9. OUTFIT

Outfit includes all nonstructural parts of a ship. Among these items are:

- Main propulsion systems and auxiliary machinery;
- Pumps and piping systems;
- Heating, ventilation, and air-conditioning (HVAC) machinery and systems;
- Electrical systems;
- Accommodation and hotel services;
- Deck and cargo spaces requirements;
- Weapons and combat systems for naval vessels.

Design of most of these systems has adequately described in the previous chapters. This chapter will highlight some quite specific design aspects on passive fire protection and thermal insulation, funnel and superstructure optimization, and airborne noise control which haven't been properly covered before while discussing main propulsion and marine auxiliary systems. Organization of and responsibility for outfit work may vary from shipyard to shipyard, subject to local traditions, subcontractor arrangements, and other considerations, but these three aspects should also be properly addressed by naval architects during ship design stage if a sound (safe, comfortable, clean and quite) vessel is deemed as desirable.

9.1. Passive fire protection (bulkheads and decks covering) and thermal insulation

Joiner work is the term generally applied to those materials used for the construction of the finished interiors of compartments which were formerly referred to as the woodwork. The current use of non-combustible materials in ship construction, in place of wood, involves a variety of materials such as inorganic composition panels, metallic core section materials, light gage steel plates and shapes, and decorative and hard soft plastic laminates of specified thickness and fibrous insulation. Joiner work thus involves a complex collection of materials together, and the design, construction and erection of these materials constitutes joiner work.

Joiner work, originally a means of subdividing a ship for reasons of utility or privacy, nowadays provides fire protection, comfort, sanitation and décor. The achievement of a satisfactory balance of all these functions is difficult for the ship designer bearing in mind that a thorough knowledge of regulatory body requirements is of prime importance also.

The most important regulations affecting joiner work deal with fire-safety measures. Safety of Life at Sea (SOLAS) exerts a dominant influence in specifying the location for and types of structural fire protection and in defining the materials which may be used.

Present day SOLAS regulations embody the following principles, having regard for the type of ships and the potential fire hazard:

- Division of passenger ships into main vertical zone by thermal and structural boundaries;

- Separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;

- Restricted use of combustible materials;

- Detection of fire in the zone of origin aboard passenger ships;

- Containment and extinction of any fire in the space of origin;

- Protection of means of escape or access for fire fighting;

- Ready availability of fire-extinguishing appliances;

- Minimization of possibility of ignition of flammable cargo vapor.

While above principles apply to all types of vessels, specific regulations are graduated depending upon age, type and size of ship, route operation, cargo carried, and the number of passengers and crew. The maximum degree of fire and life safety is required by large passenger ships operating in ocean service; less stringent requirements apply to cargo ships.

9.1.1. Classes of fire integrity of bulkheads and decks

Definitions have been established for integrity of bulkheads and decks which apply to all types of ships. Generally, the definitions below are common to SOLAS and are summarized in Table 9.1.

“A” Class Divisions must be constructed of a minimum 11 USSG steel or equivalent metal construction, suitably stiffened and capable of preventing the passage of smoke and flame for one hour when exposed to a standard fire tests. They should be made intact with the main structure of the vessel such as shell, structural bulkheads and decks. Additionally they may require insulation with approved non-combustible materials capable of meeting limit temperature-rise requirements intended to prevent the advance of fire from one space to another laterally or vertically. Higher temperature rise time limits are employed where spaces affected are critical or have significant amount of combustibles. The divisions are designated alpha-numerically. The numerical portion of the designation will indicate the amount of time that the insulation is capable of limiting the temperature rise as shown in Table 9.1.

“B” Class Divisions must be constructed of a minimum 16 USSG steel or approved non-combustible materials capable of preventing the passage of flame for one-half hour when exposed to a standard fire tests. They should be made intact form deck to deck (or ceiling to ceiling) and to shell or other boundaries. In addition their insulation value shall be capable of meeting limit temperature-rise as shown in Table 9.1.

“C” Class Divisions must be constructed of approved non-combustible materials and need not to meet no requirements as regard the passage of smoke and flame nor the limiting of temperature rise.

Non-combustible materials should neither produce flame nor give off flammable vapors in sufficient quantity for self-ignition when heated to approximately 750ºC. Any material with more than a very small percentage of organic content cannot qualify as being non-combustible.

The definitions of "A" and "B" Class Divisions necessitate careful attention to piping, electrical cable, and ventilation ducting during penetrations so that soundness of the fire integrity is not impaired.

Tab. 9.1 – Bulkhead types, according to SOLAS.

Class Divisions	Flame/smoke passage	Temperature rise	Combustible material
A60	1 hr	60 min	No
A30	1 hr/1 hr	30 min	No
A15	1 hr/1 hr	15 min	No
A0	1 hr/1 hr	0 min	No
B15	1/2 hr/0 hr	15 min	No
B0	1/2 hr/0 hr	0 min	No
C	0 hr/0 hr	0 min	No

Main vertical zones are those sections into which the hull, superstructure, and deck houses are divided by "A" Class divisions, the mean length of which on any deck does not in general exceed 40 meters. High risk spaces such as machinery spaces, galleys, cargo holds, and spaces in which flammable liquids are stowed must be enclosed by "A" Class divisions. Stairways also are enclosed in "A" Class divisions to ensure a protected means of escape. According to late revision of SOLAS, it is also required the construction of all internal bulkheads, other than those required to be "A" Class, of incombustible "B" Class divisions, generally without the installation of detection and sprinkler system in the accommodation and service spaces.

9.1.2. Design rules

The designer must not only assure that regulatory structural fire-protection requirements are met but also minimize the amount of joiner work required, integrating fire protection with other functions required of the joiner work, considering maintenance required with various construction methods, and providing an attractive décor. The designer may reduce required joiner work and insulation through basic arrangement and specification of the ship. This is done by controlling relative positioning of spaces, size of public rooms, arrangement of corridors and stairways, and specifying furniture and furnishings of non-combustible or fire-resistant type.

A further control is exercised through use of the required insulation and joiner work for other purposes such as temperature insulation and sound reduction.

Material handling and maintenance are very important considerations. Routine maintenance required by various types of joiner construction should be considered. Use of melamine or vinyl finish may mean, for example, that little attention need be given to maintain décor. On the other hand, painted surfaces have a lower initial cost but require more maintenance. It is essential to have finish materials, particularly on bulkheads that can withstand the abuse of traffic in the spaces where the surface finish is employed. Ease of installation of various types of joiner panels, insulation, and surface finishes is also an important factor. Good joiner design also has a beneficial effect on the atmosphere of the ship, since mood of the passengers and crew can be greatly influenced by their surroundings. Figure 9.1 shows various types of panels (joiner bulkheads, composition-panel bulkheads, hollow metal panels) for “A” Class divisions.

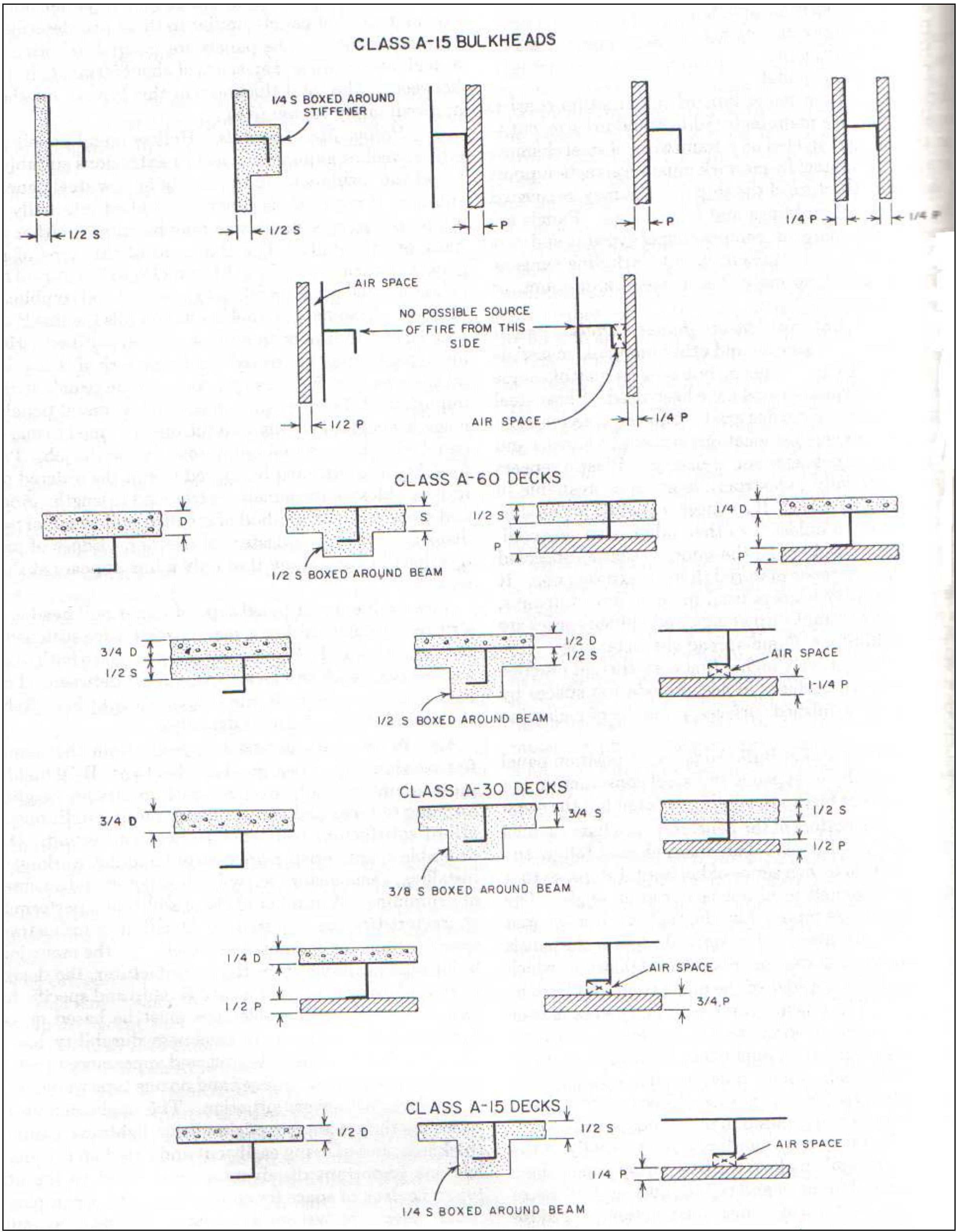


Fig. 9.1.a – Application of insulation, linings, ceilings, and deck coverings to Class A fire divisions.

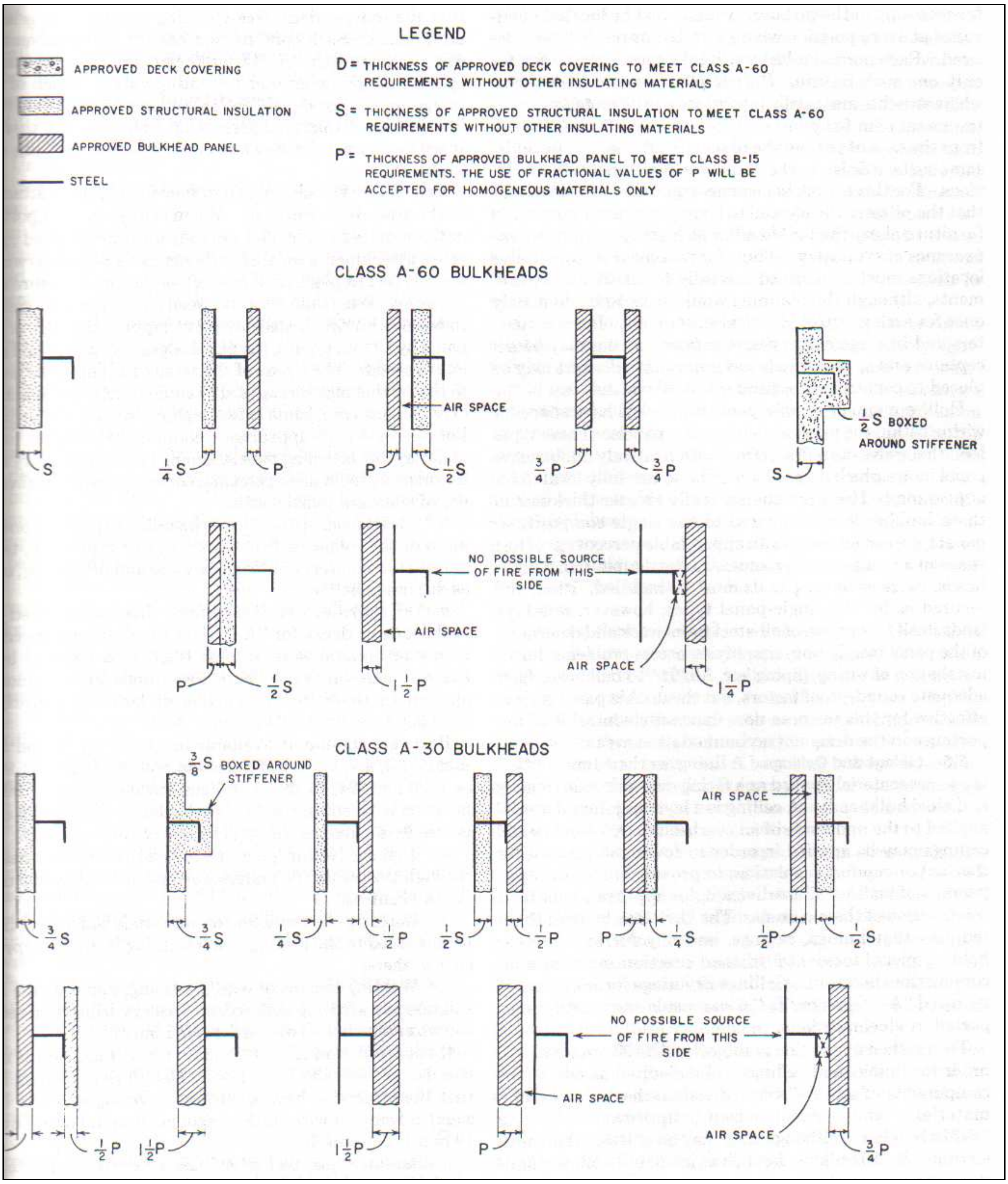


Fig. 9.1.b – Application of insulation, linings, ceilings, and deck coverings to Class A fire divisions.

9.1.3. Insulation

Insulation is installed to perform one or more of the following functions, i.e., fire protection, temperature or comfort in living spaces, sound deadening, etc.

a) Fire protection

Insulations used on bulkheads or decks of "A" Class fire divisions are commonly of mineral wool or glass fiber, held together by a fire-resistant binder. These insulations are commonly applied in the form of blankets or batts or semi-rigid boards. The sketches in Figure 9.1 show

how insulation is used in “A” Class fire divisions alone and in combination with linings, ceilings, and deck coverings.

b) Thermal comfort

Thermal or comfort insulation is insulation used to protect living and working spaces from cold or heat in adjacent spaces or the outside environment.

In marine work it has become common practice to use a minimum of 50 [mm] of insulation at the shell and deckhouses sides, and 75 or 100 [mm] against machinery spaces and galleys. Under exposed decks a minimum of 50 [mm] is used.

The designer seldom specifies insulation on lining with one purpose only in mind. Around machinery spaces and galleys, the fire control requirement would normally govern, so that fire insulation would also serve as comfort insulation.

c) Sound or acoustic insulation

The development of all-steel ship structures, the introduction of relatively light weight structures, high-speed propulsion machinery, and the widespread use of air-conditioning with its associated fans and air-conducts, have produced a need for noise reduction by means of sound or acoustic insulation. Fortunately, the modern fireproof insulations of the glass fiber types are effective sound absorbers. Fire and comfort insulation, when applied to the inside of a machinery casing and lined with sheet steel, becomes a reflecting surface which aggravates the machinery noise. When lined with material perforated to admit the sound waves, the insulation reduces the internal noise level considerably without any sacrifice in its other functions.

9.2. Funnels (exhaust gas pipelines and silencers) and superstructure optimization

The descent of funnel smoke on to the decks and superstructures of ships is a major problem to people working outside the vessel and cause a negative visual impact. It can be seen on model tests, the movement of the air over the bows and superstructure due to a combination of ship speed and wind speed sets up a region of disturbed flow over the ship. The height of this disturbed region, which has come to be called the turbulent zone, depends mainly on the shape and size of the superstructure; and the efflux from the funnel must be carried clear of the turbulent zone if the ship is to be free from smoke trouble. Two main factors determine whether this condition will be fulfilled, namely the height of the upper boundary of the turbulent zone – the turbulence boundary – and the design of the funnel, including the speed at which the smoke is emitted.

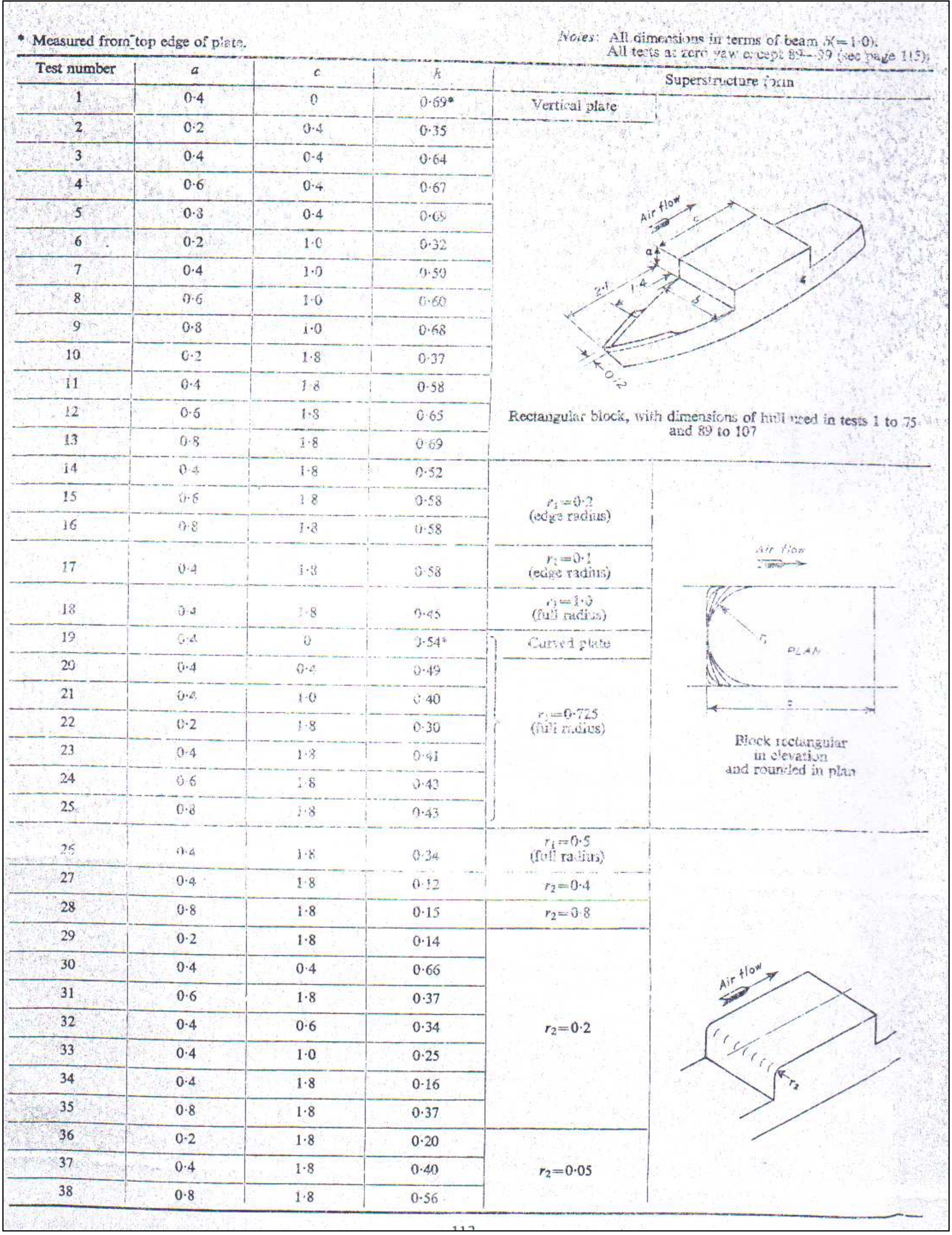
Several experiments with scaled models having different superstructure arrangements and dimensions (expressed as functions of ship’s breadth) have been carried out whose results are presented in here.

From Tables 9.2.a to 9.2.d, it can be seen that a considerable improvement (lowering of the turbulence boundary) can be obtained by:

- Rounding the sharp edges of the superstructure, both in elevation and in plan;
- Slopping or stepped-back fronts if the angle is less than 60º.

The advantage of fronts adequately rounded in elevation or sloped or stepped-back tends to be lost if the length of the superstructure is less than the ship's breadth (*b*). Moreover, conditions can be greatly improved by arranging for there to be no space close behind the disturbing edge of the superstructure in which large eddies can be formed. One way of ensuring this is to have a sufficient long superstructure (length at least equal to its beam).

Tab. 9.2.a – Superstructure design in relation to the descent of funnel smoke.

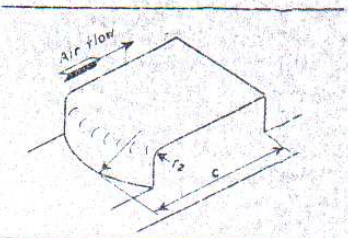
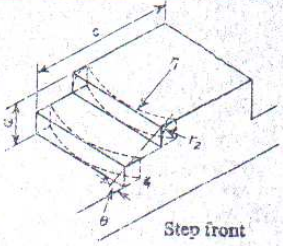
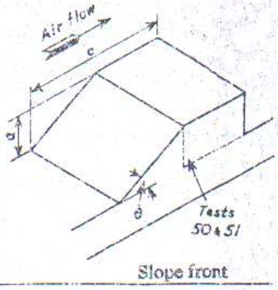
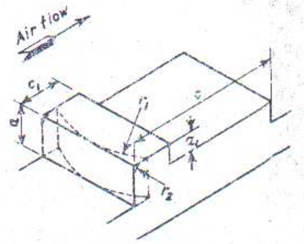
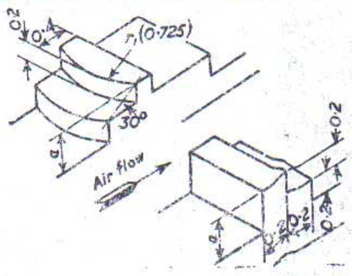


* Measured from top edge of plate.

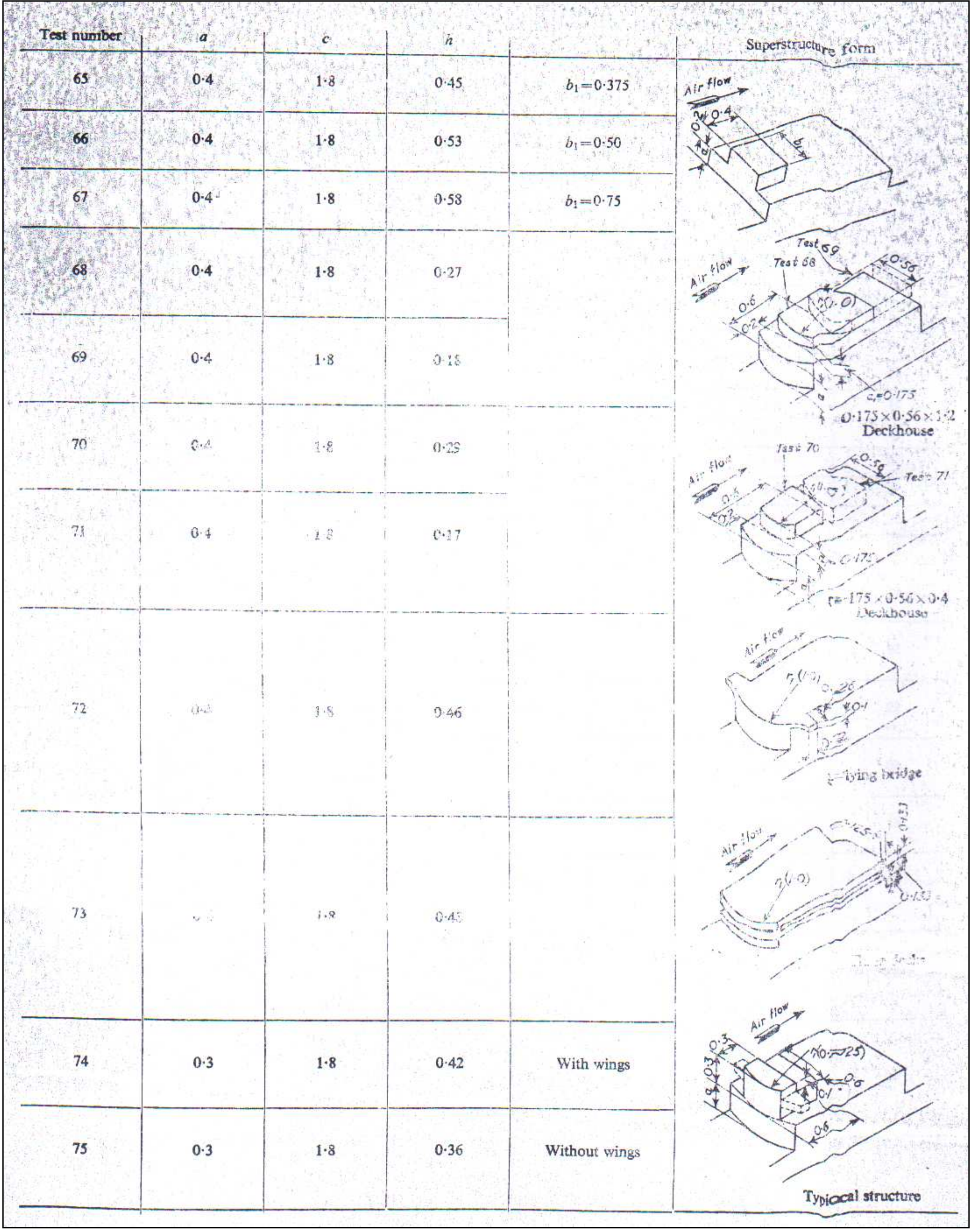
Notes: All dimensions in terms of beam $b(=1{\cdot}0)$.
All tests at zero yaw except 89–99 (see page 115).

Test number	*a*	*c*	*k*	Superstructure form	
1	0·4	0	0·69*	Vertical plate	
2	0·2	0·4	0·35		Rectangular block, with dimensions of hull used in tests 1 to 75 and 89 to 107
3	0·4	0·4	0·64		
4	0·6	0·4	0·67		
5	0·8	0·4	0·69		
6	0·2	1·0	0·32		
7	0·4	1·0	0·50		
8	0·6	1·0	0·60		
9	0·8	1·0	0·68		
10	0·2	1·8	0·37		
11	0·4	1·8	0·58		
12	0·6	1·8	0·65		
13	0·8	1·8	0·69		
14	0·4	1·8	0·52	$r_1=0{\cdot}2$ (edge radius)	Block rectangular in elevation and rounded in plan
15	0·6	1·8	0·58		
16	0·8	1·8	0·58		
17	0·4	1·8	0·58	$r_1=0{\cdot}1$ (edge radius)	
18	0·4	1·8	0·45	$r_1=1{\cdot}0$ (full radius)	
19	0·4	0	0·54*	Curved plate	
20	0·4	0·4	0·49	$r_1=0{\cdot}725$ (full radius)	
21	0·4	1·0	0·40		
22	0·2	1·8	0·30		
23	0·4	1·8	0·41		
24	0·6	1·8	0·43		
25	0·8	1·8	0·43		
26	0·4	1·8	0·34	$r_1=0{\cdot}5$ (full radius)	
27	0·4	1·8	0·12	$r_2=0{\cdot}4$	
28	0·8	1·8	0·15	$r_2=0{\cdot}8$	
29	0·2	1·8	0·14	$r_2=0{\cdot}2$	
30	0·4	0·4	0·66		
31	0·6	1·8	0·37		
32	0·4	0·6	0·34		
33	0·4	1·0	0·25		
34	0·4	1·8	0·16		
35	0·8	1·8	0·37		
36	0·2	1·8	0·20	$r_2=0{\cdot}05$	
37	0·4	1·8	0·40		
38	0·8	1·8	0·56		

Tab. 9.2.b – Superstructure design in relation to the descent of funnel smoke.

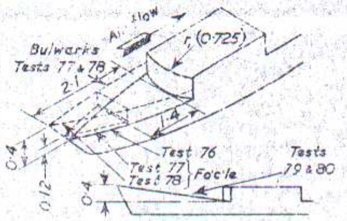
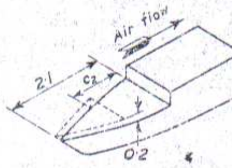
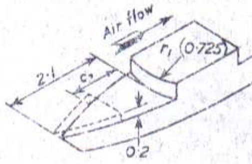
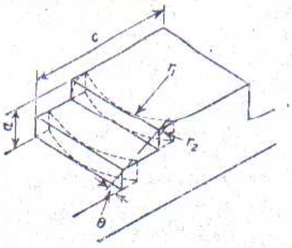
Test number	a	c	h		Superstructure form
39	0·4	1·8	0·20	$r_1=0{\cdot}725$ $r_2=0{\cdot}2$	
40	0·4	1·8	0·35	$r_1=0{\cdot}725$ $r_2=0{\cdot}05$	
41	0·8	1·8	0·35		
42	0·4	1·8	0·58	Step front	$\theta=60°$ 
43	0·4	1·8	0·52	Step front, $r_2=0{\cdot}05$	
44	0·4	1·8	0·51	Slope front	
45	0·4	1·8	0·38	Step front, $r_1=0{\cdot}725$	
46	0·4	1·8	0·30	Slope front, $r_1=0{\cdot}5$	
47	0·4	1·8	0·48	Step front	$\theta=45°$
48	0·4	1·8	0·44	Slope front	
49	0·4	1·8	0·40	Step front, $r_1=0{\cdot}725$	
50	0·4	0·69	0·67	Slope front	$\theta=30°$ 
51	0·8	1·38	0·60		
52	0·4	1·8	0·22	Step front	
53	0·4	1·8	0·29	Slope front	
54	0·8	1·8	0·23	Step front	
55	0·4	1·8	0·24	Step front, $r_1=0{\cdot}725$	
56	0·8	1·8	0·20		
57	0·4	1·8	0·42	$a_1=0{\cdot}3$ $c_1=0{\cdot}4$ $r_2=0{\cdot}2$	
58	0·4	1·8	0·63	$a_1=0{\cdot}3$ $c_1=0{\cdot}4$ $r_2=0{\cdot}05$	
59	0·4	1·8	0·67	$a_1=0{\cdot}2$ $c_1=0{\cdot}4$	
60	0·4	1·8	0·56	$a_1=0{\cdot}2$ $c_1=0{\cdot}4$ $r_1=0{\cdot}725$	
61	0·4	1·8	0·34	$a_1=0{\cdot}2$ $c_1=0{\cdot}4$ $r_2=0{\cdot}2$	
62	0·6	1·8	0·71	$a_1=0{\cdot}2$ $c_1=0{\cdot}4$	
63	0·4	1·8	0·24		
64	0·4	0·4	0·72		

Tab. 9.2.c – Superstructure design in relation to the descent of funnel smoke.



Test number	a	c	h		Superstructure form
65	0·4	1·8	0·45	b_1=0·375	
66	0·4	1·8	0·53	b_1=0·50	
67	0·4	1·8	0·58	b_1=0·75	
68	0·4	1·8	0·27		0·175×0·56×1·2 Deckhouse
69	0·4	1·8	0·18		
70	0·4	1·8	0·29		0·175×0·56×0·4 Deckhouse
71	0·4	1·8	0·17		
72	0·4	1·8	0·46		Flying bridge
73	[illegible]	1·8	0·45		[illegible]
74	0·3	1·8	0·42	With wings	Typical structure
75	0·3	1·8	0·36	Without wings	

Tab. 9.2.d – Superstructure design in relation to the descent of funnel smoke.

Test number	a	c	h		Superstructure form
76	0·4	1·8	0·42	No forecastle or bulwarks	
77	0·4	1·8	0·35	0·12 forecastle and bulwarks	
78	0·4	1·8	0·29	0·4 forecastle and bulwarks	
79	0·4	1·8	0·27	0·4 sheer	
80	0·4	1·8	0·21	0·4 sheer, with well-rounded bow	
81	0·4	1·8	0·37	$c_2=1·2$	
82	0·4	1·8	0·29	$c_2=0·4$	
83	0·4	1·8	0·42	$c_2=0$	
84	0·4	1·8	0·37	$c_2=1·7$	
85	0·4	1·8	0·29	$c_2=1·2$	
86	0·4	1·8	0·22	$c_2=0·8$	
87	0·4	1·8	0·22	$c_2=0·4$	
88	0·4	1·8	0·30	$c_2=0$	
89	0·4	0·4	0·32	Rectangular block	20° yaw
90	0·4	1·8	0·25		
91	0·6	1·8	0·18		
92	0·2	1·8	0·39	$r_2=0·2$	
93	0·4	1·8	0·18		
94	0·8	1·8	0·11		
95	0·4	1·8	0·29	$r_1=1·0$	
96	0·4	1·8	0·22	$r_1=0·5$	
97	0·4	1·8	0·23	30° step front $r_1=0·725$	
98	0·4	1·8	0·29	60° step front $r_1=0·725$	
99	0·4	1·8	0·30	Deckhouse as for Test 68 $r_1=1·0$	
100	0·2	0	0·56*	Vertical plate	
101	0·6	0	0·74*		
102	0·8	0	0·76*		
103	0·8	1·8	0·45	Step front	θ=45°
104	0·8	1·8	0·40	Step front, $r_1=0·725$	
105	0·4	0·6	0·38	Step front, $r_1=0·725$	θ=30°
106	0·6	1·8	0·23	Step front	
107	0·6	1·8	0·21	Step front, $r_1=0·725$	

* Measured from top edge of plate.

The results obtained from the tests may be used to develop a formulation to predict the height of the turbulence boundary from the geometry of the superstructure. The first step is estimating the zone height from the drawings of a ship is to determine the level above which the height of the superstructure, *a*, is to be measured. If there is no sheer of the deck forward of the superstructure and no forecastle deck, *a* is measured above deck level; but if there is sheer or forecastle, *a* must be measured from some level above deck level since the superstructure front is then partly shielded. It is assumed that the shielding due to sheer or forecastle raises the effective base of the superstructure to a height a_s above deck level (see Figures 9.3.a and b), so that a_s can be calculated from the following formulae:

- When c_2 is less than 1.25: $a_s = a_2$
- When c_2 is greater than 1.25: $a_s = 1/2\, a_2$

Deckhouses effect can be represented with sufficient accuracy by taking an effective height $a' = a - a_s + a_1 b_1$ where a_1 is the height of the deckhouse above the superstructure of full width, and b_1 is the beam of the deckhouse.

The equivalent height, measured from the top of imaginary superstructure of height a' is obtained from Figure 9.4, which should than be corrected by the following factors:

- fr_1 = front rounded in plan (see Figure 9.5);
- fr_2 = front rounded in elevation (see Figure 9.6);
- fr_0 = step or slope front (see Figure 9.7);
- fc = length of superstructure and radius r_2 (see Figure 9.8);
- fs = intermediate step down (see Figure 9.9).

Therefore, final value of h is determined by the equation: $h = h_{basic}\, fr_1\, fr_2\, fr_0\, fc\, fs$

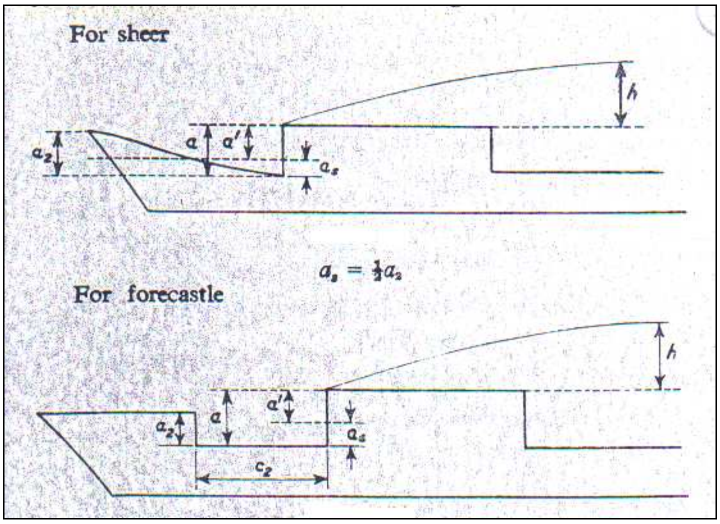


Fig. 9.3 – Raise of the effective base of the superstructure due to sheer and forecastle.

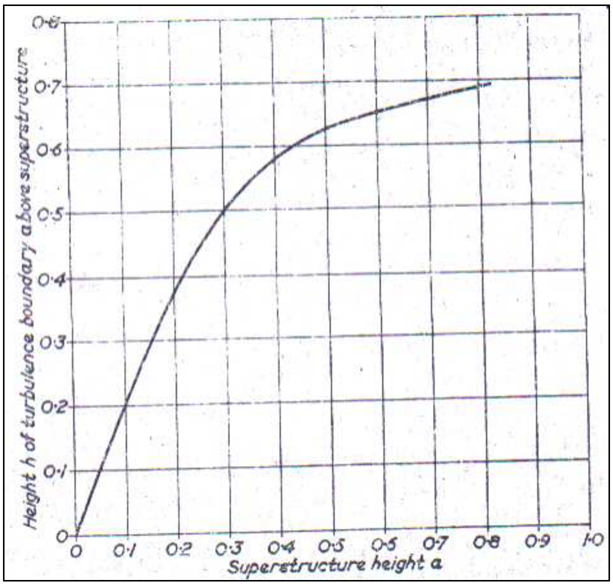


Fig. 9.4 – Height of turbulence boundary above superstructure.

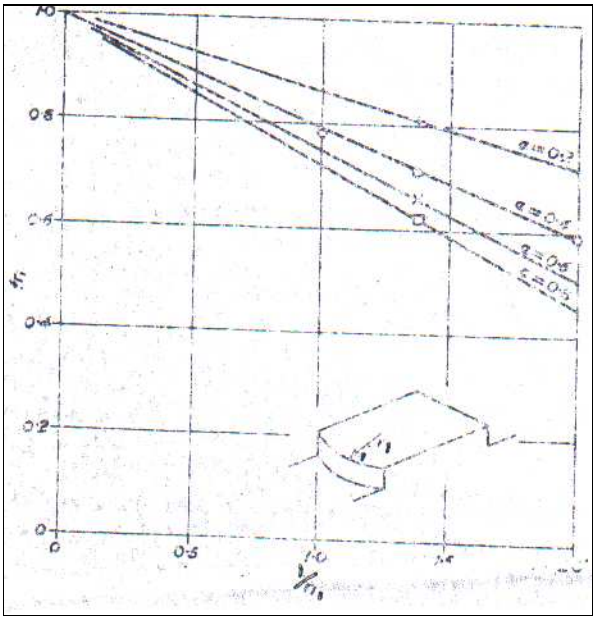


Fig. 9.5 – Correction on height of turbulence boundary due to front rounded in plan.

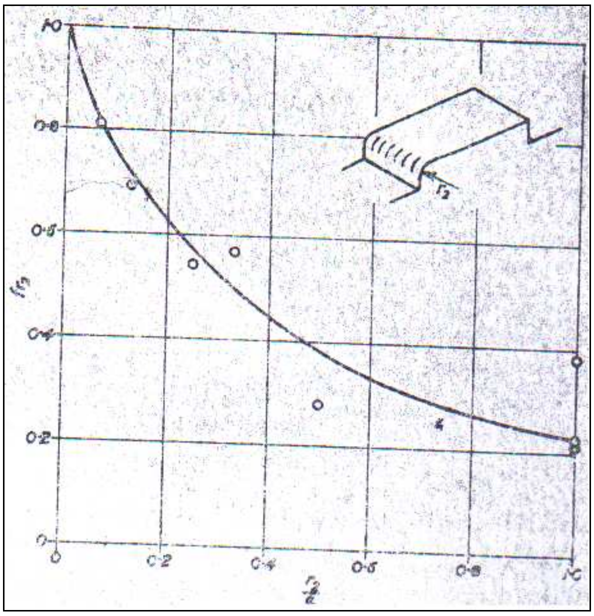


Fig. 9.6 – Correction on height of turbulence boundary due to front rounded in elevation.

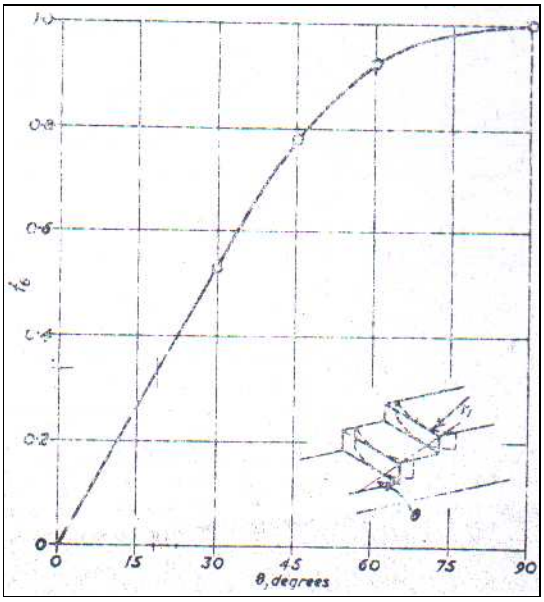


Fig. 9.7 – Correction on height of turbulence boundary due to step or slope front.

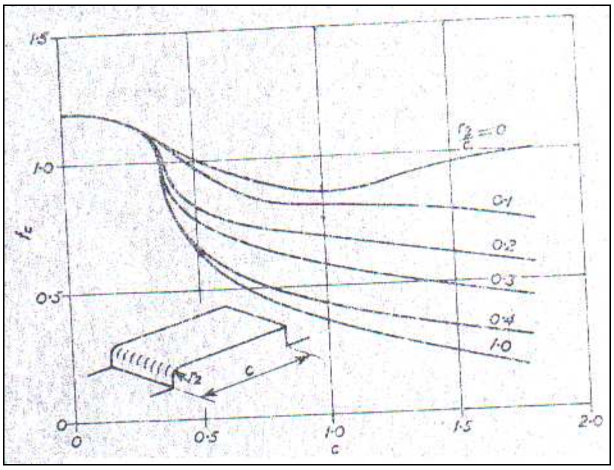


Fig. 9.8 – Correction on height of turbulence boundary due to length of superstructure and radius r_2.

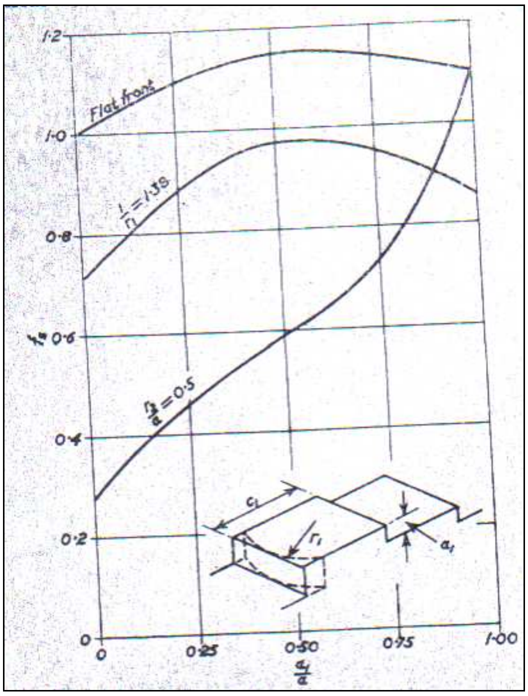


Fig. 9.9 – Correction on height of turbulence boundary due to intermediate step down.

A final remark is made to the selection of the other two dimensions of the funnel: length and beam, and its shape or configuration. Essentially, these two dimensions are driven by the required inner space to accommodate inside the funnel all the exhaust and intake ducts of the prime movers, generator sets and boilers of the vessel. Note should be given to the fact that sometimes these exhaust ducts are also fitted with silencers of quite large diameters, and the ducts should be adequately supported with dampers and thermal expansion joints to the inner structure of the ship's funnel. Hence, on the last step of a funnel design a certain shape is adopted, and then there are only two aesthetic options to be taken in respect to the funnel's inclination: in the transverse or in the longitudinal plane. Which might be further reduced to one single aesthetic option in cases where the funnel has to be transversally inclined in order to reduce the thermal and visual signatures of a combatant vessel.

9.3. Airborne noise control onboard

9.3.1. Introduction

An understanding of the noise limits required for effective oral communication, hearing protection, and crew comfort has led to the establishment of stringent noise criteria in the working and living spaces aboard ships. At the same time, the emphasis on greater ship power and reduced weight, both of which tend to increase noise levels, makes compliance with the criteria more difficult. As a result, the control of airborne noise has evolved as a specific design function to be included in the normal design process for every ship design, conversion, or modernization.

This section will help the user to develop an acoustical design that will reduce shipboard airborne noise to levels intended to meet the criteria for crew comfort, speech communication, and hearing protection. Basically, it contains procedures for predicting airborne noise levels in ship machinery spaces fitted with the most common prime movers (diesel engines coupled to reduction gearboxes). Where the airborne noise levels predicted by the procedure in these notes can be compared with the ship's noise criteria to identify the spaces that are likely to be too noisy and the noise sources and transmission paths that will be major contributors to excessive noised levels. This document is written for the ship designer who is responsible for integrating an airborne noise control program into the overall design and construction of a ship. Previous experience in the area of ship noise and vibration or familiarity with sophisticated mathematics or acoustics theory is not required for the effective use of these notes, although some prior knowledge of elementary algebra and manipulation of sound and vibration levels is useful.

The noise control program shown in Figure 9.1 is divided into five phases:

1. Initial ship design, noise predictions, and treatment selection;
2. Revision of noise treatments;
3. Consideration of non-acoustic impacts;
4. Treatment implementation and evaluation;
5. Trials and documentation.

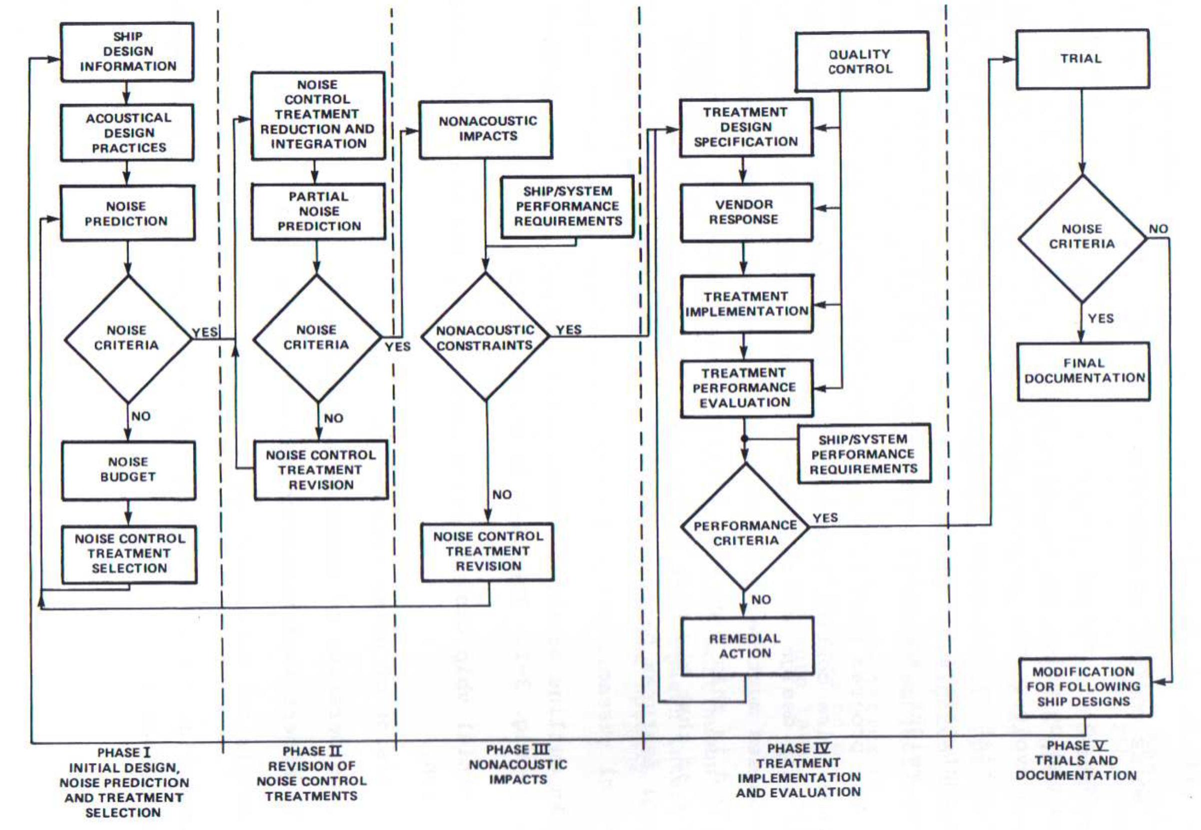


Fig. 9.1 – Airborne noise control program plan.

9.3.2. Noise source levels

<u>Airborne noise source levels</u>:

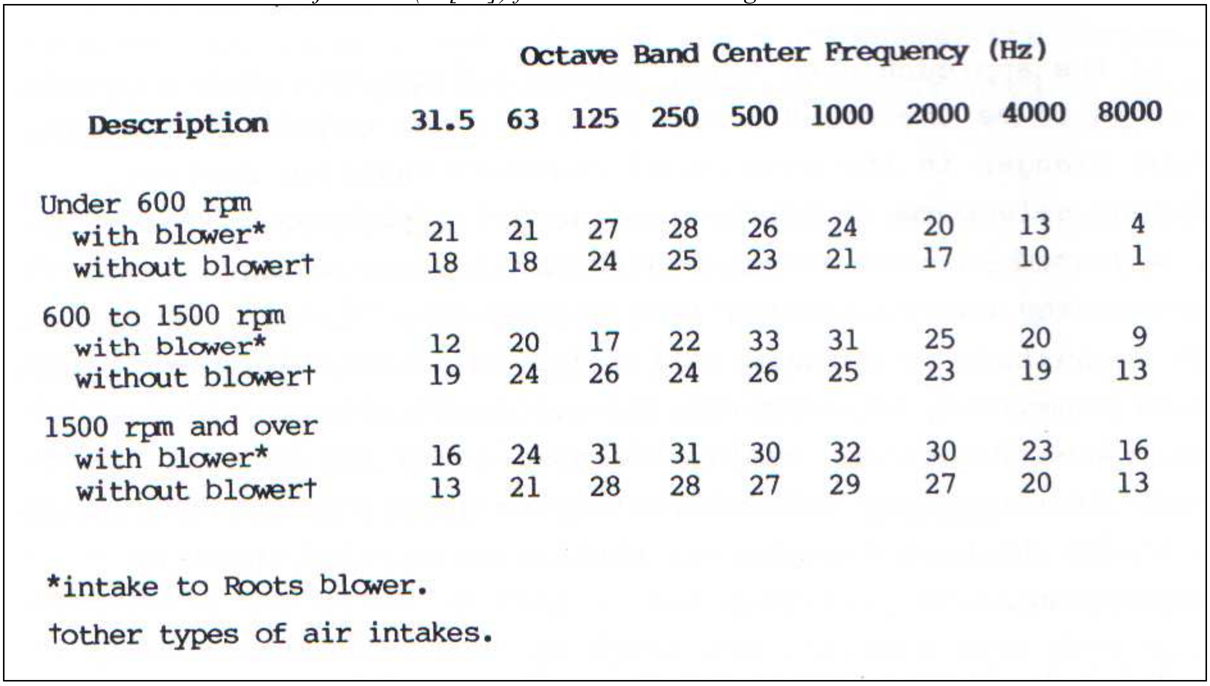
a) Diesel engines and diesel-power generator sets a.1) Diesel engine intake

When the air intake to a diesel engine is deducted from outside the diesel engine room, the air intake noise can be separated from the engine casing noise. In this case, the air intake airborne noise source levels at the intake flange are estimated by calculating a baseline level given by the following equation:

$$L_{WB} = 57 + 10\log(hp) \tag{9.1}$$

, where *hp* is the rated horsepower of the engine. The octave band airborne noise source levels are obtained by adding to the baseline level the values given in Table 9.2 for different operating speeds.

Tab. 9.2 – Octave band adjustment (in [dB]) for baseline diesel engine intake airborne noise source levels.



Description	**Octave Band Center Frequency (Hz)** **31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Under 600 rpm									
with blower*	21	21	27	28	26	24	20	13	4
without blower†	18	18	24	25	23	21	17	10	1
600 to 1500 rpm									
with blower*	12	20	17	22	33	31	25	20	9
without blower†	19	24	26	24	26	25	23	19	13
1500 rpm and over									
with blower*	16	24	31	31	30	32	30	23	16
without blower†	13	21	28	28	27	29	27	20	13

*intake to Roots blower.

†other types of air intakes.

The octave band source levels obtained by using the above procedures describe the intake noise inside the duct at the engine intake flange. When diesel intake air is ducted from outside the source space, intake noise emitted into the source space is transmitted through the duct wall; therefore, the inlet source levels must be corrected to account for the length of the duct radiating surface located in the source space and the attenuating properties (transmission losses) of the duct wall. For circular ducts the correction that must be added to each octave band of the diesel intake noise sound power level is given by:

$$10\log\left(4\,L/D\right) - TL \tag{9.2}$$

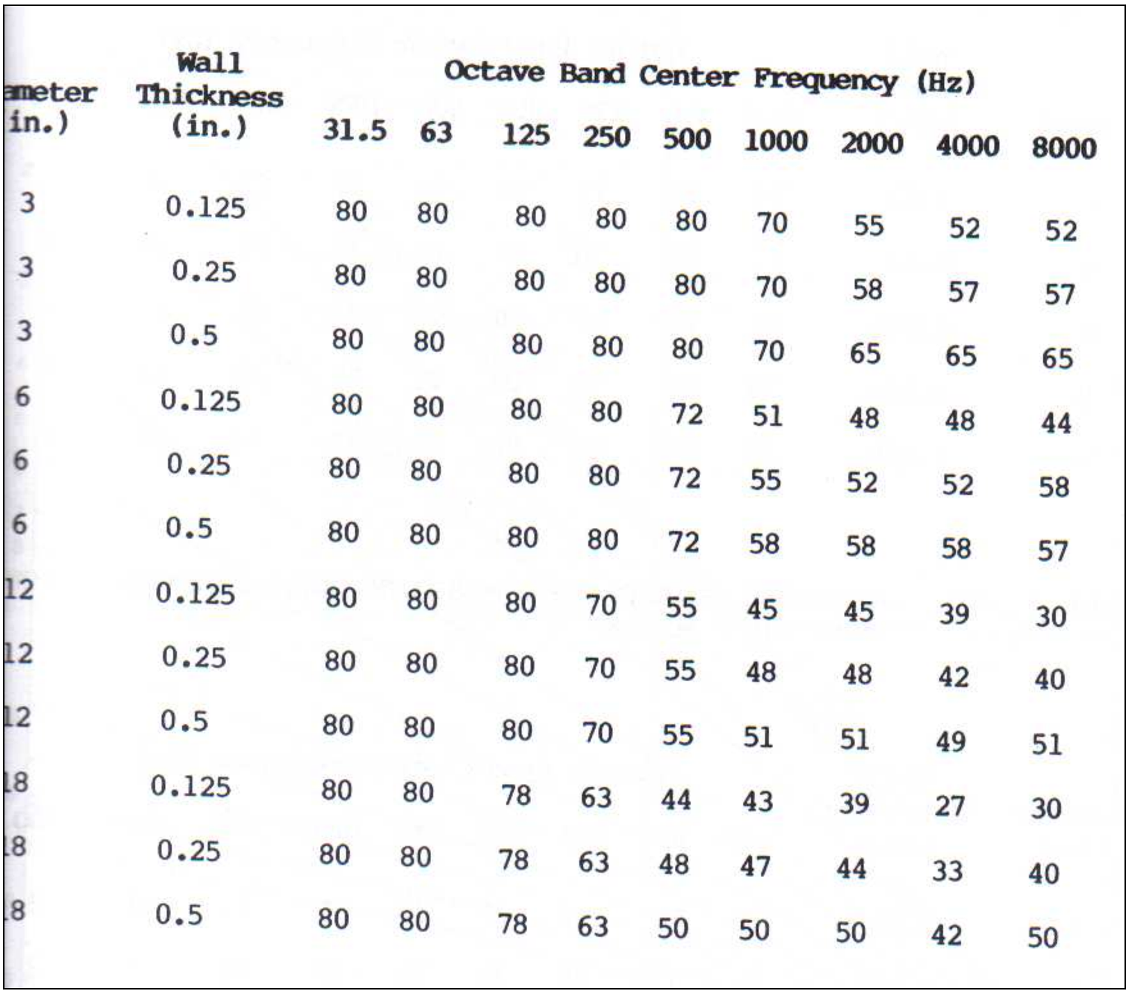
, where:

L = length of the intake duct, in [in];

D = diameter of the intake duct, in [in];

TL = duct wall transmission loss, in [dB] as determined from Table 9.3.

Tab. 9.3 – Transmission loss of steel circular pipe walls (transmission loss for aluminum circular pipes is 5 [dB] less than for steel pipes of same size at all frequencies).



ameter (in.)	Wall Thickness (in.)	Octave Band Center Frequency (Hz)								
		31.5	63	125	250	500	1000	2000	4000	8000
3	0.125	80	80	80	80	80	70	55	52	52
3	0.25	80	80	80	80	80	70	58	57	57
3	0.5	80	80	80	80	80	70	65	65	65
6	0.125	80	80	80	80	72	51	48	48	44
6	0.25	80	80	80	80	72	55	52	52	58
6	0.5	80	80	80	80	72	58	58	58	57
12	0.125	80	80	80	70	55	45	45	39	30
12	0.25	80	80	80	70	55	48	48	42	40
12	0.5	80	80	80	70	55	51	51	49	51
18	0.125	80	80	78	63	44	43	39	27	30
18	0.25	80	80	78	63	48	47	44	33	40
18	0.5	80	80	78	63	50	50	50	42	50

For rectangular ducts the correction is given by:

$$10\log\left(PL/D\right)-TL \tag{9.3}$$

, where:

P = perimeter of the intake duct, in [in];

A = cross-sectional area of the intake duct, in [in^2];

TL = duct wall transmission loss, in [dB] as determined from Table 9.4.

Tab. 9.4 – Transmission loss of HVAC rectangular and circular pipe walls.

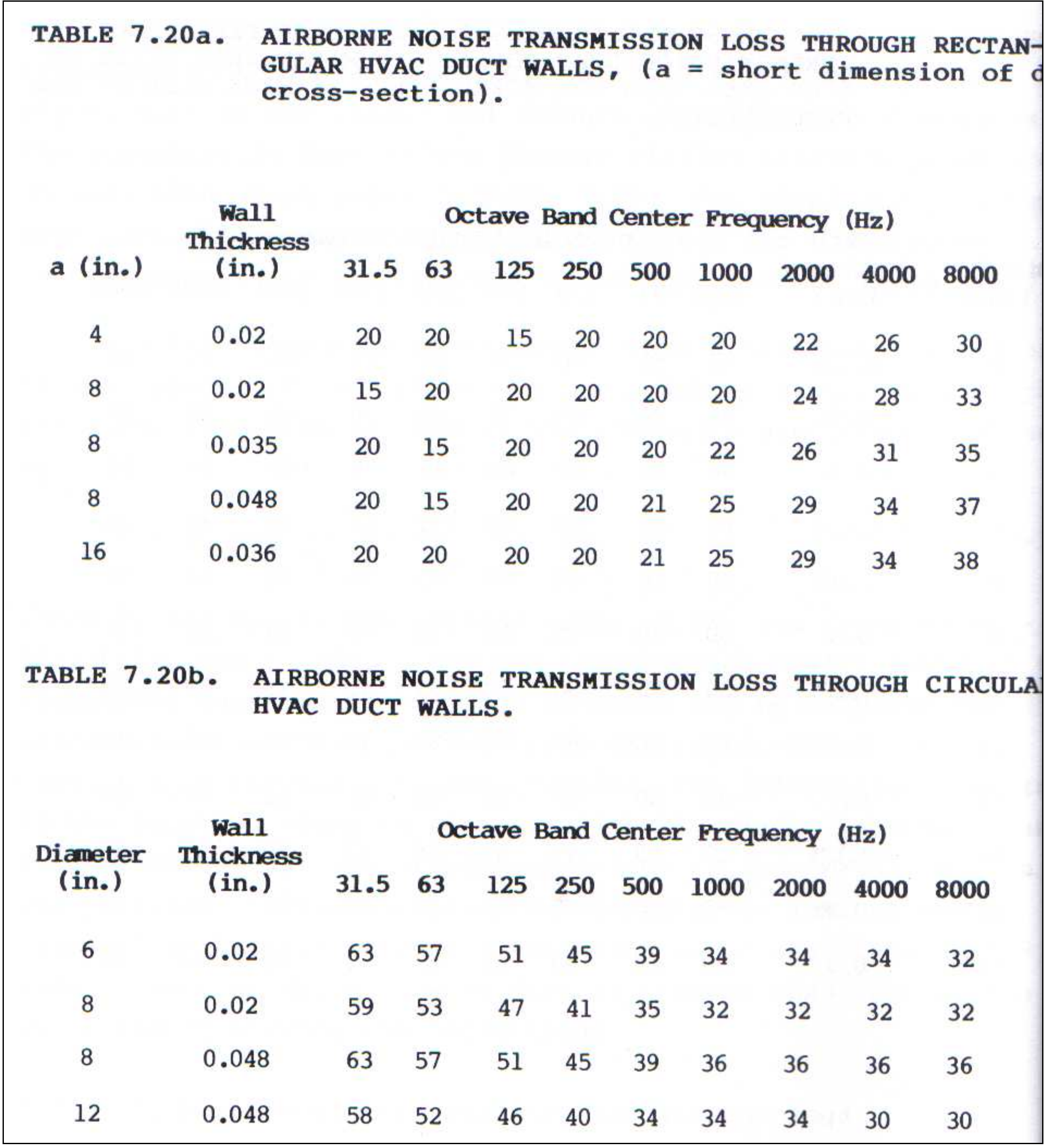


TABLE 7.20a. AIRBORNE NOISE TRANSMISSION LOSS THROUGH RECTANGULAR HVAC DUCT WALLS, (a = short dimension of d cross-section).

a (in.)	Wall Thickness (in.)	31.5	63	125	250	500	1000	2000	4000	8000
		Octave Band Center Frequency (Hz)								
4	0.02	20	20	15	20	20	20	22	26	30
8	0.02	15	20	20	20	20	20	24	28	33
8	0.035	20	15	20	20	20	22	26	31	35
8	0.048	20	15	20	20	21	25	29	34	37
16	0.036	20	20	20	20	21	25	29	34	38

TABLE 7.20b. AIRBORNE NOISE TRANSMISSION LOSS THROUGH CIRCULA HVAC DUCT WALLS.

Diameter (in.)	Wall Thickness (in.)	31.5	63	125	250	500	1000	2000	4000	8000
		Octave Band Center Frequency (Hz)								
6	0.02	63	57	51	45	39	34	34	34	32
8	0.02	59	53	47	41	35	32	32	32	32
8	0.048	63	57	51	45	39	36	36	36	36
12	0.048	58	52	46	40	34	34	34	30	30

When the air intake to a diesel engine is not ducted from outside the diesel engine room, the casing and intake noise are treated as a single component in section a.3).

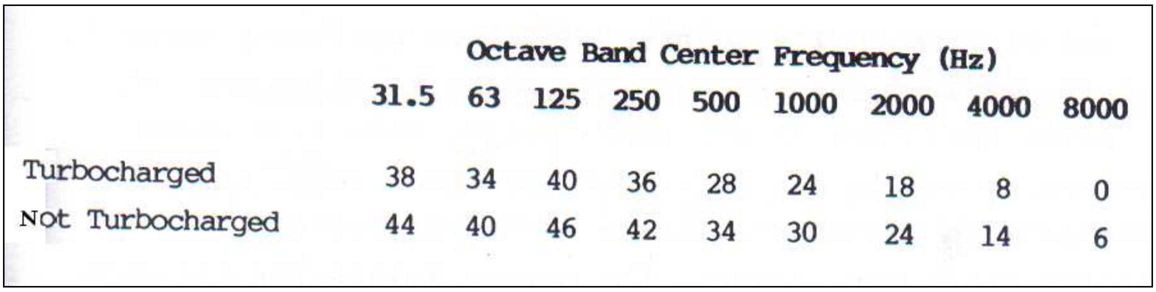
a.2) Diesel engine exhaust source

The baseline airborne noise source level for unmuffled exhausts of diesel engines operating at a constant speed is given by:

$$L_{WB} = 71 + 10\log(hp) \tag{9.4}$$

The octave band airborne noise source levels are obtained by adding to the baseline level the values given in Table 9.5.

Tab. 9.5 – Octave band adjustment (in [dB]) for baseline diesel engine unmuffled exhaust airborne noise source levels.



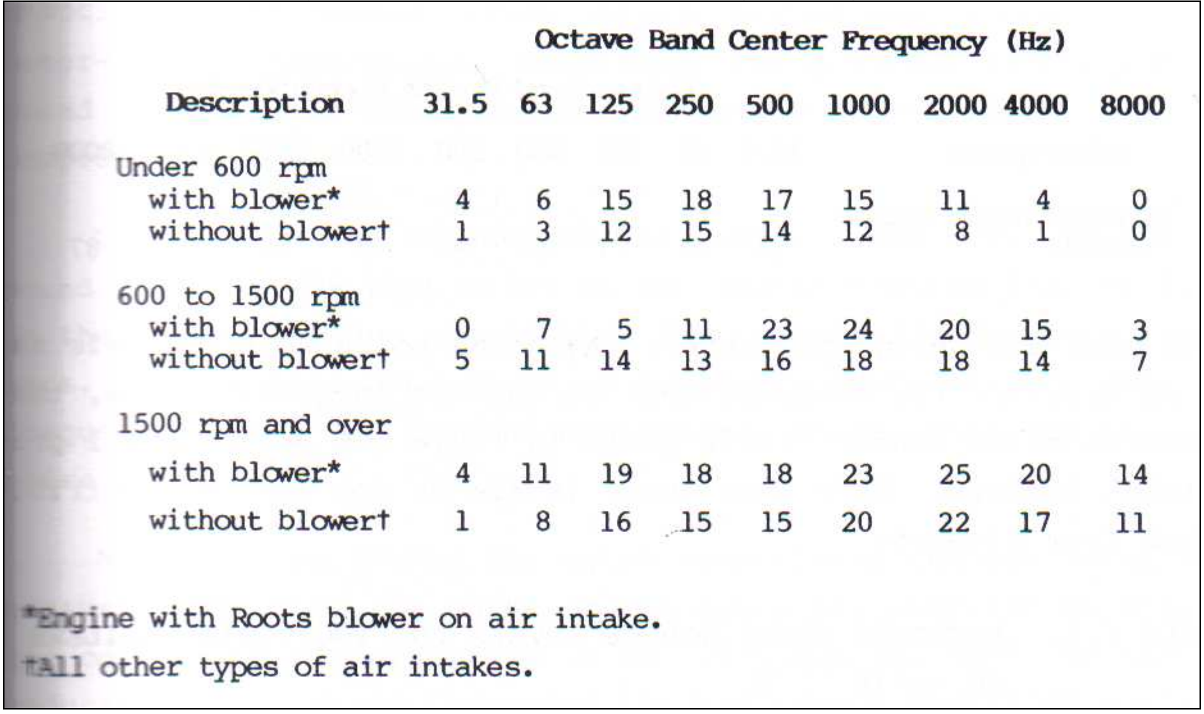
	Octave Band Center Frequency (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Turbocharged	38	34	40	36	28	24	18	8	0
Not Turbocharged	44	40	46	42	34	30	24	14	6

The octave band levels arrived at by using above procedure describe the exhaust noise inside the duct at the engine flanges. The exhaust is always ducted to outside the source room; therefore, to find the exhaust noise component of the total diesel noise contribution to the source room, one must adjust for the length and transmission loss of the exhaust duct in the source room in the same manner as described earlier for the intake noise.

a.3) Diesel engine casing

The baseline level for diesel engines casing airborne source levels is given by equation (9.1). The octave band source levels are obtained by adding the values in Table 9.6 to the baseline level computed from equation (9.1). In situations where intake and casing noise cannot be separated, the octave band levels for the combination of the intake and casing noise are obtained by adding values in Table 9.7 to the baseline level given by equation (9.1).

Tab. 9.6 – Octave band adjustment (in [dB]) for baseline diesel engine casing airborne noise source levels.

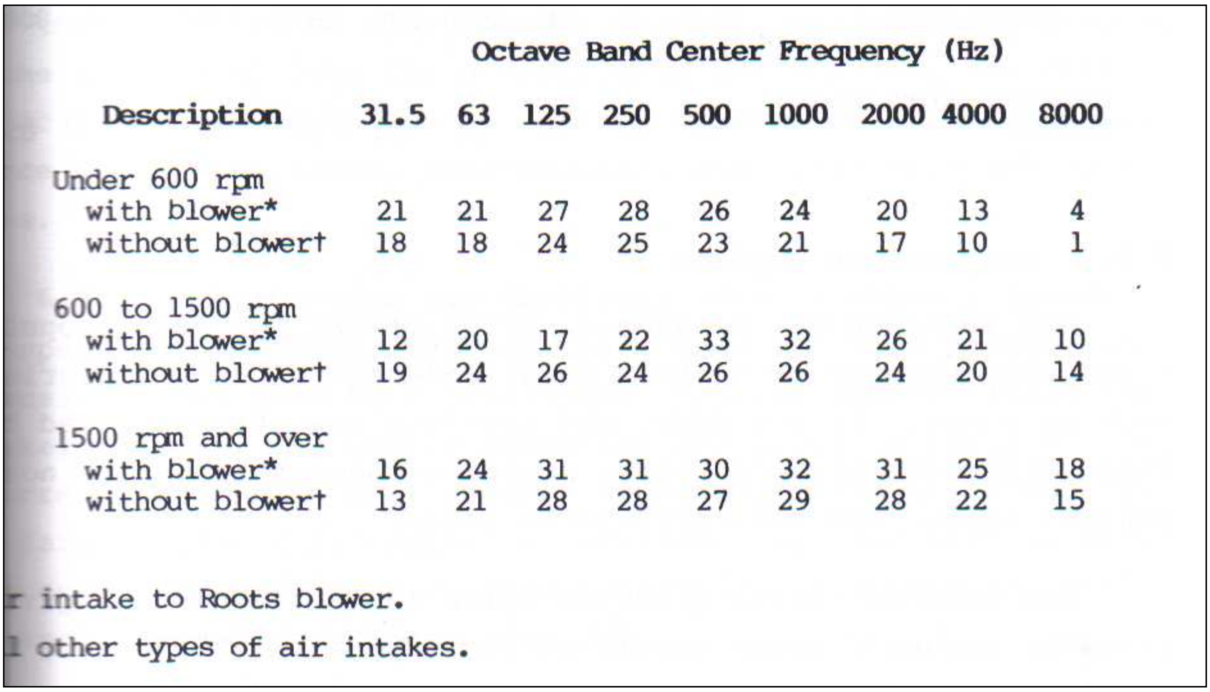


	Octave Band Center Frequency (Hz)								
Description	31.5	63	125	250	500	1000	2000	4000	8000
Under 600 rpm									
with blower*	4	6	15	18	17	15	11	4	0
without blower†	1	3	12	15	14	12	8	1	0
600 to 1500 rpm									
with blower*	0	7	5	11	23	24	20	15	3
without blower†	5	11	14	13	16	18	18	14	7
1500 rpm and over									
with blower*	4	11	19	18	18	23	25	20	14
without blower†	1	8	16	15	15	20	22	17	11

*Engine with Roots blower on air intake.

†All other types of air intakes.

Tab. 9.7 – Octave band adjustment (in [dB]) for baseline diesel casing and air intake airborne noise source levels.



	Octave Band Center Frequency (Hz)								
Description	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Under 600 rpm									
with blower*	21	21	27	28	26	24	20	13	4
without blower†	18	18	24	25	23	21	17	10	1
600 to 1500 rpm									
with blower*	12	20	17	22	33	32	26	21	10
without blower†	19	24	26	24	26	26	24	20	14
1500 rpm and over									
with blower*	16	24	31	31	30	32	31	25	18
without blower†	13	21	28	28	27	29	28	22	15

r intake to Roots blower.

l other types of air intakes.

a.4) Total diesel noise contribution

To determine the airborne noise source level for diesel engines, simply combine (not add) the contributions from casing, intake, and exhaust noise.

b) Reduction gears

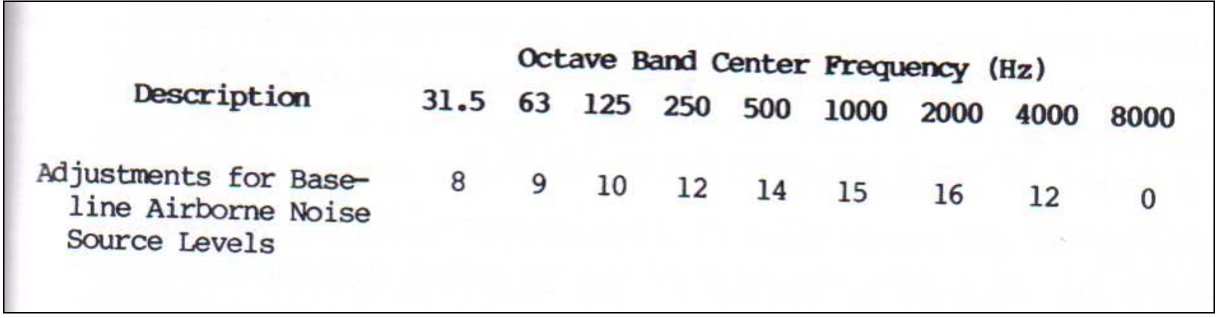
The principal mechanism by which reduction gears generate airborne noise is gear-pinion interaction. The airborne noise produced is characterized by tonal contributions at shaft rotation rates, tooth meshing frequencies and harmonics of these frequencies, and at frequencies determined by modulation between tooth meshing and rotation. The amplitudes of the various components of the airborne noise are strongly dependent on minor details of gear design and fabrication. Accurate prediction of gear airborne noise source levels requires esoteric methods beyond the scope of these notes. A description of an envelope below which a majority of the airborne noise source levels for reduction gears will lie is given in here. This method, which is based on measurements of several shipboard gears, is generally conservative in that the envelope, particularly in the mid-frequency range, is intended to encompass strong tones that shift from one octave band to another, depending on operating speed. This shifting in frequency with speed is not included in the airborne noise source level algorithms. Experience has shown that gear airborne noise is often mildly dependently on speed and load. These dependencies may be different for different noise generating mechanisms within the gear.

The baseline airborne noise source levels for reduction gears are given by the following formula:

$$L_{WB} = 69 + 3.4\log(hp) + 3.4\log(rpm) \qquad (9.5)$$

, where *rpm* is the rated full speed of the output shaft. Octave band source levels are obtained by adding to the baseline level the adjustment values given in Table 9.8.

Tab. 9.8 – Octave band adjustment (in [dB]) for baseline reduction gear source airborne noise source levels.



Description	Octave Band Center Frequency (Hz) 31.5	63	125	250	500	1000	2000	4000	8000
Adjustments for Baseline Airborne Noise Source Levels	8	9	10	12	14	15	16	12	0

It should be noted that the airborne noise source levels predicted by the above procedure are based on data for current AGMA class 12 main reduction gears in the absence of any special treatment applied to internal elements or the gear casing. The airborne noise source levels are those due to radiation from the gear casing; i.e., contributions from sub-bases and foundations are not included. Gears of higher AGMA grades have been shown to be quieter than predicted by the analytical methods given in here.

Obviously, the amount of other sources of noise generated by some of the equipment installed on ships (turbines, ventilators, compressors, pumps, etc.) is much larger than presented above. Hence, the student is encouraged to conduct further reading of other references available on noise control onboard ships. Namely, it is suggested for completeness the SNAME "Design Guide for Shipboard Airborne Noise Control", Technical Research (T&R) Bulletin Nº 3-37, in 1983.

Structureborne noise source levels:

For structures of structureborne noise, structureborne noise source levels are given in terms of free acceleration levels in [dB] re 10^{-3} [cm/s^2]. Structureborne noise source levels are sometimes given in terms of free velocity levels in [dB] re 10^{-6} [cm/s]. To convert velocity levels into acceleration levels, the following equation is used:

$$L_a = L_v + 20\log f - 44 \tag{9.6}$$

, where L_v is the velocity level and f is the octave band center frequency in hertz.

9.3.3. Transmission paths

This section presents procedures for computing the effects of transmission paths on airborne noise only. Structureborne transmission paths are therefore not addressed in here. The losses incurred along the path from a source of airborne noise to a receiver location are independent of source levels. The effects of a given transmission path are denoted quantitatively as the difference between the source level and the receiver level. The source and receiver levels are given as sound pressure levels and the transmission paths of interest include only the transmission from a source to receiver within a single compartment.

Adjustment values that account for the transmission path effects are computed using the procedure provided in this section. These adjustment values are then used with the source levels prediction of section 9.3.2 to obtain the values of sound pressure levels at the receiver locations.

Airborne transmission paths on enclosed spaces:

The transmission of airborne noise in an enclosed space (e.g., a machinery space onboard) can be divided into two fields, direct and reverberant. In the direct field, the sound pressure level is related to the sound power level of the dominant noise source, the directivity of that source, and the distance between the source and receiver. The sound pressure level in the reverberant field in an enclosed space is dependent on the level of the total sound power radiated into the space and the acoustic properties of the space, but does not vary significantly with receiver location. The acoustic properties of the space are expressed in terms of the room constant *R* (with dimensions of area), which accounts for the amount of exposed surface area in the space and the acoustic absorption properties of those surfaces. The exposed surface areas within a space affect the reverberant sound pressure level by dissipating acoustic energy by varying degrees when sound impinges on the respective surfaces. The larger the compartment or more abortive the surfaces, the larger will be the value of *R* and the smaller will be the reverberant sound pressure levels for constant values of the sound power levels (see equation (9.9)).

a) Room constant for sound absorption by boundaries

For an empty compartment in which all surfaces have the same acoustic absorption properties, the room constant, *R*, is simply the product of the total boundary surface area and the Sabine absorption coefficient, α, for the boundary surface material. The absorption coefficient is closely related to the sound incident on that surface. Thus, large values of α are indicative of very absorptive surfaces.

When the boundaries of an empty compartment are comprised of several different materials, the room constant is the sum of several terms, each of which is the product of the area and the Sabine absorption coefficient of a particular material. For example, for a compartment with two different boundary surfaces of areas S_1 and S_2 and respective Sabine absorption coefficients α_1 and α_2, *R* is given by:

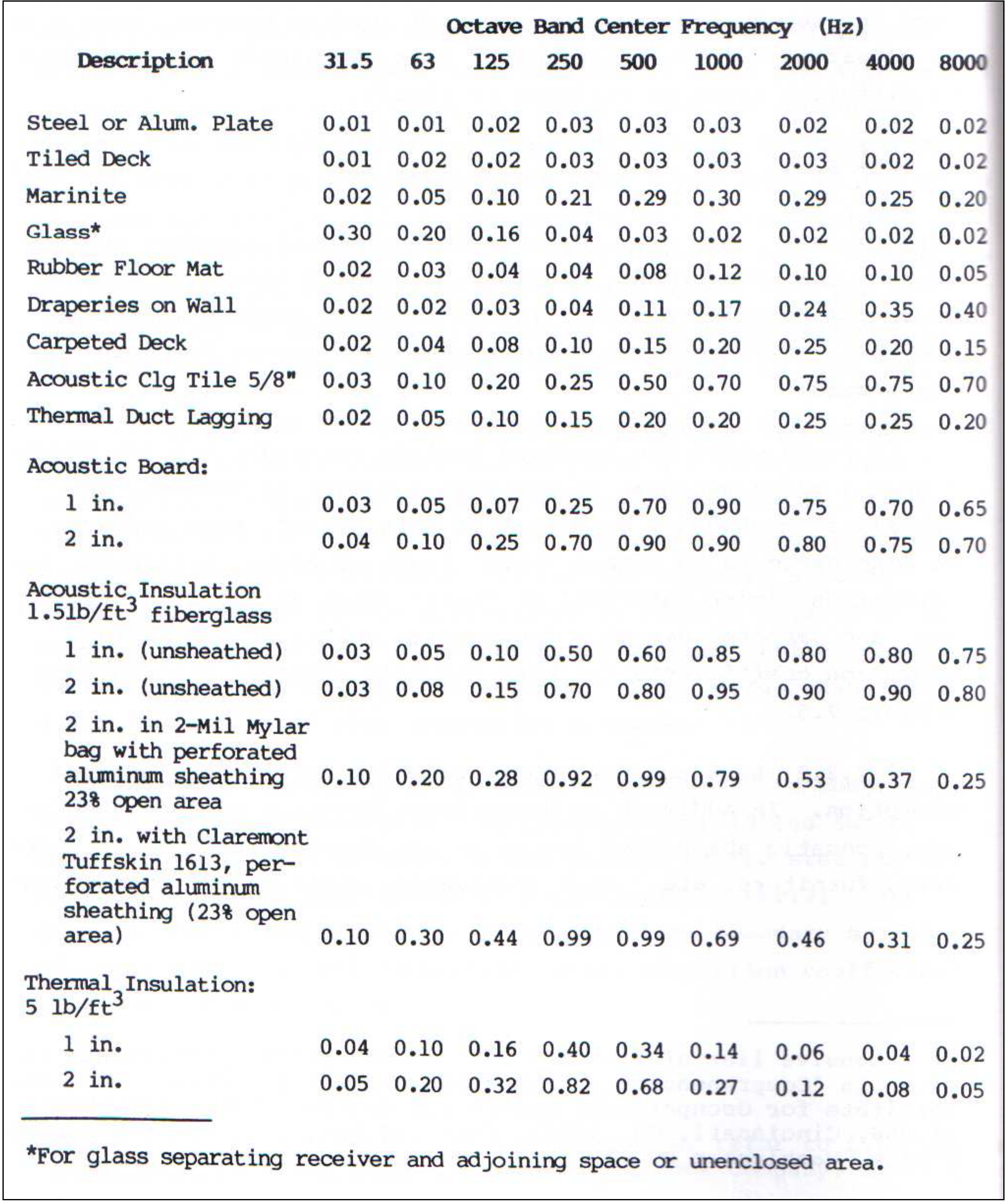
$$R = S_1\alpha_1 + S_2\alpha_2 \tag{9.7}$$

, where the sum $S_1 + S_2$ equals the total surface boundary area *S* of the compartment. The extension of this expression for more than two different types of surfaces is simply:

$$R = S_1\alpha_1 + S_2\alpha_2 + S_3\alpha_3 + \ldots + S_i\alpha_i \tag{9.8}$$

, where again S_1, S_2, S_3, … S_i are the individual boundary surface areas of the compartment. Table 9.9 contains values of Sabine absorption coefficients for typical boundary surface materials. Note that a different value for R must be computed for each octave band.

Tab. 9.9 – Sabine absorption coefficients.

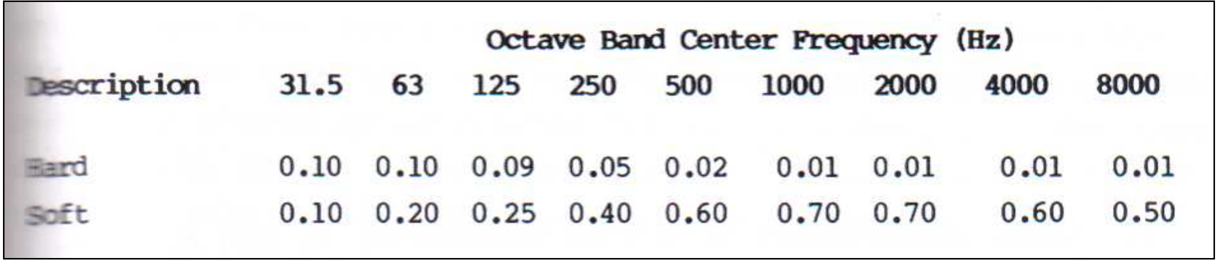


	Octave Band Center Frequency (Hz)								
Description	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
Steel or Alum. Plate	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.02	0.02
Tiled Deck	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02
Marinite	0.02	0.05	0.10	0.21	0.29	0.30	0.29	0.25	0.20
Glass*	0.30	0.20	0.16	0.04	0.03	0.02	0.02	0.02	0.02
Rubber Floor Mat	0.02	0.03	0.04	0.04	0.08	0.12	0.10	0.10	0.05
Draperies on Wall	0.02	0.02	0.03	0.04	0.11	0.17	0.24	0.35	0.40
Carpeted Deck	0.02	0.04	0.08	0.10	0.15	0.20	0.25	0.20	0.15
Acoustic Clg Tile 5/8"	0.03	0.10	0.20	0.25	0.50	0.70	0.75	0.75	0.70
Thermal Duct Lagging	0.02	0.05	0.10	0.15	0.20	0.20	0.25	0.25	0.20
Acoustic Board:									
1 in.	0.03	0.05	0.07	0.25	0.70	0.90	0.75	0.70	0.65
2 in.	0.04	0.10	0.25	0.70	0.90	0.90	0.80	0.75	0.70
Acoustic Insulation 1.5lb/ft^3 fiberglass									
1 in. (unsheathed)	0.03	0.05	0.10	0.50	0.60	0.85	0.80	0.80	0.75
2 in. (unsheathed)	0.03	0.08	0.15	0.70	0.80	0.95	0.90	0.90	0.80
2 in. in 2-Mil Mylar bag with perforated aluminum sheathing 23% open area	0.10	0.20	0.28	0.92	0.99	0.79	0.53	0.37	0.25
2 in. with Claremont Tuffskin 1613, perforated aluminum sheathing (23% open area)	0.10	0.30	0.44	0.99	0.99	0.69	0.46	0.31	0.25
Thermal Insulation: 5 lb/ft^3									
1 in.	0.04	0.10	0.16	0.40	0.34	0.14	0.06	0.04	0.02
2 in.	0.05	0.20	0.32	0.82	0.68	0.27	0.12	0.08	0.05

*For glass separating receiver and adjoining space or unenclosed area.

In cases where the boundary surface materials are not known, or when a quick estimate of the room constant is desired, and approximate method may be used. In this method, room surfaces are considered to be either "hard" (such as decks, bulkheads, and composition finish material) or "soft" (such as acoustic ceilings, and carpeted decks). Approximate values of the Sabine absorption coefficients for hard and soft surfaces are provided in Table 9.10.

Tab. 9.10 – Typical values of acoustic absorption coefficients for "hard" and "soft" surfaces.



Description	Octave Band Center Frequency (Hz) 31.5	63	125	250	500	1000	2000	4000	8000
Hard	0.10	0.10	0.09	0.05	0.02	0.01	0.01	0.01	0.01
Soft	0.10	0.20	0.25	0.40	0.60	0.70	0.70	0.60	0.50

b) Airborne noise levels in source spaces

For a compartment containing noise sources, the sound pressure level if the total airborne noise in space at a given location is related to the sound power level (L_w) of the noise sources by both the direct and reverberant sound fields. To obtain the total sound pressure level at a specific location in a compartment containing noise sources, the reverberant and direct field components presented below are computed separately and combined.

b.1) Reverberant field sound pressure level

The following expression is used for computing the compartment sound pressure level in each octave band due to reverberant sound field:

$$L_p = L_w - 10\log R + 16 \tag{9.9}$$

, where L_W is the total sound power level in each octave band due to all noise sources in the compartment, L_p is the total octave band sound pressure level in the reverberant field, and R is the room constant. The total sound power level is determined by combining, using logarithmic addition, the individual source sound power levels obtained from section 9.3.2. The room constant, R, is determined using equation (9.7).

b.2) Direct field sound pressure level

The determination of the sound pressure level in the direct field of a noise source requires the knowledge of the location of the receiver relative to the noise source and the location of the noise source relative to the compartment boundaries. The general expression for L_p in the direct filed is:

$$L_p = L_w - 20\log r + 10\log Q - 1 \tag{9.10}$$

, where L_W is the octave band sound power level of the noise source being examined, and r is the distance in feet between the acoustics center of the noise source and the receiver. The term, Q, is called the directivity factor of the noise source, and is equal to 2, 4, or 8 depending on whether the noise source (assumed to be deck-mounted and radiating sound uniformly in all directions) is located near the center of the compartment, against a bulkhead, or in the a corner.

In large machinery spaces where substantial volume of the room is occupied by equipment, piping, etc., it has been found empirically that for receiver locations more than 10 [ft] from any single noise source, sound pressure levels decrease with distance at a rate greater than the direct field equation (9.10) indicates. For calculating the noise due to sources in main machinery spaces at distances greater than 10 [ft], the following expression for direct field sound pressure level should be used:

$$L_p = L_w - 30\log r + 10\log Q + 9 \tag{9.11}$$

The total direct field sound pressure level at a receiver location due to more than one noise source is found by combining the individual sound pressure level contributions from each source as computed using either the above expression or equation (9.10).

b.3) Total sound pressure levels

As mentioned above, the total sound pressure level in a compartment containing noise sources is the combined octave band sound pressure level contributions from reverberant and direct sound fields. Note that because the value of the direct field component is dependent on the relative locations of sources and receivers, the value of the total source pressure level must be computed for each receiver location within the compartment.

The most efficient procedure is to calculate the reverberant level for a given source space first. Then calculate direct field levels at a particular receiver location (i.e., workbench watchstation, etc.) due to the strongest (highest L_w) and nearest (smallest r) sources. If for a particular receiver location there are sources that are both farther (larger r) and weaker (smaller L_w) than a source resulting in a direct field, L_p, which is more than 10 [dB] less than the reverberant of the previously calculated direct field levels, then these farther, weaker sources need not be calculated.