NRC·CNRC

NRC Publications Archive
Archives des publications du CNRC

Design of a hot gas volute

Faucher, G.; Levy, G. G.

For the publisher’s version, please access the DOI link below./ Pour consulter la version de l’éditeur, utilisez le lien DOI ci-dessous.

Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/40003812
Laboratory Memorandum (National Research Council Canada. Division of Mechanical Engineering. Engine Laboratory); no. NRC-ENG-32, 1962-05

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=05362459-01f2-40a6-9473-86d6d223859f
https://publications-cnrc.canada.ca/fra/voir/objet/?id=05362459-01f2-40a6-9473-86d6d223859f

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L’accès à ce site Web et l’utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D’UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n’arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada　Conseil national de recherches Canada

Canada

L.O. 13386A	**NATIONAL RESEARCH COUNCIL**	NO. NRC-ENG-32
FILE M2-17-13.T-6-8	**DIVISION OF MECHANICAL ENGINEERING**	PAGE 1 OF 12
PREPARED BY GF & GGL	OTTAWA, CANADA **LABORATORY MEMORANDUM**	COPY NO. 6
CHECKED BY EPC	SECTION Engine Laboratory	DATE May 1962

SECURITY CLASSIFICATION Open

SUBJECT Design of a Hot Gas Volute

PREPARED BY G. Faucher and G.G. Levy

ISSUED TO

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

NOMENCLATURE

A	Scroll cross-sectional area (sq.in.)
a,b,c	Constants of the equation describing a parabolic curve
D	Scroll cross-section diameter (ft)
f	Friction factor
g	Gravitational constant (ft/sec/sec)
L	Arc length of scroll segment (ft)
M	Mach number
P	Total pressure (PSIA)
P_s	Static pressure (PSIA)
R	Scroll radius (in)
R_e	Reynolds number
T	Total temperature (°K)
T_s	Static temperature (°K)
V	Gas velocity (ft/sec)
W	Gas mass flow (lb/sec)
x	Scroll radius ratio (R/R_i)
γ	Ratio of specific heats
μ	Absolute viscosity (lb/ft-sec)
ρ	Gas density (lb/cu.ft)
φ	Azimuth angle around scroll periphery measured from scroll entry (degrees)

Subscripts

1,2,3.....n	Cross-sections of scroll starting with 1 at scroll entry
G	Geometric centre of scroll cross-sectional area
i	Scroll inner radius (constant)
o	Scroll outer radius
r	Radial
t	Tangential
T	Total conditions

SUMMARY

A method is presented for the determination of the area distribution around a hot gas volute, taking into account wall friction, a free vortex flow pattern and compressibility of the gas.

It is concluded that rig tests on a model volute are required to complement such an analysis to determine the deviation between predicted and actual gas flow conditions.

1.0 INTRODUCTION

A basic requirement for a tip turbine driven lifting fan is a low loss gas supply volute. Ideally, the volute would supply gas to the turbine stator passages uniformly over the 360 degree circumference at the same tangential velocity and flow rate. Departure from the ideal case will result in varying stator blade incidence angles and the likelihood of additional losses as well as exciting rotor vibrations.

Early volute designs were based on the assumption of constant mean Mach number and a linear reduction of area around the duct. Rig tests on this simplified design have shown appreciable variations in flow conditions around the volute outlet plane (Ref. 1).

The objective of this memorandum is to set out a rapid design method which, while not completely rigorous, will take into account wall friction losses and a free vortex flow pattern plus a semi-rigorous treatment of compressibility.

2.0 DESIGN ASSUMPTIONS

The model taken for this study was a 360° scroll having a circular cross-section and a "goose-neck" outlet duct configuration (Fig. 1).

2.1 Flow Conditions

A free vortex flow pattern was assumed to be fully established at the volute entry plane

i.e. $$V_t = V_{ti} \times \frac{R_i}{R} = V_{ti} \times \frac{1}{x}$$

For compressible flow, the gas density varies with the duct radius and also with the angular displacement around the duct. The actual density variation was replaced by a quadratic curve of density in terms of relative radius ratio (see Appendix A1.3).

This density variation was taken into account when determining the area at each section from continuity; but not when calculating the friction pressure loss. In this latter case a geometric mean value of density was used at the given cross-section, as indicated in section 3.2f.

2.2 Static Pressure at Inner Radius

In order to provide a constant acceleration between the inner radius (goose-neck entry) and the stator outlet, the static pressure, based on tangential velocity only, was kept constant at the scroll inner radius by adjusting the volute area. The resulting radial flow was accordingly assumed to be uniformly distributed around the volute.

2.3 Total Temperature and Pressure

The total temperature of the gas was assumed to remain constant through the scroll. The total pressure was assumed to be constant over each cross-section and to vary only with scroll angle (φ).

2.4 Friction Factor

To simplify the pressure loss calculations, a constant friction factor was used. An average value was selected from the Moody diagram for straight smooth pipes, based on the average Reynolds number, using the volute cross-section diameter as the characteristic dimension.

3.0 DESIGN METHOD

3.1 Inlet Gas Conditions

The following values at the volute inlet are known or selected: total temperature, total pressure, mass flow and Mach number.

3.2 Calculation Steps

Commencing with the above values, the following steps are carried out:

(a) The entry area is calculated from the given inlet flow conditions, using $\frac{W\sqrt{T}}{A\,P} = f(M)$, from gas flow tables (Ref. 2). Initially a linear distribution of the scroll cross-sectional area with respect to scroll angle (φ) is assumed, i.e.

$$A_\varphi = A_{\text{inlet}}\left(1 - \frac{\varphi}{360^\circ}\right)$$

(b) The scroll is divided into segments of equal angle.

(c) A mean Reynolds number is calculated for the volute.

$$R_e = \frac{\rho_G V_{tG} D}{\mu}$$

where ρ_G = density at geometric mean radius

V_{tG} = tangential velocity at geometric mean radius

D = diameter of cross-section

μ = absolute viscosity

(d) With mean values of the Reynolds number, a friction coefficient is selected from the Moody diagram for straight smooth pipes (Ref. 3).

(e) The mean L/D ratio is calculated for each segment.

(f) From the selected Mach number at entry (using the gas flow tables), V_{tG_1}, P_{SG_1}, T_{SG_1} and ρ_{G_1} are found. It is assumed that ρ_{G_1} and V_{tG_1} remain constant through the segment when calculating the pressure loss.

(g) The friction total pressure loss is calculated from:

$$\Delta P_{1-2} = f\,(L/D)_{1-2} \times \frac{\rho_{G_1} V_{tG_1}^2}{2\,g \times 144}$$

and hence P_2 is determined.

(h) P_{si} is specified (being assumed constant around the scroll). At entry conditions, knowing V_{tG_1}, free vortex flow yields

$$V_{ti_1} = V_{tG_1} \times \frac{R_{G_1}}{R_i}$$

Entering the gas tables with $\frac{V_{ti_1}}{\sqrt{T}}$ yields P_1/P_{si}.

(i) The area at station 2 is determined from continuity as follows: From (g) and (h), one finds P_2/P_{si}, hence $\frac{V_{ti2}}{\sqrt{T}}$, T/T_{si2} and ρ_{i2}.

$$W = \int_i^o \rho\, V_t\, dA$$

$$W = \rho_{i2} V_{ti2} \frac{A_2}{144} \left[\frac{4a\left(\frac{x_{o2}+1}{\sqrt{x_{o2}}+1}\right)^2 + 2\,b(x_{o2}+1) + 2\,c(x_{o2}+1)}{a\,(x_{o2}+1)^2 + 2\,b(x_{o2}+1) + 4c} \right]$$

(see Appendix "A" for derivation).

This equation must be solved iteratively for A_2, using initial guesses for x_{o2} from the linear area reduction prediction, and revising this guess with the new value computed for A_2. The value of W is assumed to decline linearly with angle φ.

(j) V_{tG2} and ρ_{G2} are found from

$$V_{tG2} = V_{ti2} \times \frac{R_i}{R_{G2}} \quad \text{, hence} \quad \frac{V_{tG2}}{\sqrt{T}} \quad \text{giving} \quad T/T_{SG2} \, ,$$

$$P_2/P_{SG2} \quad \text{and} \quad \rho_{G2} \, .$$

(k) For subsequent segments, steps (g), (i) and (j) are repeated.

3.3 Sample Calculation

The results of a sample calculation are plotted in Fig. 2. The basic parameters were: $W = 23$ lb/sec., $T = 900$°K, $P = 32.12$ PSIA, $M = .35$ and $\gamma = 4/3$. The areas were calculated at angular increments of 40 degrees.

4.0 CONCLUSIONS

4.1 A maximum difference of about 3 percent is shown between the areas predicted in the sample calculation and the area derived from the basic linear variation with φ (Fig. 2).

4.2 In view of the test results quoted in Ref. 1, the small area correction indicated by the method outlined in this memorandum suggests that other factors, not treated in the analysis, may be of some importance in predicting gas flow conditions.

4.3 Rig tests on a model volute designed by this method are required to determine the deviation between predicted and actual gas flow conditions.

5.0 REFERENCES

(1) Pressure Loss Tests on a Model of a Turbine Volute
By - R.W. Bassett
Test Report MET-328
August 1961

(2) Compressible Gas Flow Tables for Specific Heat Ratio (γ) = 4/3
By - R.W. Bassett and M.S. Chappell
L.R.-324
January 1962

(3) Fluid Mechanics
By - V.L. Streeter

APPENDIX "A"

Determination of Mass Flow by Continuity Relationship

1. The continuity equation may be written

$$W = \int_i^o \rho V_t \, dA.$$

2. The free vortex flow relation is

$$V_t = V_{ti} \times \frac{R_i}{R} = V_{ti} \times \frac{1}{x}.$$

3. A density variation is assumed of the form

$$\rho = \rho_i \times f(x, x_o).$$

To relate ρ and x, x_o, a constant mean Mach number is assumed around the scroll. Values of corresponding $\frac{V_{tG}}{\sqrt{T}}$ and ρ_T/ρ_G are determined from the gas tables. $\frac{V_t}{\sqrt{T}}$ is calculated for various ratios of R/R_G, i.e. $\frac{V_t}{\sqrt{T}} = \frac{V_{tG}}{\sqrt{T}} \times \frac{R_G}{R}$ and the corresponding values of ρ_T/ρ are found from the gas tables. ρ_T/ρ_G is divided by ρ_T/ρ, giving ρ/ρ_G which is then plotted versus $R/R_G = x/x_G$ over the required range as shown in Fig. A1 for the particular case of $M_G = 0.35$.

4. The density relationship is assumed to approximate a parabolic curve, thus $\rho/\rho_G = a + b\,(x/x_G) + c\,(x/x_G)^2$. a, b and c are evaluated by taking three points from the curve (the mid-point and two extremes).

5. To obtain the inner-wall density, one sets $x = 1$, yielding

$$\rho_i/\rho_G = a + b\,(1/x_G) + c\,(1/x_G)^2$$

6. Finally ρ/ρ_i is obtained from the ratio of the above two equations and by substituting $x_G = \frac{x_o + 1}{2}$

whence $$\rho/\rho_i = \frac{a\,(x_o+1)^2 + 2\,b\,x(x_o+1) + 4\,c\,x^2}{a\,(x_o+1)^2 + 2\,b\,(x_o+1) + 4\,c}$$

7. Referring to the geometric arrangements of Fig. A2,

$dA = b\,dR$

where $b = 2\sqrt{\left(\frac{D}{2}\right)^2 - (R_G - R)^2}$

$$R_G = \frac{R_o + R_i}{2}$$

$$D = R_o - R_i$$

$$b = 2\sqrt{\left(\frac{R_o - R_i}{2}\right)^2 - \left(\frac{R_o + R_i}{2} - R\right)^2},$$

$$b = 2R_i\sqrt{-\left(\frac{R}{R_i}\right)^2 + \frac{R}{R_i}\left(\frac{R_o}{R_i} + 1\right) - \frac{R_o}{R_i}}$$

Since $\frac{R}{R_i} = x$, $\quad b = 2R_i\sqrt{-x^2 + x(x_o + 1) - x_o}$

8. Since $R = xR_i$, then $dR = R_i\,dx$.

9. Combining the above relations, one obtains

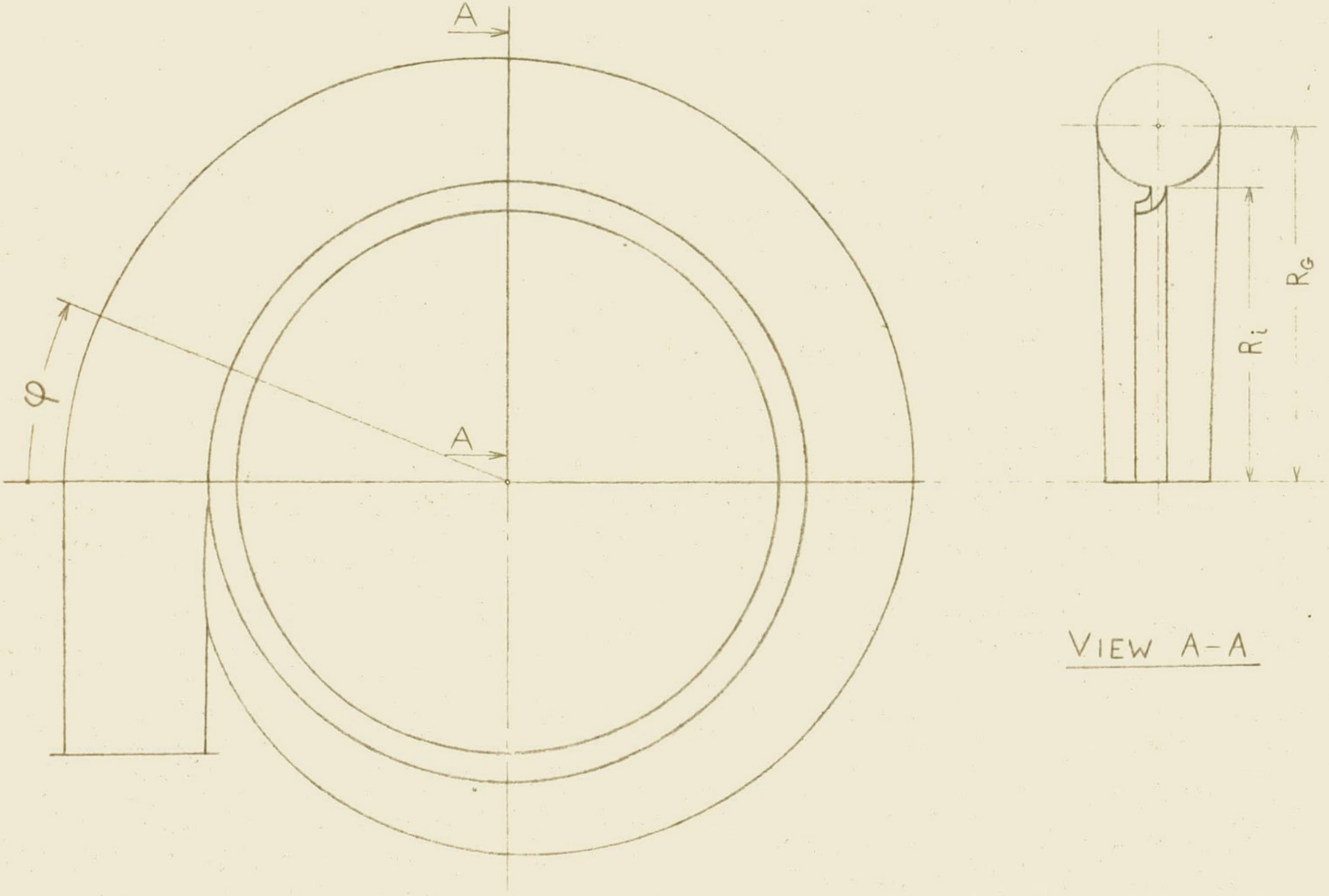
$$dA = 2R_i\sqrt{-x^2 + x(x_o + 1) - x_o} \times R_i\,dx$$

$$dA = 2R_i^2\sqrt{-x^2 + x(x_o + 1) - x_o}\;dx$$

10. Finally the velocity, density and area expressions are substituted back into the continuity integral, yielding

$$W = \frac{\rho_i V_{ti}\, 2R_i^2}{a(x_o+1)^2 + 2b(x_o+1) + 4c}\int_1^{x_o}\left(\frac{a(x_o+1)^2 + 2bx(x_o+1) + 4cx^2}{x}\right)\sqrt{-x^2 + x(x_o+1) - x_o}\;dx$$

whence $W = \rho_i V_{ti}\frac{A}{144}\left[\frac{4a\left(\frac{x_o+1}{\sqrt{x_o}+1}\right)^2 + 2b(x_o+1) + 2c(x_o+1)}{a(x_o+1)^2 + 2b(x_o+1) + 4c}\right].$



VIEW A-A

FIG. 1. DIAGRAM OF MODEL VOLUTE.

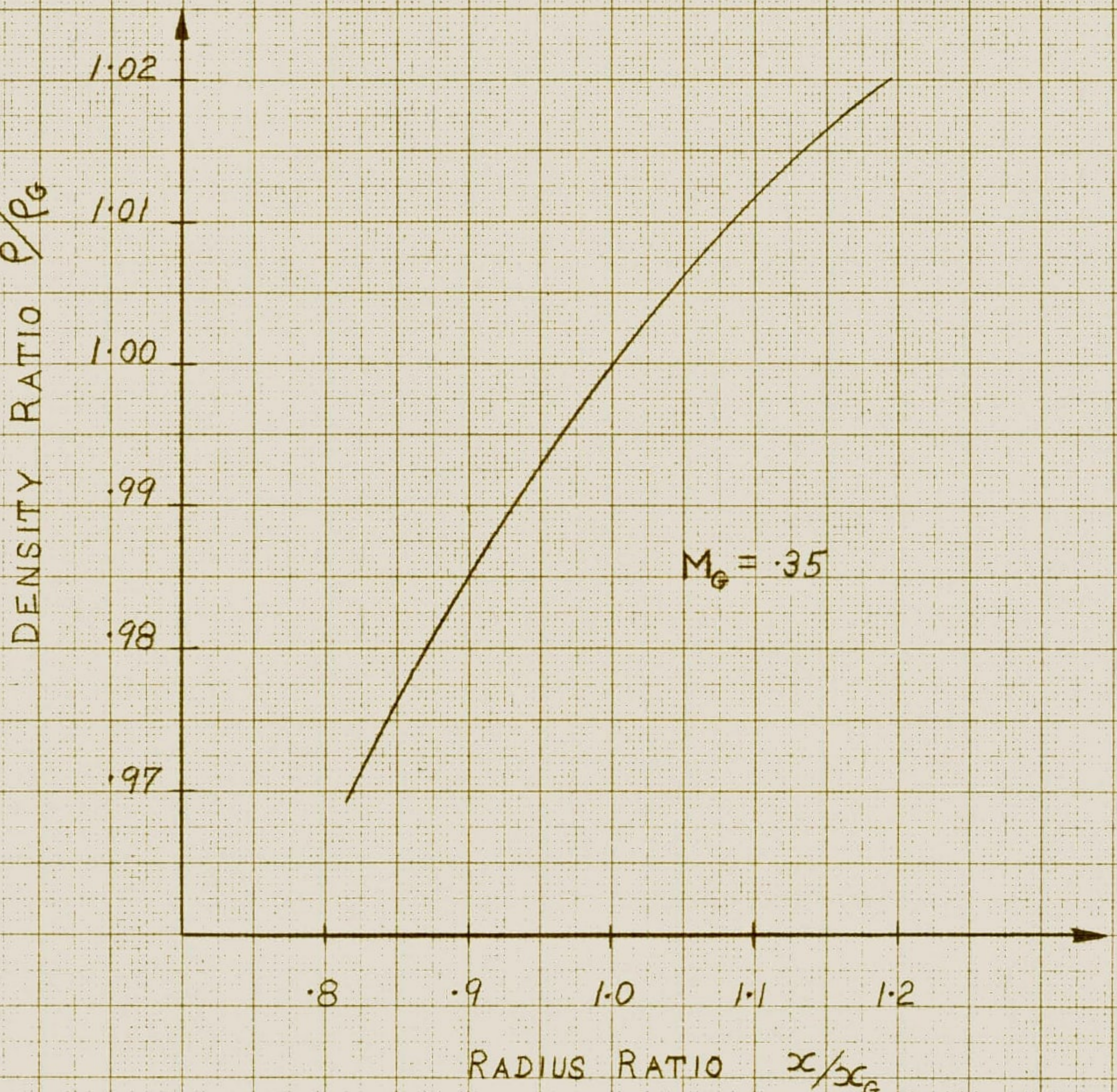


FIG. A-1. RELATION BETWEEN DENSITY AND RADIUS RATIOS.

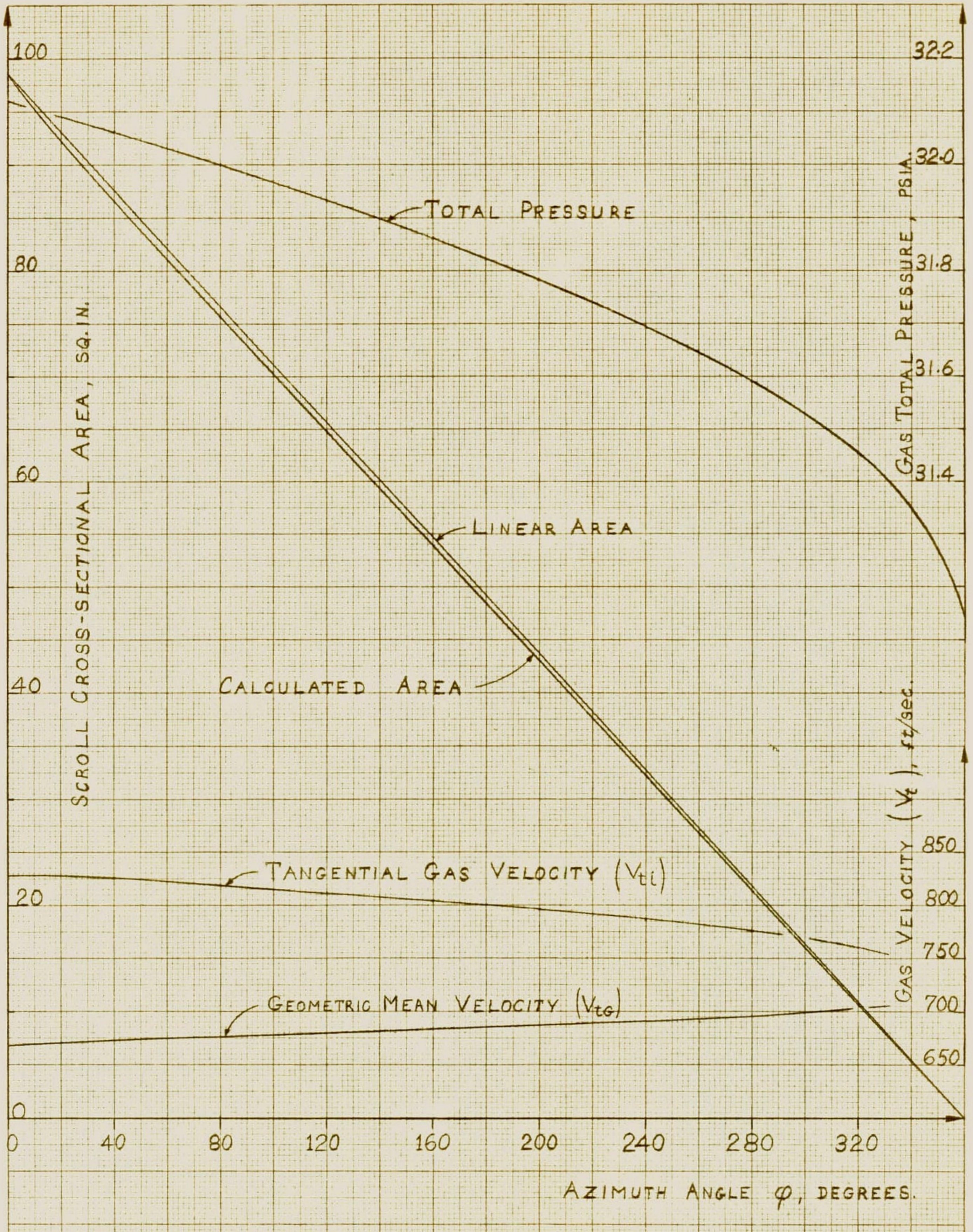


FIG. 2. CALCULATED AREAS AND GAS CONDITIONS RELATIVE TO AZIMUTH ANGLE.

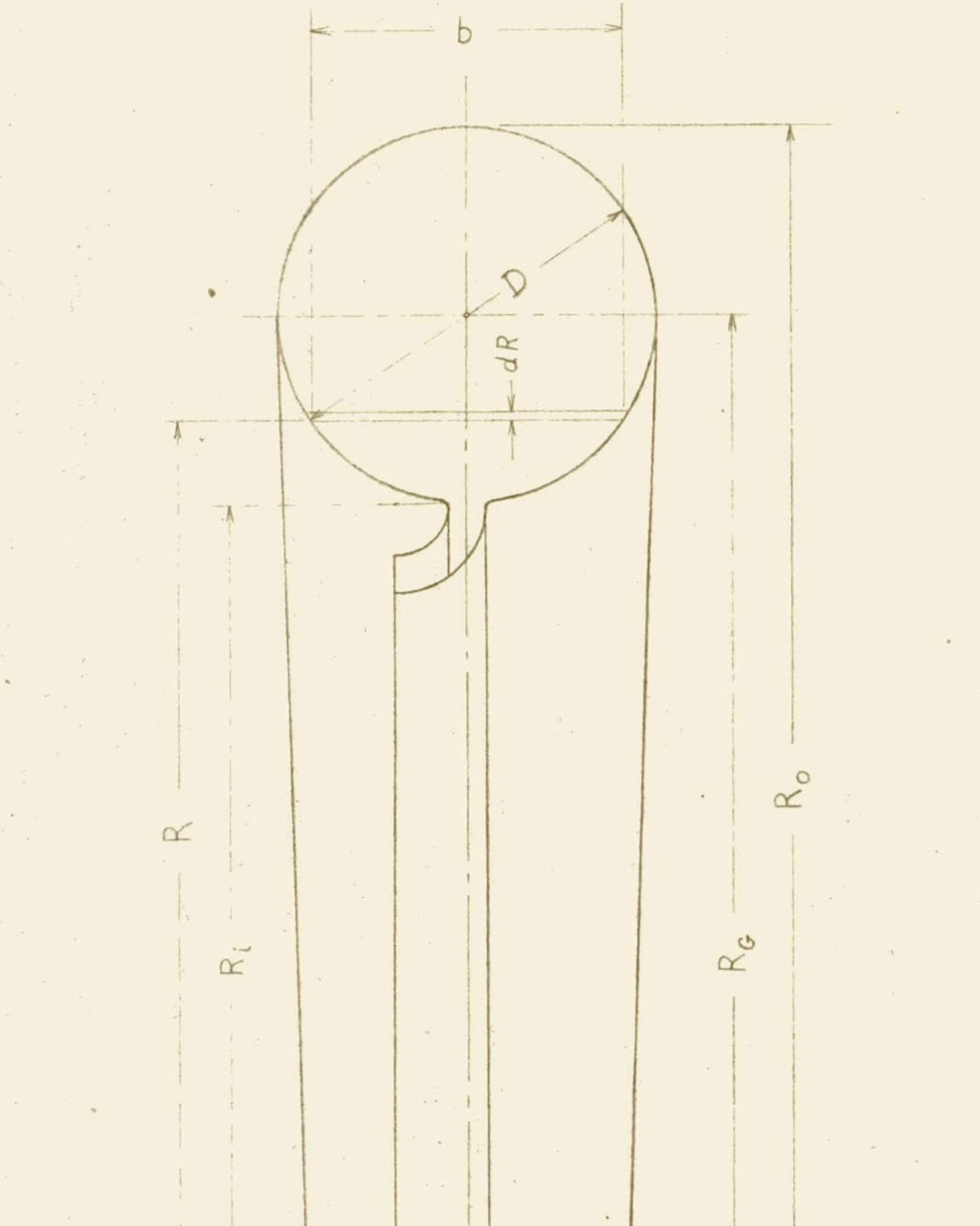


FIG. A-2. SCROLL CROSS-SECTION.