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Leader In Secondary Power

SUNDSTRAND AVIATION

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Division of Sundstrand Corporation

Semiannual Progress Report No. SA/ONR #1
1 May through 31 October 1966

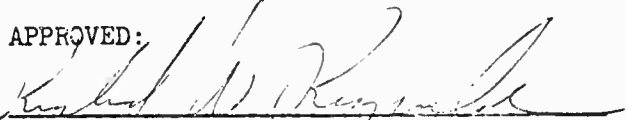
Report Date 31 October 1966

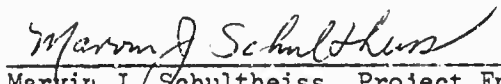
Investigations of Various Types of Nozzles to Determine the Most Feasible Concepts Applicable to Improved Turbine Nozzle Performance at Off-design Pressure Ratios for Partial Admission Impulse Turbines.

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APPROVED:


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1.0

Summary: Five test nozzle configurations were selected for testing: 1) Two Conical converging-diverging nozzles with design Mach numbers of 2.0 and 4.0; 2) an Axi-symmetric shock-cancellation nozzle with a design Mach number of 4.0; 3) a free expansion nozzle with a design Mach number of 4.0; and 4) a plug type nozzle with a design Mach number of 4.0. These nozzles have been designed and fabrication of all, except the plug nozzle, is complete. Testing was initiated and the test data is presented herein; however, the data analysis is not presented because of the limited data available.

A literature search was conducted and a summary of the reports received is presented herein. The derivation of a theoretical prediction of nozzle performance was initiated.

The program will be completed on schedule and no significant problem areas are anticipated.

2.0

Literature Search: Twenty-three reports were reviewed and ten reports ordered which concern turbine nozzles. A summary of the reports reviewed and a list of the reports ordered are included herein. The information obtained in these references aided in the selection and design of the test nozzles as noted below.

3.0

Test Nozzle Selection and Design: The nozzle types selected for this study are the following four types: 1) Conical; 2) Axi-symmetric shock-cancellation; 3) Free expansion; and 4) Plug type. These types were selected on the basis of low fabrication cost (types 1 and 3), design point performance superiority (type 2), and off-design point performance superiority (type 4). The superior performance estimates are based on rocket nozzle performance tests. The nozzle design Mach numbers were selected as 2.0 and 4.0 to provide data over the most common operational range of high energy turbines.

The nozzles have common design parameters as shown in Table I. Since seemingly insignificant geometric parameters can have significant effects on turbine performance, all possible geometric parameters were maintained constant between the nozzles as noted in Table I.

The nozzle design details are shown in Figures 1, 2, 3, and 4. The design of the conical nozzles is typical of Sundstrand design and is typical of those in References 1.1.4 and 1.2.7. The axi-symmetric shock-cancellation nozzle design is based on the procedure presented in Reference 1.3.11, the free expansion nozzle on Reference 1.2.6, and the plug nozzle on Reference 1.1.2. All nozzles have been designed and fabrication of the first three types has been completed. The plug nozzle will be completed in November.

These nozzles will be tested in the Sundstrand turbine test laboratory using the dynamometer shown in Figure 5. The turbine wheel is a 6.2 inch diameter, shrouded wheel with 0.42 inch blade height as shown in Figure 6. The exhaust housing of Figure 7 is used to shroud the wheel sides to decrease the disc friction and simulate a typical turbine installation.

Testing of the Mach 2.0 conical nozzle has been initiated and the turbine performance is presented in Figure 8. The derived nozzle velocity coefficients for these tests are shown in Figure 9. More test data will be obtained at other pressure ratios to extend the off-design pressure ratio data. No comments concerning the analysis of these data is felt to be significant at this time because of the limited data available.

4.0 Theoretical nozzle performance prediction: Three techniques of nozzle performance prediction are being considered. One is based on normal shock theory for overexpanded nozzles, the second is based on oblique shock boundary layer separation. The third technique being considered is a combination of oblique shock theory and continuity conditions through the rotor. It is anticipated that the third technique will most nearly describe the actual conditions.

5.0 Program Schedule and Problem Areas: The nozzle testing started somewhat behind schedule due to high priority testing; however, the tests for this program should continue relatively uninterrupted during the months of November, December, and January. No significant delays are anticipated and the program will be completed on time.

TURBINE NOZZLE REFERENCE MATERIAL

1.0 TURBINE NOZZLE REPORTS

- 1.1 Theoretical only.
- 1.2 Experimental only.
- 1.3 Comparison of theoretical and experimental information.

2.0 REFERENCES ON ORDER

APPLICABILITY RATING

- 1. Of particular interest and applicable to small turbines.
- 2. Of general interest and applicable to small turbines.
- 3. Applicable to small turbines but information incomplete or inconclusive.
- 4. Not applicable to small turbines.

1.1 TURBINE NOZZLE REPORTS (THEORETICAL ONLY)

1.1.1 "SHOCK FORMATION IN CONICAL NOZZLES"

H. M. Darwell and R. Badham, AIAA Journal, Vol. 1, No. 8, August 1963.

APPLICABILITY 2

A theoretical evaluation of the gas flow in conical nozzles was made using the method of characteristics. This study showed that it is possible that a shock may form in the nozzle. Computer calculations show that the shock formation can be removed by changes in the wall contour near the throat.

SIGNIFICANT CONCLUSIONS: Method to improve conical nozzle performance.

QUESTIONABLE AREAS: Theoretical only.

1.1.2 "APPROXIMATE METHOD FOR PLUG NOZZLE DESIGN"

Gianfranco Angelino, AIAA Journal, Vol. 2, No. 10, June 3, 1964.

APPLICABILITY 2

This report describes how to design plug nozzles. This type of nozzle has good performance at off-design pressure ratios and is constructed so that positioning the nozzle on a bias, as in a turbine, would not theoretically affect the flow.

SIGNIFICANT CONCLUSIONS: Method of designing nozzles.

QUESTIONABLE AREAS: No data presented.

1.1.3 "THEORETICAL STUDIES OF SUPERSONIC TWO-DIMENSIONAL AND AXI-SYMMETRIC NONEQUILIBRIUM FLOW, INCLUDING CALCULATIONS OF FLOW THROUGH A NOZZLE"

James J. Der, Ames Research Center, NASA Technical Report TR R-164, December 1963.

APPLICABILITY 2

Methods of calculating the characteristics of a supersonic nozzle with a dissociated gas flow are presented. The report is directed toward rocket type nozzles. Few turbine nozzles operate with a dissociated gas because of material limitations to temperature; however, this theory appears to be applicable for a dissociated gas.

SIGNIFICANT CONCLUSIONS: Method to calculate nozzle flow characteristics in a dissociated gas.

QUESTIONABLE AREAS: Theory only.

1.1.4 "CHARACTERISTICS OF CONICAL SUPERSONIC NOZZLES"

David Migdal and Fred Landis, ARS Journal, December 1962.

APPLICABILITY 2

Conical supersonic nozzles were analyzed by the method of characteristics to show the effects of wall angle, throat-to-cone fairing, area ratio, and the thermodynamic properties as characterized by the isentropic expansion coefficient. The study is primarily concerned with rocket nozzles; however, some of the information may be useful in turbine nozzle design.

SIGNIFICANT CONCLUSIONS: Parametric Study.

QUESTIONABLE AREAS: Theoretical Only.

1.2 TURBINE NOZZLE REPORTS (EXPERIMENTAL ONLY)

1.2.1 "REACTION TESTS OF TURBINE NOZZLES FOR SUBSONIC VELOCITIES"

Hans Kraft, Transactions of the ASME, October 1949.

APPLICABILITY 1

This report presents considerable data of converging nozzles operating at various pressure ratios. The primary objective of the study was to find the effect of nozzle geometry on performance. The geometry varied was aspect ratio, stator blade inlet angles, and stator blade shape. Kraft points out that Keenan's supersonic nozzle data are pessimistic for all supersonic data because of the method of testing (the same method was used in Kraft's tests) and "the velocity coefficients must be corrected upward by an uncertain amount."

SIGNIFICANT CONCLUSIONS: (1) Converging nozzle performance, and (2) Keenan's supersonic nozzle data are pessimistic.

QUESTIONABLE AREAS: None apparent.

1.2.2 "THE PERFORMANCE OF SUPERSONIC TURBINE NOZZLES"

B. S. Stratford, G. E. Sansome - Aeronautical Research Council Reports and Memoranda, R. & M. No. 3273, 1962.

APPLICABILITY 1

Experimental investigation of a Mach 2.5 supersonic nozzle. Tests were made at pressure ratios from 9 to 19, the design pressure ratio being 16.6. The objective being to find the effect of nozzle exit angle on nozzle pressure ratio.

SIGNIFICANT RESULTS: The conditions immediately downstream of the nozzles exert an overriding influence on the nozzle outlet flow angle.

QUESTIONABLE AREAS: None apparent.

1.2.3 "REACTION TESTS OF TURBINE NOZZLES FOR SUPERSONIC VELOCITIES"

J. H. Keenan, Transactions of the ASME, October 1949.

APPLICABILITY 1

Most complete testing of off-design supersonic nozzles available. Nozzles with area ratios of 1, 1.38, 2.34, 3.19 and 7.9 were tested. The nozzle shape was quasi-two-dimensional. All nozzles were designed for an inlet angle of 20° . All tests were reaction-tests.

1.2.3 (Continued)

SIGNIFICANT RESULTS: Off-design nozzle performance data.

QUESTIONABLE AREAS: (1) Unusual nozzle cross section. (2)
No account taken of the pressure force on the nozzle.

1.2.4 "PERFORMANCE CHARACTERISTICS OF ONE CONVERGENT AND THREE CONVERGENT-DIVERGENT NOZZLES"

H. George Krull and Fred W. Steffen, Lewis Flight Propulsion Laboratory, NACA Research Memo RM E52H12, September 29, 1952.

APPLICABILITY 2

An experimental study of 4 nozzles, applicable to rockets, was made. The nozzles area ratios were 1.0, 1.39, 1.69, and 2.65. An air flow parameter and thrust parameter are presented for all nozzles at pressure ratios from 1.2 to 25. The converging-diverging nozzles performed better than predicted when underexpanded, indicating oblique rather than normal shocks in the nozzle. Although these data are for rocket type nozzles, some insight into off-design nozzle performance can be obtained.

SIGNIFICANT CONCLUSIONS: Off-design nozzle performance data.

QUESTIONABLE AREAS: Rocket type nozzles.

1.2.5 "COMPARISON OF EXPERIMENTAL WITH PREDICTED WALL STATIC-PRESSURE DISTRIBUTIONS IN CONICAL SUPERSONIC NOZZLES"

L. H. Back, P. F. Massier, and H. L. Gier, Jet Propulsion Laboratory, Technical Report No. 32-654, October 15, 1964.

APPLICABILITY 2

Tests were made with room temperature and heated air in several conical convergent-divergent nozzles with an area ratio of 6.6. Test data are presented at off-design pressure ratios. This report should give some insight into the nozzle flow conditions at off-design pressure ratios.

SIGNIFICANT CONCLUSIONS: Conical nozzle data at off-design pressure ratios.

QUESTIONABLE AREAS: None apparent.

1.2.6 "SUDDEN EXPANSION OF A BOUNDED JET AT A HIGH PRESSURE RATIO"

Edward J. Barakauskas, AIAA Journal, Vol. 2, No. 9, April 10, 1964

APPLICABILITY 2

Tests of the flow field of converging nozzles in a circular duct. The data show that the flow field is similar to that obtained

with a convergent-divergent nozzle and if a duct is placed around the jet it has no influence unless the duct diameter is less than the jet diameter. This concept has interesting possibilities as a turbine nozzle.

SIGNIFICANT CONCLUSIONS: A sudden expansion nozzle has a similar flow field to a convergent-divergent nozzle.

QUESTIONABLE AREAS: None apparent.

1.2.7 "CONICAL ROCKET NOZZLE PERFORMANCE UNDER FLOW-SEPARATED CONDITIONS"

Sherwin Kalt and David L. Badal, Engineering Notes, AIAA Journal of Spacecraft, May-June, 1965.

APPLICABILITY 2

More information on flow separation in conical nozzles. Should provide insight into off-design turbine nozzle performance.

SIGNIFICANT CONCLUSION: Off-design pressure ratio performance data for conical nozzles.

QUESTIONABLE AREA: None apparent.

1.2.8 "SECONDARY FLOWS AND BOUNDARY-LAYER ACCUMULATIONS IN TURBINE NOZZLES"

Harold E. Rohlik, Milton G. Kofskey, Hubert W. Allen, and Howard A. Herzig, Lewis Flight Propulsion Laboratory, NACA Report 1168, 1954.

APPLICABILITY 2

This report summarizes a design point study of the nozzle flow vector of several two-dimensional nozzles. The design Mach numbers varied from 0.86 to 1.46. Flow vector profiles are presented.

SIGNIFICANT RESULTS: Rectangular nozzles operating at design pressure ratio have low flow losses and the measured discharge angle is approximately equal to the design angle.

QUESTIONABLE AREAS: These are large size nozzles, tip diameter of 16.25 in., blade height of 2.28 in., and blade chord of 1.5 in.

1.2.9 "SECONDARY FLOWS AND BOUNDARY-LAYER ACCUMULATIONS IN TURBINE NOZZLES"

Harold E. Rohlik, Milton G. Kofskey, Hubert W. Allen, and Howard A. Herzig, NACA Report 1168, 1954.

APPLICABILITY 2

This report summarizes an investigation of secondary-flow loss patterns in three sets of converging turbine nozzle blade passages.

The test technique used was flow-visualization (by means of paint on the blade surfaces and smoke gits) and detailed flow measurements with pressure and hot-wire probes. Overall mass-averaged blade velocity coefficients were 0.98 to 0.99.

SIGNIFICANT RESULTS: Microscopic examination of nozzle flow.

QUESTIONABLE AREAS: Neglects effect of rotor on nozzle performance.

1.3 TURBINE NOZZLE REPORTS (THEORETICAL AND EXPERIMENTAL)

1.3.1 "STUDY OF THE TWO-DIMENSIONAL FLOW THROUGH A CONVERGING-DIVERGING NOZZLE"

Arthur Kantrowitz, Robert E. Street, and John R. Erwin, A NASA Facsimile Reproduction of CB 3D24, 1942.

APPLICABILITY 2

A study of flow through a converging-diverging shock cancellation nozzle was made. The design Mach number was 1.44. A comparison of the measured and theoretical pressure distribution was in good agreement. This report includes initial work in the nozzle field which is generally understood at the present time.

1.3.2 "INVESTIGATION OF NEW M.E.I. NOZZLE CASCADES FOR SUPERSONIC VELOCITIES"

M. Ye. Daych, A. V. Gubarev, et al, Teploenergetika, No. 10, 1962, Foreign Technology Division FTD-TT-63-99.

APPLICABILITY 2

A "new" Russian nozzle design is proposed that will improve supersonic turbine nozzle off-design performance. This design is very similar to Ohlsson's design at MIT. Test data are presented for 22 nozzle designs and the performance does appear good; however, considerable time will be required to understand the report.

SIGNIFICANT CONCLUSIONS: Converging nozzles are best for design Mach numbers up to 1.5.

QUESTIONABLE AREAS: Cascade data only.

1.3.3 "SHOCK-INDUCED BOUNDARY-LAYER SEPARATION IN OVEREXPANDED CONICAL EXHAUST NOZZLES"

M. Arens, E. Spiegler, AIAA Journal Vol. 1, No. 3, March 1963.

APPLICABILITY 1

The flow in overexpanded supersonic conical nozzles was reviewed. Experimental data showed that oblique shocks occurred in the nozzle when operating overexpanded. When oblique shocks occur the nozzle velocity coefficient is larger than if a normal shock occurs. The prediction of the pressure ratio at which the oblique shocks and hence the boundary-layer separation occurs is of value for turbine analysis at below design pressure ratios. Good correlation was obtained with experimental data for the assumptions of this paper. A large number of data were available for comparison.

SIGNIFICANT CONCLUSIONS: Method to predict separation in conical nozzles.

QUESTIONABLE AREAS: None apparent.

1.3.4 "TRUNCATED PERFECT NOZZLES IN OPTIMUM NOZZLE DESIGN"

J. H. Ahlbert, S. Hamilton, D. Migdal, and E. N. Nilson, ARS Journal, May 1961.

APPLICABILITY 2

This report presents a method to design shock cancellation supersonic nozzles. A discussion of wall friction and separation effects is included. The work is directed toward large rocket nozzles; however, the data could provide insight into turbine nozzle performance.

SIGNIFICANT CONCLUSIONS: Method of design of shock-cancellation.

QUESTIONABLE AREAS: Information directed toward large nozzles.

1.3.5 "INVESTIGATION OF STEAM-TURBINE NOZZLE AND BLADING EFFICIENCY"

F. Dollin, Proc. I. Mech. E., Vol. 114, No. 4, 1940

APPLICABILITY 2

This report discusses the design of nozzle and rotor blade shapes. A discussion of the problems of nozzle testing is presented. Some nozzle test data are presented for a sonic nozzle and the design of an improved nozzle test rig is described. The author feels that the Reynolds number is an important parameter that has not been considered previously.

SIGNIFICANT CONCLUSION: Some nozzle data presented.

QUESTIONABLE AREAS: Discussion of nozzle test techniques.

1.3.6 "SOME RESEARCHES ON STEAM-TURBINE NOZZLE EFFICIENCY"

Henry Lewis Guy, M. Inst. C.E., Journal of Inst. of Civil Engineering Vol. 13, 1939.

APPLICABILITY 2

This paper summarizes nozzle work done by the Steam-Nozzles Research Committee. Unfortunately, the information and data presented only concern converging nozzles. Data are presented which show the effect of nozzle throat length, exit velocity, blade inlet radius, exit angle, and blade height on nozzle velocity coefficient.

SIGNIFICANT CONCLUSIONS: Variation of nozzle velocity coefficient with nozzle parameters.

QUESTIONABLE AREAS: Converging nozzles only.

1.3.7 "FIRST REPORT OF THE STEAM-NOZZLES RESEARCH COMMITTEE"

The Institute of Mechanical Engineers, January 1923.

APPLICABILITY 2

This report describes the test equipment used by the steam-nozzle committee in later tests.

SIGNIFICANT CONCLUSIONS: None.

QUESTIONABLE AREAS: None.

1.3.8 "SECOND REPORT OF THE STEAM-NOZZLES RESEARCH COMMITTEE"

The Proceedings of the Inst. Mech. Engr. March 1923.

APPLICABILITY 2

This report presents the initial studies of the committee. The majority of this paper is concerned with comments made during the discussion after presentation of the report. Data of 20° converging nozzles with thin partitions are presented.

SIGNIFICANT RESULTS: Some converging nozzle data.

QUESTIONABLE AREAS: None.

1.3.9 "THIRD REPORT OF THE STEAM-NOZZLES RESEARCH COMMITTEE"

Proceedings of Inst. Mech. Engr., May 1924.

APPLICABILITY 2

This report presents the performance of convergent nozzles with a 20° angle, with thick partitions. In addition, a series of tests were run to determine the effect of chamfer on the nozzle exit edges.

SIGNIFICANT RESULTS: Chamfer of the nozzle exit edges improved the velocity coefficient over the non-chamfered nozzle. However, the thin plate nozzles had better performance than the chamfered thick plate nozzles.

QUESTIONABLE AREAS: None apparent.

1.3.10 "FOURTH REPORT OF THE STEAM-NOZZLES RESEARCH COMMITTEE"

Proceedings of Inst. Mech. Engr., May 1925.

APPLICABILITY 2

Test results of 12° convergent nozzles with thick and thin partitions (blades) are presented. Tests to determine the effect of exit edge chamfer were conducted. Comments are made as to the effect on nozzle efficiency due to: throat length, thickness of partition plates, chamfering, and nozzle angle.

SIGNIFICANT RESULTS: Converging nozzle data.

QUESTIONABLE AREAS: None apparent.

1.3.11 "APPROXIMATION OF OPTIMUM THRUST CONTOURED NOZZLE"

Rao, G. V. R., ARS June 1960

APPLICABILITY 2

A procedure to design contoured shock-cancellation nozzles is presented. The nozzles are optimized on the basis of thrust for rocket nozzles.

SIGNIFICANT RESULTS: Simple method of determining contoured nozzle shapes.

QUESTIONABLE AREAS: Procedure valid for k between 1.2 and 1.4 only.

- 2.0 REPORTS ON ORDER
- 2.1 Allen, H. W., Kofskey, M. G., and Chamness, R. E., "Experimental Investigation of Loss in an Annular Cascade of Turbine - Nozzle Blades of Free Vortex Design," NACA Tech. Note 2871, 1953.
- 2.2 Johnston, I. H., "An Analysis of the Air Flow Through the Nozzle Blades of a Single Stage Turbine," Brit. Aeronaut. Research Council Current Paper 131, 1953.
- 2.3 Huppert, M. C. and MacGregor, C., "Comparison Between Predicted and Observed Performance of Gas Turbine Stator Designed for Free Vortex Flow," NACA TN1810, 1949.
- 2.4 Edelman, G. M., "The Design, Development, and Testing of Two-Dimensional Sharp-Cornered Supersonic Nozzles," Rep. No. 22. MIT, May 1, 1948 (Bur. Ord. Contract NOrd 9661).
- 2.5 Johnson, I. H., "Analysis of the Air Flow Through the Nozzle Blades of a Single Stage Turbine," ARC CP 131, February 1951.
- 2.6 Rohlik, H. E. et al, "Study of Secondary-Flow Patterns in an Annular Cascade of Turbine Nozzle Blades with Vortex Design," NACA TN 1897, February 1949.
- 2.7 Kofskey, M. G., et al, "Experimental Investigation of Flow in an Annular Cascade of Turbine Nozzle Blades of Constant Discharge Angle," NACA RM E52A09, 1952.
- 2.8 Johnston, I. H., "Analyses of the Air Flow Through the Nozzle Blades of a Single Stage Turbine," N.G.T.E. Memo No. 1N 108, 1951.
- 2.9 Bloomer, H. E., et al., "Experimental Study of Effects of Geometric Variables on Performance of Conical Rocket Exhaust Nozzles," NASA TN D-846, 1961.
- 2.10 Ashwood, P.E. and Corsse, G.W., "The Influence of Pressure Ratio and Divergence Angle on the Shock Position in Two-Dimensional, Over Expanded, Convergent-Divergent Nozzles," ARC Current Paper 327, 1957.

TABLE I

Geometric Parameters of the Test Nozzles and Test Turbine which are Common to all Test Configurations

Nozzle Characteristics

Nozzle Angle	16°
Nozzle Exit Dia.	0.35 inch
Nozzle Pitch Dia.	6.775 inches

Major axis of nozzle exit ellipse is tangent to wheel pitch diameter at center of ellipse.

Rotor Characteristics

Wheel Pitch Dia.	6.775 inches
Wheel Blade Angles	25°
Wheel Blade Height	0.42 inch
Wheel Blade Chord	0.3 inch

FIGURE 1
SKETCH OF CONICAL NOZZLES

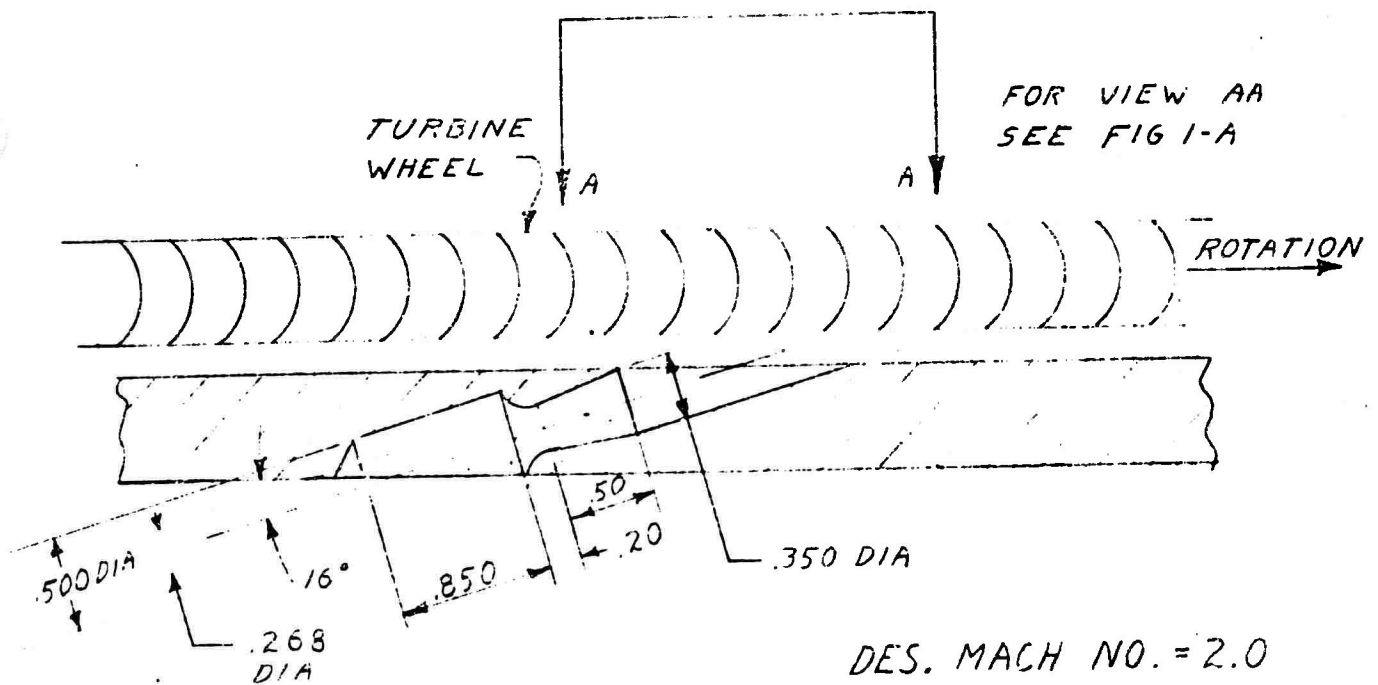
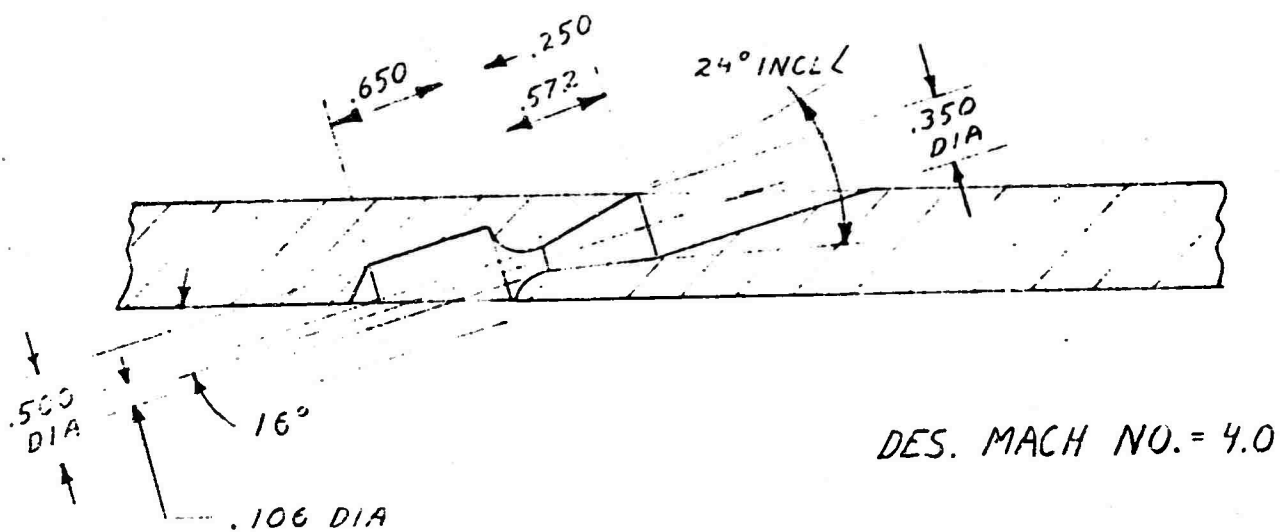
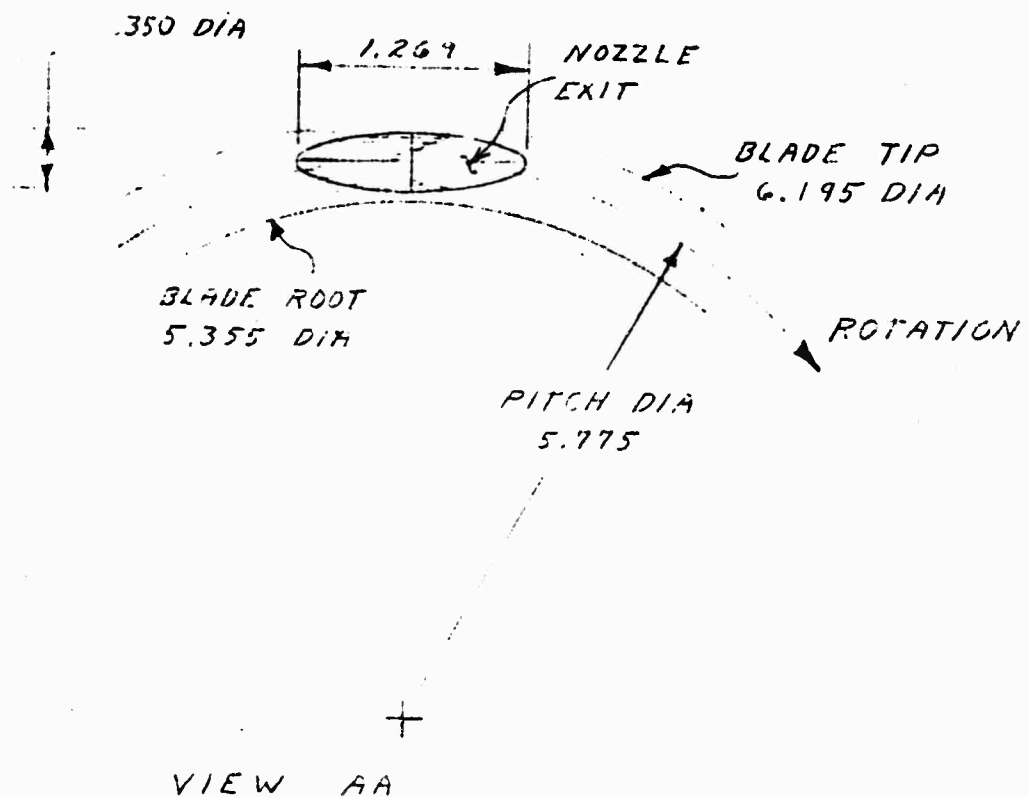


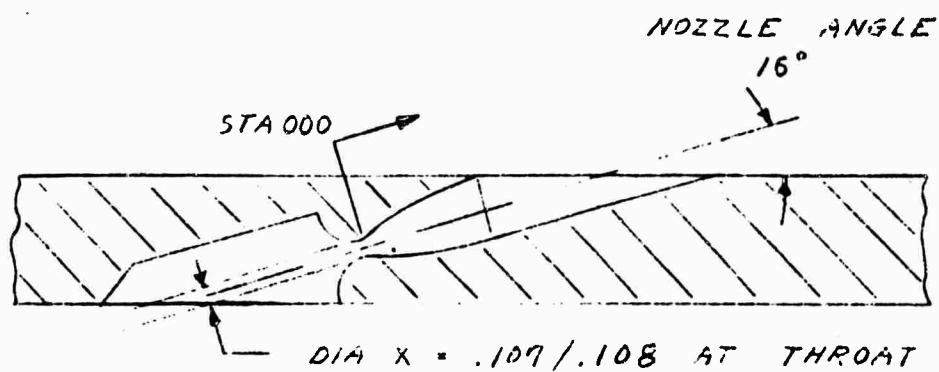
FIGURE 1-A

SKETCH OF CONICAL NOZZLE EXIT
AND WHEEL OUTLINE



NOTE: NOZZLE DESIGNED WITH 20% LAP
EQUALLY SPACED

FIGURE 2
 SKETCH OF AXI-SYMMETRIC
 SHOCK CANCELLATION NOZZLE



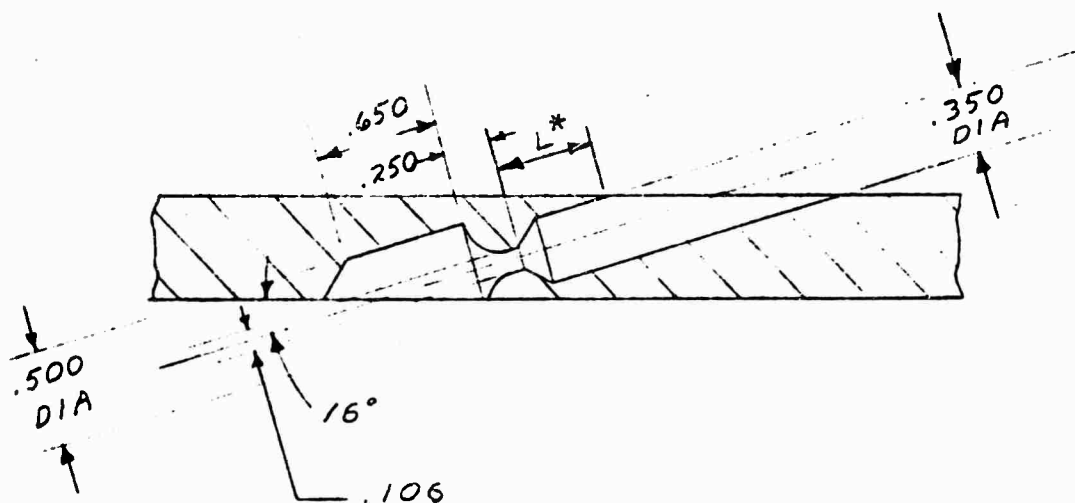
COORDINATES			
STA, IN	DIA X, IN	STA, IN	DIA X, IN
0.00	0.107	0.35	0.282
0.05	0.132	0.40	0.296
0.10	0.165	0.45	0.312
0.15	0.195	0.50	0.325
0.20	0.212	0.60	0.333
0.25	0.240	0.70	0.343
0.30	0.250	0.75	0.350

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FIGURE 3

SKETCH OF FREE EXPANSION
NOZZLE



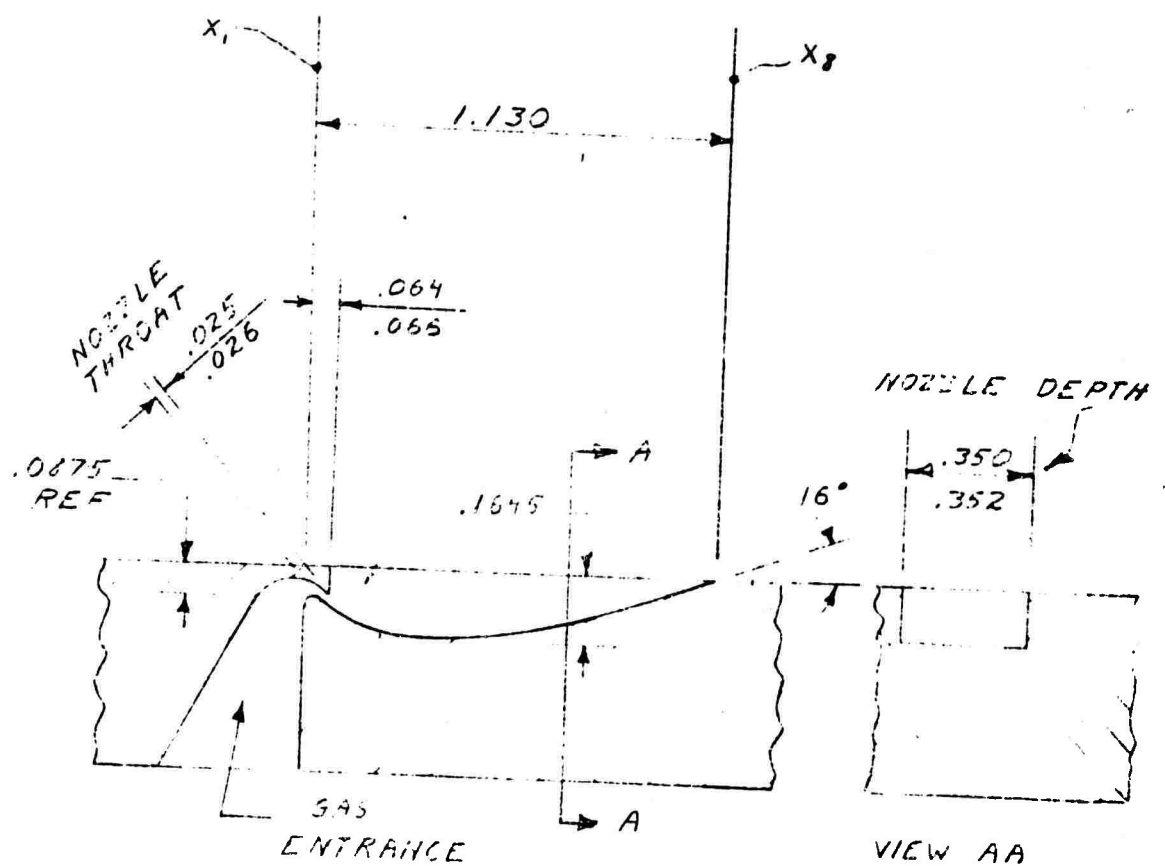
NOTE: NOZZLES WITH THE FOLLOWING
VALUES OF L^* WERE FABRICATED

- 1) 0.10
- 2) 0.50
- 3) 0.75
- 4) 1.00

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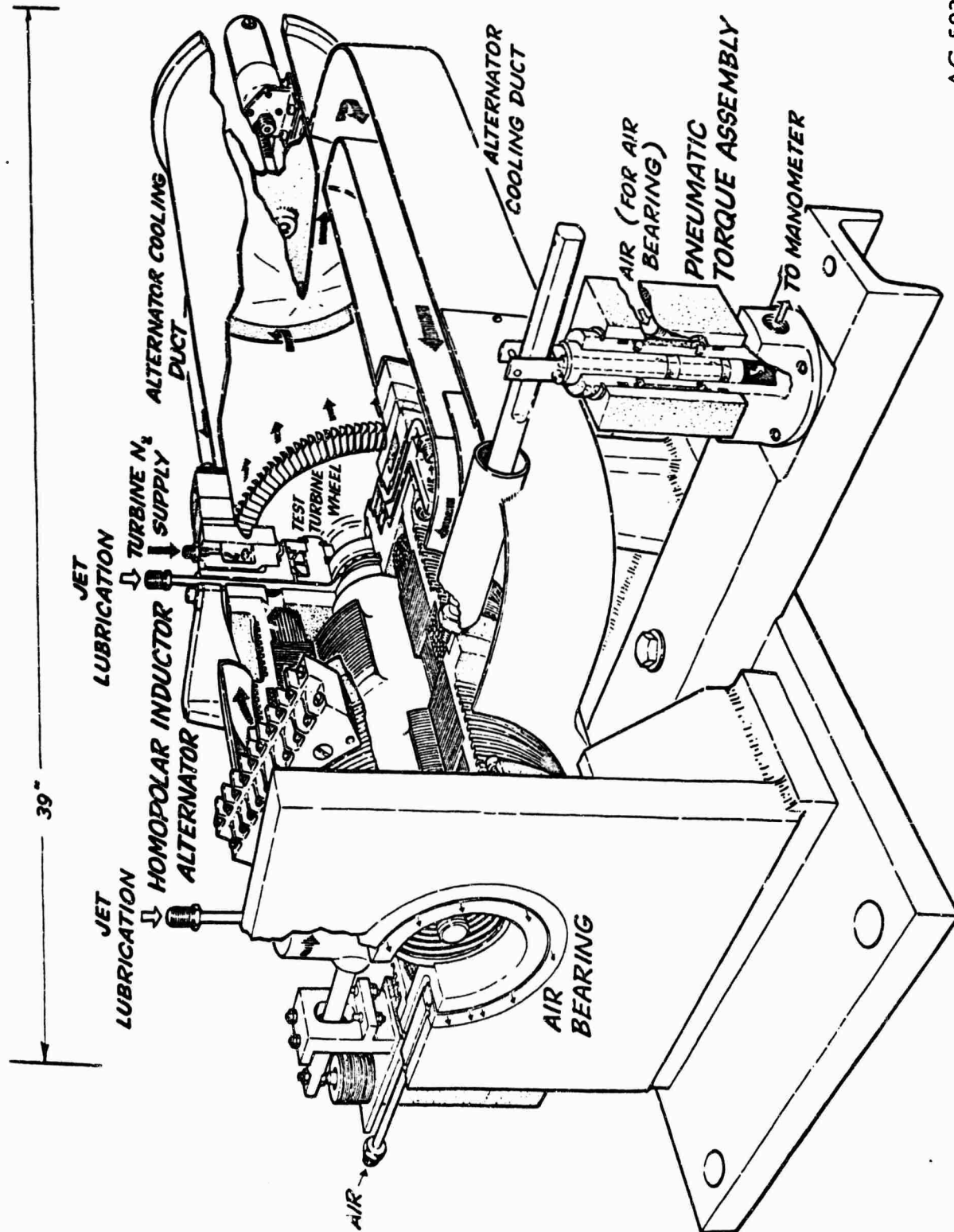
FIGURE 4
SKETCH OF PLUG NOZZLE



COORDINATES

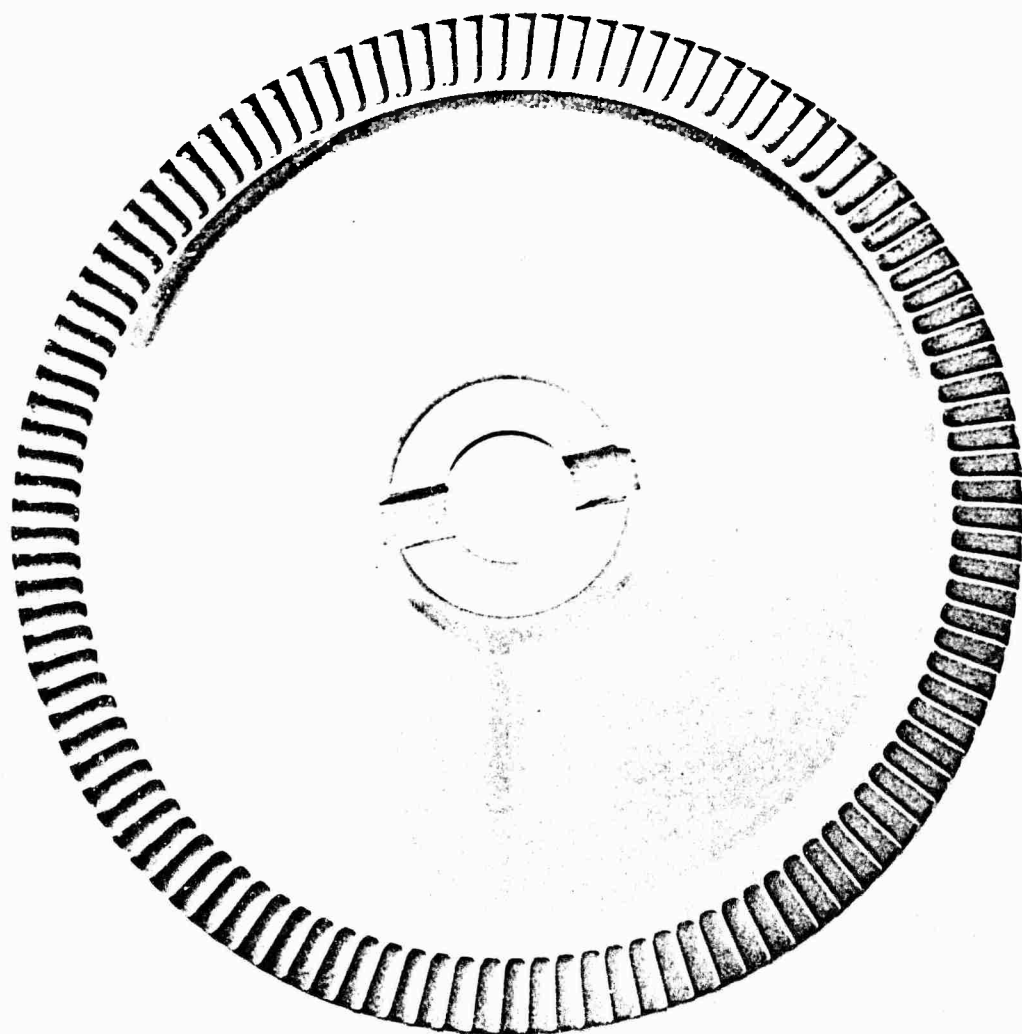
STA	X ± .001	Y ± .001
1	0	.100
2	.140	.143
3	.300	.154
4	.450	.158
5	.620	.137
6	.780	.104
7	.940	.064
8	1.100	.010

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AG 5922

Figure 5. Sectional View of Dynamometer



Tip Diameter = 6.2 in.
Blade Height = 0.42 in.
Chord = 0.3 in.
25° Symmetrical Blades
115 Blades

Figure 6. Shrouded Turbine Wheel

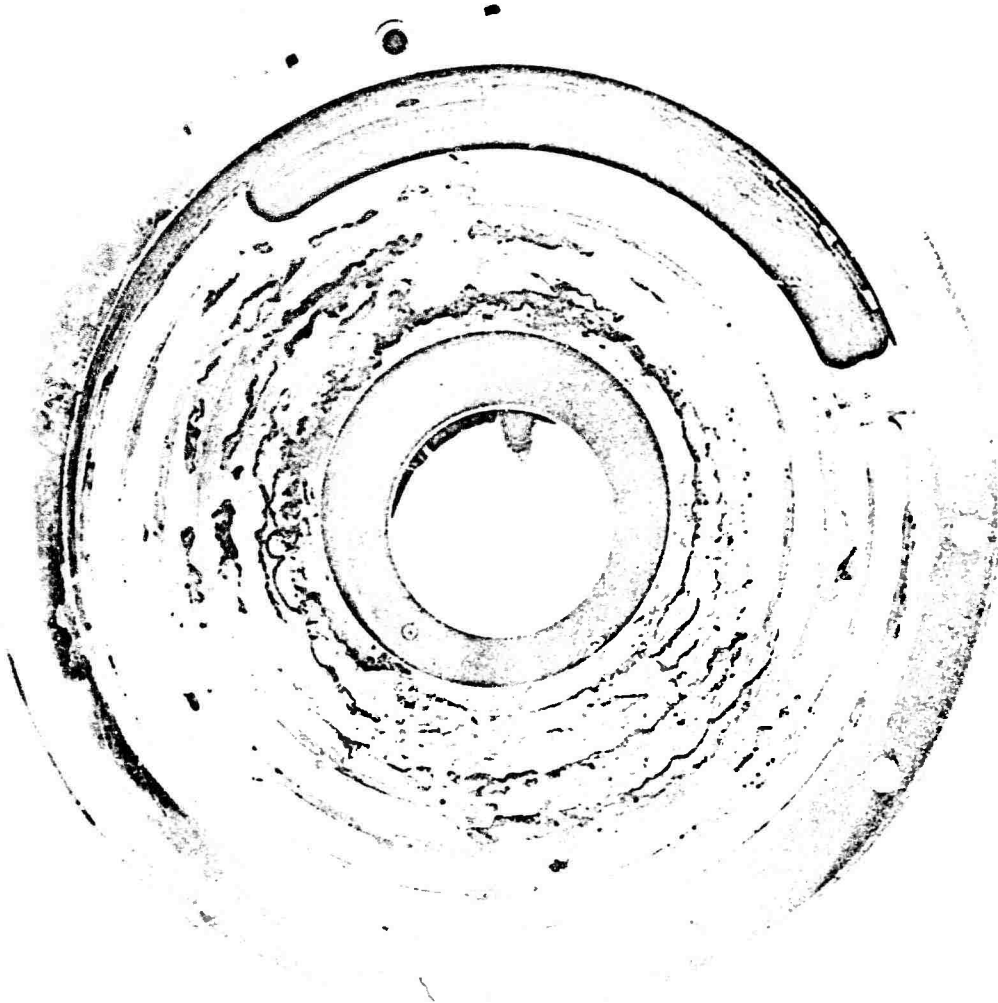


Figure 7. Turbine Assembly 331091 Exhaust Housing
Adapted for Use on the Turbine Test Lab Dynamometer

AG 7715

FIGURE 8

GAMMA NOZZLE STUDY
VARIATION OF TURBINE EFFICIENCY
WITH VELOCITY RATIO
CONICAL NOZZLES
DES. MACH. NO. = 2.0

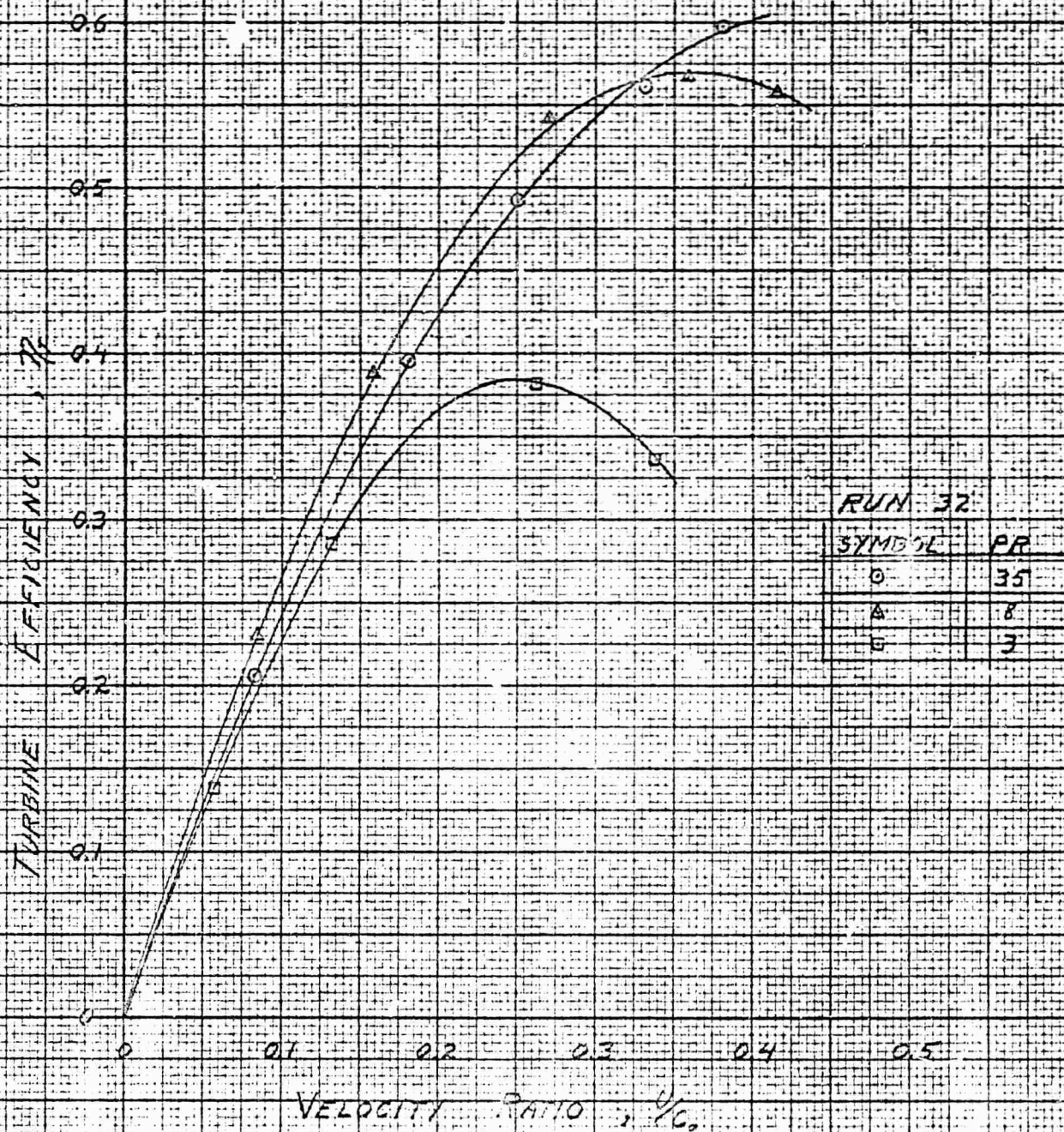
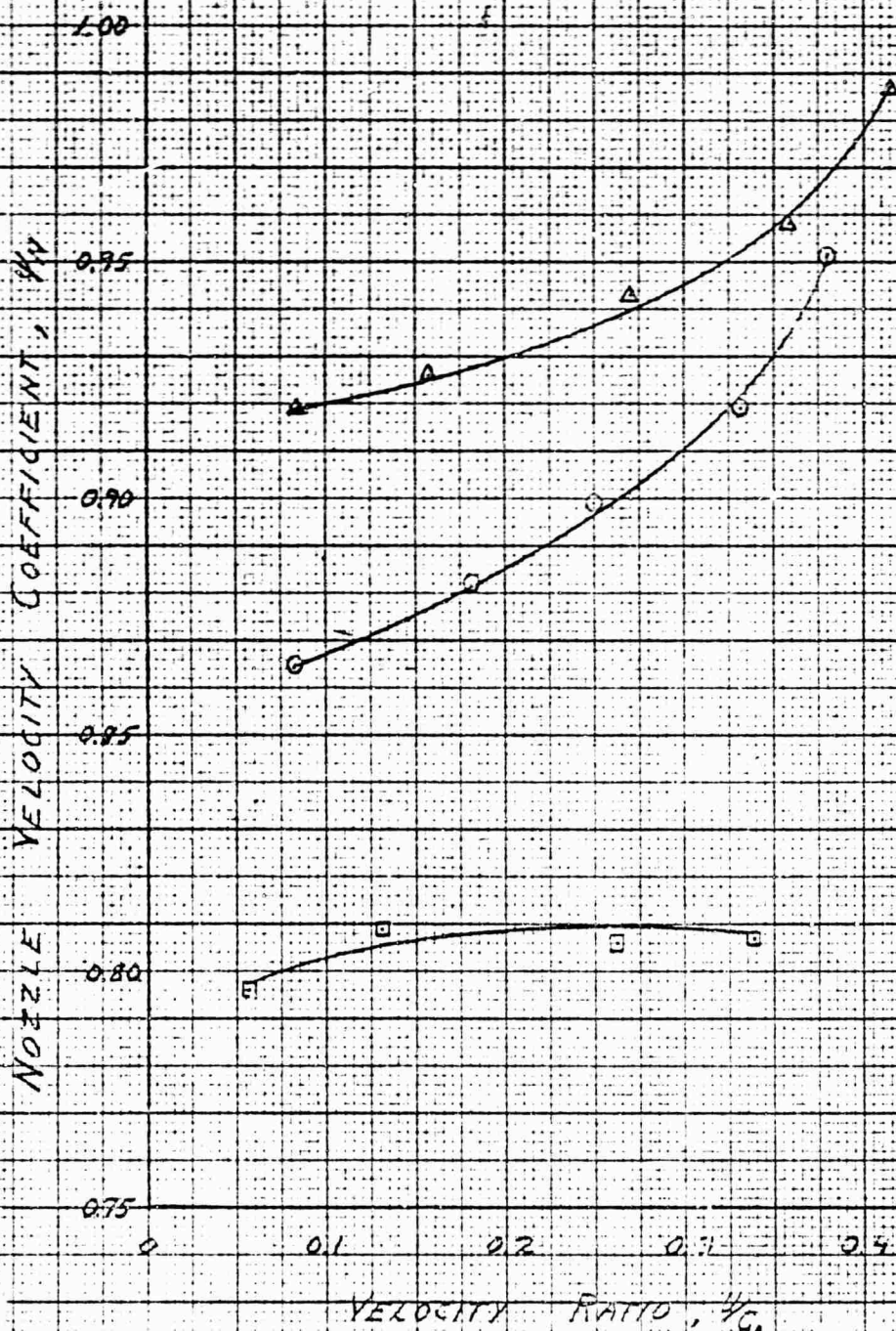


FIGURE 9

ONR NOZZLE STUDY
 VARIATION OF NOZZ VEL. COEFF.
 WITH VELOCITY RATIO
 CONICAL NOZZLES
 DES. MACH. NO. = 2.0



RUN 32

SYMBOL	PR	M/V_{des}
○	35	1.524
△	8	1.005
□	3	.640

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c.	8b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.	None	
10. AVAILABILITY/LIMITATION NOTICES "Qualified Requesters may obtain copies of this report from DDC"		
11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY Head, Power Branch Material Sciences Division Office of Naval Research Washington, D. C. 20360	
13. ABSTRACT This report is presented as part of, and in accordance with ONR Contract N00014-66-C0204, with Sundstrand Aviation, Rockford, Ill., to satisfy the specific requirement of Section F(a) of the Contract Schedule wherein a semi-annual report of work accomplished to date shall be submitted at the end of the sixth month after initial date of contract. (U) Five test nozzle configurations have been selected for design and testing to support the requirements of this contract. All designs are of the converging-diverging supersonic type. Two are of straight conical divergent wall design, one each for a design Mach number of two and of four. The remaining 3 nozzles consist of one each axi-symmetric shock-cancellation type, free expansion type, and a unique plug nozzle. Fabrication of all designs is complete but for the plug design. Testing has begun and preliminary data is herein presented. (U) A literature search was conducted and a summary of reports on hand is presented. Also, a theoretical nozzle performance prediction analysis has been started. (U) No serious problems are foreseen and the program will be completed on schedule. (U)		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fluid Mechanics Nozzle Performance Experimental Data						

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