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An Orifice Method of Producing a High Velocity Stream

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AERODYNAMIC SYMBOLS

1. GENERAL

m	Mass
t	Time
V	Resultant linear velocity
Ω	Resultant angular velocity
ρ	Density, σ relative density
ν	Kinematic coefficient of viscosity
R	Reynolds number, $R = lV/\nu$ (where l is a suitable linear dimension)

Normal temperature and pressure for aeronautical work are 15° C and 760 mm.

For air under these conditions $\begin{cases} \rho = 0 \cdot 002378 \text{ slug/cu. ft.} \\ \nu = 1 \cdot 59 \times 10^{-4} \text{ sq. ft./sec.} \end{cases}$

The slug is taken to be 32·2 lb.-mass.

α	Angle of incidence
ϵ	Angle of downwash
S	Area
b	Span
c	Chord
A	Aspect ratio, $A = b^2/S$
L	Lift, with coefficient $C_L = L/\frac{1}{2}\rho V^2 S$
D	Drag, with coefficient $C_D = D/\frac{1}{2}\rho V^2 S$
γ	Gliding angle, $\tan \gamma = D/L$
L	Rolling moment, with coefficient $C_l = L/\frac{1}{2}\rho V^2 bS$
M	Pitching moment, with coefficient $C_m = M/\frac{1}{2}\rho V^2 cS$
N	Yawing moment, with coefficient $C_n = N/\frac{1}{2}\rho V^2 bS$

2. AIRSCREWS

n	Revolutions per second
D	Diameter
J	V/nD
P	Power
T	Thrust, with coefficient $k_T = T/\rho n^2 D^4$
Q	Torque, with coefficient $k_Q = Q/\rho n^2 D^5$
η	Efficiency, $\eta = TV/P = Jk_T/2\pi k_Q$

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COMMUNICATED BY PROFESSOR R. V. SOUTHWELL, F.R.S.

Reports and Memoranda No. 1887

31*st May,* 1940

Earlier papers (Binnie 1938 and 1940) have dealt with the uniformity of the stream produced by a venturi flume and with the possibility of employing this device for testing model seaplane floats. If the velocity of the stream is to be as high as 40 ft./sec., a net head (i.e., vertical distance between the supply level and the surface of the channel) of 25 ft. is required. In a venturi flume with an expansion ratio of 2, and working at this net head, the ratio of downstream to upstream depth would be at least 0·25. Hence the gross head, or vertical distance between the supply level and the bottom of the channel, would be 33 ft., and the depth of the issuing stream would be 8 ft., which is unnecessarily large. It will be appreciated that to attain velocities of this magnitude a very great expenditure of power is required, and therefore the cross section of the stream should be as small as possible consistent with the requirements of the experiments. The expansion ratio might be increased to reduce the depth of the stream and to raise slightly its velocity, but only at the expense of its uniformity.

It is, however, possible that a satisfactory and more economical stream might be produced by means of a rectangular orifice inserted in the side of a large tank near the bottom, and discharging direct into an open horizontal channel of the same cross-section (Fig. 1). To avoid contractions, the orifice must be fitted with a trumpet. If we consider a horizontal stream line at a depth h below the surface in the channel, the constant in Bernoulli's equation is $(H + h)$, where H is the net head and the datum is the stream line itself. The pressure head along the stream line is h, hence the velocity v is given by $v^2 = 2gH$, and is therefore theoretically uniform over the cross-section.

The arrangement suffers from an obvious disadvantage. The water forming the free surface in the channel is previously in contact with the upper portion of the trumpet, where a boundary layer is formed. But it seems possible that the resulting variation in velocity would disappear within a short distance from the orifice, or it might prove practicable to suppress the boundary layer by suction or other devices. On the other hand, the arrangement has the advantage over the venturi flume of producing a stream, the depth of which is independent of the velocity. Moreover, it is not essential that the source of supply should possess a free surface.

This device does not seem to have been previously examined, and no mention of it can be discovered in text books. The simple small-scale experiments described below were therefore carried out at the Engineering Laboratory, Oxford, in order to throw light on its feasibility.

Water was led from a constant-level tank in the laboratory roof to one end of a cylindrical tank, 24 in. in diameter and 46 in. long, which served as a reservoir (Fig. 2). At the other end, the orifice, 2·00 in. wide and 1·51 in. high, was inserted, discharging into an open horizontal channel, the bottom and walls of which were flush with the orifice. To avoid spilling, the crests of the walls were raised above the top of the orifice. Both the internal trumpet and the channel were made of sheets of tinned iron soldered together. A circular wooden disc and numerous perforated baffles were fixed in the cylindrical tank in order to prevent the incoming water from disturbing the flow at the trumpet entrance. The cylindrical tank was provided with an open stand pipe to permit the escape of air and with a vertical glass tube and scale for the measurement of the head. The depth of the issuing stream at various cross-sections was determined by means of a point gauge attached to a horizontal cathetometer.

With this apparatus the depths of the stream at two cross-sections were measured at constant head, no parallel portion being added to the orifice. It was found that $\frac{7}{16}$ in. from the orifice the stream, although level, was slightly shallower than the orifice, and that $2\frac{3}{8}$ in. from the orifice the cross-section was no longer flat. Since these experiments were unsatisfactory, a parallel portion of length 2·00 in. (equal to the channel width) was added to the orifice by covering the adjacent channel with a plate. Three cross-sections were then examined, the measurements being given in Table 1. The results may be considered promising, since the increase in depth recorded at cross-sections *B* and *C* can be attributed to the effects of friction on so small a stream. It was noticed that a turbulent boundary layer was formed along the walls of the channel, but apart from this the surface at cross-section *A* was glassy and the channel bottom could clearly be seen. At cross-section *B* the surface was slightly disturbed, but it was still possible to distinguish the reflection of the point gauge. At cross-section *C* turbulence was more fully developed, although its scale was insufficient to make the depth observations difficult or to obliterate the standing waves formed when the point just touched the surface. The onset of turbulence was probably due to the fact that the Reynolds number $4mu_m/\nu$ (where m is the hydraulic mean depth, u_m the mean velocity and ν the kinematic viscosity) was as high as 150,000. Alternatively, the disturbance might have been a surface effect caused by the disappearance of the boundary layer formed in the trumpet and orifice.

In the hope that the latter explanation might be correct, a rotating drum 2 in. in diameter was held just in contact with the surface of the stream close to the orifice. The clearance between the ends of the drum and the walls of the channel was $\frac{1}{16}$ in. The bearings of the drum were carried on an adjustable vertical slide, which was supported independently of the channel, so that vibrations which might arise from the belt drive could not disturb the channel. Although interesting results were obtained, no improvement in the free surface was effected because at all peripheral speeds a mass of agitated water clung to the drum at the downstream edge of the zone of contact.

References.

1. Binnie A. M. 1938, R. and M. No. 1857.
2. Binnie. A. M., 1940, R. and M. No. 1886.

TABLE 1.

Observed Depths of the Issuing Stream.

Height of orifice, 1·51 in.

Theoretical velocity of stream, 9·2 ft./sec.

Cross-section.	Distance of cross-section from orifice in.	Distance from centre-line in.	Depth in.
A	9/16	+ 0·79	1·51
		+ 0·39	1·52
		0	1·52
		− 0·39	1·52
		− 0·79	1·53
B	2	+ 0·79	1·55
		+ 0·39	1·54
		0	1·54
		− 0·39	1·54
		− 0·79	1·54
C	$3\frac{3}{4}$	+ 0·79	1·54
		+ 0·39	1·55
		0	1·54
		− 0·39	1·54
		− 0·79	1·54

(53088) Wt. 4 500 12/40 Hw. G.371

FIG. 1.

Side Elevation of Orifice and Open Channel.

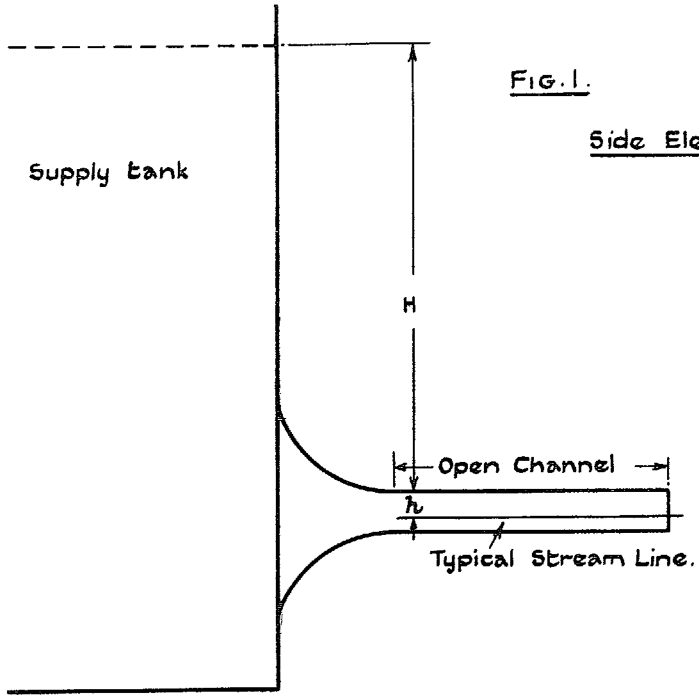
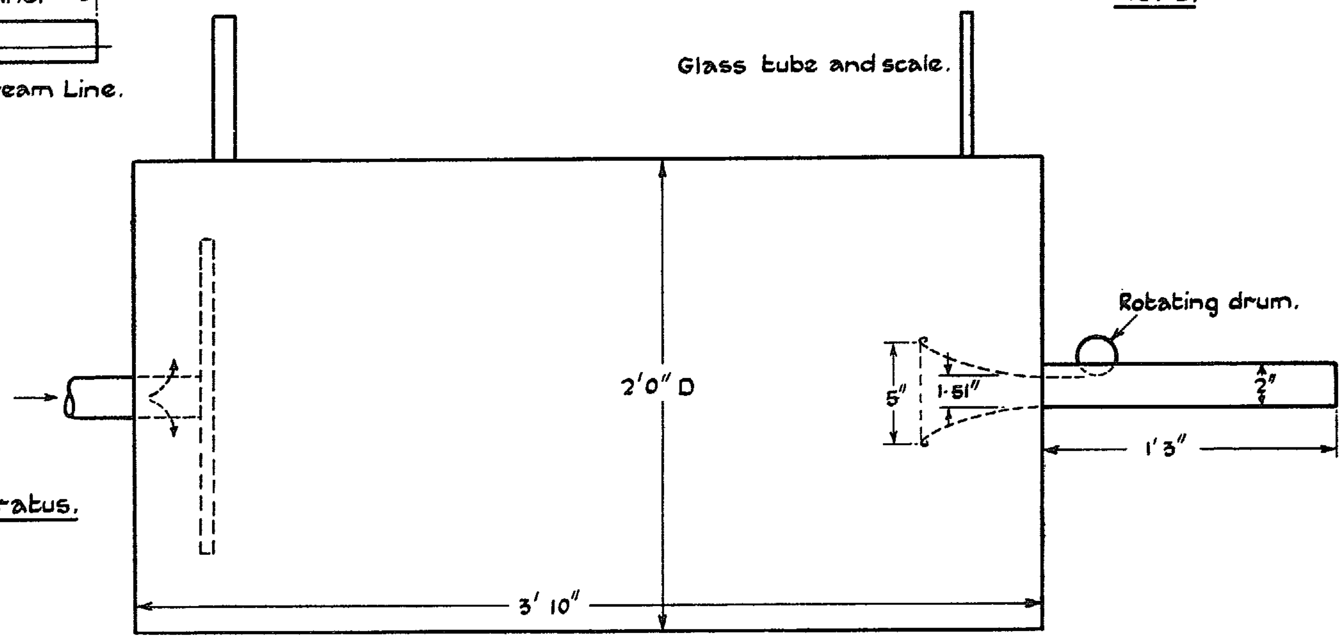


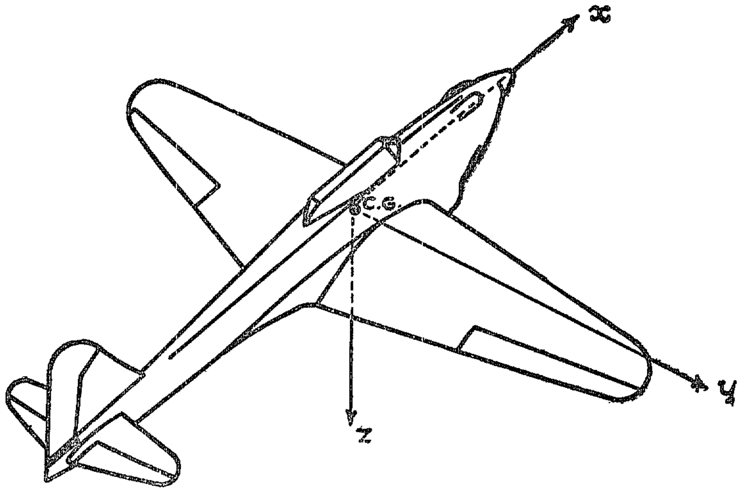
FIG. 2.



Side Elevation of the Apparatus.

E.E.M.

SYSTEM OF AXES



Axes	Symbol Designation Positive direction	x longitudinal forward	y lateral starboard	z normal downward
Force	Symbol	X	Y	Z
Moment	Symbol Designation	L rolling	M pitching	N yawing
Angle of Rotation	Symbol	ϕ	θ	ψ
Velocity	Linear Angular	u p	v q	w r
Moment of Inertia		A	B	C

Components of linear velocity and force are positive in the positive direction of the corresponding axis.

Components of angular velocity and moment are positive in the cyclic order y to z about the axis of x, z to x about the axis of y, and x to y about the axis of z.

The angular movement of a control surface (elevator or rudder) is governed by the same convention, the elevator angle being positive downwards and the rudder angle positive to port. The aileron angle is positive when the starboard aileron is down and the port aileron is up. A positive control angle normally gives rise to a negative moment about the corresponding axis.

The symbols for the control angles are :—

- ξ aileron angle
- η elevator angle
- η_T tail setting angle
- ζ rudder angle

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