AFAPL-TR-72-11

AD 749476

THRUST REVERSER AND THRUST VECTORING LITERATURE REVIEW

John E. Petit
Michael B. Scholey

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OCT 11 1972
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THE BOEING COMPANY

Technical Report AFAPL-TR-72-11
April 1972

AIR FORCE AERO PROPULSION LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

120

AFAPL TR-72-4

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I-C

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Boeing Company, Box 3999, Seattle, Wa. 98124	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

Thrust Reverser and Thrust Vectoring Systems Literature Review

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
1 July 1971 - 1 December 1971 interim report

5. AUTHOR(S) (First name, middle initial, last name)

John E. Petit and Michael B. Scholey

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
15 June 1972	120	160

8a. CONTRACT OR GRANT NO. F33615-71-C-1850	9a. ORIGINATOR'S REPORT NUMBER(S) None
b. PROJECT NO. 643A	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	AFAPL-TR-72-11

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Aero Propulsion Laboratory/TBP Wright-Patterson Air Force Base, Ohio 45433

13. ABSTRACT

The state-of-the-art of thrust reverser and thrust vectoring technology has been surveyed to identify the available test data and prediction methods in the literature. The literature review resulted in a bibliography of documents related to thrust reverser and thrust vectoring systems. The bibliography contains references to approximately 160 reports and is organized in three sections: Literature review summary, abstracts and data review summary.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Thrust reversers						
Thrust vectoring						
Nozzles						
Turbine engines						
Transport aircraft						
Aircraft braking systems						

I-B

FOREWORD

This report was prepared by John E. Petit and Michael B. Scholey of the Research and Engineering Division, Aerospace Group, The Boeing Company, Seattle, Washington. The work was conducted under USAF Contract F33615-71-C-1850, "STOL Transport Thrust Reverser/Vectoring Program." The contract was initiated under Project 643A "Tactical Airlift Technology", Task 63205F, "Flight Vehicle Subsystem Concepts" and administered by the Air Force Aero Propulsion Laboratory, Wright Patterson Air Force Base, Ohio, with Captain J. W. Schuman (AFAPL/TBP) Project Engineer. The report covers work performed from July through September 1971.

This technical report has been reviewed and is approved.

E. C. Simpson
Director, Turbine Engine Division
AF Aero-Propulsion Laboratory

ABSTRACT

The state-of-the-art of thrust reverser and thrust vectoring technology has been surveyed to identify the available test data and prediction methods in the literature. The literature review resulted in a bibliography of documents related to thrust reverser and thrust vectoring systems. The bibliography contains references to approximately 160 reports and is organized in three sections: literature review summary, abstracts, and data review summary.

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INTRODUCTION

This document contains literature and data reviews of documentation related to thrust reverser and thrust vectoring systems for turbojet and turbofan powered aircraft. The purpose of this document is to provide an assemblage of thrust reverser/vectoring information that will allow the reader to easily determine available sources of data related to his particular interest and provide an abstract of that data.

The reviews were assembled as part of the Boeing/AFAPL STOL Transport Thrust Reverser/Vectoring Program, USAF Contract F33615-71-C-1850. The objective of the program is to develop prediction techniques and design criteria for highly efficient, lightweight thrust reversing or thrust vectoring systems suitable for STOL transport aircraft. The program has three parts:

Part IA - Data Review and Analysis

Part IB - Design

Part IC - Model Testing

An essential task of Part IA is Task 1.1, Review and Correlate TR/TV Data, in which existing performance data from the literature were reviewed for possible application to analytical models of thrust reverser and thrust vectoring systems. The analytical models will be developed during Task 1.2, Construct Computerized Analytical Models. The data voids discovered during Task 1.1 will be filled wherever possible by analysis or by scale model tests to be performed during Task 1.3, Supplemental Tests.

SOURCES OF LITERATURE

The reports were obtained from many sources including literature searches of Defense Documentation Center and NASA reports. A literature survey of Boeing documents, STAR and TAB abstracts, and technical journals was made. A survey was made of foreign literature made available through the services of Boeing International Corporation. Also, Pratt & Whitney Aircraft, subcontractor to the program, conducted a similar literature search of United Aircraft documentation which is included.

CLASSIFICATION OF THE BIBLIOGRAPHY

For purposes of classifying the literature the following categories were established:

1.0 Thrust Reverser Systems

2.0 Thrust Vectoring Systems

3.0 General Thrust Reverser/Vectoring

4.0 Thrust Reverser/Vectoring Flow Fields

The "general" category was for references that contained information relevant to both thrust reverser and vectoring systems. A flow fields category was created for those reports that discussed topics such as jets in cross flows, and exhaust flow recirculation effects. The flow field literature contain data and methods applicable to thrust reverser and thrust vectoring systems.

Each reference was reviewed to identify data in the following fields of interest:

a) internal performance

b) reverser effectiveness

c) reingestion

d) aerodynamic interference

e) jet trajectory

f) jet impingement

g) field length studies

h) mechanical design

Charts were made that summarized the information extracted from each reference. The summary charts are contained in Section I.

In addition, abstracts were written for each report reviewed that describes the contents of the report and provides an objective assessment of the applicability and usefulness of contents. Key words are also listed to assist the reader in determining whether the reference relates to his particular interest. The abstracts are contained in Section II.

Each reference is identified by a two-place numbering system. The first number identifies the category in which the report was classified and the second number indicates the location of the reference within its particular category.

DATA REVIEW

A data review was conducted to obtain specific definition of the test data contained in the references.

The objective of the data review is to accurately assess the data available in the literature and to assemble a sufficient data bank from which data correlations and analytical models can be formulated. Summary charts were prepared to condense the data to manageable and visible form. Data for the following thrust reverser/vectoring systems were assembled:

- Thrust reverser systems
    1. Cascade
    2. Target
    3. Blocker/deflector
- Thrust vectoring systems
    1. Single bearing
    2. Multibearing
    3. Spherical eyeball
    4. Ventral
    5. Cascade
    6. External deflector
    7. Miscellaneous deflectors
    8. General
- Combined thrust reverser/vectoring systems

Information contained on the charts includes small sketches of the thrust reverser or thrust vectoring device together with the range of test variables and type of data contained in the report. The data review charts are contained in Section III.

SECTION I

LITERATURE REVIEW SUMMARY

NOMENCLATURE FOR

THRUST REVERSER/VECTORING BIBLIOGRAPHY

SUMMARY CHARTS

Column Heading	Abbreviation	Definition
Thrust Reverser Concepts	T	target
	BD	blocker/deflector
	C	cascade
	S	thrust spoiler
Thrust Vectoring Concepts	CN	cascade nozzle
	SB	single-bearing swiveling nozzle
	MB	multi-bearing swiveling nozzle
	ED	external deflector
	SE	spherical eyeball
	VN	ventral nozzle
Nature of Report Material	E	experimental
	A	analysis
	G	general
Type of Test	S	static
	WT	wind tunnel
	FT	flight test
	TT	taxi test
Test Article	C	component
	A/P	airplane configuration

TABLE I THRUST REVERSER SYSTEMS BIBLIOGRAPHY SUMMARY CHART

1.0 THRUST REVERSER SYSTEMS

SPECIFIC AREAS OF INVESTIGATION

REFERENCE NUMBER	YEAR OF PUBLICATION	REVERSER CONCEPT	NATURE OF REPORT MATERIAL	TYPE OF TEST	TEST ARTICLE	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH STUDIES	JET IMPINGEMENT	MECHANICAL DESIGN
1.1	1965	C, BD	E, A	S	C	X							
1.2	1970	T, BD, C	A	None	C, A/P	X	X		X	X			
1.3	1963	C, T	E	WT	C, A/P			X					
1.4	1966	C	E, A	S	C	X							
1.5	1958	BD, C	E	WT	C, A/P			X					
1.6	1964	C	E	WT	C, A/P			X				X	
1.7	1969	BD	E	WT	C, A/P			X				X	
1.8	1969	T	E	FT	C, A/P		X	X	X				
1.9	1958	C	E	WT	C, A/P			X					
1.10	1965	C	E	WT	C, A/P			X				X	
1.11	1967	C	E	WT	C, A/P			X	X				
1.12	1968	BD	E	WT	C, A/P			X				X	
1.13	1969	C	E	S	C	X							
1.14	1970	T	E	WT	C, A/P			X	X				
1.15	To Be Released	BD, T	A	None	C	X							
1.16	1968	BD, T	A	None	C	X							
1.17	1963	Any	A	None	C, A/P						X		
1.18	1963	Any	A	None	C, A/P						X		
1.19	1967	Any	A	None	C, A/P						X		
1.20	1962	Any	A	None	C, A/P						X		
1.21	1967	BD	E	FT	C, A/P		X						
1.22	1967	Any	A	None	C, A/P						X		
1.23	1963	C	E	FT	C, A/P		X						
1.24	1964	C	E	FT	C, A/P								X
1.25	1966	C	E	FT	C, A/P							X	
1.26	1970	BD	E	S, WT, FT	C, A/P								X
1.27	1968	T	E	S, WT	C, A/P	X		X					
1.28	1965	T	E	WT	C, A/P				X				
1.29	1968	T	E	FT	A/P		X	X					
1.30	1968	T	E	FT	A/P							X	
1.31	[illegible]	C, T	E	WT	C, A/P			X					
1.32	[illegible]	[illegible]	E	WT	C, A/P		X	X					

TABLE I. CONTINUED

1.0 THRUST REVERSER SYSTEMS (CONT.)

REFERENCE NUMBER	YEAR OF PUBLICATION	REVERSER CONCEPT	NATURE OF REPORT MATERIAL	TYPE OF TEST	TEST ARTICLES	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH STUDIES	JET IMPINGEMENT	MECHANICAL DESIGN
						SPECIFIC AREAS OF INVESTIGATION							
1.33	1967	C	E	S	C	X							
1.34	1967	C	E	S	C	X							
1.35	1968	C	E	S	C	X				X			
1.36	1969	C	E	FT	A/P							X	
1.37	1968	3D	E	S	C	X				X			
1.38	1968	3D	E	S	C	X				X			
1.39	1970	T	E	S	C	X							
1.40	1970	T	E	S,WT	C,A/P	X	X					X	
1.41	1954	T	E	S	C	X							
1.42	1955	C	E	S	C	X							
1.43	1956	T	E	S	C	X							
1.44	1956	T,C	E	S	C	X							
1.45	1956	C	A	None	None	X							
1.46	1956	T	E	FT	C,A/P	X							
1.47	1956	C	E	S	C	X							
1.48	1957	C	E	FT	C,A/P	X	X						
1.49	1957	T	E	WT	C,A/P	X	X		X				
1.50	1959	T	E	WT	C,A/P		X		X				
1.51	1960	C	E	WT	C,A/P		X		X				
1.52	1960	C	E	WT	C,A/P		X		X				
1.53	1961	T,C	E	WT	C,A/P			X					
1.54	1961	T	E	WT	C,A/P		X		X				
1.55	1964	C	E	WT	C,A/P		X		X				
1.56	1970	T	E	WT	C,A/P		X	X	X			X	
1.57	1970	3D	E	WT	C	X							
1.58	1967	Any	E	S	C	X							
1.59	1967	3D,C	E	FT	C,A/P	X							
1.60	1967	C	E	S	C	X							
[illegible]	1971	Any	[illegible]	None	None								X
[illegible]	1958	T	[illegible]	None	None								X
[illegible]	[illegible]	C	[illegible]	None	[illegible]								X
1.64	[illegible]	T	[illegible]	None	None								X

TABLE I, CONCLUDED

1.0 THRUST REVERSER SYSTEMS (CONT.)

REFERENCE NUMBER	YEAR OF PUBLICATION	REVERSER CONCEPT	NATURE OF REFERENCE MATERIAL	TYPE OF TEST	TEST ARTICLE	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH CRITERIA	JET IMPINGEMENT	MECHANICAL DESIGN
						SPECIFIC AREAS OF INVESTIGATION							
1.65	1960	C	E	WT,FT	C,A/P		X		X				
1.66	1960	T	G	None	None		X		X				
1.67	1966	C	E	WT	C,A/P		X		X				
1.68	1967	ET,C,BD	A,E	WT	C,A/P	X	X						
1.69	1967	C,T	E	S	C	X	X		X				
1.70	1968	BD	E	None	C								X
1.71	1969	C	[illegible]	None	C								X
1.72	1969	C	G	None	C								X
1.73	1967	Any	A	None	C		X						
1.74	1970	BD	E	WT	C,A/P	X	X		X			X	
1.75	1969	BE,T	A	None	C	X							
1.76	1970	T	A	None	C	X							
1.77	1955	T	Z	S	C	X							
1.78	1966	Any	G	None	None								X
1.79	1964	C	E	FT	C,A/P				X				
1.80	1971	Any	E	WT	C			X	X	X		X	
1.81	1960	BD,T	G	None	C	X							X
1.82	1965	T	E	S	C	X							
1.83	1969	T	E	S	C	X							
1.84	1959	T	E	FT	C,A/P	X				X		X	
1.85	1951	C	E	S,WT	C	X							
1.86	1960	C	E	S	C	X							
1.87	1959	C	E	S,WT	C	X				X		X	
1.88	1965	BD	E	S,WT	C	X	X						
1.89	1966	BD	E	S,WT	C	X	X						
1.90	1966	BD	E	S,WT	C	X	X						
1.91	1965	BD	E	S,WT	C	X	X						
1.92	1956	BD	E	S,WT	C	X	X						
1.93	1971	T	E	S	C	X							

TABLE II THRUST REVERSER SYSTEMS BIBLIOGRAPHY SUMMARY CHART

2.0 THRUST VECTORING SYSTEMS

						SPECIFIC AREAS OF INVESTIGATION							
REFERENCE NUMBER	YEAR OF PUBLICATION	VECTORING NOZZLE CONCEPT	NATURE OF REPORT MATERIAL	TYPE OF TEST	TEST ARTICLE	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH STUDIES	JET IMPINGEMENT	MECHANICAL DESIGN
2.1	1965	CN	E	S	C	X							
2.2	1963	MB	E	S	C	X							
2.3	1963	SB	E	S	C	X							
2.4	To Be Released	ED	E	S	C	X							
2.5	To Be Released	ED	E	S	C	X							
2.6	1961	CN	E	S	C	X							X
2.7	1963	CN	A	None	C	X							X
2.8	1965	CN	E	S	C	X							X
2.9	1965	ED	E	S	C	X							X
2.10	1966	SB	G	S	C	X							X
2.11	1966	CN	G	None	C	X							X
2.12	Not Known	Any	G	None	C	X							X
2.13	1967	MB,SE	E	S	C	X							
2.14	1967	SE	E	S, F.S	C	X							X
2.15	1968	MB,ED	A	None	C								X
2.16	1969	CN	G	None	C								X
2.17	1969	CN	G	None	C,A/P								X
2.18	1969	CN	G	None	C,A/P								X
2.19	1970	SB,MB	E	S	C	X					X		X
2.20	1970	SB,VN,ED	E	S	C	X							
2.21	1958	Any	A	None	C,A/P						X		
2.22	1958	SB,CD,SE	E	S	C	X							
2.23	1956	SB,MB	E	S	C	X							
2.24	1964	CN	E	S	C	X							
2.25	1969	Any	E	WT	C,A/P				X			X	
2.26	1969	Any	A	None	C,A/P				X				
2.27	1962	ED	A,E	WT	C,A/P	X							X
2.28	1959	Any	A	None	C	X			X				
2.29	1969	DL	E	WT	C			X					
2.30	1969	Any	G	None	C,A/P				X	X		X	

TABLE II, CONCLUDED

2.0 THRUST VECTORING SYSTEMS (CONT.)

REFERENCE NUMBER	YEAR OF PUBLICATION CONCEPT	VECTORING NOZZLE CONCEPT	NATURE OF REPORT MATERIAL	TYPE OF TEST	TEST ARTICLE	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH STUDIES	JET IMPINGEMENT	MECHANICAL DESIGN
						SPECIFIC AREAS OF INVESTIGATION							
2.31	1961	Any	E	WT	C,A/P				X				
2.32	1964	Any	E	WT	C,A/P				X	X			
2.33	1957	SB,MB	E	S	C	X							
2.34	1970	Any	E	WT	C				X				
2.35	1966	C	E	S	C	X							
2.36	1957	ED	E	S	C	X							
2.37	1965	CN,SE	E	S	C	X							
2.38	1973	Any	E	WT	C,A/P				X				

TABLE III GENERAL THRUST REVERSER/VECTORING BIBLIOGRAPHY SUMMARY CHART

3.0 GENERAL THRUST REVERSER/VECTORING

						SPECIFIC AREAS OF INVESTIGATION							
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER/VECTORING CONCEPTS	NATURE OF REPORT MATERIAL	TYPE OF TEST	TEST ARTICLE	INTERNAL PERFORMANCE	REVERSER EFFECTIVENESS	REINGESTION	AERODYNAMIC INTERFERENCE	JET TRAJECTORY	FIELD LENGTH STUDIES	JET IMPINGEMENT	MECHANICAL DESIGN
3.1	1964	ET, ED	E, A	S, WT	C	X			X				
3.2	1969	Any	G	None	C, A/P								X
3.3	1970	ET, IT, C, SS, MJ, SN, CN	E	S	C	X							X
3.4	1970	Any	G	None	C								
3.5	1968	Any	G	None	C	X		X					X

TABLE IV THRUST REVERSER/VECTORING FLOW FIELDS BIBLIOGRAPHY SUMMARY CHART

4.0 THRUST REVERSER/VECTORING FLOW FIELDS

REFERENCE NUMBER	YEAR OF PUBLICATION	NATURE OF REPORT MAT'RIAL	TYPE OF TEST	INTERNAL PERFOR-MANCE	RECIRCU-LATION	REINGESTION	AERODYNAMIC INTER-FERENCE	JET TRAJECTORY	JET IMPINGE-MENT	FLOW ENTRAIN-MENT
				SPECIFIC AREAS OF INVESTIGATION						
4.1	1968	A,E	WT					X		
4.2	1968	A	None					X		
4.3	1968	A	None					X		X
4.4	1969	E,A	S		X	X	X		X	
4.5	1969	E	S,WT		X	X	X		X	
4.6	1970	E	WT		X				X	
4.7	1970	G	None		X	X		X	X	
4.8	1968	G	None		X		X			
4.9	1963	A,E	WT		X		X		X	
4.10	1970	E	WT					X		
4.11	1969	G	None			X	X			
4.12	1966	A	None				X			
4.13	1966	E	WT			X	X			
4.14	1969	E	WT,FT			X	X			
4.15	1969	E	WT				X			
4.16	1967	E	WT				X			

SECTION II

ABSTRACTS

THRUST REVERSER SYSTEMS ABSTRACTS

1.1 THRUST REVERSER MODEL TESTS FOR THE C-5A AIRPLANE, Brazier, M. E., D6-10687, The Boeing Company, unreleased.

The document contains the results of a static test program using 0.0658 scale models representing the GE 1/6-F4C engine on the Boeing C-5A airplane. Parametric variations were made for five fan reversers and one primary reverser. The annular fan reversers included internal blocker doors with external deflector doors, cascades fore and aft of the nozzle exit, and various deflector ring concepts. Parametric results were obtained for fan reverser efficiency and airflow match as functions of setback, door length, and nozzle pressure ratio. The final reverser configuration had an overall static efficiency of 61 percent.

Key Words: cascade thrust reverser
static reverser performance
C-5A thrust reverser

1.2 ANALYSIS OF IN-FLIGHT THRUST REVERSER EXHAUST FLOW AND PERFORMANCE CHARACTERISTICS, Technical Proposal, D162-10298-1, The Boeing Company, September 1970.
Methods ar
Methods are presented for the prediction of in-flight thrust-reversing performance of aircraft in subsonic, transonic, and supersonic flight.

Individual analyses are proposed, each applicable to a specific region of the flow field. The model proposed for the subsonic flow regime is based on a three-dimensional method of distributed singularities for the flow about the aircraft. Separate analyses for the reverse jet flow, the internal flow in the nozzle, and the flow in the base region downstream of the thrust reverser provide data to the general three-dimensional program. The proposed model for the transonic and supersonic flow regimes is similar to the subsonic model. A two-dimensional finite difference solution of the complete equations of motion is used to develop parametric data for predicting the external flow-jet interaction and the flow characteristics in the base regions. The analytical models would predict the forces on the airplane, thrust reverser performance, and total reverse-thrust magnitude and direction. The proposed modular format of the computer programs would permit the replacement of various analyses as better computer models become available. A comprehensive experimental program designed to confirm and improve the analytical models would be formulated and proposed as an extension of the analytical program.

Key Words: in-flight thrust reverser
modulated thrust reverser
internal flow analysis
external flow analysis

1.3 THRUST REVERSER PERFORMANCE AND THE INGESTION PROBLEM, Brown, D. M., North Atlantic Treaty Organization Advisory Group for Aeronautical Research and Development Report 415, January 1963.

This report presents a summary of results from reverser reingestion and foreign object ingestion tests for conventional transport aircraft with wing mounted engines. A limited parametric study showing the importance of thrust reversal and typical results from several reingestion tests are presented. The test results consist primarily of flow visualization photographs of the reingestion flow field.

Key Words: reingestion
thrust reverser performance

1.4 THRUST REVERSER EFFECTIVENESS ON HIGH BYPASS RATIO FAN POWERPLANT INSTALLATIONS, Thompson, J. D., SAE Paper 660736, October 1966.

An analysis is presented indicating the desired effectiveness level for the individual fan and gas generator reversers for high bypass ratio engines. Design features and model testing of a circular arc blade cascade thrust reverser are discussed in detail. Reverser efficiency and discharge coefficient data for parametric variations of solidity and blade profile are presented. Using simple blunt-edge circular-arc blades with 50 degree turning arc, a 20 percent fan reverser efficiency was achieved at 1.5 nozzle pressure ratio. Cascade sets with solidity $\sigma > 1.0$ exhibited flat reverser efficiency and discharge coefficients as a function of nozzle pressure ratio. Fan reverse exhaust flow may be separated from the forward fan cowl surface using spoilers or by removing the forward blade from the cascade section.

Key Words: cascade thrust reverser
reingestion
static reverser performance

1.5 DATA REPORT, BOEING WIND TUNNEL TEST NO. 434, THRUST REVERSER TESTS ON T-170M-12, A 0.068 SCALE MODEL OF THE 707-120 AIRPLANE, Meldahl, K. R. and Hauser, J., D6-1725, The Boeing Company, May 1958.

The document presents model photographs, drawings, and a test log for a thrust reverser reingestion test of the 707-120 airplane. Two reverser designs were tested; a cascade reverser and an internal blocker door with flattened tubes venting the reverser flow. Reingestion was determined by still and motion pictures using steam flow visualization. Inlet suction was not used and there were no inlet temperature measurements.

Key Words: cascade thrust reverser
ventral thrust reverser
reingestion

1.6 RESULTS OF INGESTION WIND TUNNEL TESTING OF THE SHORT DUCT (1/12 SCALE MODEL) JT3D TURBOFAN REVERSERS, Isaacson, G. C., D6-5303, The Boeing Company, February 1969.

Results are presented for a reingestion wind tunnel test of the 707 fan and primary thrust reverser. A total of 110 runs were made on 92 different configurations at speeds from 50 to 90 knots. The 707 fan and primary reversers utilize internal blocker doors and cascade vanes. The vane angles were varied during the test to control the exhaust flow direction and reduce reingestion speed. Reingestion was detected with thermocouples in the inlet and visually by steam flow visualization photographs. Temperature measurements were made on the wing lower surface.

Key Words: cascade thrust reverser
reingestion

1.7 REINGESTION CHARACTERISTICS OF THE 2707-200 AIRPLANE, Ridgeway, R. J., D6A10998-1, The Boeing Company, February 1969.

This document reports the results of a 1/22 scale model test conducted to determine the reingestion characteristics of the 2707-200 airplane during the landing roll. The test was conducted in the 9 x 9 foot induction tunnel at the Boeing Mechanical Laboratories. Test variables included tunnel velocity, reverser discharge pattern, and reverser discharge pressure ratio. All airplane control surfaces were set in the landing position. Discharge patterns were evaluated using 500°F exhaust temperatures. In some cases steam was used for flow visualization. Test results indicate that the thrust reversers could be operated at lower landing roll speeds using an unsymmetric reverser discharge pattern as compared to a pattern that maintained symmetry.

Key Words: reingestion
tertiary door
blocker/deflector thrust reverser
pressure ratio
discharge pattern

1.8 INGESTION AND DRAG INTERFERENCE CHARACTERISTICS OF THE PRODUCTION TARGET THRUST REVERSER DURING LANDING, Hurlbe , C. F., D6-32296, The Boeing Company, November 1969.

The document presents the results of a flight test using the target thrust reverser on the 737 airplane to establish reverse thrust performance and ingestion characteristics for landing and refused takeoff conditions. Retarding forces were calculated from deceleration data taken during a series of landings and taxi runs at idle forward thrust (free roll) and in reverse thrust at engine pressure ratios of 1.6, 1.8, and 2.0 with flap positions of 5, 15, 25, and 40 degrees. No wheel brakes were used during the decelerations. Runs were also made with one reverser inoperative to simulate an engine failure. Hot gas re-ingestion was detected by thermocouples mounted in the inlet. The results showed a significant favorable airplane drag increase at all combinations of flap position, reverse thrust level, and taxi speed.

Key Words: external target reverser
flight test
taxi test
reingestion
drag interference
model 737

1.9 REINGESTION STUDY OF 0.1333 SCALE MODEL ROLLS-ROYCE THRUST REVERSER, Anderson, R. E., T6-1476, The Boeing Company, July 1958.

The thrust reverser used for this reingestion study was a scale model of a Rolls-Royce cascade reverser installed on a 0.125 scale half-model of a 707 airplane. The model was tested in a 4' x 7' induction wind tunnel. High pressure hot air was used for exhaust flow simulation and suction for inlet simulation. Reingestion data were obtained for speeds from 30 to 90 knots. The final configuration exhibited reingestion speeds between 40 and 50 knots.

Key Words: cascade thrust reverser
reingestion

1.10 0.06 SCALE C-5A REINGESTION TEST, Burke, W. K., T6-3298, The Boeing Company, May 1965.

This test document presents results of a thrust reverser reingestion and impingement test on a 0.06 scale half-model of the Boeing C-5A airplane. The fan and primary reversers utilize internal blocker doors and cascade exit vanes. Four cascade configurations were tested. The first, having a 40 degree exit angle, caused flow from the reversers to attach to the nacelles and resulted in reingestion speeds above 100 knots. The other configurations employed mechanical and aerodynamic spoilers on the first vane row. This combination lowered reingestion speed to between 60 and 70 knots, but adversely affected airflow match. The final configuration provided satisfactory airflow match and resulted in reingestion speeds between 80 and 90 knots.

Key Words: reingestion
cascade thrust reverser
C-5A

1.11 747 THRUST REVERSER EFFECTIVENESS AND INGESTION TESTS, Liptack, K. H., T6-4006, The Boeing Company, June 1967.

Model 747 cascade thrust reverser configurations were tested at 0.06 scale to simulate reverser operation of the JT9D-1 High Bypass Ratio engine. The high airflow generated by these engines is expected to create a reverser exhaust gas flow field which differs from other four engine airplanes. These flow fields were investigated to determine their effects on inlet ingestion characteristics and reverser effectiveness during thrust reverser operation. The aerodynamic characteristics (lift, drag, pitching moment) of the model, with the thrust reversers operating, was compared with the basic aerodynamic characteristics (reverser air off) to determine the effectiveness of the various cascade configurations. Each cascade configuration was tested with hot air and with steam as a flow visualization technique to obtain inlet ingestion characteristics, which, when combined with the effectiveness data, offered a means for selecting the optimum thrust reverser configuration.

Key Words: cascade thrust reverser
Model 747
reverser effectiveness
reingestion

1.12 TEST DATA REPORT - SST REINGESTION TEST - PART I, Schad, W. H., T6A11262-1, The Boeing Company, September 1968.

This report describes Part I of the SST Reingestion Test Program and presents the resulting data. A 0.0445 scale landing configuration of the 2707-200 SST airplane was tested in the Boeing 9' x 9' Induction Wind Tunnel. The test variables were tunnel speed, reverser exhaust pressure ratio, radial reversing pattern, reverser efflux area, and reverser flow, both hot air and steam. The temperature data are presented as ingestion coefficient versus reverser pressure ratio, radial variation of ingestion coefficient in the inlet, and inlet temperature distortion. Typical photographs of the reverser flow patterns with steam are included in the report.

Key Words: blocker/deflector thrust reverser
SST
reverser discharge patterns

1.13 747 THRUST REVERSER INGESTION AND EFFECTIVENESS TEST - PHASE IV - STATIC PERFORMANCE, Harkonen, D. L., T6-4135-1, Volume I-III, The Boeing Company, February 1969.

Selected fan and primary cascade model reversers from the Phase IV 747 0.06 scale model thrust reverser ingestion/effectiveness test, conducted in the 9' x 9' Low Speed Wind Tunnel, were tested for static performance on the Thrust Vector Rig II. The tests involved measuring reverse thrust and airflow for under area, match, and over area conditions. Selected computer plots of the performance data along with photographs and sketches of the reverser models are included in the report. The test log and remainder of the performance data are enclosed in Volumes II and III.

Key Words: Model 747
cascade thrust reverser
static performance

1.14 707 QUIET NACELLE TARGET REVERSER INGESTION AND EFFECTIVENESS TEST, Liptack, K. H., T6-5095, The Boeing Company, February 1970.

This report presents the results of a low speed wind tunnel test program to establish the feasibility of external target thrust reverser installation on 707 long duct quiet nacelle engines. An 0.0806 scale half-model was tested using 747 and 737 model hardware (wing, body, and thrust reversers) and 707 hardware (flaps, spoilers, nacelles). Several target reverser rotations, nozzle setback positions and reverser configurations were tested for ingestion and effectiveness characteristics.

Plots of inlet temperature versus test section velocity and wing balance forces versus test section velocity for all of the configurations tested are contained in the report. The most favorable ingestion and effectiveness characteristics were realized with the target reverser in the most forward position tested (16-inch full scale spaces), a 12° clockwise rotation on the outboard reverser and 12° counterclockwise rotation on the inboard reverser along with the half-lip reverser on the inboard nacelle and the standard reverser on the outboard nacelle.

Key Words: external target reverser
reingestion
Model 707

1.15 A TWO-DIMENSIONAL MODEL OF AN ANNULAR NOZZLE THRUST REVERSER, Pogson, J. T., D6-23243TN, The Boeing Company.

A theoretical analysis has been developed for annular internal and external target thrust reversers. The analysis approximates the reverser flow field by a two-dimensional, incompressible, inviscid flow model utilizing two free streamlines as the boundaries of the reverser flow. Complex variable theory was used to solve the equations of motion. The analysis predicts the effects of design variables such as door length, door setback, and door angle. The method predicts the effective flow area, flow angle, and velocity from which the reverser performance is determined, in terms of velocity (C_V) and discharge coefficient (C_D), static reverser efficiency (ηR_g), and airflow match (Φ).

Theoretical results were compared with model thrust reverser test data. Good agreement was obtained between the theory and the data with typical errors of from 5 to 10 percent. The theory shows agreement with the test data for the effects of thrust reverser door length on the overall reverser performance.

Key Words: annular internal target thrust reverser
external target thrust reverser
flow field analysis

1.16 A POTENTIAL FLOW-BOUNDARY LAYER ITERATION METHOD TO PREDICT DRAG FOR TWO DIMENSIONAL AND AXISYMMETRIC BODIES - USERS MANUAL FOR TEM-176, Colehour, J., D6-22777, The Boeing Company, December 1970.

The document describes a digital computer program to analyze compressible inviscid and viscous flow around cowls where local Mach number is less than 0.97. The program automatically iterates between the inviscid potential flow and viscous boundary layer solutions to determine nacelle flow field, boundary layer characteristics, and drag. Applications of the program include two dimensional or axisymmetric bodies, multiple bodies, hollow axisymmetric bodies and annular internal flows. The program will also predict boundary layer separation location.

Key Words: potential flow
boundary layer
compressible flow
two-dimensional flow
axisymmetric flow
drag

1.17 AIRPLANE LANDING ROLL ANALYSIS FOR COMPUTER PROGRAMMING WITH CONSIDERATION TO THE INTER-RELATION OF REVERSE THRUST, AERO DRAG, WHEEL BRAKING, AND OPERATIONAL PROCEDURE, Rowe, D. S. and Hurlbert, C. F., D6-4012, The Boeing Company, February 1963.

A landing roll analysis is presented to provide a method to calculate the landing roll distance of an airplane for various landing conditions and operational procedures. The energies absorbed by the various airplane braking devices can also be calculated. The method is useful to analyze the worth of possible increased reverse thrust and reverser operational changes, brake improvements, revised landing techniques, etc. It can also be used to predict brake and tire life of airplanes flying specific routes. A computer program has been written to rapidly perform the calculations. A sample problem for the Model 720B airplane is presented that duplicates the conditions of an actual full scale test.

Key Words: landing field analysis
computer program

1.18 EFFECTS OF LANDING CONDITIONS AND DEVIATIONS IN LANDING PROCEDURES ON THE LANDING ROLL DISTANCE OF A 727 TYPE AIRPLANE USING THRUST REVERSERS, Rowe, D. S. and Hurlbert, C. F., D6-4286TN, The Boeing Company, December 1963.

The purpose of this study was to determine how changes in weather conditions, field elevations, airplane gross weight, and airplane operating procedures individually effect the landing roll distance of a 727 type airplane. Parameters considered included: field altitude, wind velocity, airplane gross weight, landing velocity, braking effort, time delay for wheel braking and thrust reverser actuation, and reingestion speed. The landing roll distance and absorbed energy for each landing condition were calculated using two landing field performance computer programs (References 1.17 and 1.20).

Key Words: landing distance
analysis
computer program

1.19 THE EFFECT OF REVERSER CHARACTERISTICS AND OPERATIONAL PROCEDURES ON THE LANDING ROLL DISTANCE OF A LOW-WING JET TRANSPORT HAVING FOUR POD-MOUNTED FAN-JET ENGINES, Hurlbert, C. F., D6-9082TN, The Boeing Company, October 1963.

This study was made to determine how the magnitude of reverse thrust and the variations in reverser operational procedures affect the stopping capability of a jet transport airplane during a landing roll. The Model 720B airplane was used as the basis for this study. Ground roll distances were calculated both with and without wheel brakes applied. Reverser variables considered were: (1) reverser actuation delay time after touchdown, (2) reverser cut-off (ingestion) speed, (3) magnitude of reverse thrust, and (4) method of obtaining reverse thrust (variable reverser efflux angle versus variable engine power). Calculations were made using the landing roll analysis and computer program of References 1.17 and 1.20.

Key Words: landing distance
analysis
computer program

1.20 COMPUTER PROGRAM FOR LANDING ROLL STUDY, Pao, Yen-Ching, D6-9194, The Boeing Company, August 1962.

A computer program was written to analyze the braking and deceleration capability of an airplane during ground roll. The program calculates the kinetic energy absorbed by the nose wheel brakes, main wheel brakes, aerodynamic drag, and thrust reversers. The program also calculates velocities, distances, and times from the start of landing roll to stop. The independent variables capable of being handled are runway altitude, slope, runway condition (braking coefficient μ), wind velocities, landing gross weights, touchdown velocities, reverser efficiencies, cutoff speeds, and airplane lift and drag characteristics.

Key Words: landing distance
analysis
computer program

1.21 MODEL 737 THRUST REVERSER AND LANDING PERFORMANCE SUBSTANTIATION, Anderson, A. J., D6-32031, The Boeing Company November 1967.

The purpose of this report is to substantiate the effectiveness of the 737 blocker/deflector (clamshell) thrust reverser installation and to show the features of the 737 airplane which provide equivalent safety margins in landing performance. Reverser effectiveness derived from full scale taxi tests are presented.

Key Words: Model 737
blocker/deflector (clamshell)
thrust reverser
taxi tests

1.22 FORTRAN PROGRAM FOR CALCULATING REVERSE THRUST BRAKING DISTANCE (EREF), Bjornet, R. P., D6-24213, The Boeing Company, November 1969.

This program is used to calculate the braking portion of the landing roll when using reverse thrust. The stopping distance is calculated in three phases. The first phase from brake application to reverse thrust initiation is calculated in 0.2 second intervals for a time period of one second. The second phase from reverse thrust initiation to engine at full power in 32 small time increments. The final third phase from full reverse thrust to full stop is calculated in two knot increments. The program accounts for a thrust modulation schedule or thrust cutoff to avoid reingestion.

Key Words: field length
analysis

1.23 APPROACH PERFORMANCE FOR THE 367-80B WITH BLC BLOWN FLAPS AND INFLIGHT MODULATED THRUST REVERSERS, Raisbeck, J. D., D6-6408TN, The Boeing Company, August 1963.

The document presents predictions of approach speeds and lift coefficients for the 367-80B (707 prototype) with BLC flaps and inflight modulated primary reversers. The predictions are based on wind tunnel test resu s. Approach ground rules are presented that were determined from discussions with test pilots, from gust and maneuver loads at approach speeds, Civil Aeronautic Regulations covering both propellor and jet aircraft, and from projected mission requirements. The approach performance was derived consistent with the ground rules for controlling safety and performance philosophy. The effects of BLC momentum coefficient C_μ and thrust coefficient C_T on the airplane lift curves and trimmed drag polars are presented.

Key Words: BLC flaps
approach performance
modulated thrust reverser
inflight thrust reverser

1.24 PROPULSION SYSTEMS DEVELOPMENT FOR THE 367-80B SLOW FLIGHT PROGRAM - THRUST MODULATION AND BOUNDARY LAYER CONTROL, Brazier, M. E., D6-6193, The Boeing Company, September 1964.

The report describes the propulsion systems development and performance for the 367-80B (707 prototype) slow flight program. The flap boundary layer control system and modulating primary thrust reverser are described in detail. The BLC flap was blown with engine high pressure bleed air. The purpose of modulating the primary reverser was to spoil excess thrust developed by the gas generator. The report is an excellent description of the development of the 367-80B propulsion system. However, the data are not generally useful for other STOL transport applications.

Key Words: in-flight reverser
cascade thrust reverser
boundary layer control
modulating thrust reverser

1.25 367-80B SLOW FLIGHT TEMPERATURE SURVEY DURING THRUST MODULATION, Ridgeway, R. J., D6-9847, The Boeing Company, June 1966.

The document reports the findings of two studies conducted in support of the -80 (707 prototype) slow flight program. The studies pertain to engine accessory cooling and in-flight wing and strut structural heating during primary thrust reverser modulation.

Key Words: modulating thrust reverser
cascade thrust reverser
reverser exhaust gas impingement

1.26 PICTORIAL HISTORICAL DEVELOPMENT OF THE 727 THRUST REVERSER, Scholey, M. B., METM-70-16, The Boeing Company, September 1970.

This report contains photographs which pictorially show the historical development of the 727 thrust reverser by the airframe manufacturer. Ten different phases of experimental testing are described, leading from a 1/9 scale model static test through the certification testing. No technical data are included, but the report does provide a good description of a typical thrust reverser development program.

Key Words: Model 727
thrust reverser development
blocker/deflector thrust reverser

1.27 STATIC AND WIND TUNNEL TESTS OF TARGET REVERSERS FOR THE 737 AIRPLANE, Neal, B. and Hurlbert, C. F., D6-32035TN, The Boeing Company, January 1968.

An experimental program was conducted to determine the static performance and ingestion characteristics of an external target type thrust reverser for the 737 airplane. Parametric scale model static reverser tests were performed to determine the effect of geometric variables on target reverser performance. The static test results were used to select models for reingestion tests. The parametric static performance data showed that the lip height at the center of the door has a strong influence on reverser efficiency and that fences were effective in preventing flow splatter from the doors. Wind tunnel tests showed that reverser rotation or "clocking" angle had a strong effect on reingestion speed and body impingement temperature.

Key Words: external target thrust reverser
reingestion
static reverser performance
Model 737 thrust reverser

1.28 DIRECTIONAL STABILITY AND CONTROL DURING REVERSE THRUST OPERATION FOR THE 737 AIRPLANE EQUIPPED WITH A TARGET THRUST REVERSER, Wright, F. L., D6-32071TN, The Boeing Company, May 1968.

This report presents the results of a directional stability and control analysis of the 737 airplane equipped with a target thrust reverser during ground roll thrust reversal. The analysis was based on a low speed wind tunnel test of a powered model and a full scale taxi test with a boiler plate reverser installation. Wind tunnel results include rudder effectiveness and yaw moment data as functions of reverser rotation angle, engine power setting, yaw angle, and flow visualization data. Correlation between wind tunnel and full scale taxi tests are presented for rudder effectiveness, directional stability, reingestion, and exhaust flow patterns.

Key Words: external target thrust reverser
wind tunnel test
full scale taxi test
directional stability and control
in ground effect

1.29 RESULTS OF FULL SCALE TAXI TESTS OF TARGET TYPE THRUST REVERSERS INSTALLED ON THE 737 AIRPLANE, Hurlbert, C. F., D6-32150, The Boeing Company, July 1968.

This report describes the results of full scale taxi tests of a target thrust reverser system install.d on the Model 737 airplane. The tests were conducted to determine (1) reverser effectiveness, (2) airplane control with asymmetric reverse thrust, (3) exhaust gas reingestion characteristics, and (4) hot gas impingement temperatures on airplane surfaces. Data for airplane retarding force, roll distance and power setting effects are presented.

Key Words: Model 737
external target reverser
taxi tests

1.30 737 TARGET THRUST REVERSER EXHAUST GAS IMPINGEMENT CHARACTERISTICS, Hurlbert, C. F., D6-32232, The Boeing Company, February 1967.

This document presents airplane surface temperature data resulting from the operation of the 737 target thrust reverser installation on JT8D-9 engine. The test was conducted as part of the FAA certification of the 737 target thrust reverser installation. The airplane was decelerated from approximately 120 knots in two taxi runs using both thrust reversers. Wheel brakes were not applied. Wing and body temperatures were measured using six thermocouples and temperature sensitive points.

Key Words: Model 737
external target thrust reverser
taxi tests
surface temperature

1.31 747 REVERSER EXHAUST FLOW FIELD TEST, McClung, C. D., T6-3336, The Boeing Company, April 1967.

A reingestion test was performed for the 747 airplane equipped with annular external target thrust reversers and with cascade reversers. The reversers simulated mixed fan and primary flow. Movable blocker plates were used with the target reverser to control exhaust flow direction and obtain correct airflow match. The cascade baskets consisted of 12 rows of annular vanes at a 55 degree exit angle held rigid with 13 rows of longitudinal strongbacks. Three sets of baskets utilizing radial internal strongbacks, non-radial internal strongbacks, and non-radial external strongbacks were tested. A configuration for both the blocker door and cascade type thrust reverser was tested which gave ingestion free data down to a tunnel velocity of 40 knots.

Key Words: annular external target thrust reverser
cascade thrust reverser
Model 747
reingestion

1.32 747 THRUST REVERSER EFFECTIVENESS TEST, McClung, C. D., T6-3381, The Boeing Company, May 1967.

Directing exhaust gases to produce reverse engine thrust while landing is expected to possibly reduce the overall airplane retarding effect by altering the airplane aerodynamic forces. This test was conducted to determine the total effect the thrust reversers have on reverse effectiveness. A 0.06 scale 1/2 model 747 body and wing was installed in the Boeing 9 x 9 Low Speed Wind Tunnel. The body was mounted to a 4-component strain gage balance to measure lift, drag, pitching moment, and 1/2 rolling moment. Two nacelles, isolated from the wing and mounted by the air supply pipes, simulated reverser flow of approximately 5 lbs/sec per engine and inlet airflow of approximately 4.5 lbs/sec per engine. Cascade reversers, with varying amounts of blockage provided by exterior mounted blocker plates, were tested. The model was tested with the nacelles in 30%-60% and 40%-70% of the half span positions. The trailing edge flaps were positioned at 20°-20°, 30°-20°, and 30°-30° positions. Data included lift, drag, and pitching moment to determine airplane reverser effectiveness. Inlet temperatures were monitored during runs utilizing heated reverser air, and photographs were taken while utilizing an air-steam mixture, as a means of obtaining ingestion characteristics.

Key Words: cascade thrust reverser
Model 747 thrust reverser
reverser effectiveness
reingestion

1.33 0.06 SCALE 747 CASCADE THRUST REVERSER DEVELOPMENT AND PERFORMANCE TESTS, Marinig, E. C., T6-4008, The Boeing Company, May 1967.

An 0.06 scale 747 cascade thrust reverser model was tested to determine thrust reverser performance and airflow match characteristics for the JT9D-1 engine. Three fan and primary reverser models were selected to be tested based on earlier development tests. The model was designed with the capability of sliding the reverser units aft in increments to obtain variations in reverser flow area. The report contains static performance and airflow match data as a function of pressure ratio and reverser flow area.

Key Words: cascade thrust reverser
static performance
Model 747

1.34 747 PRIMARY AND FAN THRUST REVERSER CASCADE DEVELOPMENT - LARGE SCALE 30° SEGMENT MODEL TEST, Laurent, J. W., T6-4004, The Boeing Company, July 1967.

This test was conducted to provide airflow and reverse thrust data, at relatively high Reynold's number conditions for the development of the 747 thrust reverser cascade vanes. Models representing 30-degree segments of the fan and primary reverser were fabricated and tested. The models were designed to a 1/2.65 scale for the fan, and a 1/1.394 scale for the primary; and both contained the capability of varying the translation length to accept various vane configurations. Test variables included cascade solidity, cascade vane geometry, cascade vane inlet angle, cascade length, and exhaust flow pressure ratio. Reverser efficiency and airflow match characteristics are presented.

Key Words: cascade thrust reverser
Model 747
static reverser performance

1.35 747 THRUST REVERSER FAN DISCHARGE PRESSURE DISTRIBUTION DURING REVERSING, Laurent, J. W., T6-4010, The Boeing Company, August 1968.

This test was conducted to evaluate the effect of an asymmetrical fan thrust reverser exhaust pattern on the fan discharge pressure distribution of the JT9D-1 engine.

0.0633 scale models of four cascade fan reverser configurations and two cruise configurations were run using a turbopowered model engine. All reverser configurations were run at an area match condition and one or two additional area settings. Area match was achieved by adjusting the reverser discharge area until the airflow agreed with the fan flow measured with the cruise configuration. The fan discharge pressure distribution was determined by the use of 35 total pressure probes on 7 rakes.

Key Words: cascade thrust reverser
Model 747 thrust reverser
flow field surveys

1.36 747 AIRPLANE THRUST REVERSER EXHAUST GAS IMPINGEMENT EVALUATION, Hambly, D. and Cirineo, G. V., D6-30395, The Boeing Company, December 1969.

The document presents surface temperature data measured on the production 747 airplane with JT9D-3 engines as required for certification. Two series of tests were conducted. In the first series, two landings were performed and maximum reverse thrust was maintained on all engines until surging occurred. For the second series, two taxi tests were performed with maximum reverse thrust applied on all engines and maintained until surging occurred. Lower reverse thrust power settings were then selected and maintained down to airplane speeds of about 20 knots. Temperature sensitive point was applied to the number 1 and 2 engine struts and nacelles and to underwing and fuselage areas. Thermocouples were attached to the underwing surface. The report contains melt patterns for the temperature sensitive point and transient thermocouple data.

Key Words: impingement
reverser exhaust gas impingement
full scale test
taxi test data
cascade thrust reverser
Model 747 thrust reverser

1.37 TEST DATA REPORT - THRUST REVERSER DEVELOPMENT TEST FOR THE 2707-100 AIRPLANE - PART I SCALE: 1/10, Schad, W. H., T6A10890-1, March 1968.

This document describes a development test of a thrust reverser for the 2707-100 SST airplane and presents the test data obtained. A 0.10 scale blocker/deflector thrust reverser was tested on a static thrust facility. Model variables included blow-in-door area, blocker door position, radial reversing pattern, axial bypass area, and reverser exhaust exit angle. Reverser pressure ratio was varied from 2.2 to 3.8. Airflow and thrust performance data are plotted against nozzle pressure ratio for each of the model variables. In addition, reverser exhaust pressure profiles are presented.

Key Words: blocker/deflector thrust reverser
static reverser performance
SST thrust reverser

1.38 RESULTS OF A 1/10 SCALE THRUST REVERSER AREA MATCH TEST FOR THE BOEING 2707 AIRPLANE, Ridgeway, R. J., D6A-10915-1, The Boeing Company, January 1969.

This report describes the analysis and test results for two methods of attaining matched airflow operation of a blocker/deflector thrust reverser. The first method used a choked flow primary nozzle upstream of the reverser. The second method maintained choked flow downstream of the primary nozzle at the reverser exit. Variables in the test work included exhaust pressure ratio, reverser exit area and discharge pattern as well as the distance from the primary nozzle to the reverser flow blocker. Test results showed that a choked exit reverser required less physical exit area to obtain matched flow conditions. Higher reverser efficiency also resulted with the choked exit method.

Key Words: blocker/deflector thrust reverser
airflow match
static reverser performance

1.39 FLAT PLATE REVERSER STUDY, Ream, P. J., T162-10283-1, The Boeing Company, October 1970.

This document describes the performance tests of a 0.091 scale parametric flat plate, fuselage-mounted thrust reverser model for use with high bypass turbofan engines. The model variables included reverser door length, width, fence height, lip height, door angle with respect to the fuselage centerline, and axial distance from the primary nozzle exit plane to the reverser door. The reverser models were tested under dual flow conditions using two different fan nozzles - a short fan duct nozzle and a 3/4 length fan duct nozzle - in conjunction with the primary nozzle. The data included present the thrust and airflow performance parameters for each reverser configuration in both plotted and tabulated form.

Key Words: flat plate thrust reversers
fuselage mounted
parametric model
dual flow
thrust and airflow performance

1.40 THE FEASIBILITY OF TWO IN-FLIGHT THRUST REVERSING CONCEPTS - PART I - AERODYNAMIC CHARACTERISTICS, Baullinger, N. C., D162-10297-1TN-1, August 1970.

This document presents the results of a wind tunnel test conducted at Mach 0.4 to determine the feasibility of two in-flight thrust reversing concepts. A shroud target reverser and a two-dimensional target reverser were mounted at the aft end of a ground support fighter airplane configuration. Aerodynamic stability control surface effectiveness and reverser drag data are presented. Also, flow visualization results from tufts placed on the airplane aftbody are included.

Key Words: shroud/target thrust reverser
two-dimensional target thrust reverser
fuselage mounted
in-flight thrust reversal
aerodynamic stability and control

1.41 PRELIMINARY INVESTIGATION OF SEVERAL TARGET TYPE THRUST-REVERSAL DEVICES, Steffen, F. W., Krull, G. H. and Ciepluch, C. C., NACA RM-E53L156, July 1955.

Thrust reverser performance data for circular arc and hemispherical target-type jet deflectors of various sizes and with various modifications was obtained with unheated air over a range of nozzle pressure ratios from 1.7 to 3.0. Test results for reverser efficiency and airflow match are presented. Geometry variation included reverser setback distance and reverser height. A total of 17 reverser configurations were tested that included four basic configurations that were modified by adding side-plates and fillets and three hemispherical-type configurations.

Key Words: target thrust reverser
static performance

1.42 PRELIMINARY PERFORMANCE DATA OF SEVERAL TAIL-PIPE CASCADE-TYPE MODEL THRUST REVERSERS, Henzel, J. G. Jr. and McArdle, J. G., NACA RM E55F09, August 1955.

The reverse thrust performance of 15 different tail pipe cascade type model thrust reversers was obtained over a range of nozzle pressure ratios from 1.2 to 2.4. The models included both thin and thick impulse (symmetric) blades and thin reaction (asymmetric) blades. Solidity varied from 1.11 to 1.625 and lattice aspect ratio varied from 1.0 to 2.95. Several models were tested with and without innerbodies of various lengths. Reverser efficiency and airflow match are presented for all 15 models at full reversal. Modulated thrust and airflow performance are presented for two configurations. Total pressure and flow angle survey data are presented for three models.

Key Words: cascade thrust reverser
static performance

1.43 PERFORMANCE CHARACTERISTICS OF CYLINDRICAL TARGET-TYPE THRUST REVERSERS, Steffen, F. W. and McArdle, J. G., NACA RM E55I29, January 1956.

This study was conducted to determine the performance of cylindrical target thrust reversers over a wide range of design variables. Geometric variations included reverser frontal area (target size), setback, lip geometry and target included angle. It was determined that the ratio of the frontal area of the target to the nozzle area was the most important design variable affecting reversal and that an optimum ratio existed. Thrust modulation characteristics of a cylindrical external target design is also presented.

Key Words: target thrust reverser
static reverser performance
modulating thrust reverser

1.44 SUMMARY OF SCALE-MODEL THRUST-REVERSER INVESTIGATION, Povolny, J. H., Steffen, F. W. and McArdle, J. G., NACA TN 3664, February 1956.

An investigation was undertaken to determine the performance and other characteristics of several basic types of thrust reversers. Models of three types, target, cascade and externally mounted ring cascade, were tested with cold flow. The effects of design variables on performance and reversed-flow boundaries along with thrust-modulation characteristics were determined. All three types gave reverse-thrust ratios over 40 percent.

Key Words: target reverser
cascade reverser
flow field surveys
static reverser performance

1.45 THEORETICAL LOSS RELATIONS FOR LOW SPEED TWO-DIMENSIONAL-CASCADE FLOW, Lieblein, S. and Roudebush, W. M., NACA TN 3662, March 1956.

A theoretical analysis is conducted of the relations existing between total-pressure defect and wake momentum thickness and form factor for the incompressible flow across a two-dimensional cascade. Both the loss at a plane of measurement and the complete loss after mixing are considered. The relative importance of the various factors entering the loss relations is evaluated. Relations are obtained for the mixing-loss ratio and for the effect of trailing-edge thickness. The application of the results of the analysis to the estimation of profile loss and to the correlation of loss data is discussed.

Key Words: two-dimensional cascade
performance analysis

1.46 PERFORMANCE AND OPERATIONAL STUDIES OF A FULL-SCALE JET-ENGINE THRUST REVERSER, Kohl, R. C., NACA TN 3665, April 1956.

An axial flow turbojet engine equipped with a hemispherical target thrust reverser was installed under the wing of a cargo airplane to simulate the installation on a bomber or transport aircraft. The reverser was operated at static and taxi conditions. Test measurements included thrust, engine parameters, inlet temperature to detect reingestion and surface temperatures to detect reverse gas impingement. Several modifications of the reverse geometry were tested. A comparison of full scale and model scale reverser performance is presented.

Key Words: target thrust reverser
static reverser performance
reingestion
taxi tests
full scale

1.47 PERFORMANCE CHARACTERISTICS OF RING-CASCADE-TYPE THRUST REVERSERS, McArdle, J. G., NACA TN 3838, November 1956.

The reverse thrust performance of a family of externally mounted ring cascade model thrust reversers was obtained over a range of nozzle pressure ratios from 1.4 to 2.5. Most of the data presented are for a pressure ratio of 2.0. The models consisted of three types of cascade turning rings plus various types of deflector plates placed aft of the nozzle exit on the projected nozzle centerline. The significant geometric factors and the range of variables tested are ring spacing ratios (S/D_n) from 0.095 to 0.28, number of rings from 2 to 10, round and rectangular deflectors having blockages up to 50 percent of the exhaust nozzle area, and shrouds over the rings blocking up to 50 percent of the flow area. Reverser flow field surveys and thrust modulation performance were obtained for some of the models.

Key Words: cascade thrust reverser
externally mounted
static performance

1.48 INVESTIGATION OF A FULL-SCALE, CASCADE-TYPE THRUST REVERSER, Kohl, R. C. and Algranti, J. S., NACA TN 3975, April 1957.

This report describes a full scale thrust reverser test program installed in a single engine fighter airplane. A double set of turning vanes was carried inside the jet tailpipe. To produce reverse thrust, the tailpipe opens into two side sections and the turning vanes move outward to form a V-shaped cascade, which deflects the exhaust-gas flow. Forward and reverse net thrust were measured over a range of engine speeds with the airplane stationary. Taxi tests were made to determine the comparative stopping distances using wheel braking and reverse thrust separately, and a combination of both. The effect of turning-vane spacing on thrust-reverser performance was determined by scale-model tests using unheated air.

Key Words: cascade thrust reverser
static performance
taxi tests
model and full scale

1.49 EFFECT OF TARGET-TYPE THRUST REVERSER ON TRANSONIC AERO-DYNAMIC CHARACTERISTICS OF A SINGLE-ENGINE FIGHTER MODEL, Swihart, J. M., NACA RM L57J16, January 1958.

This report presents the results of an investigation of an external target thrust reverser on a single-engine fighter model conducted in the Langley 16-foot transonic tunnel. Test data presented includes afterbody pressure data, force and moment data, and tuft photographs. No reliable reverse-thrust data were obtained due to inaccurate force balance data. Test conditions were varied from Mach 0.20 to 1.05 at jet pressure ratios of 1 (jet off), 3 and 5 and at angle of attack from 0 to +5°.

Key Words: in-flight thrust reverser
wind tunnel test
target thrust reverser

1.50 FULL-SCALE WIND TUNNEL INVESTIGATION OF THE EFFECTS OF A TARGET-TYPE THRUST REVERSER ON THE LOW-SPEED AERODYNAMIC CHARACTERISTICS OF A SINGLE-ENGINE JET AIRPLANE, Tolhurst, W. H. Jr., Kelly, M. W. and Greif, R. K., NASA TN D-72, September 1959.

This report describes full-scale wind tunnel tests conducted to determine the effects of a semicylindrical target-type thrust reverser on the static stability and control characteristics of a single-engine jet airplane. The results are presented in the form of three-component force data obtained at Reynolds numbers ranging from 5.8 to 10.1×10^6. Vector-type plots describe the flow angularity and dynamic-pressure ratio in probable horizontal tail locations. Additional data are presented which show the effects of reversed exhaust gases on skin temperatures on the fuselage and horizontal tail and also on buffeting of the horizontal tail.

Key Words: target thrust reverser
stability and control characteristics
full-scale
flow field survey

1.51 THE EFFECTS OF THRUST REVERSAL AT MACH NUMBERS UP TO 0.86 ON THE LONGITUDINAL AND BUFFETING CHARACTERISTICS OF A TYPICAL JET-TRANSPORT CONFIGURATION, Sutton, F. B. and Brownson, J. J., NASA TN D-136, March 1960.

This report describes a wind tunnel investigation to determine the effects of thrust reversal at relatively high speeds on the longitudinal and buffeting characteristics on a typical transport airplane configuration. A cascade thrust reverser configuration was used to obtain reverse thrust. Test conditions included angle of attack, and jet pressure ratios for forward and reverse thrust at Mach numbers from 0.40 to 0.86. Aerodynamic data includes lift, drag, pitching moment, and wing and horizontal tail bending moments.

Key Words: cascade thrust reverser
in-flight reverser
longitudinal characteristics
buffet characteristics

1.52 FULL-SCALE WING-TUNNEL TESTS OF A SWEPT-WING AIRPLANE WITH A CASCADE-TYPE THRUST REVERSER, Kelly, M. W., Greif, R. K. and Tolhurst, W. H. Jr., NASA TN D-311, April 1960.

This report presents results of a full-scale wind-tunnel investigation of an F-100F airplane equipped with a cascade-type thrust reverser. Longitudinal and lateral-directional stability and control data are presented for several thrust reverser configurations.

Key Words: cascade thrust reverser
full scale
F-100F
directional stability and control

1.53 LARGE-SCALE WIND-TUNNEL TESTS OF EXHAUST INGESTION DUE TO THRUST REVERSAL ON A FOUR-ENGINE JET TRANSPORT DURING GROUND ROLL, Tolhurst, W. H. Jr., Hickey, D. H. and Auyagi, K., NASA TN D-686, January 1961.

This report describes wind-tunnel tests conducted on a large-scale model of a swept-wing jet transport configuration to study the factors affecting exhaust gas ingestion into the engine inlets when thrust reversal is used during ground roll. The model was equipped with four small jet engines mounted in nacelles beneath the wing. Cascade and external target reversers were tested.

The data obtained included the freestream velocity at the occurrence of exhaust gas ingestion in the outboard engine and the increment of drag due to thrust reversal for various modifications of thrust reverser configuration. Motion picture films of smoke flow studies were also obtained to supplement the data.

Key Words: target thrust reverser
cascade thrust reverser
reingestion

1.54 INVESTIGATION OF THE LONGITUDINAL CHARACTERISTICS OF A LARGE-SCALE JET TRANSPORT MODEL EQUIPPED WITH CONTROLLABLE THRUST REVERSERS, Hickey, D. H., Tolhurst, W. H. Jr. and Aoyagi, K., NASA TN D-786, March 1961.

An investigation was conducted to determine the effect of thrust control by means of controllable thrust reversers on the longitudinal characteristics of a large-scale airplane model with a 35° sweptback wing of aspect ratio 7 and four pylon-mounted jet engines. The model was equipped with external target thrust reversers designed to provide thrust control ranging from full forward thrust to full reverse thrust. The use of thrust control in landing-approach configurations formed the major portion of the study. Results were obtained with both leading- and trailing-edge high-lift devices. Lift, drag, and pitching-moment coefficients and reverser effectiveness data are presented. Test Reynolds numbers ranged from 4.2 to 8 million.

Key Words: target reverser
modulating reverser
longitudinal characteristics
large scale data

1.55 LARGE-SCALE LOW-SPEED WIND-TUNNEL TESTS OF A DELTA WINGED SUPERSONIC TRANSPORT MODEL TO DETERMINE AERODYNAMIC EFFECTS OF FORWARD OR REVERSE THRUST, Tolhurst, W. H. and Aoyagi, K., NASA TM X-1017, September 1964.

The purpose of the investigation was to determine the aerodynamic effects of the operation of wing-pod-mounted jet engines on the longitudinal characteristics of a supersonic transport model with a delta wing of aspect ratio 2.17. The data include longitudinal force and moment data with the engines in both forward and reverse thrust and the maximum temperature of the surface of the horizontal tail.

Test configurations included wing trailing-edge flap deflections from 0° to 30°, horizontal-tail incidence angles from 0° to -15°, and droop angles from 0° to -25°. The airplane angle-of-attack range extended from 4° to +17° with a Reynolds number range from 17.2×10^6 to 32.2×10^6.

Key Words: longitudinal characteristics
cascade reverser

1.56 FULL SCALE WIND-TUNNEL INVESTIGATION OF A TARGET-TYPE THRUST REVERSER ON THE A-37B AIRPLANE, Falarski, M. D., NASA TM X-1985, April 1970.

Full scale wind tunnel tests were conducted to determine the aerodynamic characteristics of the A-37B airplane equipped with target thrust reversers. Lift, drag, and pitching moment data are presented as a function of engine power setting and reverser position. Operation of the reversers caused large decreases in longitudinal stability and control and severe airplane buffeting. Exposure to the exhaust gas plumes caused failure of the flap and reverser control mechanisms and caused skin distortion. Reverser operation in ground effect was limited by exhaust gas ingestion into the engine inlets.

Key Words: in-flight thrust reversing
target thrust reverser
aerodynamic interference
reingestion

1.57 PERFORMANCE OF A FIXED GEOMETRY WIND TUNNEL MODEL OF AN AUXILIARY INLET EJECTOR WITH A CLAMSHELL FLOW DIVERTER FROM MACH 0 TO 1.2, Steffen. F. W. and Johns, A. L., NASA TM X-2037, July 1970.

A wind tunnel model of an auxilliary inlet ejector nozzle with a clamshell diverter was evaluated over a range of Mach numbers from 0 to 1.2. In the fully open position (supersonic cruise) the clamshell provides a conical expansion surface for internal expansion. During subsonic cruise the clamshell rotates to provide flow area for the tertiary airflow around the outside of the clamshell. When rotated fully closed, the clamshell provides the necessary blockage for reverse thrust operation. The effect of the clamshell on the nozzle cruise performance was evaluated.

Key Words: blocker/deflector reverser
auxiliary inlet ejector nozzle
cruise performance

1.58 THRUST REVERSERS FOR JET AIRCRAFT, Stimler, F. J. and McDermott, J. F., SAE Paper 112, 1957.

The state-of-the-art of jet thrust reversers as it existed in the United States in 1957 is presented. From 1955-1957 small and full scale testing and also prototype testing was conducted. Full scale and prototype units were statically tested on non-afterburning and afterburning engines. Reverser performance was measured throughout the engine operating range and included full reverse thrust, modulated thrust and some directional control information. Data shows reverse thrusts of approximately 40 to 80 percent are possible with little or no effect on overall aircraft and engine performance.

Key Words: thrust reversal

1.59 PERFORMANCE AND OPERATIONAL STUDIES OF TWO FULL-SCALE JET-ENGINE THRUST-REVERSER SYSTEMS, Kohl, R. C. and Algranti, J. S., SAE Paper 113, 1957.

This paper describes two full-scale thrust reverser installations tested by the NACA; one in a pylon-mounted engine simulating that on a jet bomber or transport (target) and the other in a fighter-type airplane (cascade thrust reverser). The effects of reverse thrust on the airplane and engine are emphasized.

Key Words: target thrust reverser
cascade thrust reverser
full scale

1.60 SUMMARY OF THE DEVELOPMENT OF AERODYNAMIC TYPE THRUST REVERSERS, McDermott, J. F. Jr., WADC Technical Report 57-18, Wright Air Development Center, May 1957.

This report presents the results of a thrust reverser development program for a non-afterburning turbojet engine. A partial blockage cascade thrust reverser was designed and tested at model scale. Full scale testing was conducted using a J47-13 engine.

Key Words: cascade thrust reverser
full scale

1.61 CONTROL SYSTEMS FOR THRUST REVERSAL, Burnett J. and Moses, D., SAE Paper 49C, April 1958.

This paper discusses controls and actuation systems for thrust reversers. Two general categories of controls are discussed; one for initiation during the landing roll and the other for initiation during flight. An actuation system that had been under development for 18 months is discussed in relation to the two major control requirements.

Key Words: thrust reverser controls
thrust reverser actuation systems

1.62 DEVELOPMENT OF THE SUPPRESSOR AND THRUST BRAKE FOR THE DC-8 AIRPLANE, Jordan, L. R. and Auble, C. M., SAE Paper 85A, October 1958.

The paper gives a description of the DC-8 thrust reverser development program including reverser performance data.

The selection of the production unit was based on a wide background of test work using both model and full scale facilities. On the basis of this work, the configuration selected for production consisted of a fixed, corrugated, suppressing nozzle with a retractable ejector. A target type thrust brake, mounted in the ejector, was chosen for the thrust brake production unit. Approximately 12 db suppression and 44% reverse thrust are provided by the unit.

The ejector is hydraulically operated and the thrust brake air actuated. Both actuation systems obtain power from the aircraft systems which provides for operation during engine-out conditions. Alternate methods of actuation are provided in case of a primary system failure.

Key Words: target thrust reverser
DC-8
thrust reverser development
sound suppressor
ejector shroud

1.63 PRACTICAL EXPERIENCE ON THRUST REVERSERS, Vincent, K. I. C., SAE Paper 85C, October 1958.

The report reviews the development progress of thrust reversers for the (1) Derwent cascade thrust reverser fitted to Meteor, (2) thrust reverser for the Avon engines on the Comet II and III aircraft and Hunter aircraft, and (3) Conway thrust reverser for the Boeing 707-420. Photographs of the various reversers are presented. Limited performance data is presented.

Key Words: cascade reverser
reverser development
Comet thrust reverser
Boeing 707-420
Meteor

1.64 THE DESIGN AND DEVELOPMENT OF THE GENERAL ELECTRIC CJ805-3 THRUST REVERSER AND NOISE SUPPRESSOR, Bertaux, W. S., SAE Paper 162B, April 1960.

The report discusses the design and development of the cascade thrust reverser and eight lobe suppressor nozzle for the Convair 880 aircraft. The report contains numerous photographs of model and full scale reversers, suppressors, and the test facilities. The nozzle velocity coefficient and afterbody drag coefficient data are included.

Key Words: cascade reverser
reverser development
Convair 880

1.65 DEVELOPMENT OF IN-FLIGHT MODULATING TYPE THRUST REVERSER FOR SINGLE ENGINE AIRCRAFT, Kehrer, W. T., SAE Paper 238A, October 1960.

The report discusses the development of a modulating cascade thrust reverser for in-flight usage on the F-100F fighter bomber aircraft. The work was performed by North American Aviation, Inc. under an Air Force contract. The function of the reverser was to provide a controllable thrust level for stabilizing the aircraft on extremely steep glide slopes. The thrust reverser design selection, wind tunnel test program and flight test program are discussed.

Key Words: in-flight reverser
modulating reverser
reverser development
aerodynamic stability and control data

1.66 SOUND SUPPRESSOR AND JET REVERSER EFFECTS ON AIRCRAFT PERFORMANCE, Walley, W. R. and Gardner, R. N., SAE Paper 238C, October 1960.

The report discusses the DC-8 sound suppressor and thrust reverser design. The effects on takeoff, climb, and cruise performance are presented, together with operating costs, continuing costs, and projected total cost. Data are presented showing the performance of the suppressor-reverser nozzle and a conical reference nozzle. The in-flight capability of the DC-8 reverser is discussed.

Key Words: sound suppressor
DC-8
target thrust reverser
aircraft performance

1.67 WIND TUNNEL INVESTIGATION OF A 0.057-SCALE C-5A SEMI-SPAN MODEL WITH POWERED NACELLES AT MACH NUMBERS 0.60 TO 0.85, Graham, F. J., AEDC-TR-66-187, October 1966.

This report describes force and pressure tests conducted with an 0.057 scale semi-span model of the C-5A airplane to obtain aerodynamic interference effects due to the engine nacelle operation. Turbopowered nacelles were used to simulate the propulsion system. Tunnel Mach numbers ranged from 0.60 to 0.85 for a constant Reynolds number of 4.2×10^6/ft. Angles of attack were set from -2 to +4 degrees.

Key Words: C-5A airplane
aerodynamic characteristics
cascade thrust reverser
aerodynamic interference characteristics

1.68 THRUST REVERSERS FOR BUSINESS JET AIRCRAFT, Pickerd, J. C. and Hinds, C. M., SAE Paper 670235, 1967.

Principles of thrust reversing are reviewed along with descriptions of most common types of thrust reversers. Various uses of reversers are discussed and limitations of reversing due to reingestion and other causes are examined. Technical aspects of thrust reverser analysis and testing are related to both static and dynamic performance. Specific uses of reversers on business jets and the resulting performance gains are demonstrated.

Key Words: thrust reversers
operation

1.69 THE AERODYNAMICS OF THRUST REVERSERS FOR HIGH BYPASS TURBOFANS, Poland, D. T., AIAA Paper 67-418, 1967.

This paper presents experimental data for blocker/deflector (clamshell and annular fan) and cascade (annular fan) thrust reversers. Performance data for Mach numbers from 0 to 0.85 and a wide range of nozzle pressure ratios are included. The effect of varying different geometric variables is shown. The effect of thrust reverser operation on inlet additive drag and airplane drag is also shown.

Key Words: blocker/deflector thrust reverser
cascade thrust reverser
static performance
aerodynamic interference
reingestion

1.70 SOME PECULIARITIES OF WORK OF REVERSIBLE DEVICES WITH CLAM SHELLS BEHIND THE NOZZLE SECTION, Aronov, B. M. and Denisov, I. N., translated from Russian, Aviation Technic, October 1968.

The report presents static performance data for a target thrust reverser. Static reverser efficiency and airflow match data are presented as a function of setback distance and nozzle pressure ratio. The report also presents total pressure survey data of the exhaust efflux and several smoke flow visualization photographs. The report describes an adapter that was attached to the nozzle exit to prevent the reversed jet from attaching to the nacelle afterbody for higher pressure ratios and tight setback spacings.

Key Words: target thrust reverser
static performance

1.71 DESIGN AND CONTROL OF THE 747 EXHAUST REVERSER SYSTEMS, Wood, S. K. and McCoy, J., SAE Paper 690409.

This paper gives a description of the 747 thrust reverser design including the control system. The paper discusses the 747 design criteria, design evolution, design integration, cascade development, materials, actuation and control system, lubrication requirements, cockpit indicators, and maintainability and reliability. The report features many detailed drawings of the nacelle, fan and primary reverser structure, actuation system, and power control system. The report contains no propulsion performance data.

Key Words: cascade thrust reverser
Model 747
thrust reverser design
thrust reverser development

1.72 DESIGN FEATURES OF THE CF6 ENGINE THRUST REVERSER AND SPOILER, Lennard, D., SAE Paper 690411, 1969.

Significant design features of the cascade thrust reverser and spoiler of the CF6 engine (powerplant for the McDonnell Douglas DC-10) are described along with the design impact of major requirements including maint ability and noise reduction. Also included is the devel ment test program which is designed to provide accelerated component and system evaluation.

Key Words: cascade thrust reverser
primary flow spoiler
DC-10
CF6

1.73 CAPABILITIES OF IN-FLIGHT THRUST REVERSING ON TACTICAL AIRCRAFT, McCormick, R. L. and Koepcke, W. W., AFFDL-TR-67-120, October 1967.

A program was conducted for the purpose of determining the performance capabilities and handling-quality characteristics of the Northrop F-5 tactical aircraft equipped with a thrust reverser. The program was performed using a combination of fixed- and moving-base simulators, and analytical techniques. Of necessity, the aerodynamic characteristics were predicted analytically and certain simplifications were made in the mathematical modeling of the F-5 airplane. To this extent the mathematical models are not precisely representative of the F-5 airplane but are representations of tactical airplanes of the F-5 type. The thrust-reverser equipped airplane was compared with the clean airplane and the airplane equipped with fixed and dynamic-pressure-limited speed brakes. Instrument landing approaches (ILS) and wave-offs were flown on the fixed-base simulator. The moving-base simulator was used to investigate weapons delivery in 30- and 50-degree dives, join-ups and formation flying, and gross deceleration maneuvers. Analytical methods were used to study ground-roll braking and rapid descent from high altitude.

Key Words: in-flight thrust reversing
flight simulator

1.74 DEVELOPMENT OF AN IN-FLIGHT THRUST REVERSER FOR TACTICAL ATTACK AIRCRAFT, Linderman, D. L. and Mount, J. S., AIAA Paper No. 70-699, June 1970.

The first phase of a three-phase program for evaluating an in-flight thrust reverser for application to tactical and attack aircraft is described. First phase effort consisted of low-speed wind tunnel tests, static propulsion system performance tests, and high-speed wind tunnel tests using a hot-jet-powered model of the test bed aircraft. By way of introduction, the proposed operational and tactical uses of the thrust control system are briefly described. Data are presented from the tests describing thrust reverser internal performance and reverse thrust effectiveness from static through approach speeds to Mach 1.3. Effects of the thrust reverser on forward thrust performance, on engine performance, and on secondary cooling ejector performance are discussed and a resume' of system influences on airplane stability and control is presented.

Key Words: blocker/deflector thrust reverser
in-flight thrust reverser
static reverser performance
wind-on reverser performance
aerodynamic characteristics

1.75 A MATHEMATICAL MODEL FOR THE BEHAVIOR OF THRUST REVERSERS, Chang, H. Y. and Waidelich, J. P., AIAA Paper 69-3, 1969.

The flow within a target type thrust reverser is analyzed, using the simplifying assumptions that the flow is inviscid, incompressible and two-dimensional. The analysis is aided by a pair of transformations which allow the ejection angle to be expressed as a function of reverser geometric variables in two equations which have the form of improper integrals. These equations are then solved by numerical integration, with an approximation technique used at the signular points. Results are presented in the form of graphs which show the jet exit angle ϕ as a function of the reverser geometric variable: L/d, H/d, sweep angle and endplate angle. Excellent agreement with test results from a two-dimensional water jet are shown.

Key Words: target thrust reverser
internal flow analysis

1.76 THRUST REVERSER ANALYSIS PROGRAM - TEM-188, VOLUME II, PROGRAMMER'S, Errington, E. R., D6-29503, The Boeing Company, July 1970.

The document describes a computer program developed for annular internal and external target thrust reversers. The analysis approximates the reverser flow field by a two-dimensional, incompressible, inviscid flow model utilizing two free streamlines as the boundaries of the reverser flow. Complex variable theory was used to solve the equations of motion. The analysis predicts the effects of design variables such as door length, door setback, door angle, and lip length. This document contains data useful to the computer programmer such as flow charts, numerical techniques, and listings. No data are presented in this report.

Key Words: annular external target thrust reverser
external target thrust reverser
flow field analysis

1.77 PERFORMANCE CHARACTERISTICS OF HEMISPHERICAL TARGET-TYPE THRUST REVERSERS, Steffen, F. W., McArdle, J. G. and Coats, J. W., NACA RM E55E18, 1955.

This report presents the results of an investigation to determine the reverse-thrust performance of hemispherical target thrust reversers over a wide range of geometric variables including nozzle boattail shape. The data were obtained from small-scale models with unheated air operated over a pressure ratio range from 1.4 to 3.0. Several factors were found which increased the flow turn angle and thus the reverse-thrust ratio. The most important of these was hemisphere diameter.

Key Words: target thrust reverser
static performance

1.78 HIGH BYPASS VERSUS LOW BYPASS ENGINE INSTALLATION CONSIDERATIONS, Kutney, J. T., SAE Paper 660735, 1966.

Installation considerations for high bypass engines in the range of 5-10 are examined. An engine and installation concept for the high bypass is described. Installation considerations discussed include the effects of nacelle shape, wing proximity, inlets, thrust reversers, and accessory location. It is pointed out that the high bypass engine may offer the flexibility to design the ideal aerodynamic installation without compromise by installation requirements.

Key Words: high bypass engine installation

1.79 MODULATED THRUST TO IMPROVE STOL AIRCRAFT PERFORMANCE (A FLIGHT TEST EVALUATION), Johnston, G. W., AGARD, in AGARDograph 89 "V/STOL Aircraft," Part I, September 1964, pp. 419-448.

Direct improvements result from the combined section of the deflected slipstream and reverse jet combination including the important interference effects possible with certain aircraft layouts. Achievable improvements based on model and full-scale measurements are given. The test aircraft, employing slipstream deflection with in-flight reverse thrust, consistently attains total landing distances from 50 ft. or less than 500 ft. in standard atmosphere at a wing loading of 23 lb/ft^2. This compares with a performance level of approximately 1,000 ft. in the unmodified configuration at the same wing loading.

Key Words: modulated thrust reverser
in-flight thrust reverser
flight test

1.80 A STUDY OF JET IMPINGEMENT ON CURVED SURFACES FOLLOWED BY OBLIQUE INTRODUCTION INTO A FREESTREAM FLOW, Tatom, J. W., et. al., First Annual Report Under NASA Grant NGR-002-034, Vanderbilt University, April 1971.

This report presents the results of an experimental and analytic program to study jets injected obliquely into a freestream flow and jet impingement on curved surfaces. The former study is further divided into an investigation of the flow field generated around a single engine nacelle by two hot, round opposing jets in the presence of a freestream and an investigation of the hot, two-dimensional jet introduced at various angles into an opposing free-stream. Both of these investigations include an analytical program. The results of the model nacelle testing suggest that pitching the reverse jets up asymmetrically is a useful technique for preventing engine exhaust ingestion. The nacelle flow field analytical model and the two-dimensional jet investigation were incomplete when the document was published. The study of jet impingement on curved surfaces was primarily an analytical effort. Experiments were performed for the purpose of verifying the assumptions on which the analysis is based. Satisfactory analytical and numerical solutions were obtained for a radial plane jet impinging on a cylindrical deflector and a round radial jet impinging on a hemispherical surface. Finally, a more general numerical program was developed for the case of a straight jet exhausting from a duct and impinging on an arbitrary curved surface. The results of experiments performed for this case are in satisfactory agreement with the analysis.

Key Words: jet penetration
reingestion
impingement

1.81 SELECTION AND DESIGN OF THRUST REVERSERS FOR JET AIRCRAFT, Pickerd, John C., IAS Paper No. 60-77, June-July 1960.

This paper discusses some of the more pertinent factors to be considered in the design of a thrust reverser for a given jet aircraft. A limited amount of model and full scale data are presented for clamshell and target thrust reversers.

Key Words: design factors

1.82 ROHR CORPORATION FOUR BAR TARGET THRUST REVERSER STATIC TEST PROGRAM, Magness, E. W., Report No. 24-3192, Rohr Corporation, 1965.

This report describes static tests conducted by Rohr Corporation to obtain Federal Aviation Agency (FAA) certification and endurance data for the four bar target thrust reverser used on the Douglas DC-9 aircraft. The FAA qualification test program demonstrated functional capability, fail safe design, and a 200 endurance cycling trial. The endurance test program consisted of additional cycling (1640 cycles total) to determine the durability of the reverser installation. The report presents full scale reverse thrust performance data.

Key Words: target thrust reverser
DC-9
reverse thrust performance
endurance test
full scale

1.83 THE BOEING COMPANY MODEL 737 THRUST REVERSER QUALIFICATION TEST, Zillner, J. W., Report No. 24-3194, Rohr Corporation, 1969.

This document presents the results of the Model 737 thrust reverser FAA qualification tests. Additional results are shown for (1) supplemental structural and functional tests, and (2) nozzle effective area match tests. The qualification tests encompassed a total of 402 normal landing reverse thrust cycles using takeoff and part power thrust settings. The reverser airflow match was within 0.02% of the Pratt & Whitney Aircraft standard. Thrust reverser efficiency was in excess of 44% at takeoff power. Forward and reversed thrust data and temperature data are shown.

Key Words: target thrust reverser
Model 737
reverse thrust
full scale

1.84 FLIGHT MEASUREMENTS OF THE EFFECT OF A CONTROLLABLE THRUST REVERSER ON THE FLIGHT CHARACTERISTICS OF A SINGLE ENGINE JET AIRPLANE, Anderson, S. B., Cooper, G. E., and Faye, A. E. Jr., NASA Memo 4-26-59A, May 1959.

A flight test was performed to determine the effect of a fully controllable cylindrical target thrust reverser on the flight characteristics of a single engine jet airplane. The thrust reverser was evaluated as an in-flight decelerating device, as a flight path control and airspeed control in landing approach, and as a braking device during the ground roll. Use of the reverser in landing approach made possible a wide selection of approach angles, a large reduction in approach speed at steep approach angles, improved control of flight path angle, more accuracy in hitting a given touchdown point, and improved wave-off characteristics. The use of the reverser as a speed brake was compromised by a longitudinal trim change at lower airspeeds. At low airspeeds, high engine power, and full reverser deflection there was insufficient elevator power to overcome the nose-down trim change.

Key Words: modulating thrust reverser
longitudinal stability

1.85 SOME EFFECTS OF SOLIDITY IN TURNING THROUGH CONSTANT-THICKNESS CIRCULAR ARC GUIDE VANES IN AXIAL ANNULAR FLOW, Mankuta and Guentert, NACA RM E51E07, 1951.

An investigation was conducted on sheet metal, circular-arc compressor inlet guide vanes in an annular cascade to determine the effect of solidity on turning through a blade row. Guide vanes of 30° to 40° camber were investigated over a range of solidity from 0.5 and 4.0. The ratio of turning angle to camber angle is plotted against solidity, the results of which are compared with several two-dimensional analytical methods. Total pressure surveys upstream and downstream of the cascades were also obtained.

Key Words: cascade
solidity
effective flow turning angle
total pressure loss
model test
analytical

1.86 RESULTS OF DECEMBER STATIC CELL TESTS OF ROTATING DOOR AND CYLINDRICAL CASCADE REVERSER CONFIGURATIONS OF THE 0.10 SCALE JT3D MODEL, McKenzie, J., Report UAR-0667, Pratt & Whitney Aircraft, 1960.

Static performance of four cylindrical primary cascade reverser configurations of the 0.10 scale JT3D nacelle was obtained. The configurations differed in solidity and reverser area.

Key Words: cascade
solidity
model test

1.87 FEBRUARY TEST RESULTS OF A 0.10 SCALE PRATT & WHITNEY JT3D CLAMSHELL THRUST REVERSER, Crockett, C., Report UAR-0265, Pratt & Whitney Aircraft, 1959.

An exploratory type test program was conducted by UAC to determine the feasibility of injecting an oil and lampblack solution into the nozzle air stream to study jet impingement on the wing and pylon. A clamshell reverser installed on a Boeing 707 nacelle with simulated wing and pylon was tested at tunnel speeds of 50, 150, and 180 knots. A few photographs of the oil patterns are presented. Isolated static performance of the clamshell reverser was obtained.

Key Words: clamshell reverser
flow visualization
impingement
model test

1.88 PERFORMANCE OF AN 0.0735 SCALE TURBOFAN NACELLE MODEL WITH PRIMARY EJECTOR REVERSERS, McKenzier, J. Report UAR-0676, Pratt & Whitney Aircraft, 1965.

An external target type ejector reverser was tested over a Mach number range of 0 to 0.80. The ejector has two large cutout areas in the shroud as well as the blow-in-door passages from which reverse flow is discharged. Primary flow reverse performance and flow coefficients were obtained for this configuration.

Key Words: external target
static and Mach number performance
model test

1.89 EXPERIMENTAL PERFORMANCE EVALUATION OF A CLAMSHELL SHROUD EJECTOR NOZZLE FOR THE SUPERSONIC TRANSPORT ENGINE, Verbridge, D., UACRL E231509-1, Pratt & Whitney Aircraft, 1966.

An internal clamshell target type reverser for the SST co-annular blow-in-door ejector was tested at Mach 0.0 and 0.6. The effect on reverser performance of blow-in-door blackage, fan to engine total pressure ratio, and shroud translation was measured.

Key Words: internal target
static and Mach number performance
co-annular blow-in-door ejector
model test

1.90 EXPERIMENTAL DETERMINATION OF FORWARD AND REVERSE THRUST PERFORMANCE OF VARIOUS BLOW-IN-DOOR EJECTORS PROPOSED FOR THE SUPERSONIC TRANSPORT ENGINES, Barrett, D., UACRL D231333-1. Pratt & Whitney Aircraft, 1966.

Isolated static performance was obtained for an internal target reverser for the SST co-annular blow-in-door ejector. Model variations included different reverse flow trippers in the vicinity of the blow-in-doors and three different reverser cone angles. A few photographs of tuft studies performed with several reverser configurations are also presented.

Key Words: internal target reverser
static performance
co-annular blow-in-door ejector
flow visualization
model test

1.91 STATIC PERFORMANCE OF 1/20 SCALE SST THRUST REVERSER CONFIGURATIONS, Verbridge, D., UACRL D231121-1, Pratt & Whitney Aircraft, 1965.

Isolated static performance was obtained on an internal target type reverser for the SST co-annular blow-in-door ejector. The effect on reverser performance of various fan exit areas, bleed, and reverser spacings was determined. Several different types of reverser bleed spoilers were also investigated, as well as blow-in-door blockage effects.

Key Words: internal target reverser
static performance
co-annular blow-in-door ejector
model test

1.92 WIND TUNNEL TESTS OF PRATT & WHITNEY AIRCRAFT BARN DOOR THRUST REVERSERS FOR THE JT3D ENGINE, McKenzie, J., Report UAR-0493, Pratt & Whitney Aircraft, 1956.

Five clamshell target type reversers were tested over a Mach number range of 0 to 0.90. The clamshell reversers, mounted downstream of the JT3D nacelle, were designed to reverse both the primary and the bifurcated fan flows. One configuration was tested with only primary flow. A few schlieren photographs are presented.

Key Words: external target
static and Mach number performance
model test

1.93 RESULTS OF A 1/5 SCALE QUICK LOOK MODEL TESTS OF A TARGET THRUST REVERSER FOR THE 727 EJECTOR/SUPPRESSOR NACELLE, Hurlbert, C. F., D6-24878TN, The Boeing Company, April, 1971

A 1/5 scale 36 lobe suppressor nozzle with an ejector was fitted with a target reverser deployed aft of the ejector exit. The axial position of the reverser was adjustable from .5 to 1.5 ejector exit diameters aft. The door angle was also adjustable from 70° to 80°. Each door had a 3-inch (full scale) lip and tapered side fences. Axial (reverse) thrust and suppressor nozzle airflow were measured at nozzle pressure ratios from 1.4 to 2.0. Three axial positions of the reverser doors and three door angles were tested. The results indicated that at near takeoff nozzle pressure ratio (2.0) a mismatch of .45 to 1.45 percent occurs for reverser axial positions (setback) of 1.5 to .5 ejector exit diameters, respectively. Percent reverse thrust ranges from about 2 percent at 1.5D setback to 47.9 percent at .5D setback. The ejector does not pump when the reverser is closer than about .75D aft of the ejector exit. Door angle had minor effect on reverser performance. However, the performance from the 80° door was slightly better. The reverse thrust was reduced by half when the lip was removed.

Key Words: target thrust reverser
reverser efficiency
airflow match

THRUST VECTORING SYSTEMS ABSTRACTS

2.1 PERFORMANCE OF A ROTATING CASCADE THRUST VECTORING SYSTEM
Patterson, M. W., D6-9842TN, The Boeing Company, February 1965.

A model scale test program was conducted to determine the performance of rotating cascade vectoring nozzles for nozzle pressure ratios from 1.5 to 3.2 and cascade rotation angles from 0 to 180 degrees. Eight cascade designs were tested with the symmetric installation, tandem installation, and a third providing flow directly into the cascade. This configuration provided a baseline for establishing performance losses due to turning and port location. The loss due to turning the flow from an axial direction 90 degrees into the cascades was about 3 percent, and an additional 3 percent C_V loss occurred through the cascades at a pressure ratio of 2.5. The discharge coefficient was nearly constant throughout the range of vector angles.

Key Words: thrust vectoring
cascade nozzle
rotating cascades
static vectoring performance

2.2 VARIABLE VECTORING NOZZLE: FLOW MODEL TEST, Johnson, C. E., D3-4643, The Boeing Company, January 1963.

A four bearing vectoring nozzle (two inclined bearings) was tested for internal flow losses at vectoring angles of 0, 22.5, 45, 67.5, and 90 degrees and nozzle pressure ratios from 1.5 to 2.3. The nozzle upstream and exit diameters were 4 and 3 inches respectively, giving an area ratio of 1.778 and design entrance Mach number of 0.35. The bend r/D was 1.175. Data presented include velocity, thrust, and discharge coefficients of a straight flow through calibration nozzle of the same length and area ratio as the vectoring nozzle. Turning losses for the vectoring nozzle are presented in percent of non-deflected nozzle performance. For the 90" vectored position, $\Delta C_V/C_{VO}$ = 0.03. Total pressure loss data for smooth pipes are used to correct the data and predict full scale nozzle performance.

Key Words: multibearing nozzle
thrust vectoring
static performance

2.3 INVESTIGATION OF THE PERFORMANCE CHARACTERISTICS OF A DUAL EXIT THRUST VECTORING NOZZLE, Barrott, W. J., D6-9083, The Boeing Company, June 1963.

A dual exit thrust vectoring nozzle was tested for nozzle pressure ratios from 1.5 to 3.0. The nozzle is capable of 180-degree rotation from cruise to full reverser, providing vertical and horizontal thrust components between these limits. Several combinations of turbine exhaust cones, splitters, nozzle geometry, and external fairings were tested. The velocity coefficient in the cruise position and a pressure ratio of 2.5 was approximately 1 percent lower than a standard convergent nozzle together with 93 percent drop in discharge coefficient. In the 90-degree vectored position, velocity and discharge coefficient dropped 6 and 4 percent, respectively, compared to a standard nozzle. Photographs of oil flows on nozzle internal and external fairing surfaces, together with shadowgraphs of the exhaust flow are presented.

Key Words: thrust vectoring
dual exit nozzle
single bearing nozzle

2.4 DEVELOPMENT OF A "FLAT PLUG" THRUST DEFLECTION NOZZLE, Morcom, R. W., D6-9844, Preliminary Report No. 1, The Boeing Company, not yet released.

The report presents design drawings of a flat plug thrust deflection nozzle for a pod mounted fan engine. The top surface of the plug is rotated up to block the nozzle exit and divert the flow downward through turning vanes located in the bottom half of the plug. The vanes are rotated to vector thrust forward through 100 degrees. The document defines the preliminary design internal and external nozzle contours.

Key Words: thrust deflection
plug nozzle
cascade vanes

2.5 THRUST DEFLECTION DOORS FOR LIFT TURBOJET ENGINES, D6-11473, The Boeing Company.

A three-phase test program was conducted to evaluate the performance of external deflector doors for pressure ratios from 1.5 to 3.0. The first phase was a parametric investigation of a flat deflection plate placed downstream of a convergent nozzle. Parameters varied in the test included door length, door angle, setback, and nozzle pressure ratio. Vectored performance with and without deflection door sideplates was determined. Data obtained in Phase I testing established a relationship between fluid impingement angle on a flat door and percent C_V loss. This relationship was used to design a curved deflector door giving improved performance for Phase II testing. The third phase tested configuration oriented designs which could be installed on the US/FRG tactical fighter. Door width, length, sideplate height, hinge point, nozzle height, seals, and the presence of adjacent deflector doors for the actual installation were accurately simulated. Oil flow visualization photographs of the flow pattern on the door are also presented.

Key Words: thrust deflection
external deflector
lift engine

2.6 NOZZLE AND DUCTING LOSSES IN PEGASUS TYPE LIFT THRUST ENGINES, Bristol Siddeley Engines, Ltd., GN 4713/1, October 1961.

This memorandum presents typical duct losses associated with the swivelling nozzle system used on lift/thrust engines of the Pegasus type. The rough analysis shows a thrust loss of about 295 pounds at takeoff and a 3.5 percent loss in cruise SFC at the tropopause. A weight comparison shows the lift/thrust system is about 230 pounds heavier than a pure cruise system filled with a thrust reverser. The four page in-house memorandum contains no references or figures.

Key Words: single bearing swivel nozzle
Pegasus
duct losses

2.7 VECTORED THRUST ENGINES FOR SINGLE AND MULTI-ENGINED AIRCRAFT, Frost, T. P. and Bishop, R. A., AIAA Preprint No. 63-471, October 1963.

In this paper the application of V/STOL power plants currently being developed by Bristol Siddeley Engines is discussed, including the Pegasus vectored thrust engine which has been undergoing bench and flight development in the Hawker P.1127 strike aircraft, and advanced developments designed to power supersonic V/STOL strike aircraft. The Pegasus engine is also suited to power V/STOL transport aircraft, and the final section of the paper is devoted to this topic. The STOL transport aircraft is considered, where the combination of the deflected thrust capability of the Pegasus type engine with wing/flap boundary layer control gives extremely short airfield performance. The VTOL transport is then discussed including the development of lightweight lift engines for this application, and finally future vectored thrust engines are considered.

Key Words: Pegasus
V/STOL transport
vectored thrust engine

2.8 RECENT DEVELOPMENTS IN VECTORED-THRUST TURBOFANS, Barrett, J. A., Aircraft Engineering.

The paper summarizes the development of the Pegasus vectored thrust turbofan, describes the "plenum chamber burning" (PCB) system development, and discusses applications to advanced V/STOL subsonic strike fighter aircraft. Nozzle performance for the Pegasus rotating cascade vectoring nozzle is shown.

Key Words: Pegasus
rotating cascade vectoring nozzle
vectoring nozzle performance

2.9 EXPERIMENTAL INVESTIGATION OF A NOVEL VTOL THRUST VECTORING NOZZLE, Hall, G. R., Journal of Aircraft, Volume 2, No. 4, July-August 1965.

A two-dimensional corner-expansion thrust vectoring nozzle, in which thrust vectoring is achieved by rotation of a single vane, is proposed for high supersonic V/STOL aircraft. A 1/10 scale model of the configuration has been statically tested with favorable results. A thrust coefficient in excess of 0.97 was demonstrated in the VTOL mode and throughout transition at nozzle pressure ratios typical of turbojet engines considered for high supersonic V/STOL applications. In addition, a thrust coefficient in excess of 0.96 was attained in the horizontal cruise mode down to a nozzle pressure ratio of 3.5. This is particularly significant when considering that the design pressure ratio of the nozzle was 21. Effective thrust vectoring was also demonstrated, with a 1:1 correspondence between vane mechanical deflection and thrust vector direction. A jet pumping effect was found to exist at very low-pressure ratios at a slightly deflected position of the thrust vectoring vane, and an alternating normal component of the total thrust vector was found to exist at low-pressure ratios in the horizontal cruise mode.

Key Words: two-dimensional thrust vectoring nozzle
static performance data

2.10 DEVELOPMENT OF THRUST DEFLECTION AND VECTORING - V/STOL, Smith, A. D. F., SAE Paper 660738, October 1966.

The progress with the use of deflected thrust in European V/STOL airplanes is reviewed. The difficulties which arise in adopting the vectored thrust concept are examined and commented upon in the light of practical experience which has been accumulated. Several configurations are discussed; an internal blocker door and ventral nozzle, blocker door with rotating cascade, and a dual swivelling nozzle. Total pressure loss data are presented for the fan and primary nozzles of the RB 193 engine.

Key Words: dual swivelling nozzles
vectoring static performance data
engine development

2.11 SOME VTOL POWERPLANT DESIGN AND DEVELOPMENT EXPERIENCE, Davies, D. O. and Coplin, J. F., Journal of the Royal Aeronautical Society, Volume 70, November 1966.

This paper describes the experience obtained by Rolls-Royce in design and development of several lift and lift cruise engines, including the RB 93, RB 108, RB 145, RB 153, RB 162, Avon, Conway, and Spey. Jet deflectors were used on the Spey (rotating cascades), a thrust diverter ventral nozzle on the RB 153, a dual swivelling nozzle on the RB 162 and RB 193, and a hinged spherical nozzle on the RB 162. The only propulsion data relating to the vectoring nozzles is a curve showing specific weight penalty versus vectoring angles. The various engine components (compressor, combustion chamber, turbine, and exhaust system) are described in detail for the RB 162 lift engine.

Key Words: lift engine
engine development
lift/cruise engine

2.12 EXTENSIONS OF THE LIFT/THRUST ENGINE PRINCIPAL IN V/STOL AIRCRAFT, Denning, R. M., SAE Paper.

The paper discusses the engine cycle selection for vectored thrust, low level strike aircraft having supersonic capability. The relative merits of different powerplant types are discussed from the engine designer's viewpoint. It is concluded that the basic engine cycles that are optimum for lift/thrust engines are also generally near optimum for all types of aircraft in the low level, subsonic cruise regime. Competing systems have little to choose from based on powerplant plus fuel weight. The choice should be made on the basis of simplicity, cost, ease of pilot control, or incidental performance advantages.

Key Words: engine cycle selection
V/STOL fighter aircraft

2.13 NOZZLES FOR JET-LIFT V/STOL AIRCRAFT, Kentfield, J. A. C., Journal of Aircraft, Volume 4, No. 4, July-August 1967.

Several types of nozzles for lift and lift/cruise engines are reviewed. Model test data are presented for two types of lift engine nozzles: a short truncated plug nozzle (non-vectoring) and a hinged hemispherical plug vectoring nozzle. The velocity and discharge coefficients for the hemispherical nozzle were substantially independent of flow-deflection angle.

Results of a theoretical analysis are presented which show that attempts to shorten and lighten lift-engine nozzles by eliminating whirl-removing surfaces may incur severe performance penalties. An oblique-joint, elliptical shape nozzle for vectoring lift/cruise engine thrust is described and test data obtained with homogeneous flow are presented. A theoretical analysis was made of the causes of performance loss with non-homogeneous flow. It was concluded that when a nozzle of this type if employed on a turbofan engine use should be made of an upstream flow mixer, or separate channels to the nozzle exit, if excessive losses are to be avoided in the vectored mode.

Key Words: thrust vectoring nozzles
V/STOL
static performance data

2.14 DEVELOPMENT OF FLIGHT-WEIGHT DEFLECTION DEVICE AND ACTUATION SYSTEM FOR TF30-P-8 ENGINE, Carlson, N. G., Final Report, PWA-3266, Pratt & Whitney Aircraft, December 1967.

An engineering program of eighteen months' duration was conducted to design, fabricate, and test a full-scale, flight-weight thrust deflection device, including an actuating system, which was compatible with the TF30-P-8 engine. The design work was supported by the testing of a number of deflector models. The design selected was a hinged spherical nozzle, fabricated from titanium. The program demonstrated the suitability of the hinged spherical nozzle concept for flight demonstration in the A-6 aircraft. Fabrication from titanium was found to be feasible, and the hardware proved to be durable. Although the design may not have produced optimum performance, the performance obtained with both deflected and undeflected thrust was adequate for a flight demonstration. In addition, two analytical studies were performed. The first of these was a study of the problems associated with installing a deflector-equipped TF30-P-8 engine in a Gruman A-6 aircraft, and the second was a study of fan-air deflection from a TF30-P-8 engine installed in an A-7A aircraft.

Key Words: thrust vectoring nozzle
hinged spherical deflector nozzle
model scale static performance
full scale static performance

2.15 REDUCTION OF LANDING SPEED OF CARRIER BASED AIRCRAFT BY THRUST VECTORING, Kuczwara, J., Report 24-2273, Rohr Corporation, January 1968.

The results of a study to determine the feasibility of reducing carrier aircraft landing approach speeds by thrust vectoring are reported. The four carrier aircraft analyzed included the Douglas A-4E, Grumman A-6A, McDonnell F-4B and North American T-2B. The study included aircraft low speed performance and controllability, conceptual layouts of the modified aircraft, installation and modification problems and comparison with the conventional unmodified aircraft. It is concluded that thrust vectoring is a feasible means of reducing carrier landing speeds thereby improving flight path control, wave-off capability and arresting gear landing loads. However, retrofitting certain existing aircraft may be prohibitive because of the structural modification or system weight required. Recommendations are made for a follow-on effort to develop the thrust vectoring concept.

Key Words: thrust vectoring nozzle design
landing speed study

2.16 THE VECTORED THRUST HARRIER, Braybrook, R. M. Vertiflite, March 1969.

This report describes the background leading to the development of the Hawker Siddeley Harrier V/STOL fighter aircraft. Performance data are not included.

Key Words: Harrier
aircraft development

2.17 A CLOSER LOOK AT THE HAWKER SIDDELEY HARRIER, Interavia, May 1969, pages 568-573.

This article summarizes the design, development, performance, construction and combat capability of the Hawker Siddeley Harrier V/STOL aircraft. Excellent drawings and photographs are included.

Key Words: V/STOL aircraft
design and development

2.18 THE HARRIER, AN ENGINEERING COMMENTARY, Fozard, J. W., The Aeronautical Journal of the Royal Aeronautical Society, Volume 73, September 1969, pages 769-788.

The report gives an excellent and very thorough engineering review of the Hawker Siddeley Harrier V/STOL aircraft. The evaluation of the Harrier is traced from its beginning as the P1127 in 1957 through the present. The article discusses the aircraft performance and design aspects including the control system and maintainability.

Key Words: Harrier V/STOL aircraft
airplane development

2.19 PRELIMINARY STUDY DATA, THRUST VECTORING FOR GE13/F2 HIGH BYPASS TURBOFAN, R70AEG356, General Electric, August 1970.

The report presents results of a conceptual design evaluation of a single bearing swivel thrust vectoring nozzle and a four bearing thrust vectoring nozzle. The report contains nacelle layout drawings for the two configurations, weight estimates, control system description and weights, predicted C_V, C_D, and SFC performance, thrust component variation with bearing angle, and actuation times.

Key Words: thrust vectoring
four bearing nozzle
single bearing swivel nozzle
installation concepts

2.20 THRUST DEFLECTION NOZZLES FOR VTOL AIRCRAFT, Disabato, V. J., Pratt & Whitney Aircraft Memo No. 122, October 1970.

The report presents a method for predicting the velocity coefficient losses for a 90° bend circular nozzle using NACA total pressure loss data for smooth pipes. Small scale model test data are presented for a single bearing swivel nozzle, ventral nozzle, ventral nozzle with rotating cascade, and aft-hood deflector. Velocity coefficient, discharge coefficient, and resultant thrust angle data are presented for nozzle pressure ratios from 1.1 to 3.0 and vector angles from 0 to 90 degrees. Also presented is the effect of ground proximity on velocity and discharge coefficient for a conical convergent nozzle impinging vertically on a ground plane.

Key Words: thrust vectoring
single bearing swivel nozzle
ventral nozzle
aft-hood deflector
static performance

2.21 A STUDY OF THE TAKEOFF AND LANDING CHARACTERISTICS OF "STOL" TYPE AIRPLANES WITH DEFLECTED JET THRUST, Zeck, H. and VanHeyningen, V. F., D2-3126, The Boeing Company, 1958.

This report presents an introductory study of the takeoff and landing characteristics of STOL airplanes using thrust deflection. The primary results of the study are presented in terms of wing loading/lift coefficient ratio versus thrust to weight ratio for various takeoff and landing field lengths. The results are applicable to jet engine powered conventional aircraft.

Key Words: STOL
deflected thrust
takeoff and landing characteristics

2.22 INTERNAL CHARACTERISTICS AND PERFORMANCE OF SEVERAL JET DEFLECTORS AT PRIMARY-NOZZLE PRESSURE RATIOS UP TO 3.0, McArdle, J. G., NACA TN 4264, June 1958.

Several model jet deflectors were tested statically to determine the effects of design variables on their performance and operating characteristics. The models included several swivelled deflectors, auxiliary nozzles, and mechanical jet deflectors. Nozzle pressure ratio was varied from 1.4 to 3.0. The maximum deflection angle was 25 degrees. The data are presented in terms of axial and side thrust ratios and airflow match.

Key Words: thrust vectoring
jet deflectors
static performance

2.23 A STUDY OF THE HIGH-SPEED PERFORMANCE CHARACTERISTICS OF 90° BENDS IN CIRCULAR DUCTS, Higginbotham, J. T., Wood, C. C. and Valentine, E. F., NACA TN 3696, June 1956.

The performance of four 90° bends in ducts of constant diameter with ratios of radius of curvature to diameter of 0.75, 1.00, 2.50, and 4.00 was investigated over a range of inlet Mach numbers extending up to the choking condition for both a thin and a thick inlet boundary layer. The variation of the measured longitudinal static-pressure gradients at low speed from those predicted by two-dimensional, incompressible, potential-flow theory was determined. It was found that an increase in the inlet boundary-layer thickness decreased the choking Mach number by a very small amount for each of the elbows and had little effect on the other performance parameters. It was concluded that, for the type of elbows tested, a mean radius-diameter ratio of approximately 2.50 would yield the greatest inlet choking Mach number with the least loss of static and total pressure.

Key Words: flow in 90° bends
internal flow losses

2.24 PERFORMANCE EVALUATION OF A THRUST VECTORING SYSTEM WITH VANES IN THE DISCHARGE PORT, Goldstein, N. H., T6-2384, The Boeing Company, March 1964.

This test document contains velocity, thrust, and discharge coefficient data for eight rotating cascade vectoring nozzles. Oil flow visualization photographs are also presented. The objectives of the test were to determine (1) the effectiveness of side oriented rotating cascade ports, (2) the effect of vane cross section, (3) effect of cascade solidity, and (4) losses due to stiffeners. Cascade blades tested included a thin flat section, thin circular arc section, and thick cambered sections. Three installations were tested for each cascade, identical cascade prots symmetrically opposed at 90 degrees, two cascade ports in tandem, and a third providing flow directly into the cascade. Data were taken for nozzle pressure ratios from 1.5 to 3.2 and cascade rotation angles from 0 to 180 degrees.

Key Words: thrust vectoring
cascade nozzle
rotating cascades
static vectoring performance

2.25 EFFECTS OF JET EXHAUST LOCATION ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A JET V/STOL MODEL, Carter, A. W., NASA TN D-5333, July 1969.

A wind tunnel investigation of the jet-location interference effects on the longitudinal aerodynamic characteristics of a jet V/STOL model has been made for an unswept, untapered wing with an aspect ratio of 6 and 30-percent-chord slotted flaps. The effects of jet location were explored systematically from several wing-chord lengths ahead to several chord lengths behind the wing. Various vertical locations of the jets were also investigated.

Key Words: thrust vectoring
aerodynamic interference
longitudinal aerodynamic characteristics

2.26 SIMPLIFIED APPROXIMATIONS OF INTERFERENCE EFFECTS ON JET V/STOL AIRCRAFT, Archino, D. T., Air Force Institute of Technology Thesis GAM/AE/68-2, May 1968.

A semi-empirical approach is used to predict performance losses and pitching moments caused by interference effects on different aircraft planforms in hover and transition. Different aircraft planforms, and variation of the jet exhaust combinations make the problem of predicting interference effects difficult. The induced flow that causes the performance losses in hover is superimposed on the freestream flow to determine the interference effects on performance and pitch during transition. An empirical factor is used to correct for the compressibility and temperature effects of the jet exhaust on the induced flow. Results are computed on the IBM 7094 computer.

Key Words: V/STOL analysis methods
V/STOL aerodynamics
aerodynamic interference
pitching moments

2.27 THRUST DEFLECTION BY MEANS OF SPOILERS FOR DUAL-FLOW ENGINES (STRAHLABLENKUNG AN ZWEIREISTRIEBWERKEN DURCH SPOILER), Seibold, W., (WGLR), October 12, 1962.

Theoretical and experimental investigation of the effectiveness of solid and pneumatic spoilers in deflecting the thrust of bypass engines, with particular reference to lifting thrust at takeoff analytical results for perpendicular spoilers in plane flow, 45° spoilers in plane flow, air-cooled vertical spoilers, and thrust deflection by lateral blowing are presented in the form of diagrams. The effectiveness of thrust deflection is examined as a function of engine design and mode of operation.

Key Words: thrust deflection
thrust spoilers
lift generation

2.28 SUR L'UTILIZATION DES JETS PROPULSIFS A L'HYPERSUSTENTATION D'UN AVION, Poisson-Quinton, Ph and Bevert, A. Techn. at Sc. Aero, September-October 1959.

Survey of various methods of lift generation by means of jets and evaluation of the jet flap principle. Wind tunnel experiments on three configurations of hypothetical aircraft capable of high speed with low aspect ratio wings are described. The lift and drag performance, as functional thrust, is compared with that obtained by simple downward deflection of the jets. The longitudinal stabilization achieved by means of auxiliary jets in the mose of the ground effect principle with results of the effect of various (intensity and orientation of the jets) as function of the distance from the ground. The similarity of results obtained on a platform and on jet flaps is pointed out and the possibility of using the favorable ground effect for takeoff and landing application to high-speed aircraft is evaluated.

Key Words: jet deflection
lift generation

2.29 REINGESTION CHARACTERISTICS AND INLET FLOW DISTORTION OF V/STOL LIFT-ENGINE FIGHTER CONFIGURATIONS, Kirk, J. V. and Barrack, J. P., Journal of Aircraft Volume 6, No. 2, March-April 1969.

Short path reingestion of exhaust gas into engine inlets during hover with high-temperature rise and inlet flow distortion during transition are two important problem areas for lift-engine powered V/STOL aircraft. These problems have been studied at NASA-Ames Research Center using a large-scale generalized lift-engine fighter model powered by J-85 engines. The factors affecting exhaust gas reingestion, engine surge, and hover performance are presented and discussed for two lift-engine arrangements. Inlet flow distortion and total pressure recovery during transition from hover to wing supported flight are shown for both lift-engine configurations. Excessive thrust loss and compressor stalls were experienced when the exhaust vector angle was 90°. Vectoring the exhaust approximately ±20° from vertical virtually eliminated reingestion.

Key Words: exhaust gas reingestion

2.30 SURVEY OF THE GROUND EFFECT ON V/STOL AIRCRAFT WITH JET PROPULSION-REPORT OF LITERATURE, Schwantes, E., NASA TT F-12, October 1969.

A tabular survey was presented of the results of 132 reports on the ground effects with jet lift V/STOL aircraft. The region of the deflected jet investigated was described and the test conditions compared.

Key Words: jet deflection
lift generation
V/STOL

2.31 INVESTIGATION IF INTERFERENCE OF A DEFLECTED JET WITH FREE-STREAM AND GROUND ON AERODYNAMIC CHARACTERISTICS OF A SEMI-SPAN DELTA-WING VTOL MODEL, Spreemann, K. P., NASA TN D-915, August 1961.

Abstract is not available.

2.32 INTERFERENCE EFFECTS OF SINGLE AND MULTIPLE ROUND OR SLOTTED JETS ON A VTOL MODEL IN TRANSITION, Vogler, R. D., NASA TN D2380, August 1964.

Data were obtained through an angle of attack range, with 10 different geometric arrangements of nozzles in the bottom of the model fuselage, with and without jet deflection. The ground effects at zero forward speed without jet deflection were obtained.

Key Words: aerodynamic interference

2.33 AN INVESTIGATION OF FLOW IN CIRCULAR AND ANNULAR 90° BENDS WITH A TRANSITION IN CROSS SECTION, Wilbur, S. W., NACA TN 3995, August 1957.

An investigation at low speed of the performance of circular and annular 90° bends of simple shapes was conducted for configurations for which the cross-sectional area was constant, expanding, and contracting. Two series of transition bends (circular to annular and annular to circular) were included, in which the transition occurred upstream of the bend, within the bend, and downstream from the bend. The data presented include the exit velocity profiles, the relative total-pressure-loss coefficients measured at the exit station, and an index for the exit total-pressure distortion.

Key Words: flow in 90° bends
internal flow losses

2.34 INFLUENCE OF A JET ON THE AERODYNAMIC PROPERTIES OF WINGS POSITIONED ABOVE THE JET, Baurnert, W. and Harms, L., DGLR-Symposium, December 1970 (German).

An experimental investigation is presented showing the influence of a jet and wing positioned above the jet. Two wings (rectangular and swept) are investigated. Position, inclination and velocity of the jet are varied. The wing was on-balance in order to determine jet interference effects. The test results show considerable influences of the jet on the wing lift and pitching moments.

Key Words: thrust vectoring
aerodynamic interference

2.35 STATIC CALIBRATION OF AN EJECTOR UNIT FOR SIMULATION OF JET ENGINES IN SMALL-SCALE WIND TUNNEL MODELS, Margason, R. J. and Gentry, Carl L., NASA TN D-3867, October 1966.

This report describes an ejector that was developed to simulate performance characteristics of a jet engine in small-scale wind tunnel models. The simulator was fitted with thrust vectoring nozzle to simulate a lift-cruise engine, with a nozzle 90° deflection angle and a lift engine with nozzle deflection angle of 0, 15, and 30°. Thrust and mass flow data are presented.

Key Words: thrust vectoring nozzles
thrust calibration
mass flow calibration

2.36 CONSIDERATIONS OF SOME JET-DEFLECTION PRINCIPLES FOR DIRECTIONAL CONTROL AND FOR LIFT, Von Glahn, U. H. and Povolny, J. H., Society of Automotive Engineers, Paper n219 for meeting September 30th, 1957.

The performance characteristics of various devices applicable for VTOL and STOL studied at the NACA Lewis Laboratory are briefly discussed. Plots of axial thrust ratio versus deflected force ratio at a nozzle pressure ratio of 2.0 are presented for the various deflector configurations. The performance of a coanda nozzle is also investigated.

Key Words: internal deflector
external deflector
eyeball
coanda
static performance
model test

2.37 LIFT ENGINE TECHNOLOGY, Foster, T. and Paget, H. D., SAE Paper, 1965.

Design criteria and operating characteristics of auxiliary lift engines similar to the Continental turbojet lift engine are discussed. Some performance data on a rotating cascade and spherical nozzle is presented.

Key Words: lift engine
rotating cascade deflector
spherical nozzle

2.38 LOW-SPEED AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE STOL TRANSPORT MODEL WITH AN AUGMENTED JET FLAP, Cook, A. M. and Aiken, T. N., NASA TM-X-62, 017, 1971

An investigation was made to study the aerodynamic characteristics of a large scale model equipped with an augmented-jet flap and underwing cruise engines with deflectable thrust capability. The flap installation was on the inboard part of the wing, with blown ailerons outboard. Primary configurations tested were those selected for landing approach and takeoff conditions. Assessment was made of the effects of the underwing engines and nacelles with variations in thrust magnitude and direction. The tests were made with and without the horizontal tail at a wind tunnel dynamic pressure of 383 newtons per square meter (9 pounds per square foot), corresponding to a Reynolds number of 2.9 million. The range of jet momentum coefficients was 0 to 1.07.

Key Words: thrust vectoring
aerodynamic stability and control

GENERAL THRUST REVERSER/VECTORING ABSTRACTS

3.1 EVALUATION OF A COMBINATION THRUST REVERSER-JET DEFLECTOR CONCEPT, Logie, R. H., Galey, D. W. and White, A. J., AIAA Paper No. 64-287, July 1964.

The paper presents the results of a study to evaluate the performance of thrust reverser/vectoring systems for deceleration during landing and refused takeoff, rapid deceleration during level flight, emergency flight path and speed control, and reduced landing speed. Evaluation was accomplished by analytical studies, model tests, and review of operational data. Experimental results show lift and thrust as a function of deflector rotation angle for a nozzle pressure ratio of 2.0.

Key Words: external target thrust reverser
external mechanical deflector door
static performance
field length analysis

3.2 OPTIMIZING THE PROPULSION/LIFT SYSTEM FOR TURBOFAN STOL AIRCRAFT, Bowling, H. T., Hurkamp, C. H. and Thornton, R. M., AIAA Paper No. 69-1131, October 1969.

A methodology is developed in which aircraft configurations are optimized and systems are compared with cost effectiveness included in the initial stages of analysis. This method is applied to a comparison of propulsive high-lift systems for a STOL configuration with high-bypass ratio turbofan engines. Three basic propulsive lift systems are considered: (1) external blowing of the trailing edge flaps, (2) flowing from the interior of the wing at both the knee and trailing edge of the flap (jet flap concept) combined with thrust vectoring, and (3) blowing from the interior of the wing at the flap knee (BLC concept) combined with thrust vectoring. These systems are optimized for a fixed takeoff distance and then incorporated into a parametric mission-sizing computer program which recognizes the weight aspects of each system. The results of this program are costed and minimum cost configurations are selected and compared.

Key words: STOL transport
high lift system
thrust vectoring
thrust reversing

3.3 PRELIMINARY STUDY DATA, THRUST VECTORING AND THRUST REVERSER SYSTEM, R70AEG336, General Electric, August 1970.

This report contains preliminary design study data for several thrust vectoring and/or thrust reversing systems applicable to STOL transports. Design considerations and a brief description of each system are presented. Static performance data (C_V) are presented for a double rotating cascade model, a single bearing swivel nozzle, a three bearing vectoring nozzle, a bifurcated swivel nozzle, and a bifurcated swivel cascade nozzle. The systems are evaluated against a list of stated design criteria. The report reviews General Electric's experience with remote tip turbine lift system capability and thrust reverser designs. Thrust reverser designs discussed include an external blocker door reverser (target type), a translating cascade design, the CF6 reverser, an internal blocker door with cascades, and the SST internally mounted target thrust reverser. Static performance data consisting of reverser efficiency, airflow match, or discharge coefficient are presented for most of these reversers.

Key Words: single bearing swivel vectoring nozzle
three bearing vectoring nozzle
bifurcated swivel vectoring nozzle
rotating cascade vectoring nozzle
cascade thrust reverser
external target thrust reverser
internal target thrust reverser

3.4 BACKGROUND AND RELATED EXPERIENCE IN EXHAUST NOZZLE REVERSER AND DEFLECTOR SYSTEMS, Pratt & Whitney Aircraft, Reference No. 70-2602, 1970

The document describes the empirical and analytical capabilities relating to reversers and deflectors that Pratt & Whitney Aircraft has developed during recent years. Descriptions of reverser and deflector systems found to be attractive in past applications are provided. Existing P&WA wind tunnel and full scale test data is also briefly reviewed. Sections are included for reverser analysis, deflector analysis, test technology, and engine stability margin analysis.

Key Words: Pratt & Whitney Aircraft
thrust reverser systems
thrust deflection systems
background and experience

3.5 SYSTEMS FOR DEFLECTION OF THE JET STREAMS OF TURBOJET ENGINES, Svyatogorov, A. A., Papov, K. N. and Khvostov, N. I., NASA-TT-F-603, March 1970. Translation of "Vstroystva dlya Otkloneniya Reaktivnoy Strui Turboreaktivorykh Dvigateley," "Mashinostroyeniye" Press, Moscow, 1968.

Thrust reverser and thrust vectoring devices for deflecting the exhaust jet of turbojet and turbofan engines are examined. The status of research and development of reversers and deflecting devices is described. The efficiency of thrust reversal in braking aircraft upon landing and in-flight is indicated, as well as efficiency in deflecting the jet exhaust downward to shorten the takeoff and landing distance. A classification is given and principles laid down for building reverser and deflecting devices and examples of the construction of a variety of devices are cited. The fundamentals of gas-dynamic calculation of reverser and deflection devices are discussed. The method of calculation is illustrated by an example of the development of a reverser design from data of experimental research. Methods of research and experimental facilities for testing models of reverser and deflecting devices are examined.

Key Words: thrust reverser
thrust vectoring
design
performance

THRUST REVERSER/VECTORING FLOW FIELDS ABSTRACTS

4.1 PENETRATION OF A JET INTO A NON-UNIFORM STREAM, Gerend, R. P., MSME Thesis, Seattle University, June 1968.

This report describes an extension of Abramovich's semi-empirical theory to analyze jet penetration into a non-uniform stream. The experiment which was performed to verify the revised theory is next described, and a somparison between the experiment and theory is made. The variation of jet penetration characteristics with main-stream Reynolds number is shown, and the measured jet spreading coefficients and thickness-to-width ratios are examined. It is shown that these coefficients differ considerably from the values used by Abramovich in his analysis. The effects of using different coefficients on the jet trajectories predicted by the revised theory are discussed. It is concluded that the revised theory provides a good representation of the axis of a jet penetrating either a uniform or non-uniform turbulent stream; however, the emprirical coefficient quoted by Abramovich are not necessarily representative of a round jet, even though, when used together in the numerical solution of the revised theory, they do provide a good representation of the jet axis due to self-compensating effects.

Key Words: jet trajectory
jet penetration

4.2 SURVEY AND STUDY OF THE PENETRATION AND DEFLECTION OF A JET INJECTED AT AN ANGLE INTO A UNIFORM STREAM, Filler, L., D6-20380TN, The Boeing Company, June 1968.

Empirical equations and analytic solutions for the trajectory of a jet injected at an angle into a uniform main stream are discussed. The empirical equations of Ivanov, Shandorov, and Margason are compared for jet injection angles of 60, 90, and 120 degrees and for jet to main stream dynamic pressure ratios of 10, 100, and 1.000. The empirical equations compare favorably with each other within their respective ranges of validity. Results are presented using Abramovich's closed form solution for the jet centerline of a sharply bent jet. Results are also presented for numerical solutions using Abramovich's theory without the approximation of a sharply bent jet.

Vizel and Mostinskii proposed an improved theory when they noted a large discrepancy between experiment and Abramovich's theory. It is shown that Vizel and Mostinskii propagate a textual error from Abramovich's report and that a correct comparison of the numerical solutions without approximating a sharply bent jet conclusively shows that Abramovich's theory is superior.

Key Words: jet penetration
jet trajectory

4.3 THE BEHAVIOR OF JETS IN CROSS FLOW, Kronauer, R., Boeing Scientific Research Laboratories Technical Memorandum No. 56, The Boeing Company, December 1968.

The report discusses the physical mechanisms of a turbulent jet exhausting at right angles into a cross flow. The report concludes that transverse shear is eight times more effective than longitudinal shear in producing transition from potential core flow to a horseshoe shaped cross section. The entrainment rate subsequent to transition is 2.5 times faster than for the free jet. The effect of the entrainment and pressure field mechanisms on the jet deflection are discussed. A method is developed for predicting jet trajectories for the SST exhaust plume using a transverse momentum analysis.

Key Words: jet trajectory
jet penetration
entrainment

4.4 RECIRCULATION EFFECTS PRODUCED BY A PAIR OF HEATED JETS IMPINGING ON A GROUND PLANE, Hall, G. R. and Rogers, K. H., NASA CR-1307, May 1969.

An experimental investigation of the recirculation effects resulting from the interaction of a pair of heated jets, a quiescent environment, a ground plane, and a pair of inlets was performed. Upwash blockage surfaces were also used for selected tests. Inlet temperature rise and upwash flow characteristics were determined for a wide range of model geometries and inlet/nozzle flow conditions. Details of the near flow field structure were obtained. Inlet temperature rise and induced aerodynamic forces have been related to the character of the near flow field. The results of the investigation lead to several significant conclusions which relate directly to model simulation of full-scale recirculation phenomena.

Key Words: impingement
recirculation
reingestion

4.5 EMPIRICALLY DETERMINED WIND AND SCALE EFFECTS ON HOT GAS RECIRCULATION CHARACTERISTICS OF JET V/STOL AIRCRAFT, Ryan, P. E. and Cosgrove, W. J., NASA CR-1445, October 1969.

The report presents results from a small scale experimental investigation into the engine inlet temperature rise (ITR) and recirculating flow field caused by the hot exhaust gases for three V/STOL fighter configurations using lift jet engines in static ground proximity. The major test parameters included wind speed and direction, model height, exhaust deflection angle, angle of attack, wing planform to jet exhaust area ratio, and model geometry. Temperature time histories measured in and about the models were used to compute steady state values of ITR and near field temperatures. Smoke flow and tuft photographs were used to evaluate recirculation patterns.

Key Words: hot gas recirculation
reingestion
recirculation flow field

4.6 INVESTIGATION OF THE RECIRCULATION REGION OF A FLOW FIELD CAUSED BY A JET IN GROUND EFFECT WITH CROSSFLOW, Binion, T. W., AEDC-TR-70-192, September 1970.

A wind tunnel investigation was conducted to determine the velocities in the recirculation region of the flow field produced by the interaction of a jet impinging on a ground plane with a low speed crossflow. Axial and vertical velocity component measurements were obtained with a forward-scattering laser Doppler velocimeter. Test results provide two-component velocity fields and indicate that the jet-to-free-stream velocity ratio is much more important in determining the flow field than the magnitude of the individual velocities.

Key Words: impingement
recirculation

4.7 JET FLOW IMPINGEMENT ON PLANE SURFACES AND THE HOT GAS INGESTION PHENOMENA OF V/STOL AIRCRAFT: A REVIEW, Sloan, D., D6-24852TN, The Boeing Company.

The document presents a comprehensive literature review of investigations related to jet flow impingement and hot gas recirculation. The report contains a general description of the flow fields which can be generated by V/STOL configurations during low speed operations close to ground. A relation is shown between jet flow impingement on the ground and inlet temperature rise together with a description of the consequences of hot gas reingestion. The report discusses preview work in detail commenting on the merits and identifying those areas in which an understanding of the flow is most lacking. Recommendations are made for future experimental and theoretical work. This document is an excellent review of jet flow impingement and hot gas recirculation problems and is recommended for those unacquainted with this field.

Key Words: impingement
recirculation
reingestion

4.8 A WIND TUNNEL INVESTIGATION OF JETS EXHAUSTING INTO A CROSS-FLOW, VOLUME I, TEST DESCRIPTION AND DATA ANALYSIS, Fricke, L. B., Wooler, P. T., and Ziegler, H., AFFDL-TR-70-154, Volume I, December 1970.

A low speed wind tunnel test of a four-foot diameter circular plate model with up to three exhausting jets was conducted to determine surface static pressure distributions, jet paths, and jet decay characteristics in the presence of a crossflow. Data were obtained for the one-jet configuration with the jet exiting at a number of angles to the plate and at various velocity ratios and sideslip angles. Two-jet arrangements were tested with the jets exiting normal to the plate for three different spacings between the two jets and at a number of velocity ratios and sideslip angles. Three-jet configuration data were obtained with the jets exiting normal to the plate for a number of velocity ratios and sideslip angles. As a result of this investigation, several conclusions are deduced pertaining to the interaction of multiple jets exhausting into a crossflow.

Key Words: jet penetration
jet in a crossflow
jet trajectory

4.9 GENERALIZED HOT-GAS INGESTION INVESTIGATION OF LARGE-SCALE JET VTOL FIGHTER-TYPE MODELS, McLemore, H. C. and Smith, C. C. Jr., NASA TN D-5581, January 1970.

An investigation was conducted to study the problem of hot gas reingestion on large-scale jet VTOL fighter-type aircraft configurations. The investigation included tests of configurations with several exhaust nozzle arrangements, inlet positions, and wing positions and sizes for a range of nozzle heights from about 1 to 5 effective nozzle diameters above the ground. The inlet and nozzle arrangements simulated airplane configurations with inlet above the exhaust nozzles (direct lift engines) or configurations with side inlets and thrust vectoring nozzles. The tests were conducted for a range of forward speeds from zero to approximately 35 knots and for side winds from about 8 to 12 knots.

Key Words: VTOL
reingestion

4.10 THE "FOUNTAIN EFFECT" AND VTOL EXHAUST INGESTION, Hall, G. R. and Adarkar, D. B., Journal of Aircraft, Volume 6, No. 2, March-April 1969.

This paper presents the results of an experimental study of the ingestion and flowfield characteristics of the interaction of two parallel jets of heated air, a quiescent environment, a perpendicular "ground" plane, and a pair of inlets. The flowfield was observed visually, and the transient response of the inlet thermocouples was recorded on an oscillograph over a range of configuration and flow parameters, e.g., spacing ratios, angles, and velocities. The major contribution of this study is the obtaining of a detailed qualitative picture of the upwash flowfield and its relation to ingestion levels. Data were obtained also with the "image plane" technique (and with the addition of simulated fuselage and wings to better approximate a VTOL aircraft). Some apparent discrepancies between previous full-scale and small-scale VTOL exhaust ingestion tests are explained. This study also points out that inlet temperature fluctuations are a random process and that a statistical approach to data analysis is desirable.

Key Words: exhaust gas reingestion
fountain effect

4.11 A COMPREHENSIVE REVIEW OF V/STOL DOWNWASH IMPINGEMENT WITH EMPHASIS ON WIND INDUCED RECIRCULATION, Unitt, P. J., Air Force Institute of Technology Thesis GAM/AE/69-9, May 1969.

This report contains a summary of the work, both analytic and experimental, that has been performed in the last decade, on rotor and jet downwash impingement for V/STOL aircraft. The various aspects of the problem as gathered from available reports, are discussed in detail. The direct lift jet and rotor downwash fields are described and inherent operational difficulties are enumerated. One aspect of impingement, recirculation, is treated in a similar manner. Its causes are given, underlying mechanisms are suggested and operational problems are presented. Analytic solutions and experimental investigations for both the impingement and recirculation problems are discussed. A classified bibliography of 35 references is included in which the reports surveyed are listed in ready reference form, according to type and content. In an attempt to analyze wind induced recirculations, a solution is given which is a re-interpretation of the allied problem of jet inclination, as solved by T. Strand. Although the recirculation problem is not solved, some indication is given of the effect of a light wind on a normally impinging jet.

Key Words: downwash
impingement
recirculation
V/STOL analysis methods

4.12 AN ANALYTICAL METHOD OF DETERMINING GENERAL DOWNWASH FLOW FIELD PARAMETERS FOR V/STOL AIRCRAFT, Hohler, D. J., Technical Report AFAPL-TR-66-90, November 1966.

This report presents a method of analytically determining the general downwash flow field parameters of various types of V/STOL aircraft. V/STOL aircraft produce high downwash air velocities that impinge and spread out over the surface of the ground. Past theoretical methods based on incompressible flow theory have been unsuccessful in establishing a means of computing this downwash flow field. A combined method, however, of experimental data and analytical approaches have yielded a useful means of predicting the general downwash flow field parameters. This report presents these approaches and demonstrates their usefulness. The report contains 30 references.

Key Words: downwash
impingement
V/STOL analysis methods
V/STOL aerodynamics

4.13 JET RECIRCULATION EFFECTS ON V/STOL AIRCRAFT, Cos, M. and Abbott, W. A., Journal of Sound and Vibration, Volume 3, No. 3, 1966.

Gases from the jets of lifting engines may be recirculated to the engine intakes and cause a loss of thrust. Model tests with heated jets were made to provide data on velocities in the jet around the impingement region and to assist the correlation of model and full-scale measurements. Vertical and inclined jets were studied under steady and transient conditions during the initial establishment of the wall jet flow and the relationship between these two cases is given. Tests with jets from nozzles moving over the ground showed that the distance the wall jet travels before being turned back by the relative wind may be obtained from measurements with stationary jets. Experiments with heated jets showed that a parameter including the initial dynamic pressure and the temperature of the jet may be used to correlate the vertical penetration of a free jet and the lateral extent of an impinging jet to the point where it separates from the ground due to buoyancy effects.

Key Words: impingement
jet recirculation
reingestion

4.14 STUDIES OF EXHAUST-GAS RECIRCULATION FOR VTOL AIRCRAFT, Kemp, E. D. G., Journal of Aircraft, Volume 6, No. 2., March-April 1969.

The ingestion of hot, recirculated exhaust gas is an important consideration for VTOL aircraft since it can lead to serious performance penalties and engine handling problems. Model scaling laws have been established by other investigators and the reliability of the scaling has been confirmed by unpublished results of model and full-scale tests on the P.1127 VTOL strike fighter. This paper discusses the model techniques and their limitations, which have been used by Hawker Siddeley Aviation to study exhaust-gas recirculation for VTOL transport aircraft. Typical results are given from intake temperature measurements and flow visualization experiments using smoke and ground surface oil flow patterns. The results show that very useful information on the position of hot gas "fountains" can be obtained from a redimentary half-model but that a study of transient temperatures during realistic VTOL maneuvers requires a complete, moving model. It is shown that in some circumstances a synthesis of results from a fixed model can be misleading.

Key Words: exhaust gas recirculation

4.15 V/STOL AIRCRAFT AERODYNAMIC PREDICTION METHODS INVESTIGATION, Wooler P. T., et. al., Interim Report NOR 70-121, Northrop Corporation, June 1970.

This report presents results obtained during Phase I of a study aimed at developing analytical methods for predicting the aerodynamic stability and control coefficients and derivatives for lift jet, lift fan, and vectored thrust V/STOL aircraft operating in the hover and transition flight regimes. Analytical models are presented for predicting the nonlinear aerodynamics of a wing or body, a jet in a crossflow, and the effects of inlet flows when the inlet centerline is inclined at a large angle to the mainstream. The methods can be used to predict forces and moments on wings or bodies in the neighborhood of jets or fans, including the effects of the contribution of power to the derivatives and coefficients. The theoretical aerodynamics of the singular case of true hover are presented. The problem of deriving a handbook technique for calculating

SECTION III

DATA REVIEW

NOMENCLATURE FOR DATA REVIEW

SUMMARY CHARTS

Column Heading	Abbreviation	Definition
Thrust Reverser Concepts	T	target
	BD	blocker/deflector
	C	cascade
	S	thrust spoiler
Thrust Vectoring Concepts	CN	cascade nozzle
	SB	single-bearing swiveling nozzle
	MB	multi-bearing swiveling nozzle
	ED	external deflector
	SE	spherical eyeball
	VN	ventral nozzle
Scale of Test	MS	model scale
	FS	full scale
Type of Test	S	static
	WT	wind tunnel
	FT	flight test
	TT	taxi test
Test Variables	A_n	nozzle exit area
	A_p	projected area of target thrust reverser
	A_r	thrust reverser geometric exit area
	C_T	thrust coefficient
	C	momentum coefficient
	i_t	tail incidence angle
	M	Mach number
	NPR	nozzle pressure ratio

NOMENCLATURE (CONTINUED)

Column Heading	Abbreviation	Definition
Test Variables (Cont.)	q	freestream dynamic pressure
	R_e	Reynolds number
	r/D	radius of turn/entrance diameter ratio
	RPM	engine revolutions per minute
	S	door setback distance
	V	freestream velocity
	α	angle of attack
	σ	cascade solidity, chord length/spacing
	ψ	angle of yaw
	θ_{door}	thrust reverser door angle measured from engine centerline
Test Data	C_L	lift coefficient
	C_{DA}	airplane drag coefficient
	C_F	thrust minus drag coefficient
	C_{FG}	gross thrust coefficient
	$C_{FG_{rev}}$	reverser gross thrust coefficient
	C_m	pitching moment coefficient
	C_v	velocity coefficient
	C_{VX}	velocity coefficient based upon measured axial component of thrust
	C_D	discharge coefficient
	F_g	gross thrust
	F_r	reverser thrust component
	I_T	impingement temperatures on aircraft surfaces
	P_T	total pressure
	F_V	flow visualization

NOMENCLATURE (CONTINUED)

Column Heading	Abbreviation	Definition
Test Data (Cont.)	V_e	effective velocity ratio
	V_j/V_∞	jet velocity/freestream velocity ratio
	V_r	reingestion speed, knots
	W_r	reverser mass flow
	η_r	thrust reverser efficiency data*
	ΔT_{inlet}	inlet temperature rise
	ϕ	thrust reverser airflow match data*
	θ_{actual}	actual thrust vector angle

*There are many different definitions of η_r and ϕ. The symbols η_r and ϕ as used here refer to a type of data rather than a specific definition.

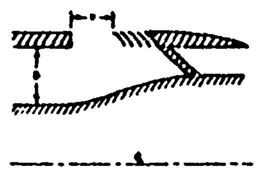
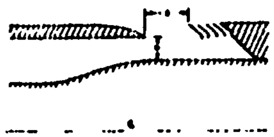
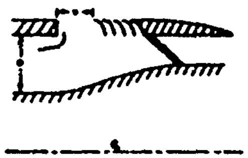
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.1	1965	C	C-5A	GE 1/6-F4C PWA JTF 14E/28	0.0658	S	4		NPR = 1.4 → 1.7 σ = 1.54 x/D = 0.13 → 0.78 BLADE ENTRANCE ANGLE = 90° BLADE EXIT ANGLE = 40, 50° NUMBER OF BLADES = 4, 5, 6 THIN REACTION BLADE PROFILE	F_r w_r	ANNULAR FAN NOZZLE CASCADE THRUST REVERSER
1.1	1965	C	C-5A	GE 1/6-F4C PWA JTF 14E/28	0.0658	S	2		NPR = 1.4 → 1.7 σ = 1.54 x/D = 0.0656 → 1.06 BLADE ENTRANCE ANGLE = 90° BLADE EXIT ANGLE = 40° NUMBER OF BLADES = 4, 6 THIN REACTION BLADE PROFILE	F_r w_r	ANNULAR FAN NOZZLE POST EXIT CASCADE THRUST REVERSER
1.1	1965	C	C-5A	GE 1/6-F4C PWA JTF 14E/28	0.0658	S	4		NPR = 1.4 → 1.7 σ = 1.54 x/D = 0.22 → 0.46 BLADE ENTRANCE ANGLE = 90° BLADE EXIT ANGLE = 40° NUMBER OF BLADES = 4, 5, 6 NUMBER OF TURNING VANE CONFIGURATIONS - THIN REACTION BLADE I	F_r w_r	ANNULAR FAN NOZZLE CASCADE THRUST REVERSER WITH TURNING VANES
1.1	1965	C	C-5A	GE1/6-F4C PWA JTF 14E/28	0.0658	S	1		NPR = 1.2 → 1.6 σ = 1.54 x/r = 0 → 0.25 BLADE ENTRANCE ANGLE = 90° BLADE EXIT ANGLE = 40° NUMBER OF BLADES = 3 THIN REACTION BLADE PROFILE	F_r w_r	ANNULAR PRIMARY NOZZLE CASCADE THRUST REVERSER

TABLE V-1

THRUST REVERSER DATA REVIEW
CASCADE THRUST REVERSERS

1.1 1.2 1.3

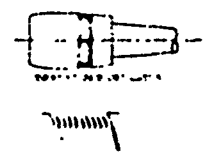
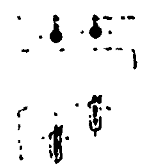
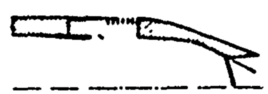
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.69	1967	C	C-5A	TF39	MS	S, WT	1		NPR = 1.0→2.0 M = 0→0.85 BLADE ENTRANCE ANGLE = 55° BLADE EXIT ANGLE = 55° REACTION TYPE BLADES	η_r ϕ SCHLIEREN PHOTOGRAPHS CASCADE FLOW APPROACH ANGLE CASCADE EXIT STATIC PRESSURES THRUST REVERSER AND INLET DRAG COEFFICIENTS C_F	PRESENTS LIMITED RESULTS OF STATIC AND WIND TUNNEL TEST OF ANNULAR CASCADE THRUST REVERSER
1.3	1963	C	COMET II 707-420	CONWAY	MS	WT	1		FREESTREAM VELOCITY THREE REVERSER CONFIGURATIONS	REINGESTION VELOCITY FLOW FIELD TEMPERATURE ISOTHERMS SMOKE FLOW VISUALIZATION	THE REPORT DOES NOT CONTAIN ADEQUATE GEOMETRIC DEFINITION OR DATA TO BE OF MUCH USE
3.3	1970	C	ADVAN-CED FIGHTER AIRCRAFT	G	MS	S, WT	1		NPR = 1.0→6.0 M = 0→0.9 BLOCKER FLAP ANGLE = 0→75°	$C_{f_{grev}}$ C_D	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ALL THE DATA
3.3	1970	C	ADVAN-CED FIGHTER AIRCRAFT	G	MS	S, WT	1		NPR = 1.0→6.0 M = 0→0.9	$C_{f_{grev}}$ C_D	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ALL THE DATA

TABLE V-1, CONTINUED

THRUST REVERSER DATA REVIEW
CASCADE THRUST REVERSERS

1.1 1.2 1.3

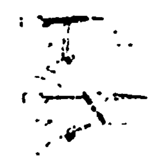
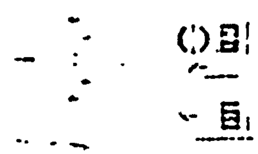
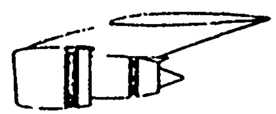
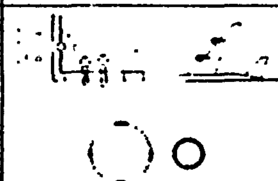
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.3	1970	C	C-5A	TF39	1.0	S	1		NPR = 1.275 → 1.525	$C_{f_{grev}}$	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ALL THE DATA
1.52	1961	C	SUBSONIC TRANS-PORT	G	.15	WT	12		q = 10 → 25 psf $\alpha = 0^\circ$ BLADE EXIT ANGLE = 35 → 77° 12 CONFIGURATIONS VARYING VANE EXIT ANGLES, CANT ANGLES, AND EXTERNAL BLOCKER PLATES Re = 0 → 6.6×10^6	V_r F_B F_r w SMOKE FLOW VISUALIZATION INTERFERENCE DRAG	REINGESTION WIND TUNNEL TEST OF A LARGE SCALE FOUR ENGINE JET TRANSPORT. ALSO TESTED A TARGET THRUST REVERSER AS DESCRIBED ON PAGE 2
1.36	1969	C	747	JT9D-3	1.0	FT	1		EPR = 1.4 V = 20 → 120 KNOTS $\delta_{flaps} = 30^\circ$	IMPINGEMENT TEMPERATURES	IMPINGEMENT TEMPERATURES WERE MEASURED ON ENGINE STRUTS AND NACELLES, UNDERWING, AND FUSELAGE
1.11	1967	C	747	JT9D	0.06	WT	8		NPR = 1.4 → 1.5 V = 40 → 140 KNOTS 4 FAN REVERSER CONFIGURATIONS AND 4 PRIMARY REVERSER CONFIGURATIONS	η_r ΔT_{inlet} C_L C_{DA} C_m FLOW VISUALIZATION	WIND TUNNEL REINGESTION AND EFFECTIVENESS TEST OF THE 747 THRUST REVERSER. TESTED WITH LEADING AND TRAILING EDGE FLAPS RETRACTED AND EXTENDED

TABLE V-1, CONTINUED

1.1 1.2 1.3

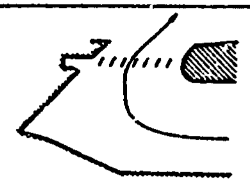
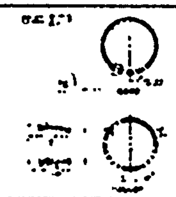
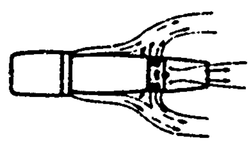
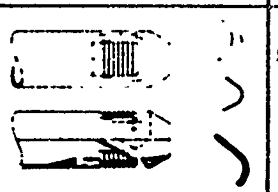
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.4	1966	C	DC-10	CF6	0.23	S	1		NPR = 1.1 → 1.8 σ = 0.574 → 1.912 BLADE ENTRANCE ANGLE = 90° BLADE EXIT ANGLE = 40° NUMBER OF BLADES = 0 → 9 BLOCKER DOOR ANGLE = 133°	C_{V_x} C_D FLOW VISUALIZATION	ANNULAR FAN NOZZLE CASCADE THRUST REVERSER. TESTED 20° PIE SHAPED SEGMENTS USING CIRCULAR ARC CASCADE BLADES.
1.6	1964	C	707-120	JT3D	0.0833	WT	92		V = 50 → 100 KNOTS 92 CONFIGURATIONS VARYING STRONGBACK CANT ANGLE, EXIT ANGLE, AND CIRCUMFERENTIAL BLOCKAGE	ΔT_{inlet} REINGESTION FLOW VISUALIZATION	FAN AND PRIMARY NOZZLE CASCADE THRUST REVERSER REINGESTION WIND TUNNEL TEST.
1.26	1965	C	367-80B	JT3D	1.0	S, FT	1		NPR = 1.1 → 1.8	F_B AREA MISMATCH ENGINE PERFORMANCE DATA	DESCRIBES DEVELOPMENT OF THE MODULATING PRIMARY NOZZLE CASCADE THRUST REVERSER, BLC, AND PROPULSION SYSTEM FOR THE 367-80B AIRPLANE (707 PROTOTYPE) SLOW FLIGHT PROGRAM.
1.42	1955	C	G	G	MS	S	15		NPR = 1.2 → 2.4 σ = 1.1 → 1.625 ℓ/w = 1.0 → 2.95 BLADE ENTRANCE ANGLE = 30, 60° BLADE EXIT ANGLE = 25, 30° BLADE PROFILES = 3 CONFIGURATIONS (THICK IMPULSE, THIN IMPULSE, THIN REACTION) TURBINE CONE POSITIONS = 5 $\theta_{blocker\ door}$ = 5 → 30°	η_r ϕ EXIT FLOW FIELD SURVEY THRUST MODULATION CHARACT.	PARAMETRIC STATIC TEST OF 15 CASCADE THRUST REVERSERS VARYING SOLIDITY, BLADE PROFILE AND APERTURE ASPECT RATIO. OBTAINED TMC DATA BY VARYING DUCKBILL BLOCKER DOOR ANGLE. TESTED WITHOUT AND WITH 5 TURBINE CONE POSITIONS.

TABLE V-1, CONTINUED

1.1 1.2 1.3

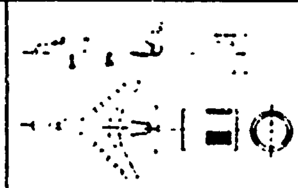
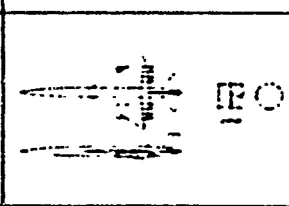
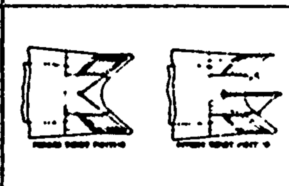
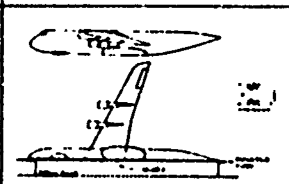
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.52 1.65	1960	C	F-100F	J57-P-21A	1.0	WT, FT	5		TPR = 1.0 → 1.8 q = 10 → 67 psf α = 0 → 21° ψ = -8 → 10° PERCENT MODULATION = 0 → 100% $\delta_{horizontal}$ = 0 → -25° δ_{rudder} = 0 → -15° 5 CONFIGURATIONS	ΔC_{DA} ΔC_m THRUST MODULATION CHARACT.	FULL SCALE TEST OF A CASCADE THRUST REVERSER FOR THE F-100F AIRPLANE.
1.55	1964	C	SST	G	LS	WT	1		q = 25 → 100 psf α = -4 → 17° δ_{flaps} = 0 → 30° $\delta_{horizontal}$ = 0 → -15° TAIL DIHEDRAL = 0 → -25° C_T = 0 → 0.6 R_e = 17.2 × 10^6 → 32.2 × 10^6	C_L C_{DA} C_m THRUST MODULATION CHARACT. EXHAUST IMPINGEMENT TEMPERATURE	LARGE SCALE TEST OF CASCADE THRUST REVERSERS FOR AN SST AIRPLANE
1.58	1957	C	F-86	J47	1.0	S	1		RPM = 70 → 100% PERCENT MODULATION = 0 → 100%	THRUST MODULATION CHARACT.	POST EXIT CASCADE THRUST REVERSER FOR THE F-86 FIGHTER AIRPLANE
1.67	1966	C	C-5A	TF39	0.057	WT	4		NPR = 1.025 → 1.2 M = 0.6 → 0.85 α = -2 → 4° SPOILER DEFLECTIONS = 0, 20° AILERON DEFLECTIONS = 0, ±15° PYLON CONFIGURATIONS = 7 THRUST REVERSER CONFIGURATIONS = 4	C_L, C_{DA} C_m	FAN NOZZLE CASCADE THRUST REVERSER FOR THE C-5A AIRPLANE

TABLE V-1, CONTINUED

1.1 1.2 1.3

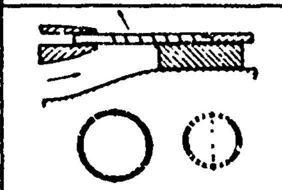
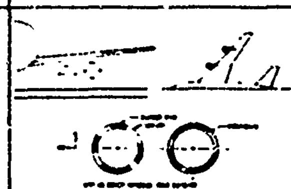
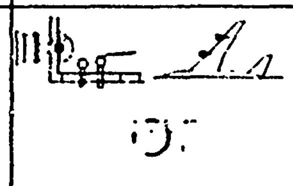
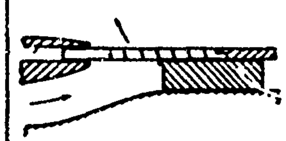
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.13	1967	C	747	JT9D	0.06	S	5		NPR = 1.2 → 1.7 SETBACK NUMBER OF OPEN VANES = 3.7 → 11 BLADE ENTRANCE ANGLE = 55 → 90° BLADE EXIT ANGLE = 50° 3 FAN REVERSER CONFIGURATIONS AND 2 PRIMARY REVERSER CONFIGURATION	C_V C_{Vx} C_D η_r ϕ FLOW VISUALIZATION	STATIC MODEL TEST OF 747 CASCADE THRUST REVERSER
1.31	1967	C	747	JT9D	0.06	WT	9		NPR = 1.3 → 1.5 V = 40 → 120 KNOTS NACELLE LOCATIC [illegible] 50% OF SEMISPAN 9 CONFIGURATIONS VARYING EXTERNAL BLOCKER DOORS WITH IDENTICAL INBOARD AND OUTBOARD PATTERNS	ΔT_{inlet} FLOW VISUALIZATION	PURPOSE OF TEST WAS TO DETERMINE REVERSER EXHAUST FLOW FIELD AND REINGESTION CHARACTERISTICS OF AN EARLY 747 AIRPLANE USING MIXED FAN AND PRIMARY FLOW. ALSO TESTED ANNULAR TARGET THRUST REVERSER
1.32	1967	C	747	JT9D	0.06	WT	9		NPR = 1.44 V = 30 → 110 KNOTS NACELLE LOCATIONS AT 30--60% AND 40--70% of SEMISPAN δ_{flaps} = 40, 50, 60° $\delta_{spoilers}$ = 0, [illegible]5° 9 LOCATIONS VARYING EXTERNAL BLOCKER DOOR	ΔT_{inlet} C_L C_{DA} C_m C_l FLOW VISUALIZATION	PURPOSE OF TEST WAS TO DETERMINE INSTALLED REVERSER EFFECTIVENESS, EFFECTS ON AIRPLANE LONGITUDINAL CHARACTERISTICS, AND REINGESTION SPEEDS. CASCADE REVERSER SIMULATED A MIXED FAN AND PRIMARY FLOW. IDENTICAL INBOARD AND OUTBOARD [illegible] PATTERNS
1.33	1967	C	747	JT9D	0.06	S	7		NPR = 1.2 → 1.7 σ = 1.15, 1.7 BLADE EXIT ANGLE = 50° BLOCKER DOOR POSITION 4 FAN REVERSERS AND 3 PRIMARY REVERSERS	η_r ϕ C_{Vx} C_D	STATIC MODEL TEST OF 747 CASCADE THRUST REVERSER

TABLE V-1, CONTINUED

1.1 1.2 1.3

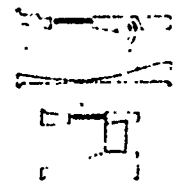
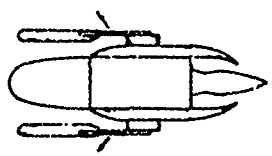
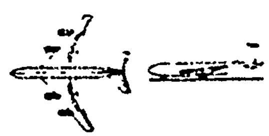
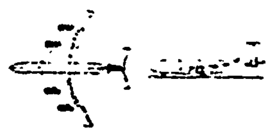
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.34	1967	C	747	JT9D	0.367 0.717	S	30		NPR = 1.2 → 1.6 σ = 1.15, 1.36, 1.5, 1.7 BLADE ENTRANCE ANGLE = 45,60,80,90° BLADE EXIT ANGLE = 50° AIRFOIL AND CONSTANT THICKNESS TYPE BLADE PROFILES BLOCKER DOOR POSITION (FLUSH AND 10 INCHES AFT FULL SCALE)	η_r ϕ FLOW VISUALIZATION P_T SURVEY AT REVERSER EXIT	LARGE SCALE 30 DEGREE SEGMENT MODEL TEST OF THE 747 FAN AND PRIMARY REVERSER MADE 275 RUNS FOR ALL POSSIBLE COMBINATIONS OF SOLIDITY RATIO AND BLADE PROFILE, INCLUDING SOME RUNS WHERE BLADES WERE REMOVED ONE AT A TIME
1.35	1965	C	747	JT9D	0.0633	S, WT	6		NPR = 1.54 RPM = 4 REVERSERS 2 CRUISE NOZZLES	P_T SURVEY AT FAN DISCHARGE	MEASURED FAN DISCHARGE PRESSURE DISTRIBUTIONS DURING REVERSING USING TURBOPOWERED NACELLE SIMULATORS
1.23	1963	C	367-80B	JT3D	MS	WT	1		V = 75 → 120 KNOTS α = -4 → 26° C_T = 0 → 0.61 C_μ = 0 → 0.12 δ_{flaps} = 30,70°	C_L C_{DA} $C_{L_{approach}}$ $V_{approach}$ FLOW VISUALIZATION	PURPOSE OF TEST WAS TO DETERMINE APPROACH SPEED AND C_L FOR 367-80B AIRPLANE WITH MODULATING PRIMARY REVERSER AND BLC. NACELLES WERE NOT ON BALANCE
1.33	1966	C	367-80B	JT3D	1.0	S, FT			EPR V	IMPINGEMENT TEMPERATURE	CONTAINS TEMPERATURE SURVEY DATA FOR THE 367-80B MODULATED PRIMARY REVERSER WITH BLC. MEASURED HEATING ON WING, STRUT, AND IN ENGINE ACCESSORY AREA.

TABLE V-1, CONTINUED

1.1 1.2 1.3

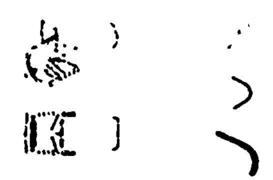
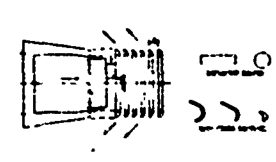
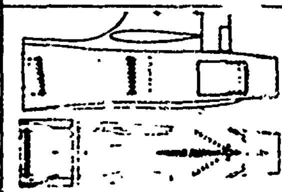
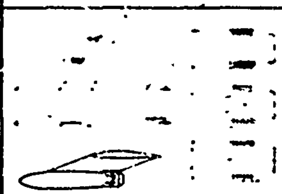
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.44	1956	C	G	G	0.25	S	1		NPR = 1.4 → 2.4 σ = 1.1 → 1.65 BLADE ENTRANCE ANGLE = 30, 60° BLADE EXIT ANGLE = 25, 30° PERCENT MODULATION = 45 → 100% BLADE PROFILES = 3 CONFIGURATIONS l/w (THICK IMPULSE, THIN IMPULSE, THIN REACTION)	η_r EXIT FLOW FIELD SURVEY	REFERENCE 1.44 CONTAINS SUMMARY OF SCALE MODEL STATIC TESTING FOR TARGET, TAIL-PIPE CASCADE, AND RING CASCADE THRUST REVERSER
1.44 1.47	1956	C	G	G	MS	S	117		NPR = 1.4 → 3.0 $A_{deflector}/A_r$ = 0.16 → 0.5 s/d_n = 0.08 → 0.31 L/d_n = 0.5 BLADE PROFILES = 3 CONFIGURATIONS DEFLECTORS = 5 CONFIGURATIONS NUMBER OF RINGS = 2 → 10	η_r ϕ THRUST MODULATION CHARACT. MACH NUMBER PROFILES OF EXHAUST	RING CASCADE THRUST REVERSER REFERENCE 1.44 IS A SUMMARY DOCUMENT. MOST OF THE DATA ARE CONTAINED IN REFERENCE 1.47
1.48	1957	C	SINGLE ENGINE FIGHTER	NON AFTER-BURNING TURBOJET	1.0	S, TT	1		NPR = 1.1 → 2.1 σ = 0.5 → 1.4 RPM = 50 → 100% V = 0 → 85 KNOTS BLADE ENTRANCE ANGLE = 30° BLADE EXIT ANGLE = 30°	F_B F_r η_r ϕ SMOKE FLOW VISUALIZATION STOPPING DISTANCE	FULL SCALE TEST OF A CASCADE THRUST REVERSER FOR A SINGLE ENGINE FIGHTER AIRCRAFT
1.51	1960	C	SUBSONIC TRANSPORT	G	LS	WT			NPR = 1.0 → 4.0 M = 0.4 → 0.86 α = -4 → 14° δ_{tail} = 0 → -4° Re = 2.0 × 10⁶ BLADE ENTRANCE ANGLE = 30° BLADE EXIT ANGLE = 30° THICK IMPULSE TYPE BLADE	C_L C_{DA} C_m BUFFET	PRESENTS EFFECTS OF THRUST REVERSAL AT MACH NUMBERS UP TO 0.86 ON THE LONGITUDINAL AND BUFFETING CHARACTERISTICS OF A TYPICAL JET TRANSPORT

TABLE V-1, CONTINUED

1.1 1.2 1.3

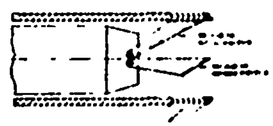
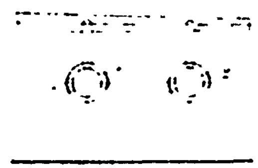
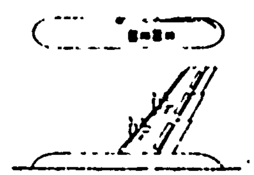
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.81	1950	C	G	J47-13	MS, 1.0	S	1		NPR = 1.1 → 1.7 RPM = 70 → 100% BLOCKER SETBACK	F_g F_r w FLOW FIELD SURVEY THRUST MODULATION CHARACT. IMPINGEMENT ON SIMULATED WING	PRESENTS RESULTS OF TESTS TO DEVELOP A CASCADE THRUST REVERSER WITH A PARTIAL BLOCKAGE BLOCKER DOOR TO AERODYNAMICALLY DEFLECT FLOW INTO THE CASCADE BLADES
1.82	1958	C	707-420	CONWAY	0.1333	WT	6		V = 30 → 90 KNOTS NPR = 1.1 → 2.6 6 CONFIGURATIONS	ΔT_{inlet}	REINGESTION WIND TUNNEL TEST OF 707-420 AIRPLANE WITH CONWAY ENGINE AND ROLL-ROYCE THRUST REVERSERS
1.83	1965	C	C-5A	GE1/6-54C PWAJTF 14E/28	0.06	WT	4		V = 40 → 100 KNOTS NPR = 1.5, 1.6 BLADE EXIT ANGLES = 40°, 50°	ΔT_{inlet} IMPINGEMENT TEMPERATURES FLOW VISUALIZATION	DETERMINED REINGESTION CHARACTERISTICS AND IMPINGEMENT TEMPERATURES ON BOEING C-5A WIND TUNNEL MODEL. TESTED SLOTS AND SPOILERS TO PREVENT FLOW ATTACHMENT ON COWL SURFACE.

TABLE V-1, CONCLUDED

THRUST REVERSER DATA REVIEW
CASCADE THRUST REVERSERS

1.1 1.2 1.3

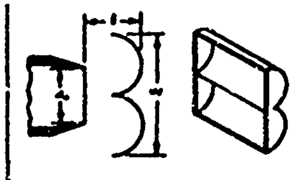
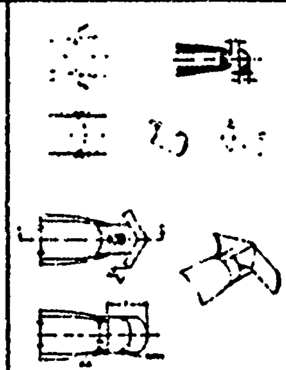
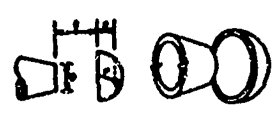
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.41	1955	T	G	G	MS	S	17		NPR = 1.7→3.0 ℓ/d_n = 0.28→1.50 w/d_n = 1.0, 1.5, 2.0 A_p/A_n = 1.275→5.1 LIP ANGLES = 0° END PLATE ANGLES = 0°, 90° (NO END PLATES)	η_r ϕ FLOW FIELD SURVEY	CYLINDRICAL AND HEMISPHERICAL TARGET THRUST REVERSERS. TESTED SINGLE CYLINDER, DOUBLE CYLINDER, OPEN AND CLOSED ENDS, HEMISPHERES, AND A CUP SHAPED TARGET
1.43 1.44	1956	T	G	G	MS	S	6		NPR = 2.0 a/b = 0.62→2.5 ℓ/d_n = -0.3 → 1.01 x/r = 0→1.0 A_p/A_n = 1.6→5.2 LIP ANGLES = 0, 34° END PLATE ANGLES = 0, 60, 90° END PLATE HEIGHT/d_n = 0→0.38 θ_{door} = 60→90° PERCENT MODULATION = 0→90% END PLATE CONFIGURATION = 6 WITH AND WITHOUT COVER PLATES WITH AND WITHOUT BAFFLES	η_r ϕ FLOW FIELD SURVEY THRUST MODULATION CHARACT. DOOR LOADS AND MOMENTS	REFERENCE 1.43 CONTAINS MOST OF THE DATA FOR CYLINDRICAL TARGET REVERSERS. REFERENCE 1.44 CONTAINS SUMMARY OF SCALE MODEL STATIC TESTING FOR TARGET, TAIL-PIPE CASCADE, AND RING CASCADE THRUST REVERSERS.
1.44 1.77	1956 1953	T	G	[illegible]	MS	S	3		NPR = 1.4→3.0 ℓ/D = -0.43→0.58 A_p/A_n = 1.76→3.61 x/r = 0.17→0.30 BOATTAIL GEOMETRY LIP ANGLE = 0°	η_r ϕ θ_{actual} FLOW FIELD SURVEY BOATTAIL PRESSURES TUFT FLOW VISUALIZATION	REFERENCE 1.77 CONTAINS MOST OF THE DATA; REFERENCE 1.44 IS A SUMMARY DOCUMENT.

TABLE V-2

1.1 1.2 1.3

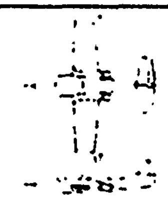
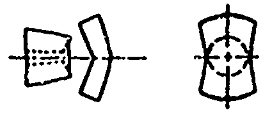
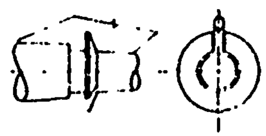
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.56	1970	T	A-37B	J-85-17A	1.0	WT	1		q 30 → 59 psf α -3° → 16° RPM = 50% → 97% PERCENT MODULATION = 0 → 100% $\delta_{elevator}$ = -20° → 5° θ_{door} = 0° → 50° ℓ/d_n = 1.25	C_L V_r C_{DA} C_m F_g F_r THRUST MODULATION CHARACT. IMPINGEMENT TEMPERATURES	FULL SCALE WIND TUNNEL TEST OF A TARGET THRUST REVERSER FOR THE A-37B AIRPLANE. THRUST REVERSER OPERATION HAD SEVERE EFFECTS ON AERODYNAMIC STABILITY AND CONTROL, IMPINGEMENT TEMPERATURES, AND REINGESTION SPEEDS.
1.58	1957	T	F-86	J47	1.0	S	1	 FORWARD THRUST POSITION · REVERSE THRUST POSITION	RPM = 72.5 → 100% PERCENT MODULATION = 0 → 100% ℓ/d_n = 1.39 θ_{door} = 36°	η_r THRUST MODULATION CHARACT.	TARGET THRUST REVERSER FOR THE F-86 AIRPLANE
1.69	1967	T	G	G	MS	S,WT	1		NPR = 1.2 → 2.0 θ_{door} = 73° → 85° A_p/A_n = 0 → 4.0 END PLATE HEIGHT/d_n = 0.05 → 0.25 DOOR WRAP AROUND ANGLE = 80°→180° M = 0 → 0.85	η_r ϕ NOZZLE PLANE EXIT STATIC PRESSURES THRUST REVERSER DRAG COEFFICIENTS	TARGET THRUST REVERSER MODEL TESTS
1.69	1967	T	G	G	MS	S, WT	1		NPR = 1.0 → 2.7 M = 0 → 0.85 END PLATE HEIGHT = 0 → 10 IN. FULL SCALE ℓ/d_n = 1.5 → 5.0 ANNULAR TARGET DIAMETER = 135 → 180 IN.	η_r ϕ SCHLIEREN PHOTOGRAPHS STATIC PRESSURE PROFILES IN REVERSER WAKE NOZZLE PLANE EXIT STATIC PRESSURES THRUST REVERSER DRAG COEFFICIENTS	ANNULAR TARGET THRUST REVERSER MODEL TESTS

TABLE V-2, CONTINUED

1.1 1.2 1.3

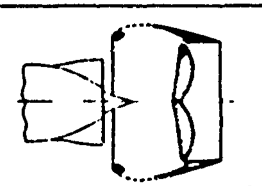
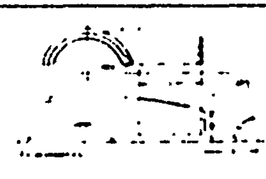
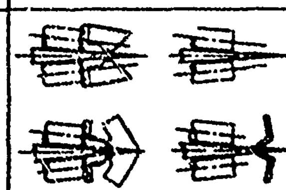
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.62	1958	T	DC-8	JT3C	FS	S	1		NPR = 1.1→2.5	η_r w	TARGET THRUST REVERSER FOR THE DC-8 EJECTOR SUPPRESSOR NOZZLE
1.92	1971	T	727	JT8D	0.2	S	1		NPR = 1.4→2.0 S/D = 0.5, 1.0, 1.5 α = 70, 75, 80° L/D = 1.0 3 IN. LIP FULL SCALE TAPERED SIDE FENCES	η_r ϕ	TARGET THRUST REVERSER FOR AN EJECTOR SUPPRESSOR NOZZLE
1.39	1970	T	AX	HIGH BYPASS RATIO TURBOFAN	0.091	S	1		NPR = 1.1 1.5 θ_{door} = 75, 80, 85, 90° $\ell/d_{primary}$ = 1.0→5.0 $S/d_{primary}$ = 3.08→6.15 DOOR WIDTH/$d_{primary}$ = 2.46→3.7 $t/d_{primary}$ = 0→0.092	η_r ϕ C_D FLOW VISUALIZATION	STATIC TEST OF A FUSELAGE MOUNTED FLAT PLATE THRUST REVERSER. TESTED SHORT DUCT AND A 3/4 LENGTH FAN DUCT NACELLE. TESTED WITH AND WITHOUT A 45° BLOCK AND LARGE TAPERED SIDE FENCES.
1.60	1970	T	AX	HIGH BYPASS RATIO TURBOFAN	0.1	WT	2		NPR = 1.0→1.6 M = 0.4 α = 0→22° ψ = -12→8° $\delta_{elevator}$ = 0, 20° δ_{rudder} = 0, 20° θ_{door} = 60, 80, 114, 147°	AERODYNAMIC STABILITY AND CONTROL FLOW VISUALIZATION	WIND TUNNEL TEST OF AN EJECTOR SHROUD TARGET REVERSER AND A TWO DIMENSIONAL TARGET REVERSER. SEVEN VARIATIONS OF THESE CONCEPTS WERE TESTED INCLUDING 2 SHROUDS, 2 LIP GEOMETRICS, AND 4 FENCES

TABLE V-2, CONTINUED

THRUST REVERSER DATA REVIEW
TARGET THRUST REVERSERS

1 1.2 1.3

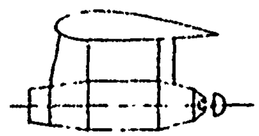
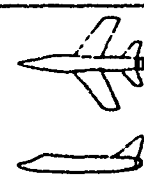
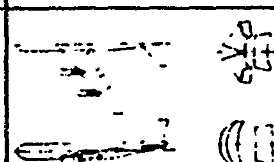
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.46	1956	T	C-82	TURBOJET	0.25 1.0	S, TT	1		NPR = 1.1 → 1.8 RPM = 45 → 100% V = 0 → 75 KNOTS ℓ/d_n = 0.621 A_p/A_n = 2.25	F_g ΔT_{inlet} η_r IMPINGEMENT TEMPERATURES FLOW FIELD SURVEY	TAXI TEST TO DETERMINE REINGESTION SPEED AND IMPINGEMENT TEMPERATURES ON A SIMULATED WING SURFACE
1.49	1958	T	SINGLE ENGINE FIGHTER	TURBOJET	MS	WT	1		NPR = 1.0, 2.0, 5.0 M = 0.2 → 1.05 α = 0 → 5° Re = 5.0×10^6	AERODYNAMIC STABILITY AND CONTROL AFTERBODY PRESSURE DATA	CYLINDRICAL TARGET THRUST REVERSER FOR A SINGLE ENGINE FIGHTER
1.50	1959	T	YF-86D	J-34	1.0	WT	1		q = 15 → 45 psf θ_{door} = 12 → 90° α = -2 → 20° RPM = 58 → 95% C_T = 0.02 → 0.36 Re = 5.8×10^6 → 10.1×10^6	ΔT_{inlet} C_L C_{DA} C_m IMPINGEMENT TEMPERATURE FLOW FIELD SURVEY	FULL SCALE TEST OF A CYLINDRICAL TARGET THRUST REVERSER FOR THE F-86 AIRPLANE
1.54	1961	T	SUBSONIC TRANSPORT	J-30	LS	WT	4		V = 68 → 120 KNOTS q = 10 → 50 psf α = -4 → 19° δ_{flaps} = 0 → 50° LEADING EDGE SLAT DEFLECTION PERCENT MODULATION = 0 → 100% C_μ = 0 → 0.014 C_T = -0.2 → 0.5 Re = 4.2×10^6 → 8×10^6	C_L C_{DA} C_m THRUST MODULATION CHARACT.	LARGE SCALE TEST OF A TARGET THRUST REVERSER FOR A SUBSONIC TRANSPORT AIRPLANE

TABLE V-2, CONTINUED

1.1 1.2 1.3

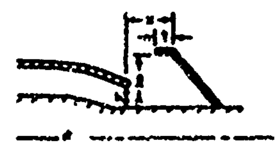
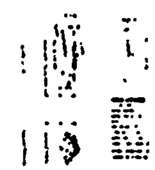
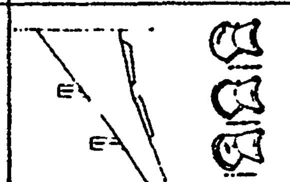
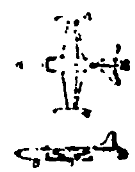
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.4	1970	T	G	G	MS	S	1		NPR = 1.65 x/h 0.25 → 1.8 ℓ/h = 1.66 → 2.39 t/h = 0 → 1.4 θ_{door} = 30, 20°	C_{Vx} C_D	ANNULAR FAN NOZZLE THRUST REVERSER WITH AND WITHOUT KICKPLATE. REFERENCE 3.4 IS A PROPOSAL DOCUMENT AND DOES NOT CONTAIN THE COMPLETE SET OF TEST DATA
1.27	1968	T	737	JT8D	0.100	S, WT	13		NPR = 1.2 → 1.98 V = 20 → 120 KNOTS CLOCK ANGLE = 0 → 40° L/D = 0.9 → 1.2 Λ = 0 → 15° α = 0 → 10° ℓ/D = 0.8 → 0.95 ϕ = 120 → 180° β = 0 → 40°	η_r ϕ V_r C_L C_{DA} IMPINGEMENT TEMPERATURE	ALSO TESTED CONSTANT HEIGHT AND TAPERED LIPS AND FENCES TO CONTROL FLOW DIRECTION
1.14	1970	T	707	JT3D	0.0896	WT	13		V = 40 → 120 KNOTS CLOCK ANGLE = -36 36°	η_r ΔT_{inlet} C_{DA} FLOW VISUALIZATION IMPINGEMENT TEMPERATURES	TARGET THRUST REVERSER FOR A LONG DUCT QUIET NACELLE
1.86	1959	T	F-86C	J48-P-5	FS	FT	1.0		V= 0 → 200 KNOTS RPM = 65, 75, 85%	AERODYNAMIC STABILITY AND CONTROL REVERSER EFFECTIVENESS THRUST MODULATION CHARACT. BUFFET CHARACT.	A COMPARISON IS SHOWN OF REVERSER EFFECTIVENESS FROM FULL SCALE STATIC AND FLIGHT TESTS AND SMALL SCALE COLD AIR TESTS

TABLE V-2, CONTINUED

THRUST REVERSER DATA REVIEW
TARGET THRUST REVERSERS

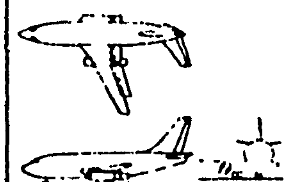
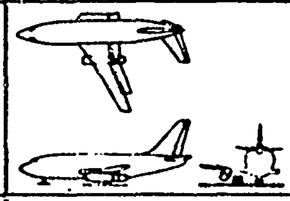
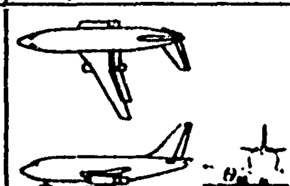
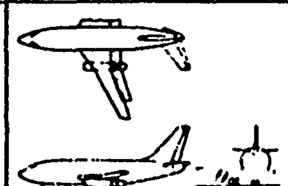
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.29	1968	T	737	JT8D	1.0	TT	1		V = 0 → 120 KNOTS EPR = 1.0 → 1.95 δ_{flaps} = 40° GROSS WEIGHT = 85,000 → 95,000 LB	F_r V_r HYDRAULIC SYSTEM PERFORMANCE DIRECTIONAL CONTROL CHARACTERISTICS GROUND ROLL DISTANCE	PRESENT RESULTS OF FULL SCALE TAXI TESTS OF 737 AIRPLANE WITH TARGET THRUST REVERSER
1.8	1969	T	737	JT8D	1.0	FT, TT	1		V=0 →120 KNOTS EPR = 1.2 → 2.0 δ_{flaps} = 5 → 40°	ΔT_{inlet} V_r F_r η_r DRAG BRAKING FORCES	LANDING AND TAXI TESTS OF 737 AIRPLANE WITH TARGET THRUST REVERSERS TO DETERMINE INSTALLED REVERSER EFFECTIVENESS AND REINGESTION CHARACTERISTICS. TESTED WITH ONE ENGINE OUT TO SIMULATE ENGINE FAILURE.
1.2[illegible]	1968	T	737	JT8D	0.091, 1.0	WT, TT	1		EPR = 1.0 → 1.98 V = 50 → 130 KNOTS α = 0° ψ = -25 → 5° CLOCK ANGLE = -20 → 35° C_T = 0 → 3.28	V_r RUDDER EFFECTIVENESS DIRECTIONAL STABILITY FLOW VISUALIZATION	RUDDER EFFECTIVENESS AND DIRECTIONAL STABILITY FROM WIND TUNNEL TEST AND FULL SCALE STATIC TEST.
1.30	1967	T	737	JT8D	1.0	TT	1		EPR = 1.4, 2.0 V = 40 → 120 KNOTS	IMPINGEMENT TEMPERATURES	DETERMINED REVERSER EXHAUST GAS IMPINGEMENT TEMPERATURES ON WING, FLAPS, AND BODY. SHOWED NO DETRIMENTAL EFFECTS.

TABLE V-2, CONTINUED

1-1 1-2 1-3

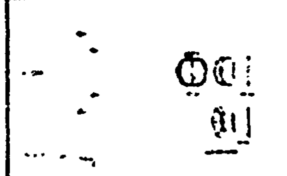
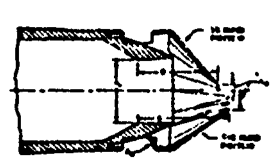
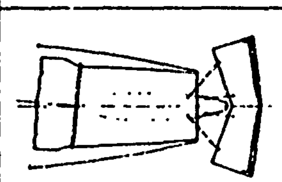
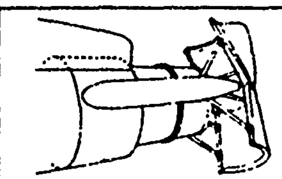
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.53	1961	T	SUBSONIC TRANSPORT	G	LS	WT	18		q = 10 25 psf α = 0° δ flaps = 0, 50° θ door = 25 35° 18 CONFIGURATIONS VARYING EXIT ANGLE, END PLATE TABS, AND CLOCKING ANGLE	V_r F_g F_r w SMOKE FLOW VISUALIZATION INTERFERENCE DRAG	REINGESTION WIND TUNNEL TEST OF A LARGE SCALE FOUR ENGINE JET TRANSPORT. ALSO TESTED A CASCADE THRUST REVERSER AS DESCRIBED ON PAGE 1.1.6
3.4	1970	T	G	G	MS	S,WT	2		NPR = 1.5 6.0 M = 0 A_8/A_1 = 0.03 0.83	C_{Vx} ϕ	EXTERNAL TARGET THRUST REVERSER FOR A VARIABLE CONVERGENT-DIVERGENT NOZZLE
1.84	1965	T	DC-9	JT8D	1.0	S	1		EPR = 1.05 2.0 DOOR GAP = 0 34 INCHES	F_g F_r w THRUST MODULATION CHARACT. ACTUATOR AND DOOR LOADS CHARACTERISTICS DURING DEPLOY AND STOW OPERATIONS TEMPERATURE SURVEYS ON REVERSER DOOR	REFERENCE DESCRIBES TEST WORK PERFORMED TO OBTAIN FAA CERTIFICATION AND FOR ENDURANCE TESTING THROUGH 2000 CYCLES
1.85	1969	T	737	JT8D	1.0	S	1		EPR = 1.4 2.0	F_g F_r ϕ ACTUATOR LOADS TEMPERATURE SURVEYS ON REVERSER DOOR	REFERENCE DESCRIBES QUALIFICATION TEST WHICH INCLUDED ENDURANCE TEST OF OVER 400 DEPLOY AND STOW CYCLES AND RESULTS OF AREA MATCH TEST

TABLE V-2, CONTINUED

1.1 1.2 1.3

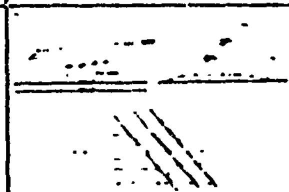
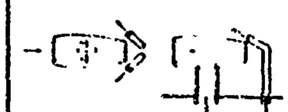
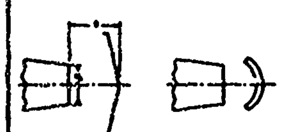
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.31	1967	T	747	JT9D	0.06	WT	6		NPR = 1.3 → 1.5 V = 40 → 120 KNOTS θ_{door} = 50° NACELLE POSITIONS AT 30%—60% AND 40%—60% OF SEMISPAN 6 CONFIGURATIONS VARYING EXTERNAL BLOCKER DOORS	ΔT_{inlet} FLOW VISUALIZATION	PURPOSE OF TEST WAS TO DETERMINE REVERSER EXHAUST FLOW FIELD AND REINGESTION CHARACTERISTICS OF AN EARLY 747 AIRPLANE USING MIXED PRIMARY AND FAN FLOW. ALSO TEST ANNULAR CASCADE THRUST REVERSERS.
1.70	1968	T	G	G	MS	S	1		NPR = 1.2 → 2.4	η_r ϕ FLOW FIELD SURVEY SMOKE FLOW VISUALIZATION	CLAMSHELL TARGET REVERSER STATIC TEST RESULTS. TRANSLATED FROM RUSSIAN
1.88	1971	T	G	G	MS	WT	1		V_j/V_∞ = 12, 21 EXHAUST PITCHUP ANGLE = 0, 30° EXHAUST LATERAL ANGLE = 0 → 45° ϕ = 0, 30°	T_{inlet} SMOKE FLOW VISUALIZATION	PRESENTS RESULTS OF A SMALL SCALE TEST TO DETERMINE FUNDAMENTAL REINGESTION DATA AS A FUNCTION OF EXHAUST POSITION AND DIRECTION. FLOW WAS PITCHED UP AND AWAY FROM NACELLE.
1.81	1969	T	G	G	MS, 1.0	S	1		NPR = 1.7 → 3.1 ℓ/d_n = 0.75 → 1.15 PERCENT MODULATION = 0 → 100%	η_R ϕ V_r w THRUST MODULATION CHARACT. ACTUATOR LOADS	PRESENTS A LIMITED AMOUNT OF MODEL AND FULL SCALE STATIC DATA FOR CLAMSHELL TYPE TARGET REVERSERS

TABLE V-2, CONCLUDED

1.1 1.2 1.3

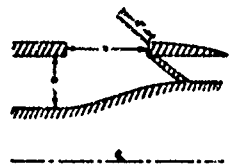
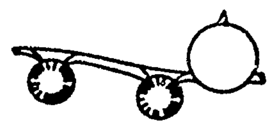
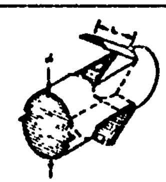
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.1	1965	BD	C-5A	GE 1/6-F4C PWA JTF 14E/2B	0.0658	S	1		NPR [illegible] θ_{door} [illegible] X/D = 1.197 [illegible] DL/D = 0.688 → 1.625 $\theta_{blocker\ door}$ = 110° FROM ENGINE CENTERLINE	η_r SETBACK DISTANCE x FOR MATCHED AIRFLOW CONDITIONS	ANNULAR BLOCKER WITH EXTERNAL DEFLECTOR DOOR. STATIC PERFORMANCE TEST.
1.7	1969	BD	2707-200 SST	GE4/J5P	0.0455	WT	12		V = 60 → 140 KNOTS 12 CONFIGURATIONS BLOCKING VARIOUS TERTIARY AIR DOORS NPR = 3.2	ΔT_{inlet} REINGESTION CIRCUMFERENTIAL TEMPERATURE PROFILES FLOW VISUALIZATION	INTERNAL BLOCKER DOOR THRUST REVERSER FOR 2707-200 SST AIRPLANE. REINGESTION WIND TUNNEL TEST.
1.38	1969	BD	2707-200 SST	GE4/J5P	0.1	S	4		NPR = 2.6 → 3.5 $A_r/A_{primary}$ = 1.0 → 2.0 $\ell/d_{primary}$ = 0.92 → 1.18 $\theta_{tertiary\ door\ exit}$ = 40°, 50° $\theta_{blocker\ door\ exit}$ = 65° 4 CONFIGURATIONS	η_r ϕ	INTERNAL BLOCKER DOOR THRUST REVERSER FOR 2707-200 SST AIRPLANE. STATIC MODEL TEST TO DETERMINE REVERSER EFFICIENCY AND AIRFLOW MATCH.
1.44	1956	BD	G	G	MS	S	1		NPR = 1.4 → 2.5 θ_{door} = 30° L/d = 0.98 PERCENT BLOCKAGE = 100% $\theta_{blocker\ door}$ = 65° FROM ENGINE CENTERLINE	η_r	INTERNAL BLOCKER DOOR WITH EXTERNAL DEFLECTOR DOOR.

TABLE V-3

THRUST REVERSER DATA REVIEW
BLOCKER/DEFLECTOR THRUST REVERSERS

1.1 1.2 1.3

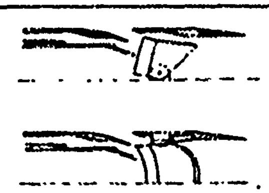
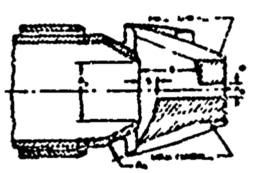
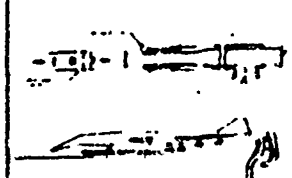
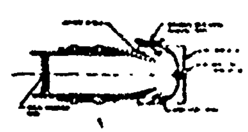
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.57	1972	BD	G	G	MS	WT	1		NPR = 1.6 → 9.0 M = 0 → 1.2 PRIMARY NOZZLE AREA CLAMSHELL DOOR POSITION EJECTOR INLET DOOR ANGLE = 0 → 20° BLOCKER DOOR ANGLE IN FULL REVERSE THRUST = 127° FROM ℄ BLOCKER DOOR SETBACK = 1.42	C_F EJECTOR PUMPING CHARACTERISTICS DOOR HINGE MOMENTS SHROUD FLAP HINGE MOMENTS BOATTAIL PRESSURE DRAG	CLAMSHELL BLOCKER DOOR THRUST REVERSER
3.4	1970	BD	G	G	MS	S, WT	2		NPR = 2.0, 5.0 A_R/A_J = 0.7 → 1.34 M = 0, 1.2 A_B/A_J = 0 → 0.3 CLAMSHELL CONFIGURATIONS = 2	C_{Vx} ϕ	CLAMSHELL BLOCKER DOOR THRUST REVERSER FOR A VARIABLE CONVERGENT–DIVERGENT NOZZLE
1.12	1968	BD	2707-200 SST	GE4/J5P	0.0445	WT	9		NPR = 1.9 → 3.2 V = 45 → 140 KNOTS 9 REVERSER DISCHARGE PATTERNS	η_r ϕ C_D AT inlet INLET TEMPERATURE DISTORTION FLOW VISUALIZATION P_T SURVEY OF EXHAUST	REINGESTION WIND TUNNEL TEST OF INTERNAL BLOCKER DOOR THRUST REVERSER FOR 2707-200 SST AIRPLANE
1.37	1968	BD	2707-100 SST	GE4/J5P	0.1	S	5		NPR = 2.2 → 3.8 A_r/A_n = 0.50 → 1.98 S/D_n = 0.39 → 1.18	η_r ϕ C_V P_T SURVEY OF EXHAUST	STATIC MODEL TEST TO DETERMINE REVERSER EFFICIENCY AND AIRFLOW MATCH OF INTERNAL BLOCKER DOOR THRUST REVERSER FOR 2707-200 SST AIRPLANE

TABLE V-3, CONTINUED

1.1 1.2 1.3

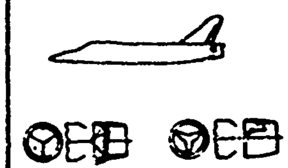
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
1.74	1970	BD	F-11A	J65	0.085 0.133	S, WT	10		NPR = 1.5 → 2.0 BLOCKER DOOR ANGLE = 23 → 60° e_{jet}/q = 0 → 40 α = -3 → 15° β = -5 → 10° M = 0 → 1.3 PERCENT MODULATION = 0 100% BLOCKER DOOR CONFIGURATIONS = 10	η_r ϕ ΔC_m C_F THRUST MODULATION	REFERENCE 1.74 PRESENTS LIMITED STATIC AND WIND TUNNEL TEST DATA ON AN INFLIGHT THRUST REVERSER FOR THE F-11A AIRPLANE

TABLE V - 3, CONCLUDED

1.1 1.2 1.3

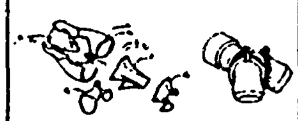
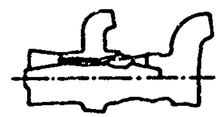
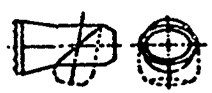
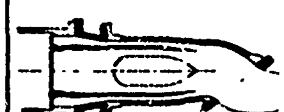
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.3	1963	SB	G	JT4A	0.1111	S	9		NPR = 1.5→3.0 $\theta_{mechanical}$ = 0 → 180° BEARING PLANE ANGLE = 25° FROM ENGINE CENTERLINE	C_V C_D OIL FLOW VISUALIZATION SHADOWGRAPHS	DUAL SINGLE BEARING NOZZLE. TESTED 2 TURBINE CONES (C_1, C_2) 2 NOZZLES (N_1, N_2), 2 SPLITTERS (S_1, S_2), AND 3 FAIRINGS (F_1, F_2, F_3)
2.10	1966	SB	VAK-191B	RB-193	MS	S	1		DUCT ENTRY MACH NUMBER = 0.18→0.42 BEARING PLANE ANGLE = 0° FROM ENGINE CENTERLINE NOZZLE OFFSET/$d_{entrance}$ = 1.2	FAN DUCT TOTAL PRESSURE LOSS PRIMARY DUCT TOTAL PRESSURE LOSS	RB-193 SINGLE BEARING NOZZLE
2.13	1967	SB	G	G	MS	S	3		NPR = 1.6 → 4.0 $\theta_{mechanical}$ = 0, 100° $r/D)_{turn}$ = 0.4 $A_{entrance}/A_{exit}$ = 2.0 BEARING PLANE ANGLE = 40° FROM NOZZLE CENTERLINE NO RADIAL OFFSET	C_V C_D θ_{actual}	SINGLE BEARING VECTORING NOZZLE. MODIFIED NOZZLE BY ADDING FILLETS TO IMPROVE INTERNAL PERFORMANCE
3.3	1970	SB	G	G	MS	S	1		NPR = 1.5 → 4.0 $\theta_{mechanical}$ = 0→90° BEARING PLANE ANGLE = 37.5° FROM NOZZLE CENTERLINE $r/D)_{first\ turn}$ = 0.84 $r/D)_{second\ turn}$ = 0.75 $A_{entrance}/A_{exit}$ = 1.79 NOZZLE OFFSET/$d_{entrance}$ = 0.41	C_V	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ACTUAL TEST DATA. THE DATA PRESENTED ARE OF MARGINAL USEFULNESS.

TABLE VI-1

THRUST VECTORING DATA REVIEW
SINGLE BEARING NOZZLES

1.1 1.2 1.3

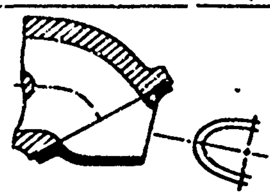
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.3	1976	SB	G	G	MS	S	1		NPR = 1.25 → 4.0 $\theta_{mechanical}$ = 0, 45, 90, 110° r/D) first turn = 0.61 r/D) second turn = 0.68 $A_{entrance}/A_{exit}$ = 2.59 BEARING PLANE ANGLE = 28° FROM ENGINE CENTERLINE NOZZLE OFFSET/$D_{entrance}$ = 0.64	C_V	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ACTUAL TEST DATA. THE DATA PRESENTED ARE OF MARGINAL USEFULNESS
3.5	1968	SB	G	G	MS	S	2		NPR = 1.3 → 2.7 WALL ANGLE = 10, 20° BEARING PLANE ANGLE = 32.5° FROM NOZZLE CENTERLINE $A_{entrance}/A_{exit}$ = 2.09 NOZZLE EFFECT/$D_{entrance}$ = 0.44 $r/D)_{first\ turn}$ = 0.5	C_V θ_{actual} AXIAL AND LATERAL FORCE RATIOS TOTAL PRESSURE LOSSES	TRANSLATED FROM RUSSIAN
2.20 3.4	1970	SB	G	G	MS	S	1	NOT DEFINED	NPR = 1.1 → 2.8 $\theta_{mechanical}$ = 0, 30, 60, 90°	C_V C_D θ ACTUAL	STATIC MODEL TEST DATA FOR A SINGLE BEARING NOZZLE GEOMETRY IS NOT DEFINED, BUT A PHOTOGRAPH OF THE NOZZLE IS SHOWN

TABLE VI-1, CONCLUDED

1.1 1.2 1.3

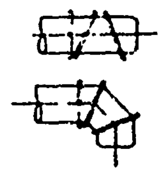
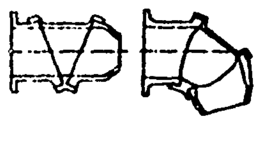
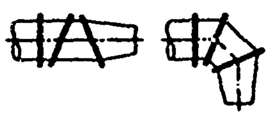
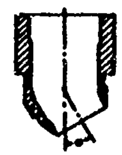
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.2	1963	MB	G	G	MS	S	1		NPR = 1.5 → 2.3 $\theta_{mechanical}$ = 0, 22.5, 45, 67.5, 90° $r/D)_{turn}$ = 1.175 $A_{entrance}/A_{exit}$ = 1.778 NOZZLE PROJECTION/$d_{entrance}$ = 1.6 BEARING PLANE ANGLE = 67.5° Re = 0.8 x 10^6 → 1.1 x 10^6	C_V C_D	THREE BEARING NOZZLE (TWO INCLINED BEARINGS)
3.4	1970	MB	G	G	MS	S	1		NPR = 1.4 → 2.2 $\theta_{mechanical}$ = 0, 50, 75, 96° $r/D)_{turn}$ = 0.69 $A_{entrance}/A_{exit}$ = 1.6 NOZZLE PROJECTION/$d_{entrance}$ = 1.23 BEARING PLANE ANGLE ≈ 66°	C_V C_D θ_{actual}	THREE BEARING NOZZLE (TWO INCLINED BEARINGS)
3.3	1970	MB	G	G	MS, 1.0	S	1		NPR = 1.5 → 4.0 $\theta_{mechanical}$ = 0, 45, 90° CALCULATED BEARING PLANE ANGLE = 67.5°	C_V	THREE BEARING NOZZLE (TWO INCLINED BEARINGS). GEOMETRIC CHARACTERISTICS OF NOZZLE ARE UNKNOWN. REFERENCE 3.3 IS A PRESENTATION DOCUMENT AND NOT A TEST DOCUMENT. THE C_V DATA ARE QUITE HIGH AND ARE QUESTIONABLE. REFERENCE SHOWS PICTURE OF A FULL SCALE MODEL BEING TESTED, BUT DOES NOT HAVE THE DATA.
2.35	1967	MB	G	G	MS	S	1		NPR = 1.0 → 1.48 $\theta_{mechanical}$ = 0, 15, 30	F θ_{actual} SECONDARY AIR FLOW	STATIC CALIBRATION OF AN EJECTOR UNIT FOR SIMULATION OF JET ENGINES IN SMALL SCALE WIND TUNNEL MODELS

TABLE VI-2

1.1 1.2 1.3

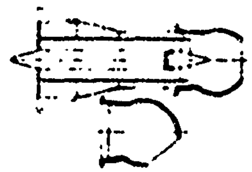
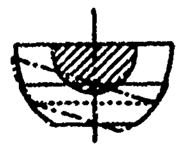
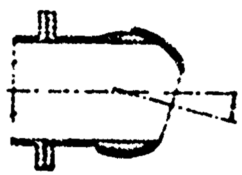
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.14 3.4	1967 1970	SE	A-6 A-7A	TF30-P-8	0.2, 1.0	S	1		NPR = 1.45 - 2.15 $\theta_{mechanical}$ = 0, 50°	C_V C_D ϕ θ_{actual} P_T, T_T surveys	REFERENCE 2.14 CONTAINS MODEL SCALE AND FULL SCALE DATA FOR THE DEVELOPMENT OF A FLIGHT-WEIGHT SPHERICAL ELBOW NOZZLE.
2.13	1967	SE	G	LIFT ENGINE	MS	S	1		NPR - 1.5 - 3.0 $\theta_{mechanical}$ = 0, 10, 20° $A_{entrance}/A_{exit}$ = 1.6	C_V C_D θ_{actual} DISPLACEMENT OF THRUST AXIS	STATIC MODEL TEST OF A SPHERICAL EYEBALL NOZZLE.
2.22	1970	SE	G	G	MS	S	1		NPR = 2.0 - 2.8 θ = 0 - 20°	ϕ AXIAL AND LATERAL FORCE RATIOS	LIMITED STATIC TEST DATA FOR A SPHERICAL EYEBALL NOZZLE

TABLE VI-3

THRUST VECTORING DATA REVIEW
SPHERICAL EYEBALL NOZZLES

1.1

1.2

1.3

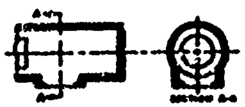
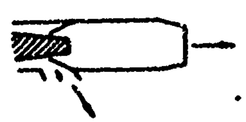
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.22	1958	VN	G	G	MS	S	3		NPR = 2.0 → 2.8 A_{bleed}/A_n = 0.093 → 0.257	AXIAL AND LATERAL FORCE RATIOS BLEED NOZZLE PRESSURE RATIO BLEED NOZZLE AIRFLOW/PRIMARY NOZZLE AIRFLOW	STATIC TEST DATA FOR FIRST BLEED NOZZLE, ANALYTICAL PERFORMANCE FOR NOZZLES 2 AND 3. NO BLOCKER DOOR USED FOR PRIMARY NOZZLE.
3.4	1970	VN	G	G	MS	S	1		NPR = 1.2 → 3.1 $\theta_{mechanical}$ = 0, 90° ENTRANCE MACH NUMBER = 0.2	C_V C_D θ_{actual}	STATIC TEST DATA FOR A VENTRAL NOZZLE
3.5	1968	VN	G	G	MS	S	1		NPR = 2.2 BLOCKER DOOR ANGLE = 0 → 32°	θ_{actual} AXIAL AND LATERAL FORCE RATIOS	VENTRAL NOZZLE WITH GUIDE VANE. TRANSLATED FROM RUSSIAN.

TABLE VI-4

1.1 1.2 1.3

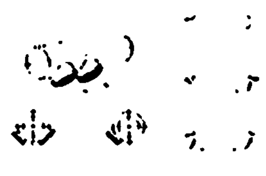
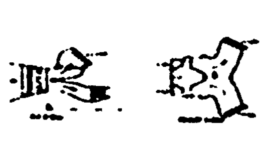
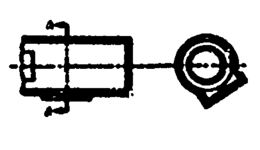
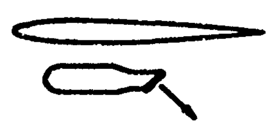
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.1 2.36	1965 1964	CN	G	G	MS	S	8		NPR = 1.5 → 3.2 σ = 1.0, 1.5, 2.0 BEARING ROTATION ANGLE = 0 → 180° VECTOR ANGLE = 35 → 145° BLADE ENTRANCE ANGLE = 15° BLADE EXIT ANGLE = 45°	C_V C_D L/V THREE COMPONENT FORCE DATA	STATIC TEST OF 8 CASCADE CONFIGURATIONS INCLUDING FLAT AND CIRCULAR ARC THIN BLADES, AND CAMBERED THICK BLADES
2.8	UNKNOWN	CN	KESTREL	PEGASUS	MS	S	1		NPR = 1.2 → 2.0 FAN NOZZLE DESIGN TURNING ANGLE = 85° PRIMARY NOZZLE DESIGN TURNING ANGLE = 75°	C_V θ_{actual}	PEGASUS ROTATING CASCADE NOZZLES
2.20 3.4	1970	CN	G	G	MS	S	1		NPR = 1.2 → 2.0 $\theta_{mechanical}$ = 55 → 90° ENTRANCE MACH NUMBER = 0.2	C_V C_D θ_{actual}	STATIC MODEL TEST OF A ROTATING CASCADE NOZZLE
2.34	1970	CN	G	G	MS	WTA	1		V_j/V_∞ = 0 → 8.5 α = -6 → 17° θ = 0 → 90°	C_L ΔC_L ΔC_m NOZZLE TOTAL PRESSURE PROFILES	GERMAN REPORT PRESENTING AERODYNAMIC INTERFERENCE DATA FOR A CASCADE VECTORING NOZZLES NEAR A SWEPT WING

TABLE VI-5 THRUST VECTORING DATA REVIEW CASCADE NOZZLES

1.1 1.2 1.3

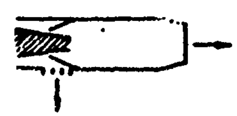
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.3	1970	CN	G	G	ME	S	1		NPR = 1.5→4.0 $\theta_{mechanical}$ = 0→120° BLADE EXIT ANGLE = 40° NUMBER OF BLADES = 12	C_V	REFERENCE 3.3 IS INTENDED FOR PRESENTATION PURPOSES AND DOES NOT CONTAIN ACTUAL TEST DATA. CONSEQUENTLY, THE DATA PRESENTED ARE OF MARGINAL USEFULNESS.
3.5	1968	CN	G	G	MS	S	1		NPR = 1.6→2.2 $\theta_{mechanical}$ = 90°	AXIAL AND LATERAL FORCE RATIOS	TRANSLATED FROM RUSSIAN
3.5	1968	CN	G	G	MS	S	2		NPR = 1.3→2.6 σ = 1.28, 1.43	C_V θ_{actual} AXIAL AND LATERAL FORCE RATIOS TOTAL PRESSURE LOSSES	TRANSLATED FROM RUSSIAN
3.5	1968	CN	G	G	MS	S	1		NPR = 1.2→2.4 σ = 1.25→3.25 NUMBER OF VANES = 3, 4, 5	C_V AXIAL AND LATERAL FORCE RATIOS	TRANSLATED FROM RUSSIAN

TABLE VI-5, CONTINUED

141

1.2

1.3

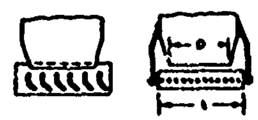
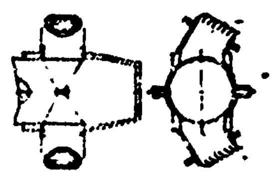
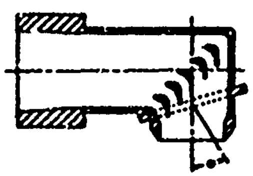
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.5	1968	CN	G	LIFT ENGINE	MS	S	1		NPR = 1.2→2.5 ℓ/D = 1.14, 1.33, 2.5 θ_{vane} = 1.9, 30°	C_V ϕ	CASCADE SHUTTER VANES FOR LIFT ENGINE APPLICATION. TRANSLATED FROM RUSSIAN
3.5	1968	CN	G	G	MS	S	1		NPR = 1.3→2.6 σ = 1.43 BLADE ENTRANCE ANGLE = 0° BLADE EXIT ANGLE = 60°	C_V ϕ AXIAL AND LATERAL FORCE RATIOS NOZZLE TOTAL PRESSURE LOSSES	TRANSLATED FROM RUSSIAN
2.37	1967	CN	G	G	MS	S	1		NPR = 1.0→1.48 $\theta_{mechanical}$ = 0, 15, 30°	F θ_{actual}	STATIC CALIBRATION OF AN EJECTOR UNIT FOR SIMULATION OF JET ENGINES IN SMALL SCALE WIND TUNNEL MODELS

TABLE VI-5, CONCLUDED

THRUST VECTORING DATA REVIEW
CASCADE NOZZLES

1.1 1.2 1.3

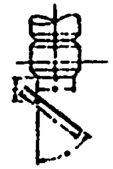
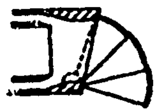
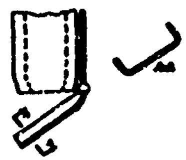
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CON. EPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.5	NOT RELEASED	ED	V/STOL FIGHTER	RB-108 LIFT ENGINE	0.383	S	3		NPR = 1.5→3.0 $\theta_{mechanical} = -30 \to 70°$ S/D = 0.33, 0.66, 1.0 L/D = 1.0, 1.5, 2.0 DEFLECTOR GEOMETRY	C_V C_D θ_{actual} LFV	EXTERNAL DEFLECTOR DOOR FOR LIFT ENGINE APPLICATIONS. TESTED 3 DEFLECTOR CONTAINERS, FLAT PLATE, SINGLE CURVATURE, AND DOUBLE CURVATURE.
2.30 3.4	1970	ED	G	G	MS	S	1		NPR = 1.3→3.2 $\theta_{mechanical} = 0 \to 96°$	C_V C_D θ_{actual}	AFT HOOD EXTERNAL DEFLECTOR NOZZLE (LOBSTERTAIL)
3.5	1966	ED	G	LIFT ENGINE	MS	S	2		NPR = 1.1→2.5 $\theta_{mechanical} = 45°$	C_V ϕ	TESTED FLAT PLATE WITH AND WITHOUT SIDE PLATES. TRANSLATED FROM RUSSIAN.
3.5	1968	ED	G	G	MS	S	1		NPR = 1.6→2.2 $\theta_{mechanical} = 90°$	AXIAL AND LATERAL FORCE RATIOS	TRANSLATED FROM RUSSIAN

TABLE VI-6

THRUST VECTORING DATA REVIEW
EXTERNAL DEFLECTOR NOZZLES

1.2

1.3

REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.9	1966	ED	FIGHTER	G	MS	S	1		NPR = 2.0 → 5.0 θ_{vane} = -25 → 90°	C_V θ_{actual}	CORNER EXPANSION NOZZLE ACHIEVES THRUST VECTORING BY ROTATION OF A SINGLE VANE. HAS APPLICATION TO A HIGH SUPERSONIC V/STOL FIGHTER EMPLOYING A LARGE AREA RATIO CON-DI NOZZLE
2.23	1958	ED	G	G	MS	S	1		NPR = 2.0 → 2.8 θ = 0 → 90°	AXIAL AND LATERAL FORCE RATIOS	PRESENTS TEST DATA FOR SEVERAL PRIMARY NOZZLES WITH TILTED SHROUDS. ANALYTICAL DESIGN CURVES FOR EXTERNAL DEFLECTORS

TABLE VI-6, CONCLUDED

THRUST VECTORING DATA REVIEW
EXTERNAL DEFLECTOR NOZZLES

1.1 1.2 1.3

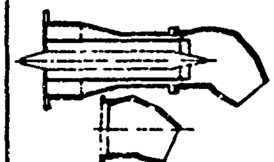
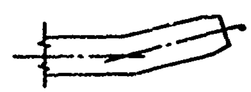
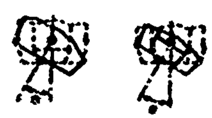
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.14	1967	HINGED NOZZLE	A-6 A-7A	TF30-P-8	0.2	S	1		NPR = 1.4 → 2.1 $\theta_{mechanical}$ = 25, 50°	C_V C_D θ_{actual}	HINGED CONVERGENT VECTORING NOZZLE
2.22	1958	TILTED TAILPIPE	G	G	MS	S	1		NPR = 1.4 → 2.8 $\theta_{mechanical}$ = 0 → 24.5°	AXIAL AND LATERAL FORCE RATIOS	PRESENTS EXPERIMENTAL AND ANALYTICAL RESULTS FOR AXIAL AND LATERAL FORCE RATIOS
3.5	1968	HINGED NOZZLE	G	LIFT ENGINE	MS	S	3		NPR = 1.2 → 2.6 $\theta_{mechanical}$ = 25°	C_V θ	TRANSLATED FROM RUSSIAN

TABLE VI-7

1.1 1.2 1.3

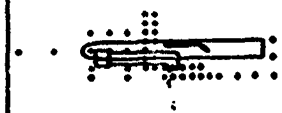
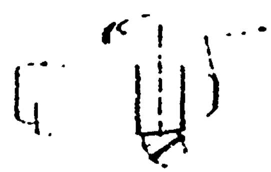
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
2.35	1969	G	G	G	MS	WT	1		$\theta_{mechanical} = 60, 90^\circ$ $\delta_{flaps} = 0, 40^\circ$ $V_e = \sqrt{\frac{\rho_\infty V_\infty^2}{\rho_j V_j^2}} = 0 \div 0.25$ VERTICAL AND HORIZONTAL JET LOCATION $\alpha = 0^\circ$ $Re = 0.9 \times 10^6$	ALC $\frac{\Delta C_L}{C_T}$, $\frac{\Delta C_{DA}}{C_T}$, $\frac{\Delta C_m}{C_T}$ FLOW VISUALIZATION WING PRESSURE DISTRIBUTIONS	PRESENTS RESULTS OF WIND TUNNEL TEST TO DETERMINE AERODYMANIC INTERFERENCE EFFECTS OF JET EXHAUST LOCATION AND VECTOR ANGLE ON LONGITUDINAL CHARACTERISTICS OF A HIGH, UNSWEP, WING. NACELLE WAS NOT ON BALANCE.
2.38	1971	AB	BUFFALO CV-7A	J85	LS	WT	1		$C_T = 0 \div 1.90$ $\alpha = -12 \div 30^\circ$ $\psi = -10 \div 0^\circ$ $\theta_{mechanical} = 0, 55, 85, 100^\circ$ $q = 8$ PSF $\delta_{flaps} = 30, 75^\circ$ $Re = 2.9 \times 10^6$	AERODYNAMIC STABILITY AND CONTROL	ALSO VARIED AUGMENTOR JET COEFFICIENT, AILERON DROOP, HORIZONTAL TAIL AND ELEVATOR DEFFECTION, AILERONS FOR ROLL CONTROL, AND AUGMENTOR THROTTLING.

TABLE VI-8

1.1 1.2 1.3

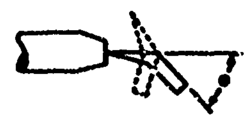
REFERENCE NUMBER	YEAR OF PUBLICATION	THRUST REVERSER VECTORING CONCEPT	AIRPLANE MODEL	TYPE OF ENGINE	SCALE OF TEST	TYPE OF TEST	NUMBER OF CONFIGURATIONS TESTED	SKETCH OF CONFIGURATIONS	TEST VARIABLES	TEST DATA	COMMENTS
3.1	[illegible]	T, ED	G	G	MS	S	1		NPR = 2.0 $\theta = 10 \to 35°$	AXIAL AND LATERAL FORCE RATIOS	TARGET THRUST REVERSER IS PIVOTED TO FORM AN EXTERNAL DEFLECTOR FOR VECTORING

TABLE VII COMBINED THRUST REVERSER/VECTORING DATA REVIEW

1.1 1.2 1.3