, headaches, fatigue, tinnitus etc., should wear Canadian Forces standard issue ear plugs or earmuffs while being thus exposed.

ACKNOWLEDGEMENTS

The authors wish to thank Capt. J. Butterfield, AMDU, CFB Trenton, and Capt. R. Payne, AMCRO, CFB North Bay, for the cooperation and assistance provided by they and their staffs during this investigation.

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TABLE I

SOUND PRESSURE LEVELS IN dB re $2x10^{-5}$ N/m^2 IN THE AMCRO ULTRASONIC CLEANER ROOM, CFB NORTH BAY

CONDITION AND LOCATION	OVERALL SPLs in dB			OCTAVE-BAND SPLs in dB										
	Linear 2Hz-40 kHz	C-wt dBC	A-wt dBA	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 KHz	2 KHz	4 KHz	8 KHz	16 KHz	31.5 KHz
Operator Position Lid Closed Cabinet Closed	79	67	65	62	56	58	53	52	46	42	43	59	77	68
Operator Position Lid Closed Cabinet Open	99	95	94	63	52	64	55	53	53	51	62	81	97	95
Operator Position Lid Open Cabinet Open	108	100	97	63	53	65	55	55	53	55	71	84	107	98
Workbench (12') Lid Closed Cabinet Closed	73	66	62	62	63	55	56	50	51	40	39	47	72	64
Workbench Lid Open Cabinet Open	98	90	87	58	58	52	55	50	50	49	59	71	98	68
Desk (18') Lid Closed Cabinet Closed	60	61	53	55	50	52	49	48	48	46	44	43	49	41
Desk Lid Open Cabinet Open	87	70	71	54	53	53	52	49	48	48	61	74	86	80
Operator Position Lid Open Cabinet Open Cabinet Front Open	106	101	96	60	58	57	57	56	55	54	67	76	106	86
Operator Position Room Ambient (Cleaner Off)	61	60	45	60	47	49	49	43	39	36	32	27	25	23

TABLE II

SOUND PRESSURE LEVELS IN dB re $2x10^{-5}$ N/m^2 IN THE AMDU ULTRASONIC CLEANER ROOM AT THE OPERATOR POSITION (CFB TENTON)

CONDITION	OVERALL SPLs in dB			OCTAVE-BAND SPLs in dB										
	Linear 2 Hz-40 kHz	C-wt dBC	A-wt dBA	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz	31.5 kHz
Generator No. 688 Lid Closed	85	78	79	47	44	53	54	48	45	41	43	64	86	70
Generator No. 688 Lid Open	93	85	84						70	68	65	63	88	73
Generator No. 684 Lid Closed	100	91	89						50	50	60	77	100	87
Generator No. 684 Lid Open	104	89	90	49	51	53	59	63	49	53	61	80	103	90
Generator No. 684 Lid Closed Spray, Circulation, Blowers On	100	89	89	54	60	71	69	68	60	57	60	77		
Generator No. 1063 Lid Closed	99	90	89						50	48	59	77	99	80
HIPS Cleaner No Circulation	102	93	95	47	49	56	48	50	51	56	78	83	102	81

TABLE III

SOUND PRESSURE LEVELS IN dB re $2x10^{-5}$ N/m^2 IN THE AMDU ULTRASONIC CLEANER ROOM AT THE OPERATOR POSITION USING PLASTIC GEOMETRIC SHAPES AS SURFACE ABSORBERS (GENERATOR NO. 684)

CONDITIONS	OVERALL SPLs in dB			OCTAVE-BAND SPLs in dB										
	LINEAR 2 Hz-40 kHz	C-wt dBC	A-wt dBA	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz	31.5 kHz
Lid Closed	106	92	95	51	53	53	53	55	50	49	61	83	106	94
Lid Open	112	101	102	51	57	54	54	56	52	53	65	84	112	98
Lid Closed, Water Surface Covered with Plastic Shapes	104	94	93	52	54	54	53	55	52	55	64	86	104	94
Lid Open, Water Surface Covered with Plastic Shapes	106	95	94	51	54	55	53	55	54	56	65	87	106	93
Lid Open, Plastic Shapes Removed Basket Removed	116	102	102	51	57	52	55	55	52	55	68	92	113	98

TABLE IV

SOUND PRESSURE LEVELS IN dB re $2x10^{-5}$ N/m^2 IN AND AROUND THE AMDU ULTRASONIC CLEANER ROOM.
(GENERATOR NO. 1063 OPERATING UNLESS NOTED)

CONDITION AND LOCATION	OVERALL SPLs in dB			OCTAVE-BAND SPLs in dB										
	LINEAR 2 Hz-40 kHz	C-wt dBC	A-wt dBA	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz	31.5 kHz
Cleaner Room 1 m from Corner Near Door	85	78	77						46	42	45	65	88	72
1 m Outside Closed Door of Cleaner Room	62	54	50						32	29	25	24	55	45
Lunch Room at Table									29	25	26	23	31	22
Cleaner Room Ambient (Cleaner Off)									33	27	23	26	21	21
Lunch Room Ambient (Cleaner Off)									27	25	23	22	21	22
Ambient Outside Cleaner Room, 1 m from Door (Cleaner Off)									23	17	13	16	11	11

TABLE V

SOUND PRESSURE IN dB re $2x10^{-5}$ N/m^2 IN AND AROUND THE ULTRASONIC ROOM AT CFB TRENTON (HANGAR NO. 3) USING GENERATOR NO. 1063

CONDITION AND LOCATION	OVERALL SPLs in dB			OCTAVE-BAND SPLs in dB										
	LINEAR 2 Hz-40 kHz	C-wt dBC	A-wt dBA	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	16 kHz	31.5 kHz
Operator Position Lid Closed	102	93	94	66	60	56	57	56	57	56	59	78	101	86
Operator Position Lid Open	104	94	94	65	57	54	55	56	57	57	63	76	100	87
Silting Index Bench Lid Open	66	59	54	58	49	43	47	45	40	37	39	43	65	43
Silting Index Bench Room Ambient	60	56	52											
Filter Bench Lid Open	63	56	51	56	45	40	45	42	38	36	37	48	66	42
Filter Bench Room Ambient	63	52	44											

TABLE VI

ONE-THIRD OCTAVE-BAND SOUND PRESSURE LEVELS IN
dB re 2×10^{-5} N/m^2 AT THE OPERATOR POSITION OF THE AMCRO ULTRASONIC CLEANER

CENTRE FREQUENCY	LID OPEN CABINET OPEN	LID CLOSED CABINET CLOSED	LID CLOSED CABINET CLOSED
6.3 kHz	78dB	74dB	53dB
8 kHz	81dB	79dB	55dB
10 kHz	86dB	83dB	61dB
12.5 kHz	77dB	75dB	52dB
16 kHz	86dB	84dB	52dB
20 kHz	105dB	100dB	78dB
25 kHz	97dB	97dB	65dB
31.5 kHz	80dB	79dB	50dB
40 kHz	71dB	72dB	44dB
12.5kHz + 16kHz	87dB	85dB	55dB

TABLE VII

ONE-THIRD OCTAVE-BAND SOUND PRESSURE LEVELS IN
dB re 2×10^{-5} N/m^2 AT THE OPERATOR POSITION OF THE AMDU ULTRASONIC CLEANERS

CENTRE FREQUENCY	LEWIS GEN. NO. 1063 LID OPEN	LID CLOSED	LEWIS GEN. NO. 688 LID OPEN	LID CLOSED	HIPS ULTRASONIC CLEANER
6.3 kHz	64dB	62dB	53dB	53dB	79dB
8 kHz	71dB	73dB	55dB	55dB	77dB
10 kHz	75dB	74dB	59dB	57dB	81dB
12.5 kHz	56dB	55dB	83dB	81dB	71dB
16 kHz	97dB	95dB	89dB	89dB	82dB
20 kHz	103dB	98dB	61dB	60dB	103dB
25 kHz	76dB	70dB	72dB	68dB	77dB
31.5 kHz	70dB	67dB	75dB	67dB	73dB
40 kHz	69dB	69dB	60dB	57dB	70dB
12.5kHz + 16kHz	97dB	95dB	90dB	90dB	82dB

TABLE VIII

ONE-THIRD OCTAVE-BAND SOUND PRESSURE LEVELS IN dB re $2x10^{-5}$ N/m^2 OF THE AMDU ULTRASONIC CLEANER, USING PLASTIC GEOMETRIC SHAPES AS SURFACE ABSORBERS

CENTRE FREQUENCY	LID OPEN		LID CLOSED	
	SHAPES IN	SHAPES OUT	SHAPES IN	SHAPES OUT
6.3 kHz	73dB	73dB	74dB	69dB
8 kHz	89dB	76dB	77dB	73dB
10 kHz	87dB	83dB	88dB	82dB
12.5 kHz	77dB	75dB	77dB	73dB
16 kHz	87dB	90dB	87dB	88dB
20 kHz	106dB	110dB	107dB	107dB
25 kHz	84dB	87dB	86dB	84dB
31.5 kHz	80dB	77dB	76dB	73dB
40 kHz	77dB	80dB	76dB	75dB
12.5kHz + 16kHz	87dB	90dB	87dB	88dB

TABLE IX

ONE-THIRD OCTAVE-BAND SOUND PRESSURE LEVELS IN db re $2x10^{-5}$ N/m^2 IN AND AROUND THE CFB TRENTON ULTRASONIC CLEANER (HANGAR NO. 3)

CENTRE FREQUENCY	INSIDE CLEANING ROOM		OUTSIDE CLEANING ROOM	
	LID OPEN	LID CLOSED	SILTING BENCH LID OPEN	FILTER BENCH LID CLOSED
6.3 kHz	69dB	73dB	37dB	47dB
8 kHz	72dB	72dB	37dB	37dB
10 kHz	73dB	74dB	39dB	38dB
12.5 kHz	73dB	74dB	35dB	37dB
16 kHz	91dB	85dB	60dB	60dB
20 kHz	101dB	100dB	67dB	65dB
25 kHz	72dB	75dB	39dB	38dB
31.5 kHz	80dB	73dB	36dB	35dB
40 kHz	81dB	75dB	43dB	39dB
12.5kHz + 16kHz	91dB	85dB	60dB	60dB

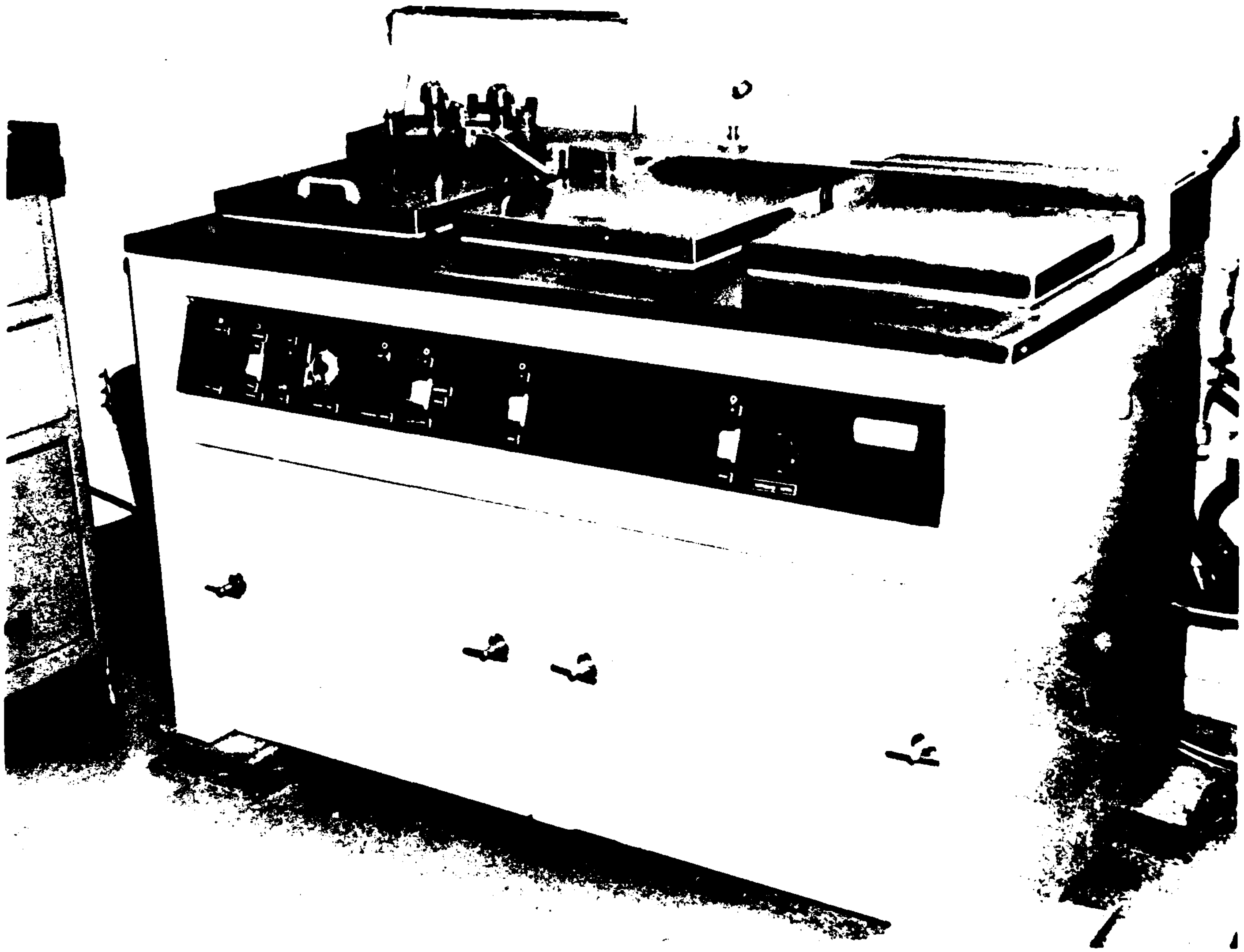

Figure 1: Lewis Ultrasonic Cleaner Model L/C 136H.

Figure 2: Cleaning tank of the Lewis Ultrasonic Cleaner.

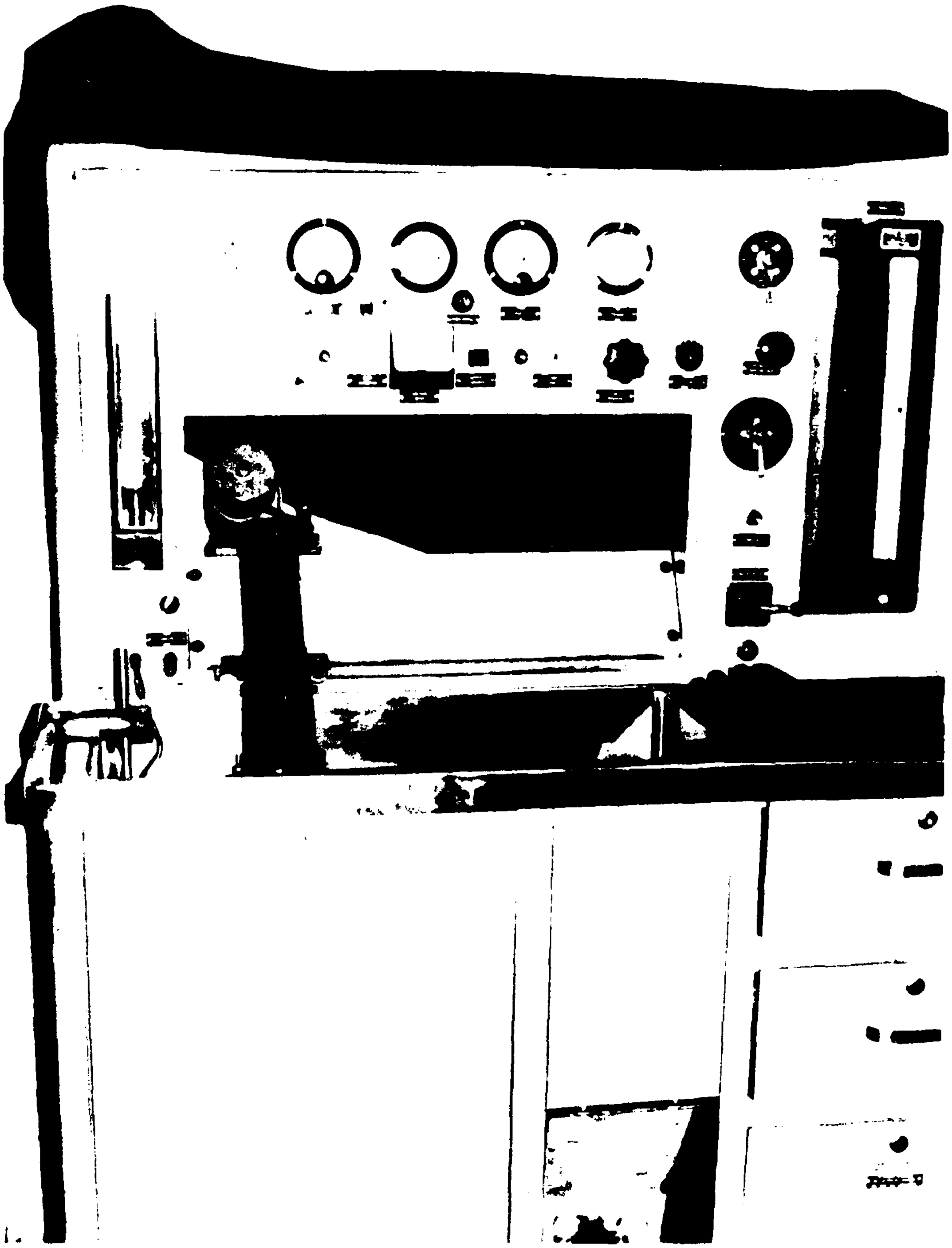

Figure 3: Hyper-Intense Proximal Scanning (HIPS) Ultrasonic Cleaner.

Figure 4: Cleaning tank and transducer of the HIPS Ultrasonic Cleaner.

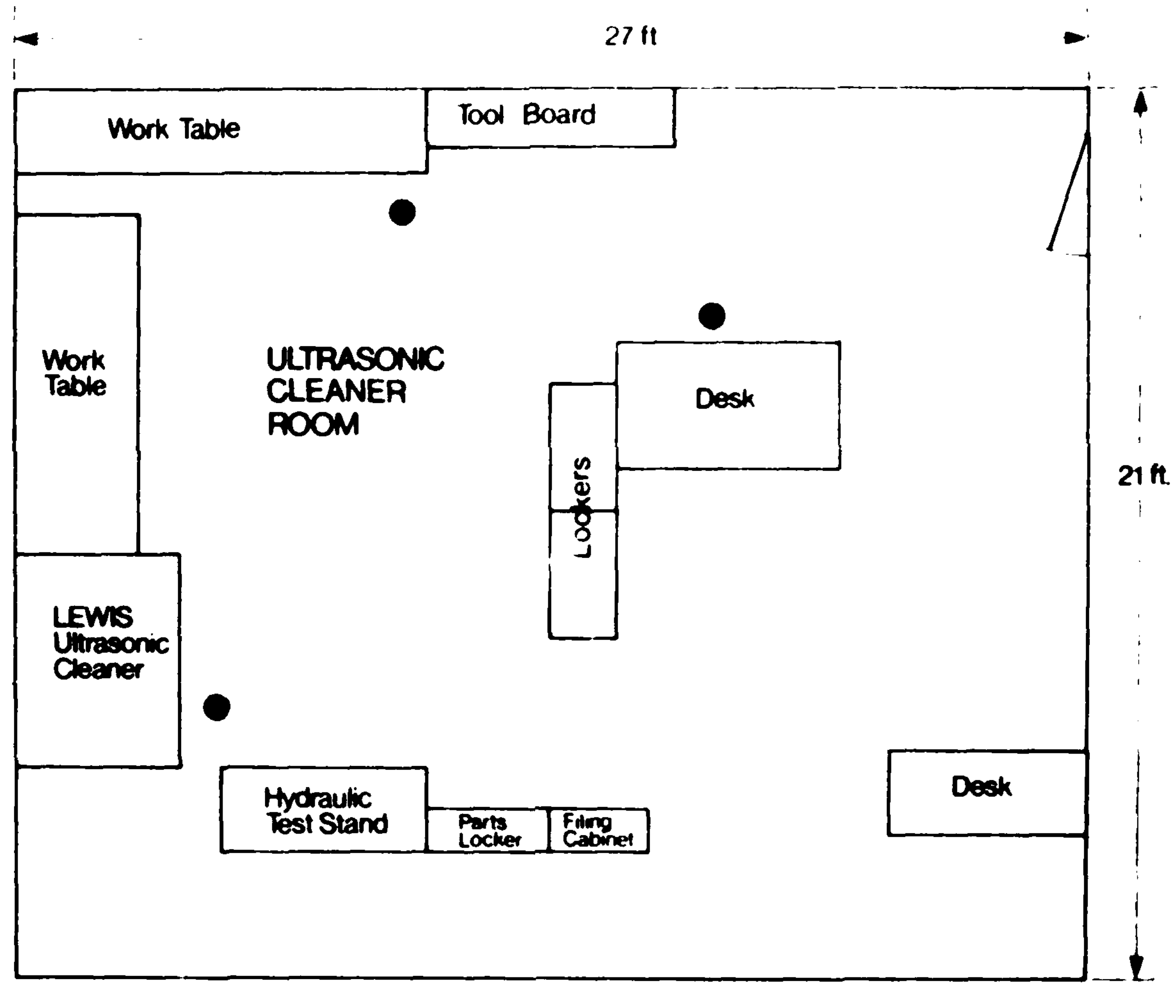

Figure 5: Plan of the Ultrasonic Cleaning Facility at CFB North Bay.

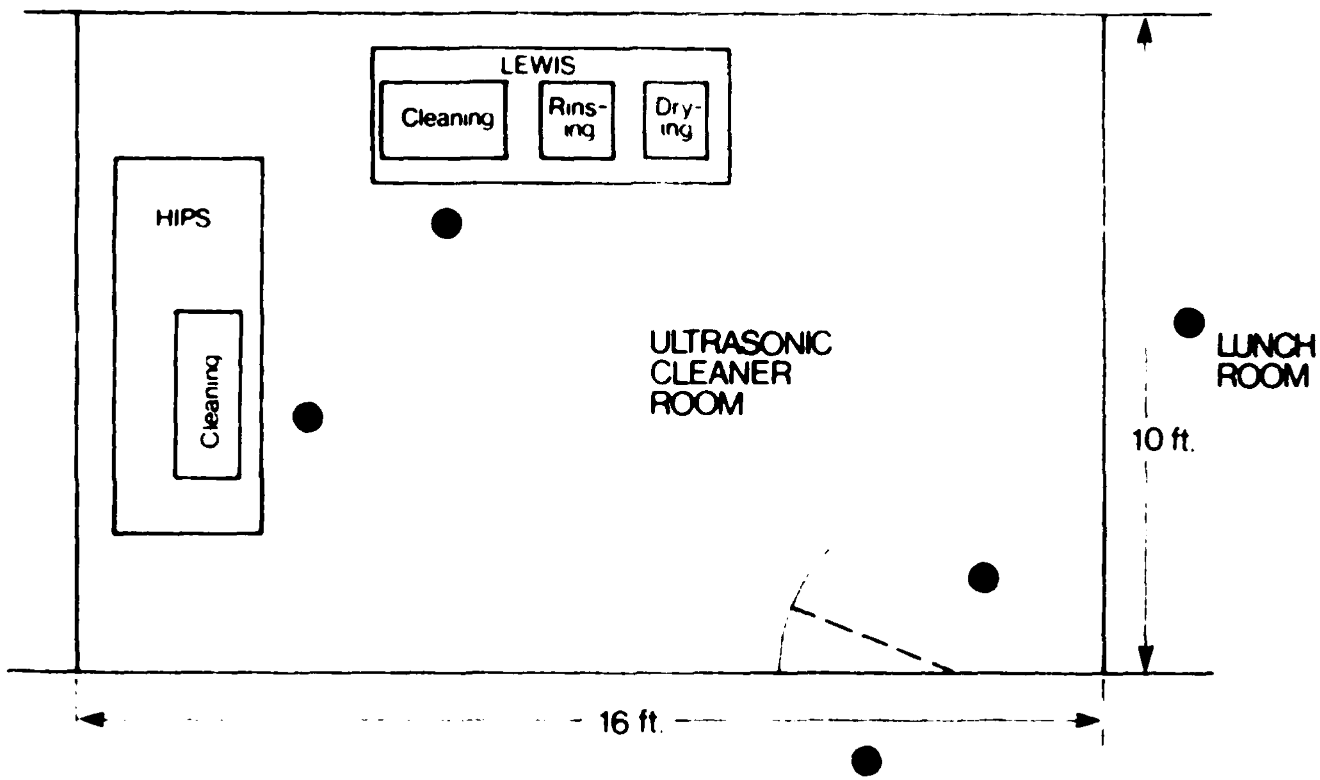

Figure 6: Plan of the AMDU Ultrasonic Cleaning Facility, CFB Trenton.

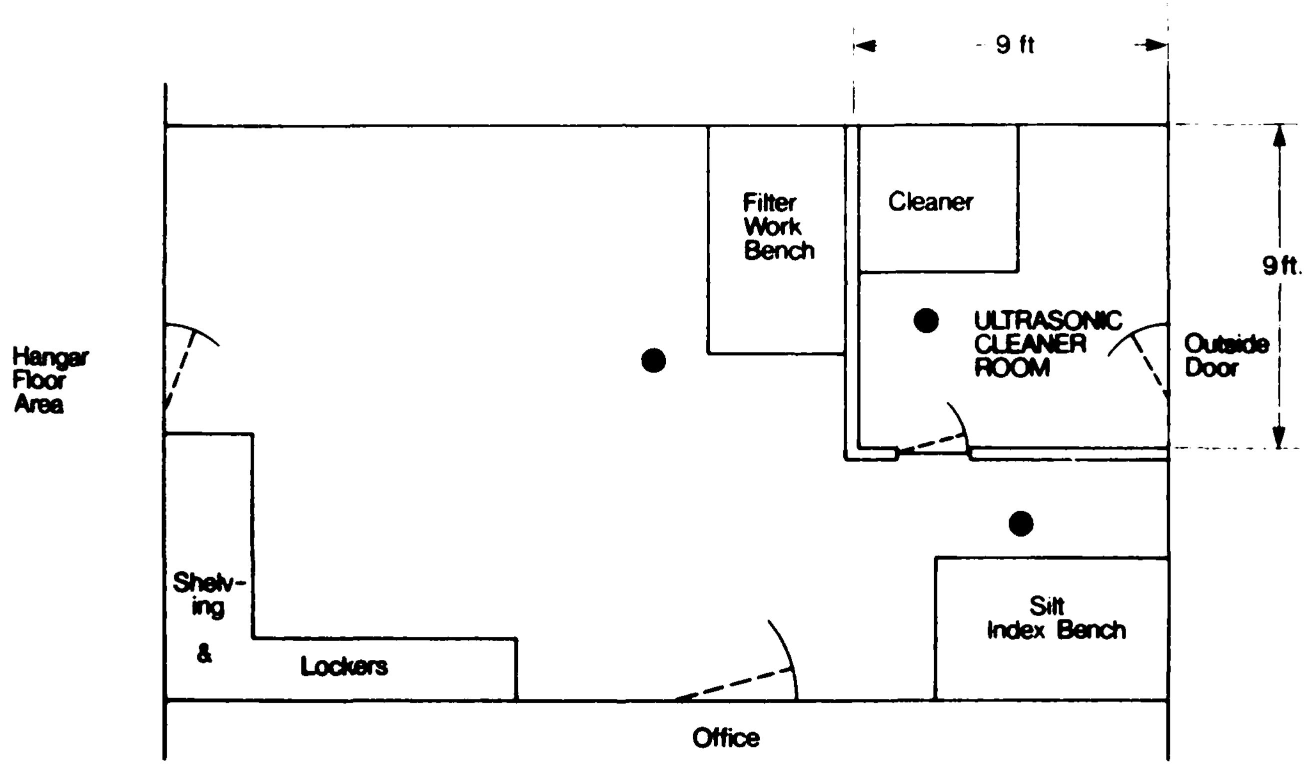

Figure 7: Plan of the Hangar No. 3 Ultrasonic Cleaning Facility, CFB Trenton.

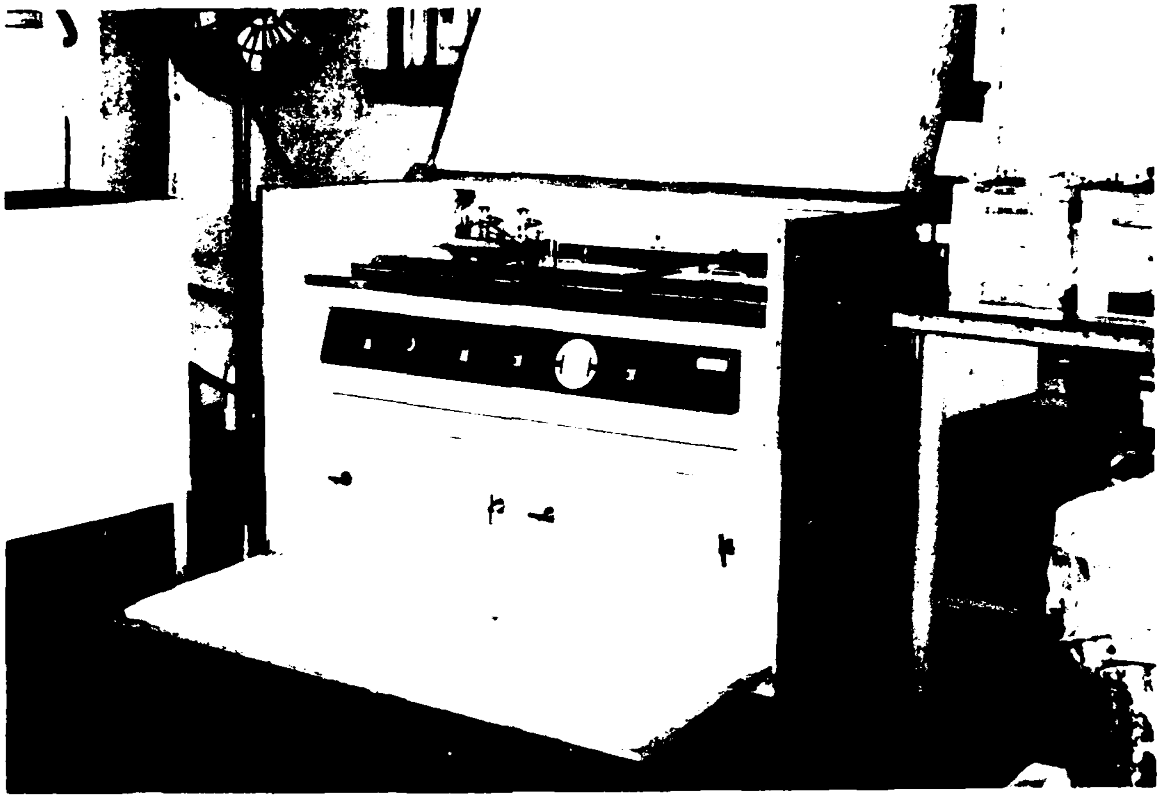

Figure 8: Enclosure for the Lewis Ultrasonic Cleaner, CFB North Bay. Lid and front panel are shown open.

Figure 9: Enclosure for the Lewis Ultrasonic Cleaner, North Bay. Lid is open to permit access to tanks and controls.

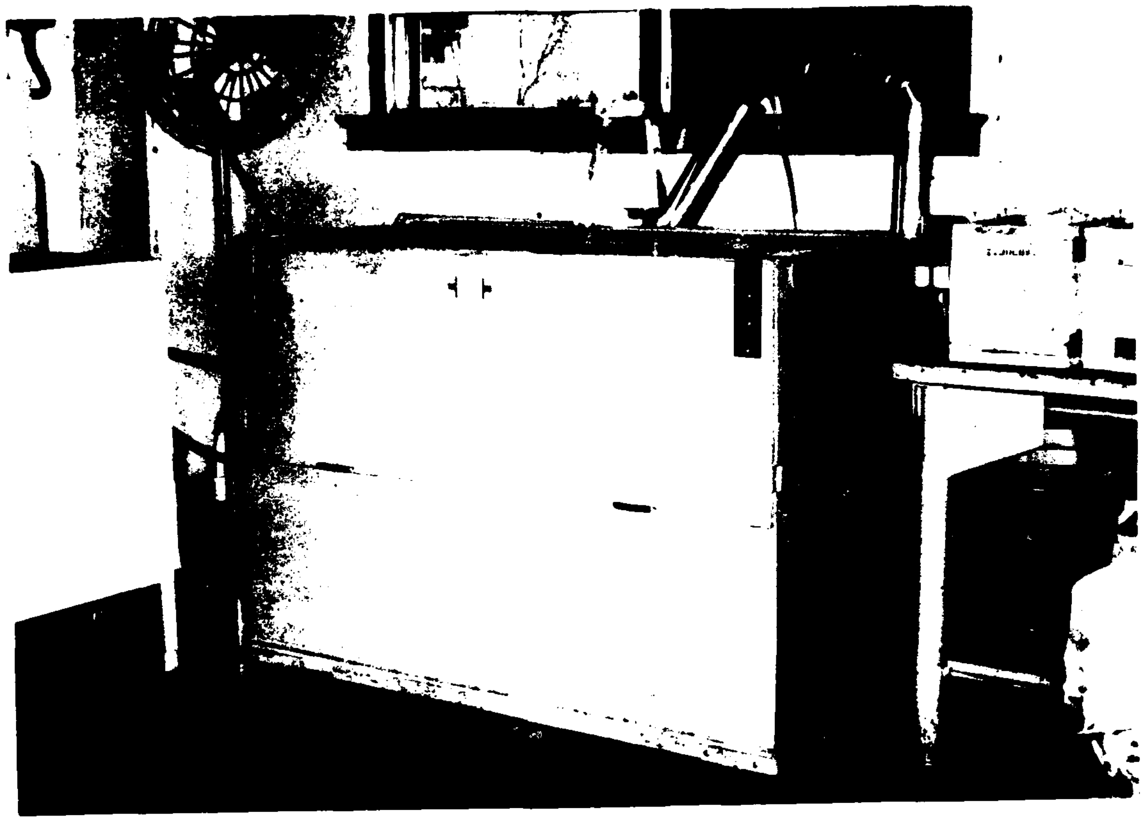

Figure 10: Enclosure for Lewis Ultrasonic Cleaner, CFB North Bay, closed down for normal operation.