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UNITED STATES
EXPERIMENTAL MODEL BASIN

NAVY YARD, WASHINGTON, D.C.

AIR FLOW THROUGH SMALL SEGMENTS OF ARMOR GRATINGS WITH DUCT APPROACHES

EXPERIMENTAL MODEL BASIN
ERECTED 1898
BUREAU OF
CONSTRUCTION AND REPAIR
NAVY DEPARTMENT

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JANUARY 1940

REPORT NO. 463

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INTRODUCTION

The first work on air flow through armor gratings recorded in Experimental Model Basin files was reported (6)* in 1921. Grating bars of various sections and also assembled bar gratings were tested in half-scale wood models by mounting in the wind tunnel. Instead of loss of head, the quantity measured was drag on the bar or grating. It was concluded that there is benefit in streamlining if smooth surfaces can be maintained. At that time, the results were considered not good enough quantitatively to justify conversion into terms of loss of head, as is necessary for application in design of air-flow systems. In 1922 a further report (9) was made on flow through a bar grating with divergent approach and convergent discharge ducts. A bulkhead was built across the wind tunnel, the test assembly mounted in it, and measurements of pressure loss were made. A single grating of bar type was chosen from those previously tested, and the taper of the connecting ducts was varied.

Armor gratings are at best a compromise between the conflicting requirements of air flow and ballistic protection. In later tests (1 to 5), gratings of a type proposed (7) in 1921 were examined with respect to their resistance to air flow, and compared with gratings of older type. The impossibility of duplicating service conditions was clear from the beginning, but it was hoped that some indications of relative merit of different designs might be obtained.

The first of these later series (1) consisted of five gratings; this was later increased (2) by four items lettered A to D. Six additional items were made up by the Experimental Model Basin, and report (3) was submitted by letter on 3 November 1929.

Further work was requested (4) on 28 November 1930; the report (5) was submitted 13 December 1930.

The present report summarizes the data on air flow thus obtained, and offers comment on their value and significance for full-scale design. The data on noise requested (4) in 1930, appear not to have been taken because of lack of facilities.

TEST PROCEDURE AND SPECIMENS

Associated with armor gratings in service are radical changes in section of ducts and in direction of flow. In planning these tests an effort was made to differentiate between the losses in the ducts and those in the gratings proper.

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* Numbers in parentheses designate references at end of report.

In the 1929 series (1), (2), (3), air was blown through a 12-inch duct (whether round or square not known) in which was inserted a conversion piece diverging to a 20-inch square section to take the grating, and then converging to a 12-inch section. Pitot tubes were placed in the 12-inch sections, 8 feet, 9 inches apart, one upstream and one downstream from the 20-inch segment. Readings were taken with a grating model inserted in the 20-inch section, and with an open dummy model in place.

The models were all made to fit in the 20-inch square segment of duct. They were of wood, and represented areas 40 inches square to half-scale. However, no attempt was made to attain exact similitude. The earliest models simply provided the possible number of uniformly spaced round holes, but in later models variants were tried by introducing additional smaller holes and by blocking off some of the larger holes.

The area of the holes, in proportion to the area of the 12-inch duct, ranged from 156 per cent for the bar grating and 133 per cent for the original gratings with round holes, to 100 per cent with one-fourth of the holes blanked off.

In the later series (4) models of various overall dimensions were used, and the convergent discharge was eliminated. The duct system consisted of a short divergent coupling just preceding a frame for the grating which was then followed by a parallel duct. In some tests the fan discharged directly into the divergent coupling, in others a parallel duct was interposed. Pitot tubes were provided in the parallel ducts, and static taps in the divergent coupling. Figure 1 contains the only details available.

For each size of duct used, a traverse was made to determine the ratio of pitot readings at center to the average value. This ratio was measured at a single air speed. At other speeds the value found at the center was converted to a mean value by multiplication by the measured ratio.

Although no great difference in results appeared when the fan was close-coupled, the final readings were taken with a length of straight duct interposed between fan and grating, as shown in Figure 1. This permitted the use of a pitot tube at

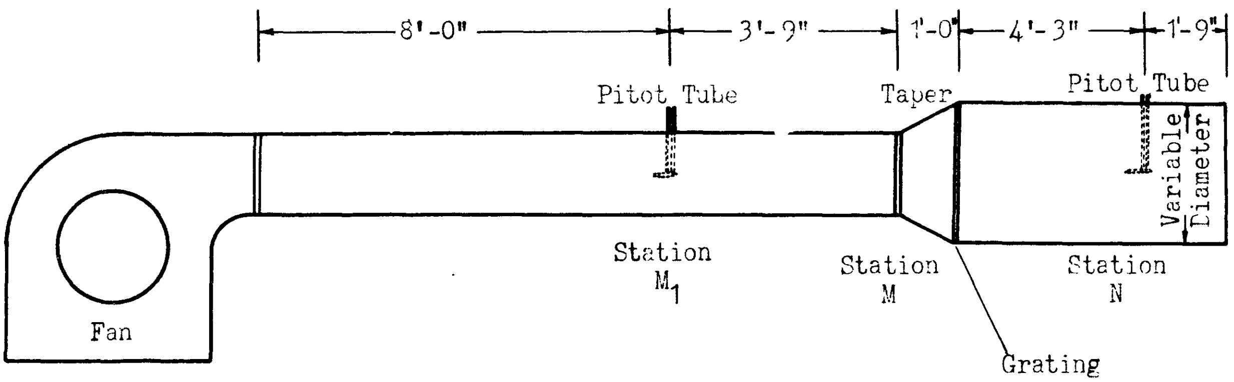

Figure 1. Diagrammatic Sketch of Apparatus

Station M_1, and while the conditions for standard tests were not wholly complied with, it is believed that the results have adequate validity.

All gratings in the final series were identical, with circular holes 1-11/16 inches in diameter on 2-inch centers, with their edges moderately chamfered. Plate thickness was 2 inches.

The 1930 series included four models, differing in the area of the grating and the taper of the divergent couplings. The latter were all 18 inches in diameter at the entrance end and about 9 inches in axial length.

The test procedure consisted first in measurement of the loss in total head or pressure (static plus velocity pressure) for the divergent coupling without grating. Without other change in the set-up, the grating was then inserted in the air stream at the downstream end of the coupling and the observations repeated. The loss in total pressure (or head) was thereby increased. It might be assumed that a value of pressure loss due to the grating alone could be obtained by subtraction. Such an assumption would be hard to justify, since the grating cannot be tested separately from the ducts. However it is not unreasonable to expect that from the series of eight different conditions of test, some clues to the best design choices with respect to air flow through armor gratings may be found.

RESULTS

The data in the various series of tests were reported in different terms. For the sake of comparability they are here reduced to the same terms, all expressed as the ratio of loss in total pressure (or head) to the velocity pressure (or head) at the entrance to the assembly.

This may be related to a characteristic of the grating, viz., ratio of area of openings A_h to total area A_t, and also to a characteristic of the divergent approach duct, viz., ratio of its outlet area A_o to its inlet area A_i. Since the outlet area of the tapered duct A_o equals the gross area of the grating A_t, the product of the two ratios $A_h/A_t \times A_o/A_i$ gives the ratio A_h/A_i of area of openings in the grating to area of inlet in the duct.

Air speed naturally strongly influences pressure loss. However, pressure loss is nominally proportional to the square of air speed. Since velocity pressure is also proportional to the square of air speed, the ratio of loss to velocity pressure is nominally independent of speed. Actually some variations with speed occur. The investigation of these variations would be a matter of importance in a more refined study, especially if model scale ratios departing widely from unity were used.

For the present purpose, however, the observed value of the ratio at speeds approximately 3000 feet per minute is accepted, and its variation with speed is ignored. In some cases additional data at about 6000 feet per minute are included.

1921 Tests (6).

These gratings were placed in the open air stream without any enclosing duct, and the drag was measured, after the manner of testing aircraft models. Loss of pressure may be expressed as quotient of drag by an area, but it is difficult to choose a value of area appropriate to the case. For lack of a better choice, the gross area of the grating is used, which was 260 square inches. The openings have an area of about 184 square inches, or 71 per cent of the gross area.

The four gratings differed only in the sections of the bars. The bars differed in sectional area and are believed to be not equivalent to each other ballistically.

TABLE 1 - NOMINAL PRESSURE LOSS, UNENCLOSED FLOW, IN PERCENTAGE OF VELOCITY PRESSURE

Grating Number	Bar Section	Pressure Loss in Per Cent	
		3000 f.p.m.	6000 f.p.m.
8	Rounded (A)	25	23
9	" (E)	23	20
9 (reversed)	" (E)	25	23
10	Rectangular (G)	31	28
11	Streamlined (D)	21	17

1922 Tests. (9)

Total pressure loss was measured directly, and no attempt was made to segregate that of the divergent duct from that of the grating. Ratio of net to gross area of grating was about 70 per cent in all cases.

All of the assemblies (converging plus diverging ducts plus grating) had

TABLE 2 - OBSERVED PRESSURE LOSS, IN PERCENTAGE OF VELOCITY PRESSURE, BAR GRATING TYPE A, VARIABLE DIVERGENCE IN DUCT

Assembly Number	L/D Ratio	Ratio of Grating Area to Area of Straight Duct in Per Cent		Pressure Loss in Per Cent	
		Gross	Net	3000 f.p.m.	6000 f.p.m.
A_1	3.15	267	187	27	27
B_1	3.15	174	122	24	23
A_2	4.08	222	155	22	22
B_2	4.08	156	109	23	21
A_3	5.82	180	126	16	16
B_3	5.82	138	97	27	25
A_4	10.10	144	101	27	24
B_4	10.10	121	85	33	31

the same length in the A-series. In the B-series the tapers were the same as in the A-series, but the lengths of the diverging and converging ducts were cut in half. L/D is the ratio of length of taper to change in side of square section, as tabulated in (8).

1929 Tests (1), (2), (3).

Solid plates with cylindrical openings, as suggested (7) in 1921, were tested in half-scale, using three sizes of openings, three plate thicknesses, and bar gratings of conventional type for comparison. All models were of the same external dimensions and all were fitted in the same duct system. The loss of pressure in the duct system with an open dummy in place of a grating, at 3000 feet per minute in the small end of the divergent approach, was 29 per cent. When the various gratings were inserted in place of the dummy at the point of maximum section in the duct, the pressure loss was increased to the values given in Table 3.

TABLE 3 - OBSERVED PRESSURE LOSS, PERFORATED PLATE GRATINGS

Grating Number	Pressure Loss in Per Cent of Velocity Pressure in Duct	Ratio of Grating Area to Area of Straight Duct, in Per Cent	
		Gross	Net
Dummy	29	354	354
1	33	354	170
2	32	354	169
3	33	354	170
4 (parallel bars)	32	354	199
5 (oblique bars)	64		
A	32	354	170
B	31	354	199
C	32	354	170
D	32	354	169

These figures have been recalculated to place them in form comparable with the others. The data given in the report (3) of 1929 refer to a net value of pressure loss obtained by subtracting loss in dummy set-up from total loss with grating in place. The values as now quoted refer to overall loss in the unit as a whole.

Additional data in the 1929 report (3) referring to variations in disposition of holes are not quoted as they are of doubtful significance in the present summary.

1930 Tests (4), (5).

Data obtained are shown graphically in Figures 2 to 4. From Figure 4, values at 3000 feet per minute at fan discharge are read off and listed for comparison with other data in Table 4. Figure 4 shows the ratio of pressure loss due to velocity pressure to be nearly independent of speed.

TABLE 4 - OBSERVED PRESSURE LOSS IN PLATE GRATING. VARIABLE DIVERGENCE IN DUCT

Discharge diameter, inches	Case Number	Loss in Total Pressure at 3000 f.p.m., Per Cent of Velocity Pressure	Area Ratios in Per Cent	
			Outlet to Inlet	Holes to Inlet
18	4	65	100	65
20-3/8	2	58-1/2	128	83
23-1/8	1	35	165	106
35	3	65	378	244

Data were also taken on loss due to the divergent duct only, with no grating in place. These afforded rough confirmation of handbook data (8), but as they served no other useful purpose, they are quoted only as shown in Figure 3.

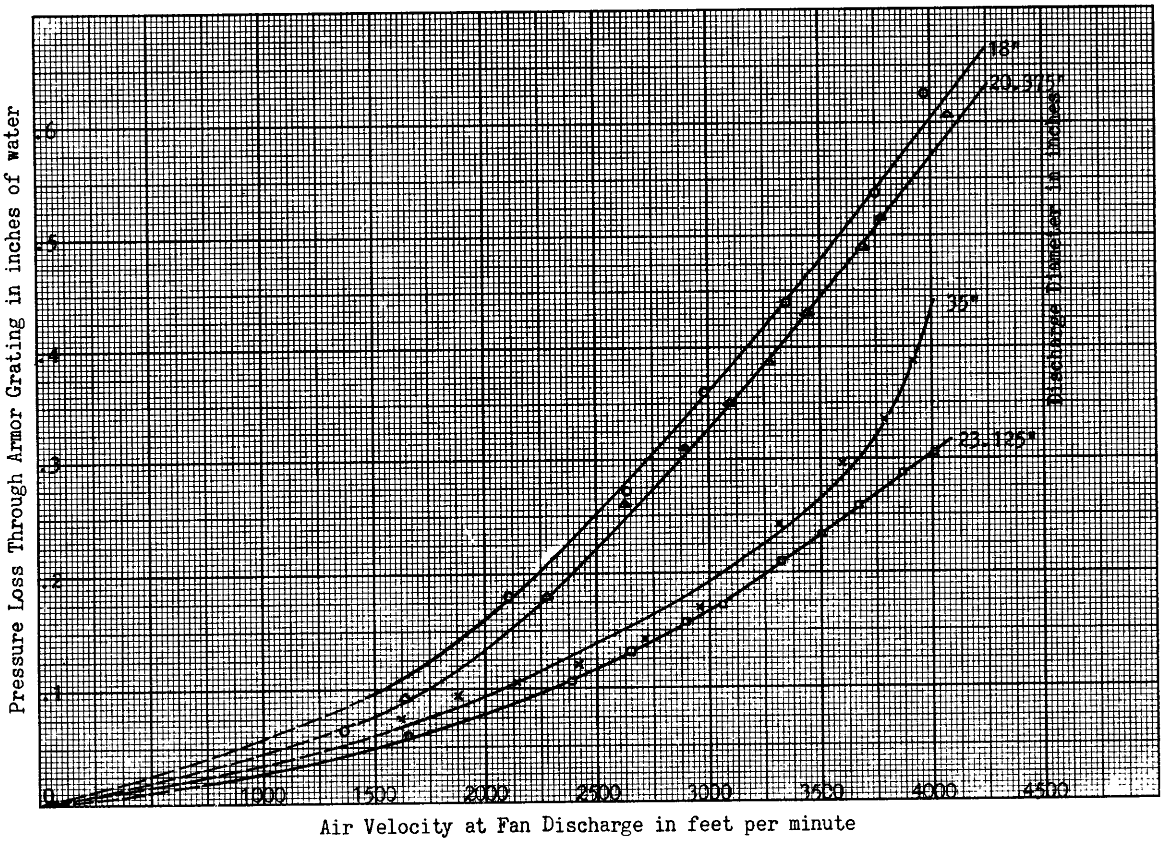

Figure 2. Pressure Loss Through Armor Grating on Air Speed

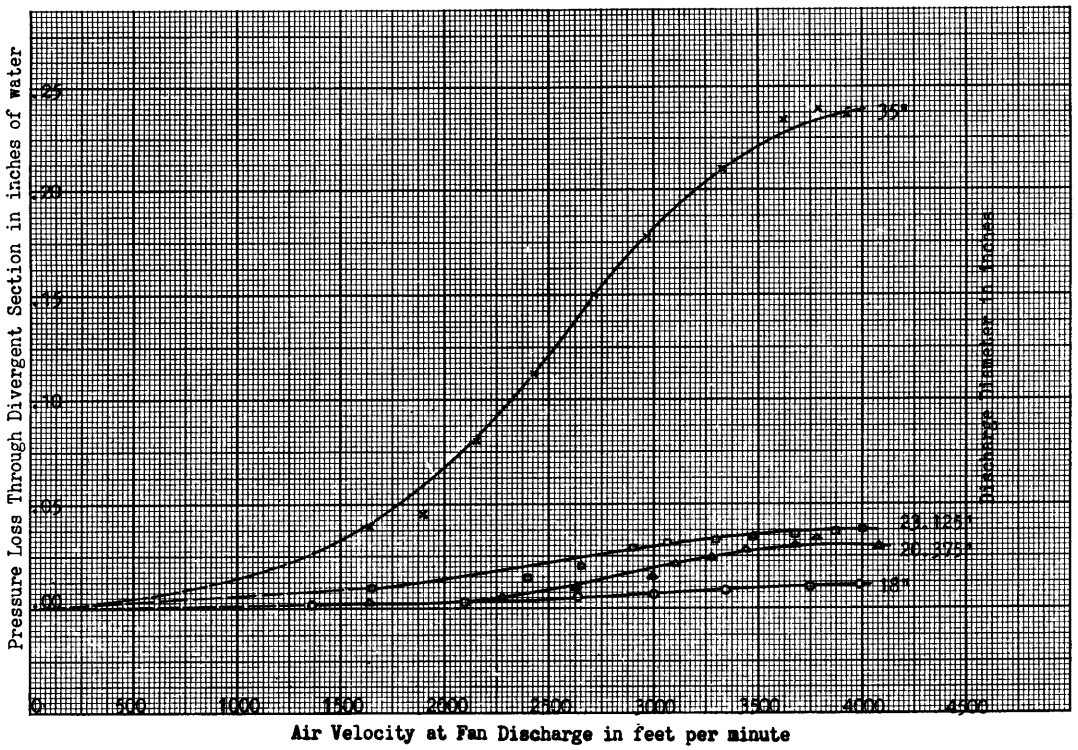

Figure 3. Pressure Loss Through Divergent Section on Air Speed

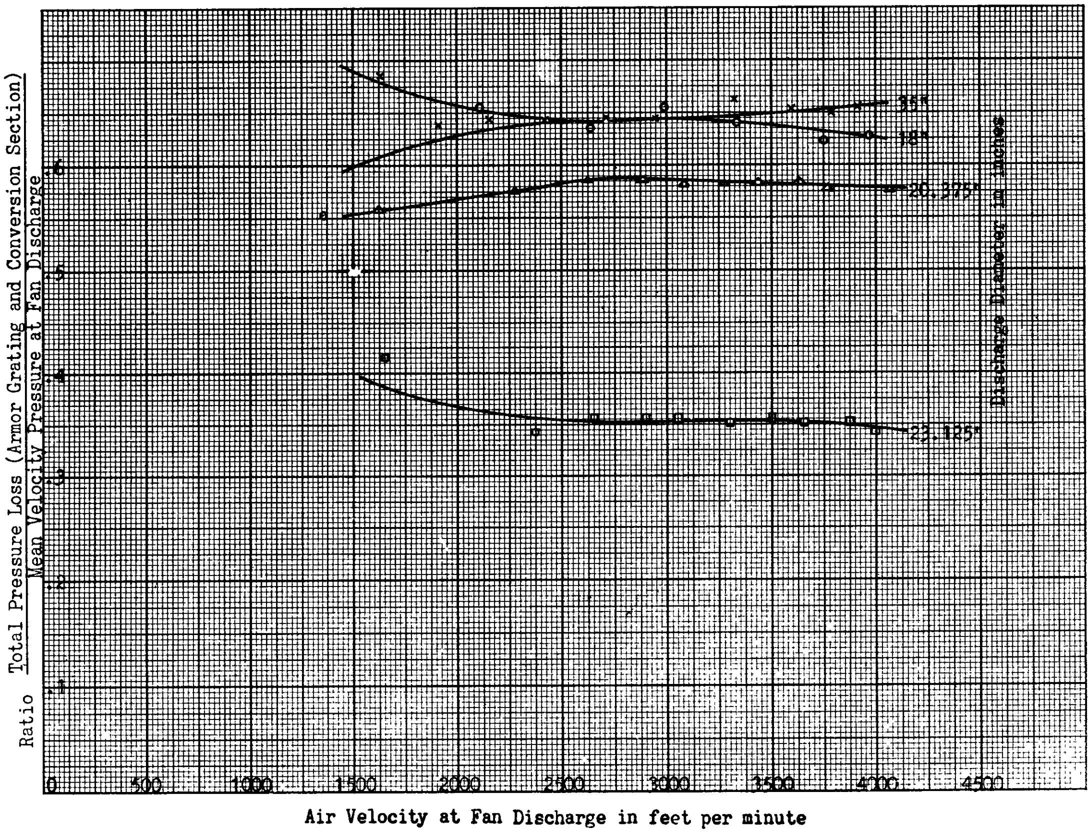

Figure 4. Total Pressure Loss as Percentage of Velocity Pressure

DISCUSSION

The assumption that pressure loss is proportional to velocity pressure, and hence to the square of the linear velocity taken at some standard reference section, is for present purposes sufficiently accurate. For convenience the standard section is taken at the fan discharge, or, what is the same thing for present purposes, at the entrance to the divergent section.

It is not possible to separate loss in the grating from loss in the divergent section, as these losses are in no sense additive. The insertion of the grating in the air stream, without other change, so thoroughly alters the nature of the flow that the loss can be considered only with relation to the whole assembly. The problem really involves two parameters, taper of the divergent coupling, and characteristics of the grating; the complete solution would involve tests of complete assemblies in which both features were varied.

This, roughly, has been accomplished. The 1929 tests show that the variations in the gratings (with exception of obliquely placed bars) had very little influence on total loss. It is probable that greater changes in area ratio would have caused somewhat greater variations in pressure loss but the limits of variation of ratio of net to gross area are not wide, and within these limits it is apparent that the size and disposition of the holes has little effect on the total loss of pressure. In this sense is it correct to say that the loss is mainly in the divergent fitting.

The 1930 tests throw additional light on the matter. They show that under the conditions of the test there is an optimum degree of divergence and that a rise in pressure loss may occur, due to either its increase or decrease. This result is quite different from what would be obtained without the grating. Reference (8) shows a continually increasing loss (diminishing regain) with increasing divergence, except that beyond an L/D ratio of about 1.75 the loss does not increase further. These data are roughly confirmed by observations shown in Figure 3. Under the conditions of the present tests, however, the presence of the grating offered further obstruction to the flow; and while the holes took up a constant fraction of the whole area of the grating, namely 65 per cent, the ratio of flow area through the grating to that in the duct varied as shown in Table 4. Subject to this condition it can be said that the grating was held constant while the divergence was varied.

The existence of an optimum divergence is confirmed by the 1922 tests, which show a lower minimum than was attained in the 1930 tests.

The absolute values of losses obtained in these tests should be regarded with some reserve. It was felt when the work was done that greater precautions would have been necessary to obtain full consistency. There is also some question as to scale effects. It is questionable whether results from a small section of grating with full-size holes could be extended to apply to a full-size grating, even though vanes in the divergent section were used. Nevertheless it is considered that the conclusions, as set forth in this report, are justified.

Comparisons between results in different series are also somewhat questionable, and are less certain than comparisons between different members of a single series.

With respect to the single case of bar grating in the 1929 series, which shows no certain difference from the plate gratings in the same series, it is considered that this is not enough to outweigh the low values of 1922 on bars compared with the high values of 1930 on plates.

Further development of such tests as these would be much more convincing if conducted on the actual operating ship. It seems probable that by suitably disposed guide vanes in the divergent approach, a considerable saving might be effected. The fittings of light divergent nozzles of moderate taper at the discharge end of the cylindrical perforations in the grating could be depended upon to reduce loss. Whether either of these schemes is practicable or possible or whether either may have already been tried is not known by the Experimental Model Basin. The chief difficulty in tests on an operating ship lies in the evaluation of the loss in total pressure, since the conventional methods are not available because of lack of space. If flow through the remainder of the circuit could be suitably controlled, the pressure obtained in the compartment to which air flowed from the grating should give a satisfactory measure of the efficiency of the grating unit. It is possible that losses in the remainder of the circuit are so high that improvement in the grating unit may offer only small chance of improvement in the system as a whole. At the same time it is noted that in these tests losses in the grating unit rose in some cases to high values, as much as 65 per cent of entrance velocity pressure. This would be an inadmissible fraction of the whole loss in the circuit from open air to open air in an operating installation. However, in cases where the fan works against a high static pressure, the total pressure loss around the circuit (static plus velocity pressure) may become a large multiple of the entrance velocity pressure, and so, in this case the loss in the grating becomes relatively unimportant.

Aside from the possibility of grating-unit tests on shipboard, a solution of the problem seems to require tests on a more extensive scale, both in size of units and in number of tests.

CONCLUSIONS

1. Overall losses in total pressure due to flow through gratings and approaches are expressed as a percentage of velocity pressure at the entrance to the unit. With bar gratings, values as low as 16 per cent have been observed; with perforated plates, as low as 34 per cent.

2. Loss in total pressure due to flow through a grating and approaches is proportional to velocity pressure, within the limits of air speed and accuracy of these tests.

3. Pressure losses in armor gratings are so involved with those in the divergent approach that they cannot be separated. The grating and adjoining ducts must be regarded as a unit.

4. Pressure losses in such units are less with bar gratings than with perforated solid plates.

5. Changes in the divergent approach affect overall pressure losses more than changes in the grating.

6. It appears likely that in systems operating at low static pressure, further experiments with gratings might lead to reduction of losses. In systems operating at high static pressures, amounting to several times the velocity pressure, it is doubtful whether gratings contribute a significant part of the total loss.

RECOMMENDATIONS

1. It is recommended that a coordinated attack on problems of air flow, including air flow through armor gratings, be made.

PERSONNEL

Search of files, examination of records, and preparation of this summary has been carried out by Lt. Comdr. W. P. Roop, (CC), U.S.N. The original experimental work is believed to have been done by persons no longer attached to the Experimental Model Basin Staff.

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5. "Preliminary Report on Armor Grating Ventilation Test" of 13 December 1930; copy on Experimental Model Basin File L5-2/S13-1(2).
6. Experimental Model Basin Report No. 24, January 1921, Bureau of Construction and Repair File 35-105.
7. Bureau of Construction and Repair letter 164-4(DN) of 26 April 1921 to Bureau of Ordnance, Experimental Model Basin File L5-2/S13-1(1).
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