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The LB Wind-Tunnel

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by Larry Bennett

CONTENTS

ILLUSTRATIONS

ABSRTACT:

A small subsonic wind-tunnel has been developed for further understanding of aerodynamic principles. This tunnel is small enough to be used on table tops so the student can get first-hand experience. The tunnel's working section is a clear plexiglass tube for easy viewing and provides ample work room. The biggest advantage of this tunnel is that it can be built in the average home workshop for approximently $60.00.

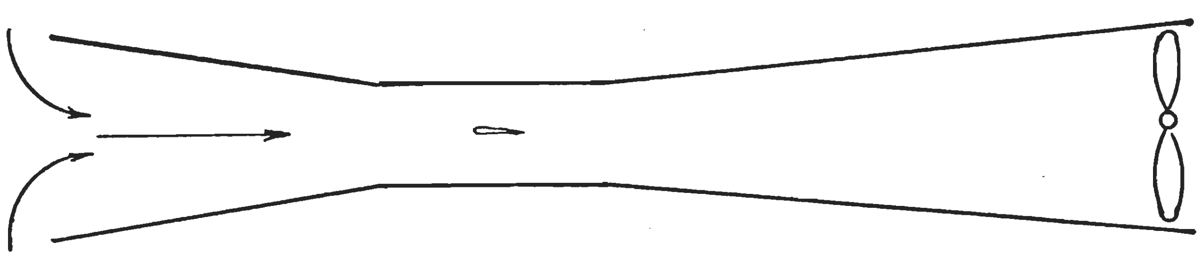
INTRODUCTION:

The need for a greater understanding of wind-tunnels and aerodynamic principles has long been a desire. Therefore, research and construction of a small table top wind-tunnel was undertaken to help fill this desire. As a project to be reviewed by a review committee and judged on its performance a challange for quality is present and hopefully will be fulfilled.

RESEARCH

In the intial stages of the wind-tunnel project an investigation began into the many possible types of wind-tunnels which could be built. The research turned up four types of subsonic wind-tunnels. The four types are open circuit, closed circuit, compressed air and whirling arm.

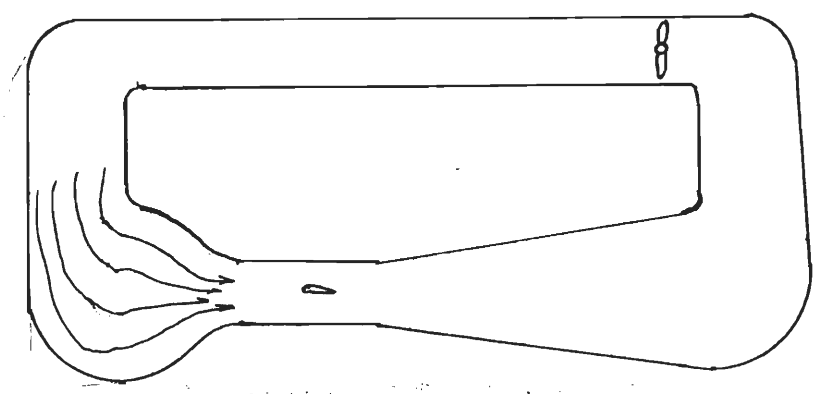
The open circuit is basically a long tube in which air is either blown or drawn through a straight or convergent-divergent channel. At some station in the tunnel an object is mounted. Through differing techniques data can be obtained on the objects interactions with the airflow. (fig. 1)



open circuit tunnel

Fig. 1

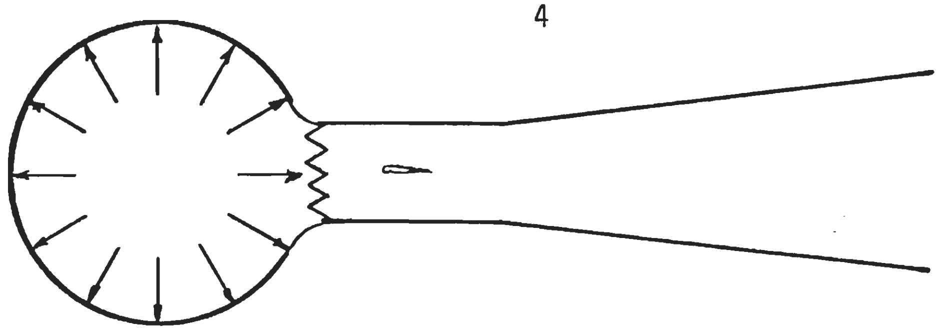
The closed circuit tunnel is, for the most part, an open circuit tunnel which has been routed end to end in order to provide a return airflow. The theory behind this is to use the exiting airflow's energy in addition to that provided at the source to create a faster flow for the same input. (fig. 2)



closed circuit tunnel

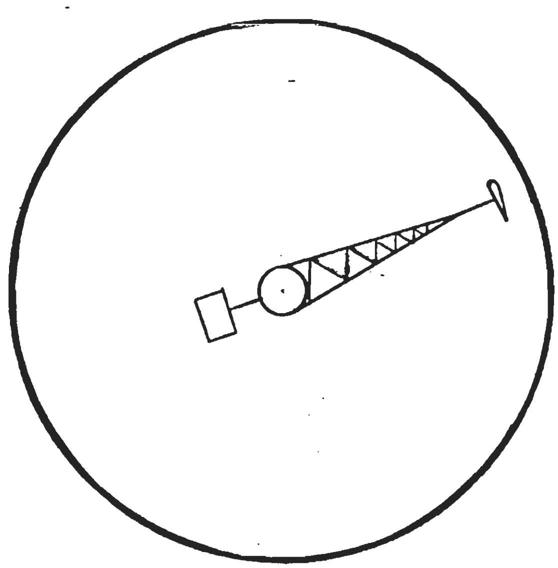
Fig. 2

The compressed air tunnel consists of a large chamber, which is pressurized to varying levels, connected to an open circuit tunnel with some sort of door to separate these two parts. When the blockage between the chamber and tunnel is removed the high pressure air rushes out through the tunnel to create a high velocity airflow. (fig.3)



compressed air tunnel
Fig. 3

The last type is the whirling arm. This type is quite different from the first three. Here, instead of moving the air past a stationary object, the object is spun around through stationary air in a large circular room on the end of a support beam. (fig. 4)

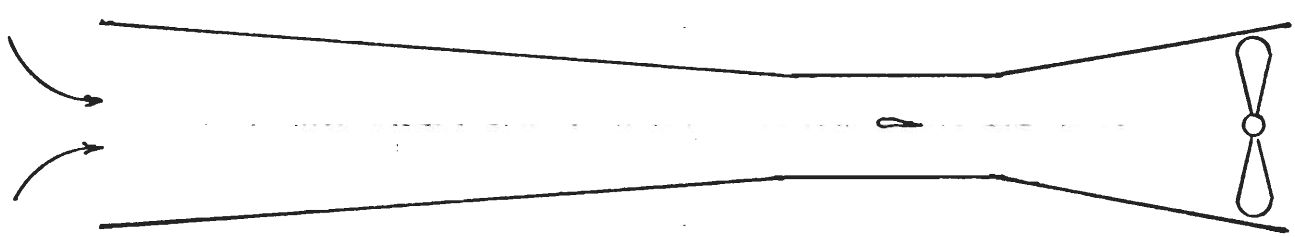


whirling arm
Fig. 4

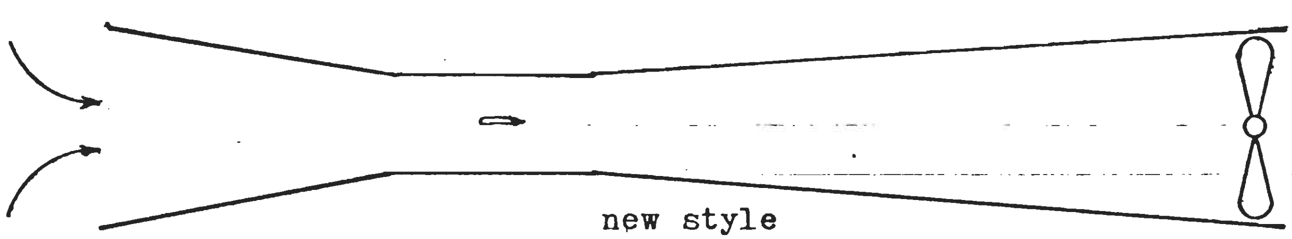
Since the open circuit tunnel was considered to be the easiest and cheapest to construct, this was the type of tunnel design chosen to build.

After studying the many variations of the open circuit tunnel the National Physic Labratory (N.P.L.) type was the type the L.B. Tunnel was chosen to be modeled after. However, the were a few changes made.

The N.P.L. type tunnel originally began sometime before World War I in Great Brittain at the N.P.L. At that time the tunnel design called for a low contraction ratio in the effuser (front cone) and a high expansion ratio in the diffuser (rear cone). (fig. 5) As the years passed and data was collected the contraction ratios increased and the expansion ratios decreased creating higher efficiencies. (fig. 6)



old style



new style

Figs. 5 and 6

The theory of the N.P.L. type tunnel is based on the venturi and Bernoulli's principles. As a mass of air is drawn into the effuser through a large opening the size of the tunnel is decreased. As the flow moves through the tunnel, the velocity must increase to satisfy the continuity equation. (see Appendix A)

This phenonena creates a smooth high velocity airflow in the working section along with a reduction in the static pressure. (fig. 7)

Once the air leaves the working section the air is expanded and the velocity is lowered to the maximum velocity for high fan efficiency.

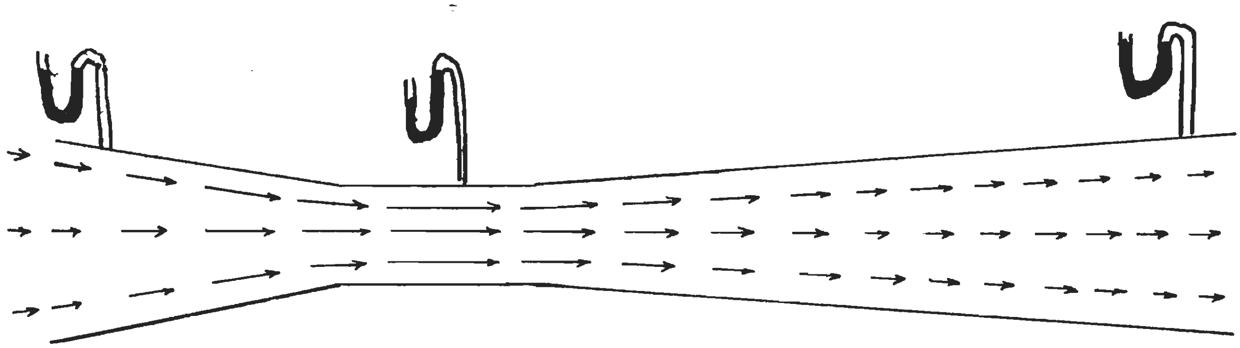


Fig. 7

TUNNEL CONSTRUCTION

WORKING SECTION

The working section (fig. 8) is the part of the tunnel in which all the measurements are taken on both the tunnel's output and the effect of the airflow on the mounted object.

This section was made from a 13 inch section of 7 inch O.D. tubular plexiglass. Mounted within the tunnel is the object to be tested, a total pressure probe, a static pressure port and a transversing total pressure probe (for drag calculations).

The total pressure probe is basically a pitot tube used to sense the total pressure of the working section. It is located in front of the object being tested and is positioned to point into the wind.

The static pressure port is basically a hole located somewhere along the working section wall to sense the working section static pressure. This port must be perpendicular to the airflow. There can be more than one of these ports located elsewhere along the wall to achieve an average static pressure.

The transversing total pressure probe is used to move up and down behind the object to sense the pressure defect. This can be used to calculate momentium loss which is an indication of drag. (see Appendix A)

The location of the transversing total pressure probe is approximately 12% of the chord length of the object behind the object.

All of these probes can be seen in figure 8.

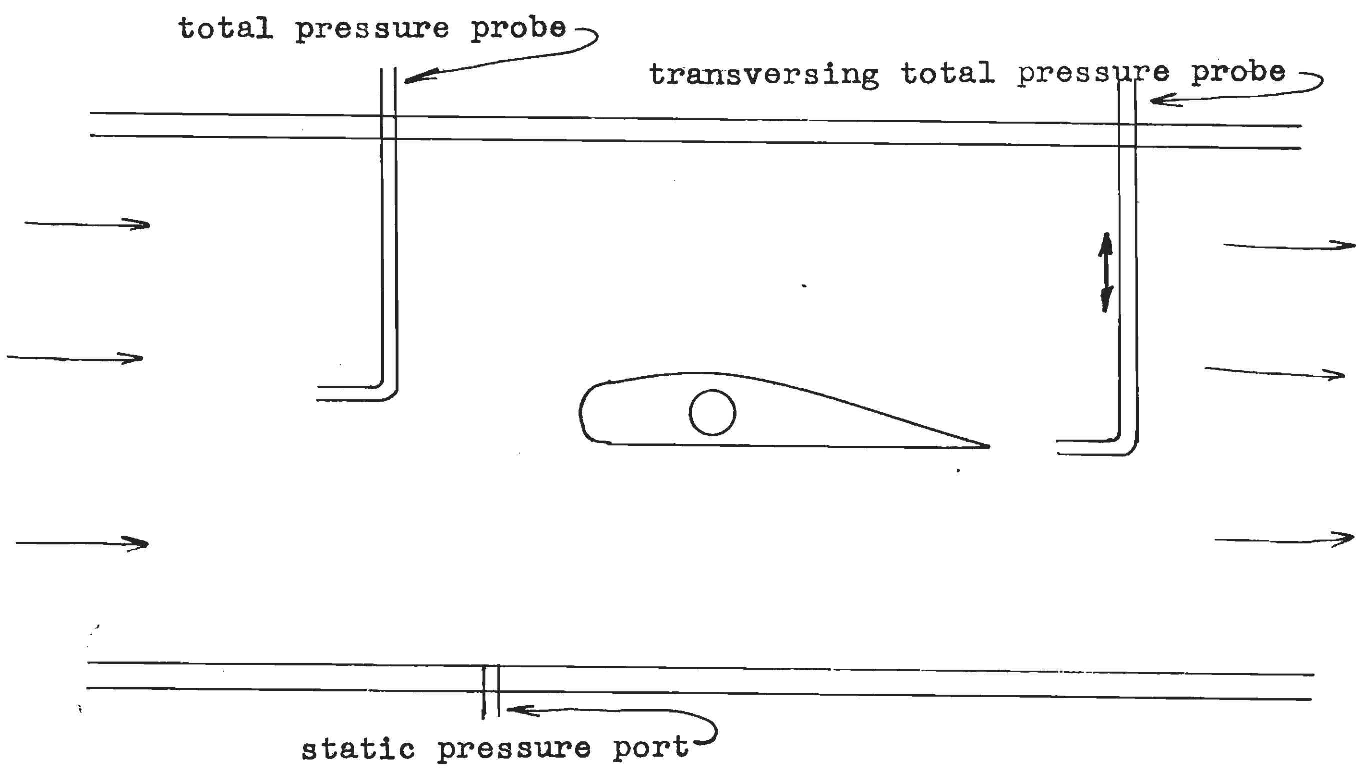


Fig. 8

MANOMETER

The manometer (fig. 9) is the pressure reading instrument of the tunnel. It operates on the basic U tube principle. Filling the manometer with a fluid, such as water in which the specific gravity is known, pressure differential is indicated when two different pressures are applied at each end. The higher pressure causes the water level to lower on its side and rise on the low pressure side, until an equilibrium condition is reached. The differential height of water is an indication of the pressure differential.

All pressures taken from the tunnel are reference to static pressure and used to indicate such things as velocity and force. (see Appendix A)

The manometer is constructed from 1/8 inch glass tube, 1/8 inch brass tube, 1 inch brass tube, 1/8 inch surgical tubing, scrap wood and graph paper.

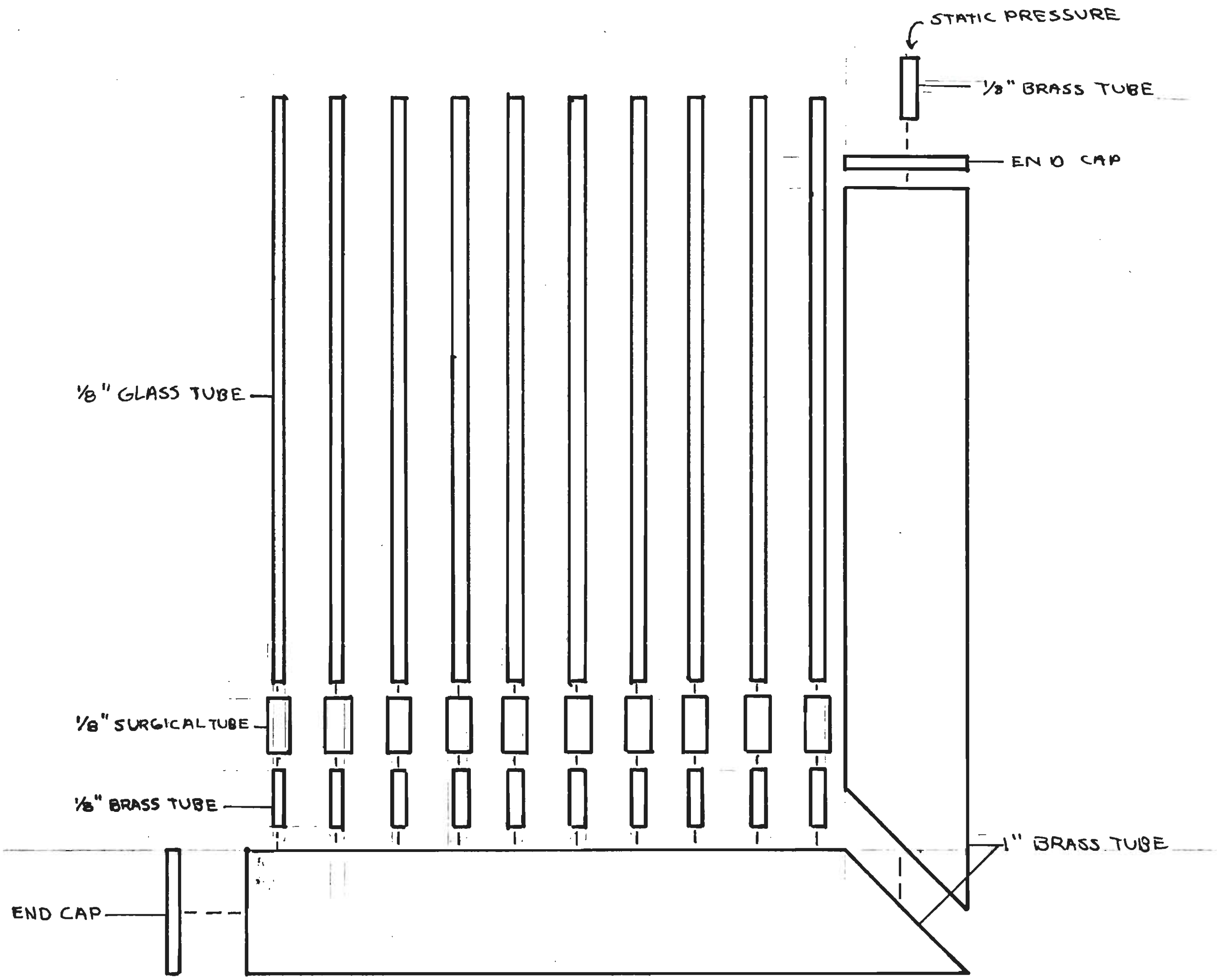

STATIC PRESSURE
1/8" BRASS TUBE
END CAP
1/8" GLASS TUBE
1/8" SURGICAL TUBE
1/8" BRASS TUBE
1" BRASS TUBE
END CAP

Fig. 9

EFFUSER

The effuser's job is to smoothly narrow down the tunnel area from the intake to the working section, creating as little turbulence as possible. Thus, the pressure energy is changed to kinetic energy (velocity). To accomplish this, without creating a great deal of turbulence, the contraction ratio of the L.B. Tunnel is approximately 4:1 (A_1/A_0) over a length of 15 inches. Some of the tunnels around are larger and some are smaller. (fig. 10)

DIFFUSER

The diffuser's job is to recieve the air from the working section and convert it's kinetic energy into pressure energy. This allows the fan to move a slower moving air mass to create a suction at the effuser.

The diffuser must have a narrow taper to keep the air from separating from the walls and creating reverse flow regions which destroy the pressure gradients and laminar flow. To achieve this smooth flow the conical angle of the diffuser should be 5° to 6°.[1]

Due to the material availability the angle on the L.B. Tunnel is up around 7.4°. However, this value proved to be quite adequate for the speeds incountered. (fig. 11)

1. Pankhurst, R. C. and Holder, Wind-Tunnel Technique. Sir Isaac Pitman & Sons Ltd. London, 1952 p. 73

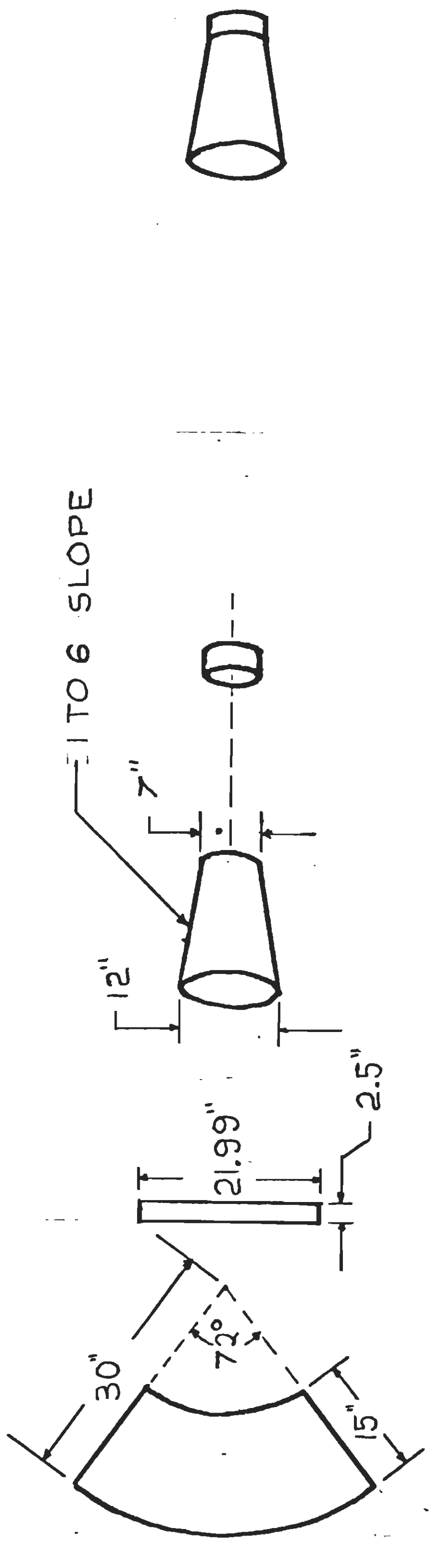


FIG. 10

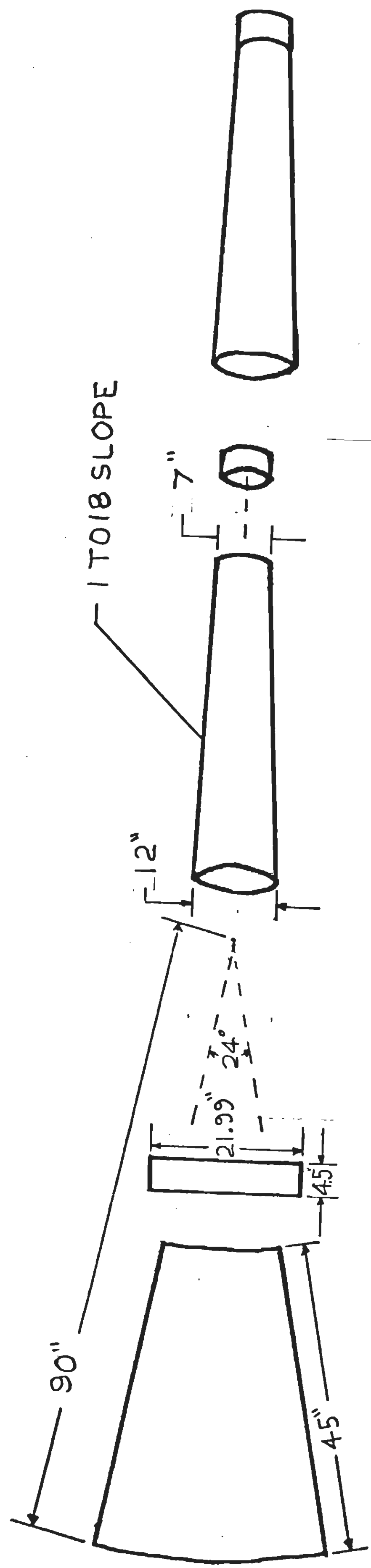


FIG. 11

The effuser and diffuser are made from .060 inch A.B.S. plastic. They were cut from a 4X8 sheet and rolled into a conical shape. The butted edges are held together by a 2 inch strip of plastic spanning the length of the cone.

SOURCE

The source consists of a Skill Saw Motor and circular fan. The motor was used due to its high rpm and availability. The gear reduction was taken out to increase the motors rpm from its normal rpm. The fan is a 12 inch circular CCW rotating rimmed fan.

The source is moved as far into the diffuser as possible to reduce the pressure losses around the rim of the fan and tunnel wall. (fig. 12)

BASE

The base of the tunnel was cut from 3/4 inch partical board to support the wind-tunnel structure. The base for the motor (oddly enough) is a hubcap off of a truck. These materials were chosen for their availability and cost effectiveness. (fig. 13)

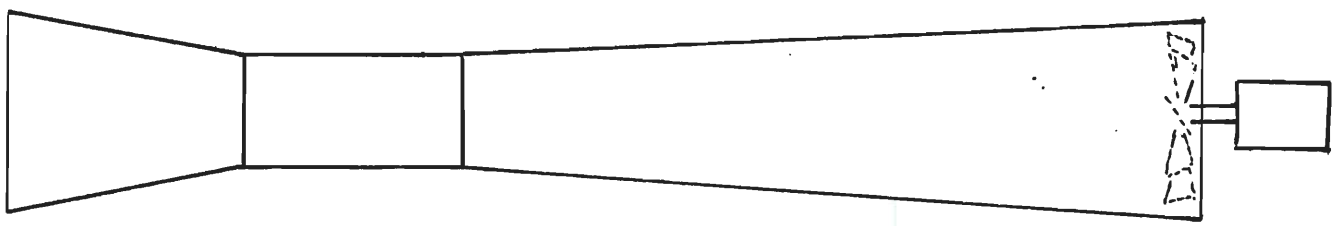


Fig. 12

Fig. 13

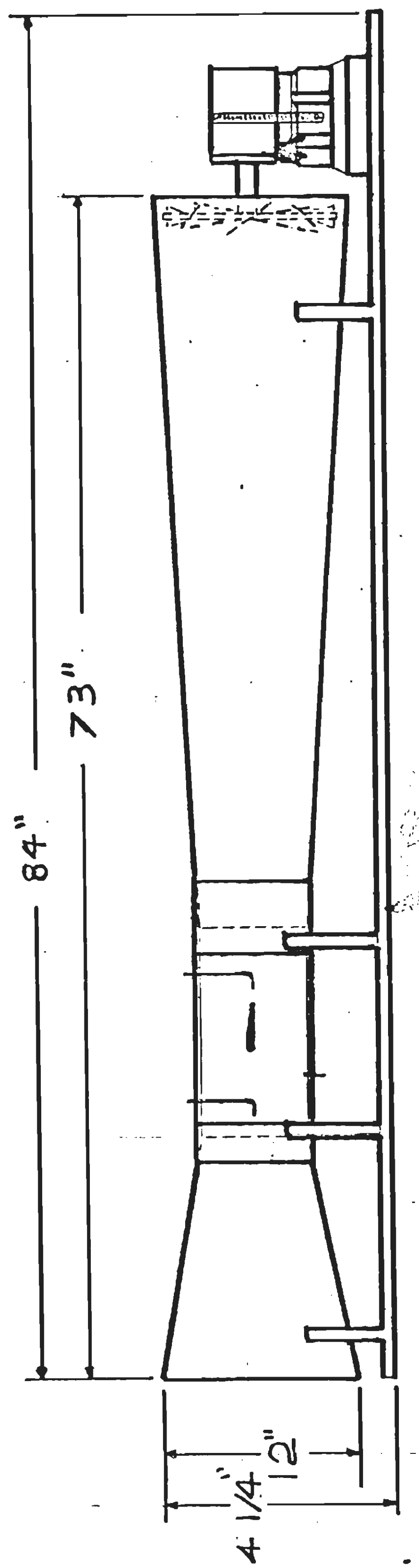


FIG 14

OVERALL

The finished product turned out to be 84 inches long, 14 inches high, 12 inches wide, produces a velocity of 63 miles/hour and has a tunnel Reynolds number of 3.4×10^5. (fig 14)

CONCLUSION

The need for a greater understanding of wind-tunnels and aerodynamic principles was fulfilled. The knowledge gained was well worth the time and energy spent in research and construction.

APPENDIX A

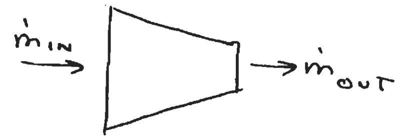
Continuity equation

$\dot{m}$ = MASS FLOW RATE

ρ = DENSITY

A = AREA

V = VELOCITY



$\dot{m}_{in} = \dot{m}_{out}$

$\dot{m} = \rho AV$

$\rho AV_{in} = \rho AV_{out}$

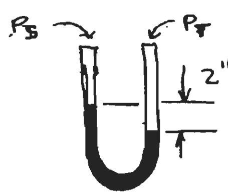
$\rho_{in} = \rho_{out}$ (ASSUME INCOMPRESSABLE FLOW)

$AV_{IN} = AV_{OUT}$

SINCE $A_{in} > A_{OUT}$

$V_{IN} < V_{OUT}$ ///

Pressures to velocity and force



U-TUBE MANOMETER

(ASSUME)

$SP.WT._{H_2O} = 62.4\ lbs/FT^3$

$\rho_{air} = .00237\ sec^2/FT^4$

VELOCITY

$H = 2\ IN = .1667\ FT$

$Pressure = SP.WT \times H = 62.4 \times .1667 = 10.4\ lbs/FT^2$

$P_T = P_S + P_D$

$P_T - P_S = P_D$

$P_D = \frac{1}{2}\rho V^2$

$P_D = 10.4\ lbs/FT^2$

$\frac{1}{2}\rho v^2 = 10.41\ lb/ft^2$

$V = \sqrt{(2)(10.4)/.00237}$

$V = 93.7\ Ft/sec$ or $63.9\ mi/hr$ ///

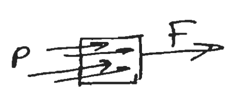
Force

$P = 10.4\ lbs/FT^2$

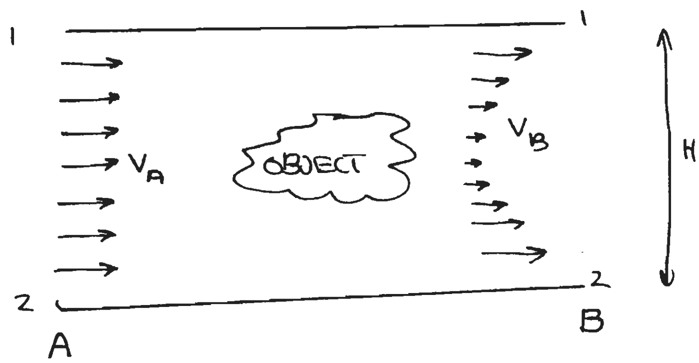
$Area = 2\ ft^2$

$F = PA$

$F = (10.4)(2) = 20.8\ lbs$



Drag calculations by momentium loss



$$F_D = \sum_1^2 \dot{m}_A V_A - \dot{m}_B V_B$$

ASSUME $\dot{m}_A = \dot{m}_B$ (STEADY STATE)

$$\therefore F_D = \sum_1^2 \dot{m}_B (V_A - V_B)$$

$$\dot{m}_B = \rho_B V_B A_B$$

ASSUME A TO BE AN AREA ; WITH A UNIT DEPTH OF 1

$$\therefore A = H$$

$$\therefore F_D = \sum_1^2 \rho_B V_B H_B (V_A - V_B)$$

$$P_T - P_S = \tfrac{1}{2} \rho v^2 = P_{DIFF}$$

$$V = \sqrt{2(P_{DIFF})/\rho}$$

$$F_D = \sum_1^2 \left(\rho \sqrt{2(P_{DIFF_B})/\rho}\right)(H)\left(\sqrt{2(P_{DIFF_A})/\rho} - \sqrt{2(P_{DIFF_B})/\rho}\right)$$

$$F_D = \sum_1^2 \left(\sqrt{2(P_{DIFF_B})}\right)(H)\left(\sqrt{2(P_{DIFF_A})} - \sqrt{2(P_{DIFF_B})}\right)$$

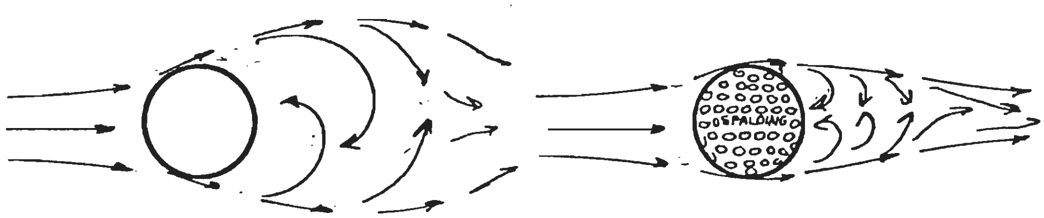
Cost Analysis

Item	Material	Cost
Base	96"X12"X3/4" particalboard	$2.00
Constaint Equip.	springs, clamps, wire, chain	$0.00
Effuser & Diffuser	4'X8' sheet .060" ABS plastic	$20.00
Working Section	7" OD tubular plexiglass	$0.00
Pressure Tubing	1/8" surgical tubing	$5.00
Manifold & Mounts	3/8" brass tubing	$0.70
Velocity Probes	1/8" brass tubing	$0.35
Pressure Pts.	1/8" copper tubing	$0.50
Manometer Brass	1" brass tubing	$3.40
Model	fiberglass & balsawood	$0.75
Manometer Rack	1/2" round & 12"X11"X1/4" pine	$0.60
Manometers	1/8" glass tubing	$0.00
Source	Skill Saw motor & 12"ccw fan	$1.25
Glue	T.H.F. Solvent	$0.00
Speed Control	Knight Motor Speed Control	$0.00
Golf Balls	(2) golf balls	$0.00
	TOTAL	$33.95

EXPERIMENT #1

TITLE: The Effect of Dimples on Golf Balls in Drag Reduction.

THEORY: The theory of dimples on golf balls is they reduce the drag by creating a turbulent boundary layer around the golf ball. The turbulent boundary layer can withstand a higher pressure gradient than the laminar boundary of the smooth ball. Thus, the air will not separtate (causing drag) until a later point on the surface.



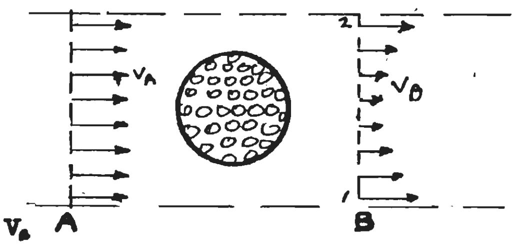
smooth ball (laminar boundary layer) dimpled ball (turbulent boundary layer)

OBJECTIVE: To measure the pressure variation behind the golf ball by means of a transversing pitot tube and calculate drag force. Then, compare the values for the drag at equal speeds on a smooth and dimpled golf ball. Therefore, the effect of dimples can be analyzed.

EQUIPMENT: wind-tunnel
two golf balls, one smooth, one dimpled
transversing pressure probe
manometers
computer

CALCULATIONS:

Drag force is the sum of the momentum loss from A to B over the area behind the golf ball.



$F=\sum_1^2 \dot{m}_A v_A - \dot{m}_B v_B$

assume $\dot{m}_A = \dot{m}_B$ (steady state)
$\therefore F=\sum_1^2 \dot{m}_A (v_A - v_B)$

$\dot{m} = eva$
let a (area) be for a unit depth of one
$\therefore a = \text{height} \times 1 = h$
$\therefore F=\sum_1^2 e v_B h (v_A - v_B)$

$P_T = P_S - \frac{1}{2} ev$
$P_T - P_S = \frac{1}{2} ev = P_{diff}$
$\therefore v = \sqrt{2(P_{diff})/e}$

$\therefore F=\sum_1^2 \not{e}\sqrt{2(P_{diff})/\not{e}}\; h \left(\sqrt{2(P_{diff})/\not{e}} - \sqrt{2(p_{diff})/\not{e}}\right)$

For experiment: h=1/8" or .01042 ft.
e_{air} (assume $e_A = e_B$) = .00237 lb. sec^2/ft^4.

Use computer to calculate summation of drag.

$$C_d = \frac{Drag}{\frac{1}{2}\, e\, V^2} = \text{Drag Coef.}$$

DATA: D= Drag pressure (inch H_2O)
P= Dynamic pressure (inch H_2O)
V= Velocity (miles/ hour)
e= air density (lbs sec^2/ft^4)
x= probe spacing (ft)

	without dimples			with dimples		
P	.25	.50	1.50	.25	.50	1.50
V	22.6	31.94	55.32	22.6	31.94	55.32
e	.00237	.00237	.00237	.00237	.00237	.00237
x	.01042	.01042	.01042	.01042	.01042	.01042
D	.25	.50	1.50	.25	.50	1.50
	.25	.50	1.40	.25	.50	1.50
v	.25	.50	1.40	.20	.50	1.40
a	.25	.50	1.25	.20	.50	1.40
l	.20	.45	1.10	.15	.45	1.25
u	.15	.35	.95	.10	.45	1.10
e	.15	.25	.60	.05	.40	.70
s	.10	.20	.40	.10	.30	.50
	.05	.10	.25	.10	.25	.65
	.05	.05	.15	.10	.15	.50
	0.0	.05	.20	.10	.10	.50
	.05	.10	.25	.20.	.10	.75
	.05	.20	.40	.20	.25	1.00
	.15	.25	.75	.25	.30	1.25
	.20	.35	1.25	.25	.35	1.50
	.25	.45	1.25	.25	.45	1.50
	.25	.50	1.50	.25	.50	1.50
Results: Drag Coef.	.084	.100	.110	.087	.082	.082

Note: These values are comparison values only. To get true drag values one must transverse horizontially along with vertically.

SUMMARY: The effect of dimples is evident even at the slower velocities of my wind-tunnel.

At the slower speeds the effect was minimal. However, as the speed goes up the increase in drag occures at a slower rate than that of a smooth ball.

I can now see why at the normal speeds of a golf ball the effect of dimples is an important factor.

note: It was stated in Shape And Flow; The Fluid Dynamics of Drag. that for a normal swing causing a normal golf ball to travel 200 yds. will only propel a smooth ball 50 yds.

EXPERIMENT # 2

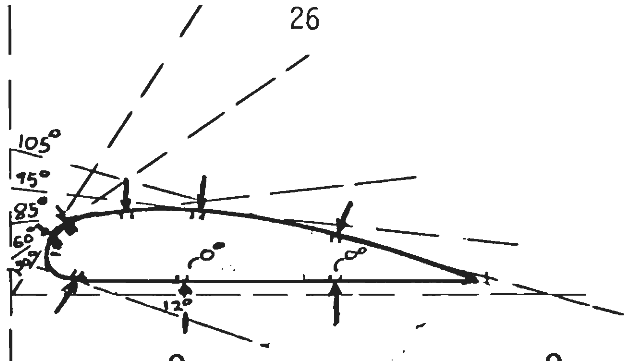
TITLE: Lift and Drag Calculations of a Simple Airfoil.

THEORY: By measuring the pressure distributions on the top and bottom of an airfoil a net lifting and drag force can be calculated from the resultant forces vertical and horizontal components.

OBJECTIVE: To take the pressure readings from the wind-tunnel and calculate lift and drag. To accomplish this a careful examination of the airfoils geometry must be under taken.

EQUIPMENT: wind-tunnel
airfoil with pressure points
transversing probe
manometers
computer

CALCULATIONS:



pt. 1 drag=F xcos 330° lift=F xsin 330°

pt. 2 drag=F xcos 300° lift=F xsin 300°

pt. 3 drag=F xsin 12° lift=F xcos 12°

pt. 4 drag=F xcos 275° lift=F xsin 275°

pt. 5 drag=F xsin 0° lift=F xcos 0°

pt. 6 drag=F xcos 265° lift=F xsin 265°

pt. 7 drag=F xsin 0° lift=F xcos 0°

pt. 8 drag=F xcos 255° lift=F xsin 255°

total drag= sum 1-8
total lift= sum 1-8

$C_d = \frac{Drag}{\frac{1}{2} e V^2}$ = Drag Coef. ((C_l) (Lift) (Lift Coef.))

If the airfoil is at an angle of attack other than 0° we must divide the resultant forces up into their horizontal and vertical components and add them to correct for angle of attack.

DATA: D= Drag pressure (inches H_2O)
P= Dynamic pressure (inches H_2O)
Pn= Pressure at that point. n from 1-8 (inches H_2O)
V= Velocity (miles/hour)
e= Air density (lbs sec^2/ft^4)
x= probe spacing (ft)
q= angle of attack (degrees)

q	0	10	-10	0	10	-10
P	.75	.75	.65	1.75	1.75	1.75
V	39.11	39.11	36.41	59.75	59.75	59.75
e	.00237	.00237	.00237	.00237	.00237	.00237
P1	.65	-1.05	.60	1.50	-.65	1.65
P2	-.10	-1.00	.35	-1.00	-3.50	1.00
P3	-.60	-.85	-.30	-2.00	-2.50	-1.00
P4	-.45	-.55	-.35	-1.15	-1.50	-1.00
P5	-.35	-.35	-.20	-.90	-.95	-.75
P6	-.60	-.20	-.50	-1.50	-.10	-2.25
P7	-.20	0.00	-.50	-.45	-.10	-1.00
P8	-.10	-.05	-.15	-.25	-.15	-.50
C_d	.064	.053	.070	.025	.008	.033
C_l	.063	.066	.073	.022	.022	.036
D Values	.75	.75	.55	1.75	1.75	1.75
	.65	.55	.60	1.75	1.75	1.75
	.65	.60	.60	1.75	1.75	1.75
	.65	.55	.60	1.75	1.75	1.75
	.75	.60	.60	1.75	1.75	1.75
	.75	.60	.65	1.75	1.75	1.75
	.75	.60	.60	1.75	1.75	1.50
	.75	.60	.25	1.50	1.75	1.00
	.75	.60	.20	1.15	1.75	1.00
	.60	.60	.30	1.50	1.75	.75
	.55	.50	.40	1.75	1.50	1.00
	.75	.40	.50	1.75	1.25	1.75
	.75	.50	.55	1.75	1.50	1.75
	.75	.75	.55	1.75	1.75	1.75
C_d	.020	.063	.016	.013	.012	.038

SUMMARY:

The comparison of drag values obtained in both the component and transversing probe methods was very interesting. Five of the eight values compare quite well. However, the other three differ by quite a margin. After careful examination of the component method I feel the error(s) exist in this method. These errors stem from:

1. tunnel blockage; When ever the angle of attack was large in the + or - direction blockage would cause the motor to load down. This was evident due to the velocity loss. Thus, the pressures <u>of the tunnel</u> could vary with angle of attack.

2. end effect; Due to the wing tips, which exist on the end of the airfoil, vortices are created which effect the pressures on the top of the airfoil.

3. profile smoothness; The smoothness of the pressure points on the airfoil would have a large effect on the pressure readings.

4. airfoil geometry; The difficulty in measuring the angles the pressure points form with the airfoil chord make the accuracy of these measurements questionable.

To help reduce these errors I would enlarge the working section or reduce the size of the airfoil to help eliminate tunnel blockage. Also, the pressure points would be moved closer to the middle of the airfoil to help eliminate the end effect.

References

Anderson, John D. Introduction to Flight. McGraw-Hill, Inc. New York, 1978.

Daugherty, Robert L. and Franzini, Joeseph B. Fluid Mechanics with Engineering Applications. McGraw-Hill, Inc. New York, 1977.

Pankhurst, R. C. and Holder, Wind-Tunnel Technique. Sir Isaac Pitman & Sons Ltd. London, 1952.

Shapiro, Ascher H. The Dynamics and Thermodynamics of Compressible Fluid Flow. The Ronald Press Company. New York, 1953.

Shapiro, Ascher H. Shape and Flow: The Fluid Dynamics of Drag. Anchor Books, Doubleday & Company, Inc. Garden City, New York, 1961.