

AD P00514



AN OVERVIEW OF SUPERSONIC EJECTOR PERFORMANCE ANALYSES

A. L. (~~Tad~~) Addy
Professor and Associate Head
Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign
1206 W. Green Street
Urbana, IL 61801

Telephone: (217) 333-1126

Ejector Workshop for Aerospace Applications
2-5 August 1981
Dayton, Ohio

PRESENTATION SUMMARY

AN OVERVIEW OF "SUPERSONIC" EJECTOR PERFORMANCE ANALYSES

Three general approaches are available for the analysis of "supersonic" ejector performance. In order of complexity, they are: (1) one-dimensional flow models, (2) combined one- and two-dimensional interactive flow models with a superimposed viscous mixing component, and (3) application of finite-difference approximations of the Navier-Stokes equations to the overall flowfield within the ejector. The constant-pressure and constant-area one-dimensional flow models are well developed and understood. The constant-area ejector model has the advantage in that this simplified model retains most of the essential features which are observed in ejector operation. The constant-pressure model is restricted in the features which can be included and in the range of ejector operating characteristics which can be predicted. The combined one- and two-dimensional interactive flow models have been developed during the past twenty years. These flow models provide a means for predicting overall supersonic ejector performance and details of the flowfield in the interaction region for non-constant area mixing ducts. Unfortunately, this approach is, in general, both tedious and computationally time consuming. The finite-difference approach to analyzing supersonic ejector performance is in the developmental stage. This general approach offers many positive incentives; however, there are still considerable difficulties to be overcome.

→ The objectives of this presentation will be to provide a brief overview of each of the methods for predicting "supersonic" ejector performance, to outline the significant features and advantages/disadvantages of each method, and to suggest possible future directions for consideration.

NOMENCLATURE

Symbols

C_p	Specific heat at constant pressure
h	Specific enthalpy
L	Length
M	Mach number
M_w	Molecular weight
P	Pressure
R	Gas constant
r_d	Diffuser compression coefficient
V	Magnitude of velocity
w_a	Mass flowrate
W	Work, shaft and shear
γ	Ratio of specific heats
ρ	Density
μ	Secondary-to-primary mass flowrate ratio, w_s/w_p

Subscripts

O	Stagnation state or location
1, 2, 3, 4	System locations
ATM	Atmosphere
B	Back
BO	Break-off conditions
M	Mixed
MAX	Maximum
P	Primary
S	Secondary
T	Total
T_0	Refers to stagnation temperature function
X, Y	Upstream and downstream normal shock locations

PRESENTATION SLIDES

GENERAL EJECTOR CLASSIFICATIONS:

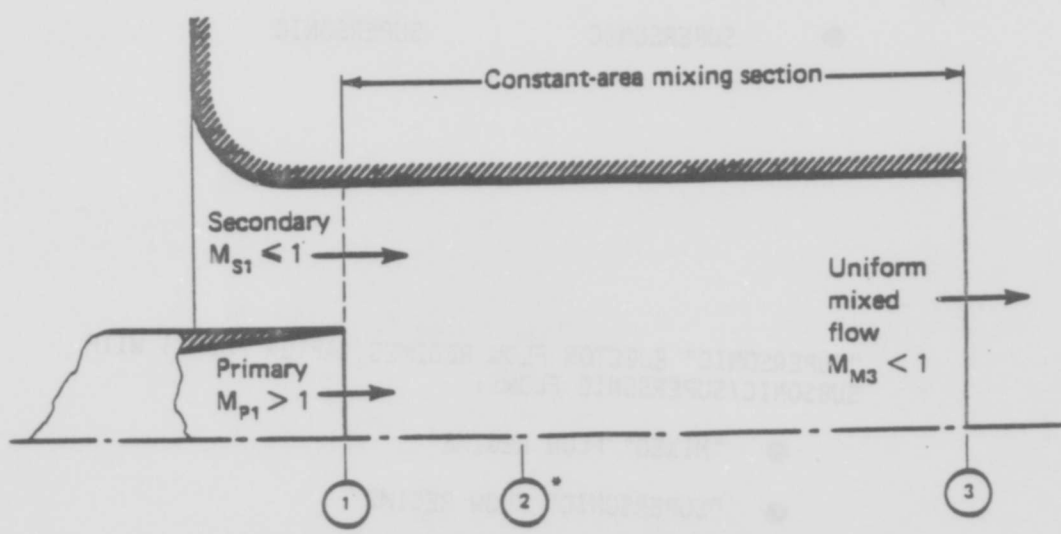
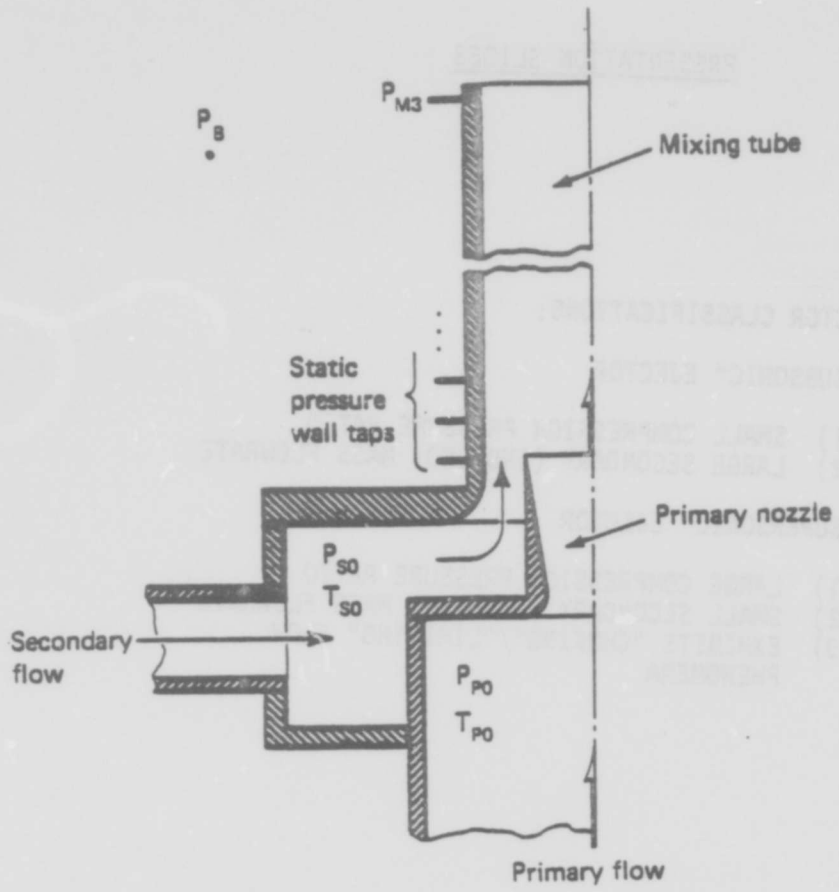
- "SUBSONIC" EJECTOR
 - (1) SMALL COMPRESSION PRESSURE RATIO
 - (2) LARGE SECONDARY (INDUCED) MASS FLOWRATE
- "SUPERSONIC" EJECTOR
 - (1) LARGE COMPRESSION PRESSURE RATIO
 - (2) SMALL SECONDARY (INDUCED) MASS FLOWRATE
 - (3) EXHIBITS "CHOKING"/"LIMITING" FLOW PHENOMENA

POSSIBLE "SUPERSONIC" EJECTOR ENTRANCE FLOWS:

	<u>PRIMARY (DRIVER)</u>	<u>SECONDARY (INDUCED)</u>
●	SUPERSONIC	SUBSONIC
●	SUPERSONIC	SUPERSONIC

"SUPERSONIC" EJECTOR FLOW REGIMES (AFTER FABRI) WITH SUBSONIC/SUPERSONIC FLOWS:

- "MIXED" FLOW REGIME
- "SUPERSONIC" FLOW REGIME
- "SATURATED SUPERSONIC" FLOW REGIME



* Exists only for the "supersonic" regime

EJECTOR FLOW REGIMES

"MIXED" FLOW REGIME CHARACTERISTICS:

- SECONDARY (INDUCED) FLOW IS UNCHOKED AND IS DEPENDENT ON THE DOWNSTREAM PRESSURE BOUNDARY CONDITION
- MIXING TUBE WALL PRESSURE DISTRIBUTION IS AFFECTED BY THE DOWNSTREAM PRESSURE BOUNDARY CONDITION

EJECTOR FLOW REGIMES

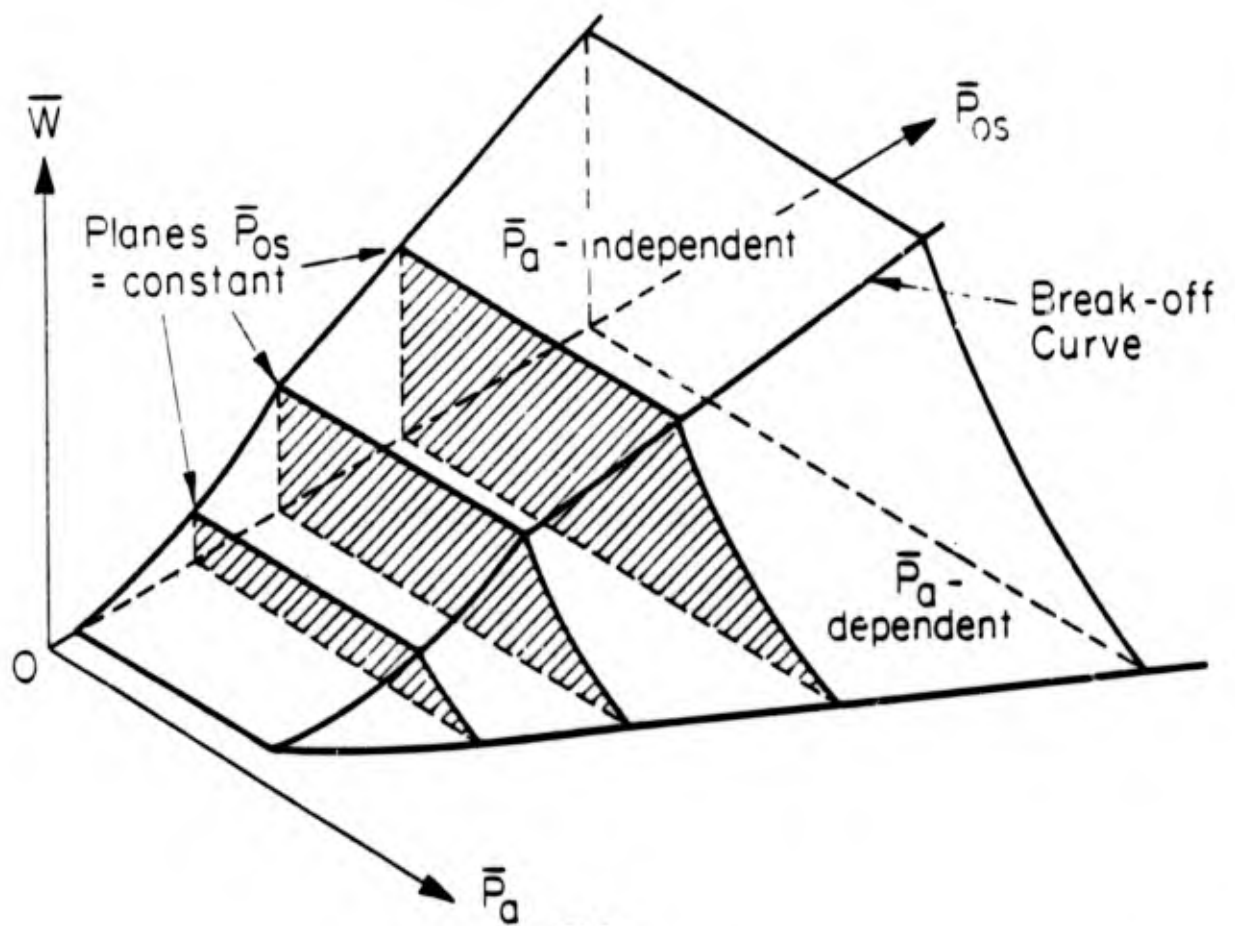
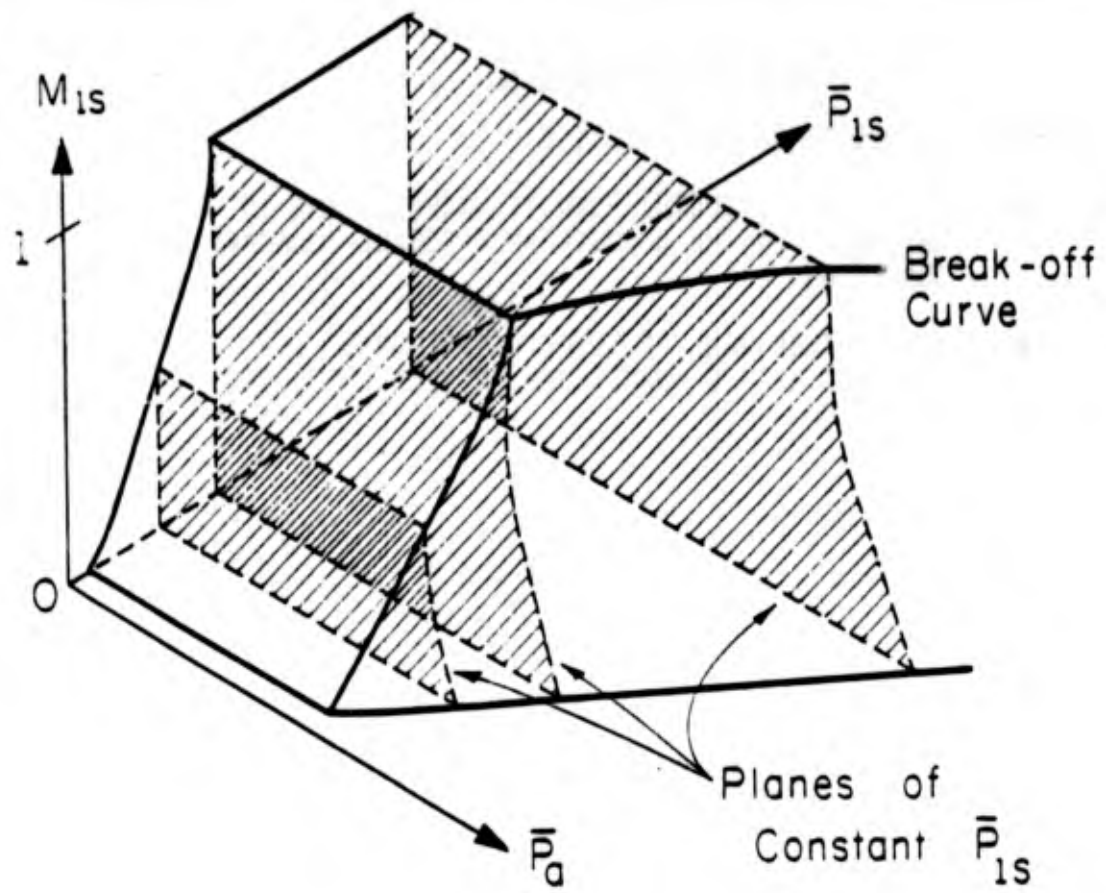
"SUPERSONIC" FLOW REGIME CHARACTERISTICS:

- SECONDARY (INDUCED) MASS FLOWRATE IS "CHOKED" AND IS INDEPENDENT OF THE DOWNSTREAM PRESSURE BOUNDARY CONDITION
- MIXING TUBE WALL PRESSURE DISTRIBUTION DOWNSTREAM OF THE AERODYNAMIC THROAT IS AFFECTED BY THE DOWNSTREAM PRESSURE BOUNDARY CONDITION

EJECTOR FLOW REGIMES

"SATURATED-SUPERSONIC" FLOW REGIME CHARACTERISTICS:

- SECONDARY (INDUCED) FLOW IS "CHOKED" AT THE EJECTOR ENTRANCE AND IS INDEPENDENT OF THE DOWNSTREAM PRESSURE BOUNDARY CONDITION
- MIXING TUBE WALL PRESSURE DISTRIBUTION IS AFFECTED BY THE DOWNSTREAM PRESSURE BOUNDARY CONDITION



EJECTOR ANALYSES :

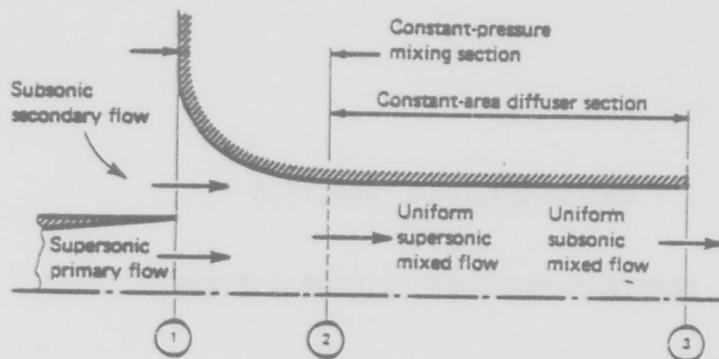
- **QUASI-ONE-DIMENSIONAL EJECTOR FLOW MODELS**
 - **CONSTANT-PRESSURE EJECTOR FLOW MODEL**
 - **CONSTANT-AREA EJECTOR FLOW MODEL**
- **TWO-DIMENSIONAL EJECTOR FLOW MODELS**
 - **INVISCID INTERACTION COMPONENT**
 - **MIXING COMPONENT**
 - **RECOMPRESSION COMPONENT**
- **FINITE-DIFFERENCE EJECTOR FLOW MODELS**



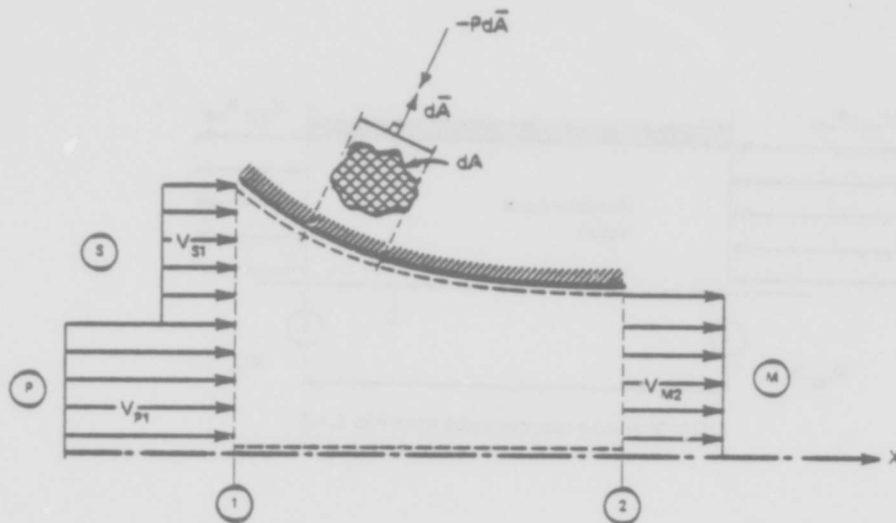
**ONE-DIMENSIONAL ANALYSIS
OF
CONSTANT-PRESSURE EJECTOR SYSTEMS**

CONSTANT-PRESSURE EJECTOR FLOW MODEL :

- **SUPERSONIC PRIMARY NOZZLE**
- **VARIABLE-AREA, CONSTANT-PRESSURE MIXING SECTION**
- **DIFFUSER SECTION**



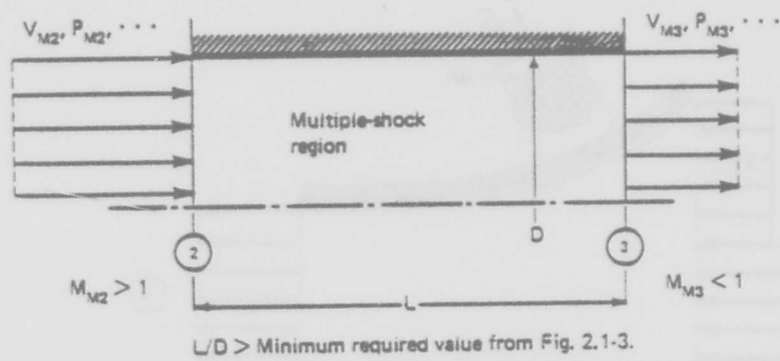
Axisymmetric constant-pressure ejector configuration



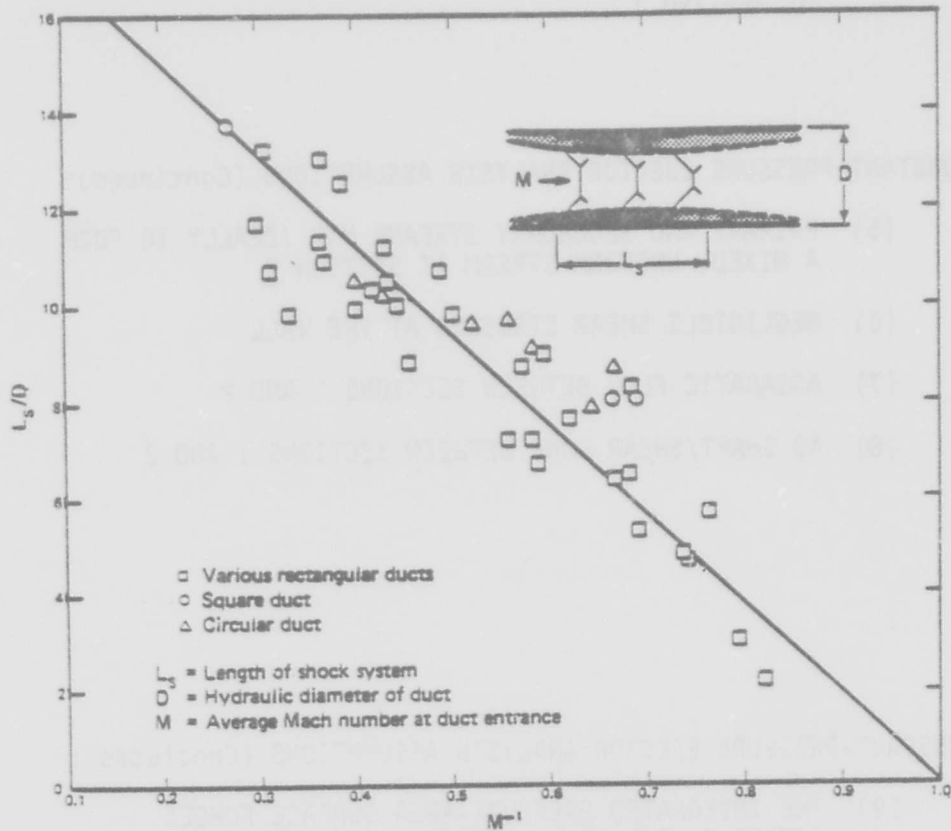
----- Control volume

$P, \rho, A, V, T, M, \text{etc.}$ are defined for each stream at sections 1 and 3.

Constant-pressure mixing section control volume



Constant-area supersonic diffuser notation



Empirical correlation for length-to-diameter ratio of constant-area supersonic diffusers

CONSTANT-PRESSURE EJECTOR ANALYSIS ASSUMPTIONS:

- (1) STEADY FLOW
- (2) PIECEWISE UNIFORM FLOWS AT SECTION 1 AND UNIFORM FLOW AT SECTIONS 2 AND 3
- (3) PRIMARY AND SECONDARY GASES OBEY THE PERFECT GAS RELATIONSHIPS
- (4) PRIMARY AND SECONDARY FLOWS ARE ISENTROPIC FROM THEIR RESPECTIVE STAGNATION STATES TO THE STATES AT SECTION 1

CONSTANT-PRESSURE EJECTOR ANALYSIS ASSUMPTIONS (Continued):

- (5) PRIMARY AND SECONDARY STREAMS MIX IDEALLY TO FORM A MIXED, UNIFORM STREAM AT SECTION 2
- (6) NEGLIGIBLE SHEAR STRESSES AT THE WALL
- (7) ADIABATIC FLOW BETWEEN SECTIONS 1 AND 2
- (8) NO SHAFT/SHEAR WORK BETWEEN SECTIONS 1 AND 2

CONSTANT-PRESSURE EJECTOR ANALYSIS ASSUMPTIONS (Concluded):

- (9) THE INTEGRATED PRESSURE-AREA SURFACE FORCES ACTING IN THE FLOW DIRECTION ARE ZERO

THE CONSTANT-PRESSURE EJECTOR IS A SPECIAL CASE SATISFYING ASSUMPTION (9)

THE MIXING SECTION AREA VARIATION IS ASSUMED TO VARY SO THAT THE STATIC PRESSURE OF THE MIXING FLOW IS CONSTANT WITHIN THE MIXING SECTION

CONSERVATION OF MASS:

$$\oint_{CS} \rho \bar{V} \cdot d\bar{A} = 0$$

$$\rho_{P1} V_{P1} A_{P1} + \rho_{S1} V_{S1} A_{S1} = \rho_{M2} V_{M2} A_{M2}$$

$$w \equiv \rho AV, \quad w_P + w_S = w_M$$

$$\mu \equiv w_S/w_P$$

CONSERVATION OF MOMENTUM:

$$\rightarrow \sum F_x = \oint_{CS} V_x (\rho \bar{V} \cdot d\bar{A})$$

$$\rightarrow \sum F_x = P_{P1} A_{P1} + P_{S1} A_{S1} - P_{M2} A_{M2} - \hat{z}_x \cdot \int_{A_w} P d\bar{A}$$

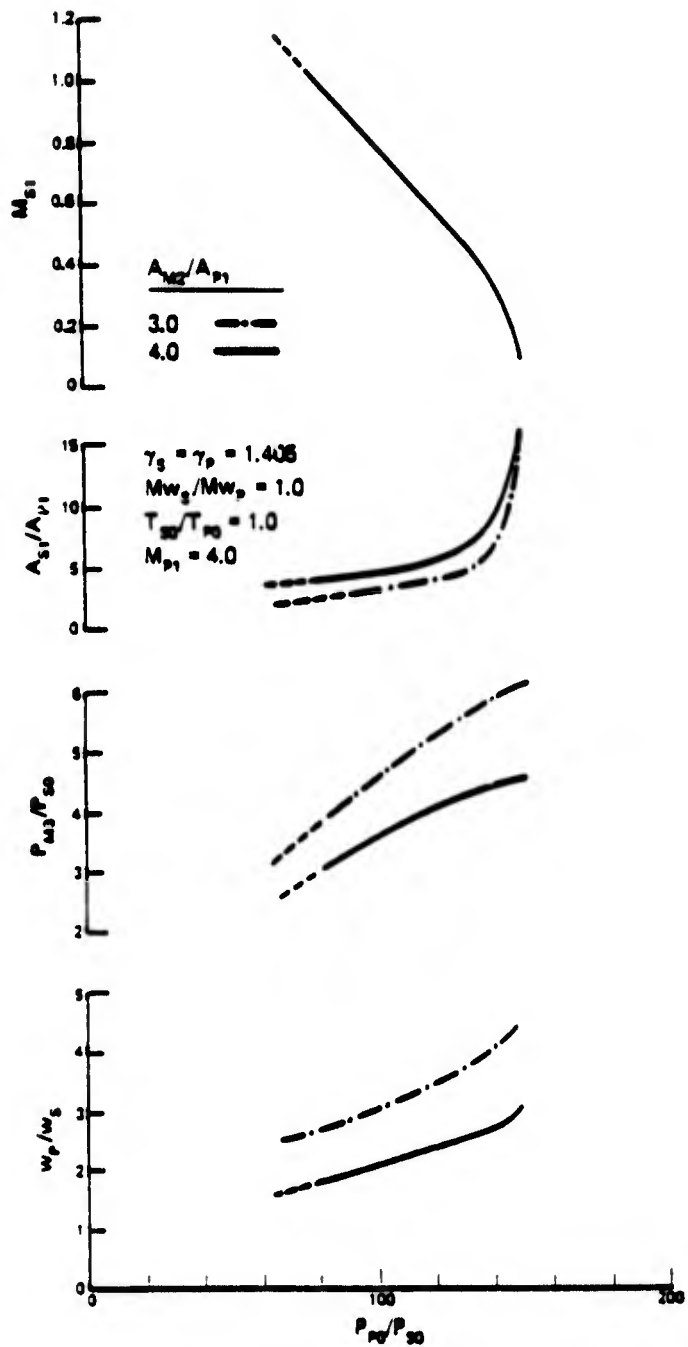
$$\gamma_P M_{P1}^2 + \frac{A_{S1}}{A_{P1}} \gamma_S M_{S1}^2 = \frac{A_{M2}}{A_{P1}} \gamma_M M_{M2}^2$$

CONSERVATION OF ENERGY:

$$\oint_{CS} (h_0) \rho \bar{V} \cdot d\bar{A} = 0$$

$$w_P h_{P0} + w_S h_{S0} = w_M h_{M0}$$

$$\frac{T_{M0}}{T_{P0}} = \frac{1}{(1+\mu)} \left[\frac{(C_p)_P}{(C_p)_M} \right] \left[1 + \mu \frac{(C_p)_S}{(C_p)_P} \cdot \frac{T_{S0}}{T_{P0}} \right]$$



Representative characteristics for a constant-pressure ejector

- AREA DISTRIBUTION OF THE MIXING SECTION IS:
 - (1) UNKNOWN,
 - (2) DEPENDENT ON THE EJECTOR OPERATING POINT,
AND
 - (3) NOT DETERMINABLE FROM THE ANALYSIS.

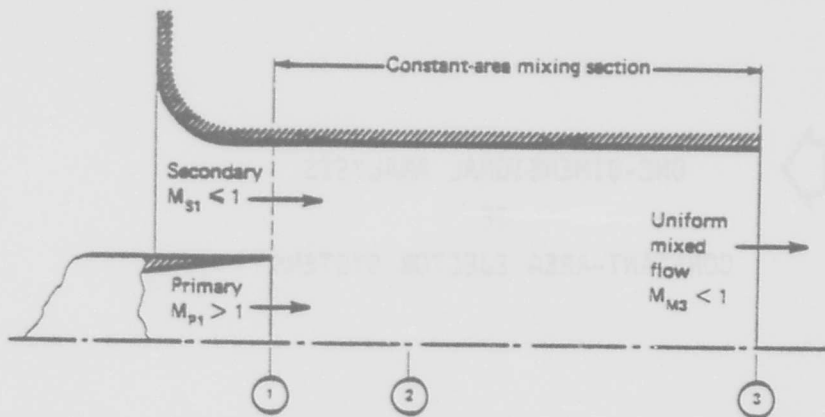
- FLOW MODEL DOES NOT INCLUDE KNOWN EJECTOR PHENOMENA AND REGIMES:
 - (1) INTERACTION BETWEEN STREAMS AND
 - (2) "CHOKING".



ONE-DIMENSIONAL ANALYSIS
OF
CONSTANT-AREA EJECTOR SYSTEMS

CONSTANT-AREA EJECTOR FLOW MODEL:

- SUPERSONIC PRIMARY NOZZLE
- CONSTANT-AREA MIXING SECTION



* Exists only for the "supersonic" regime

Axisymmetric constant-area ejector configuration

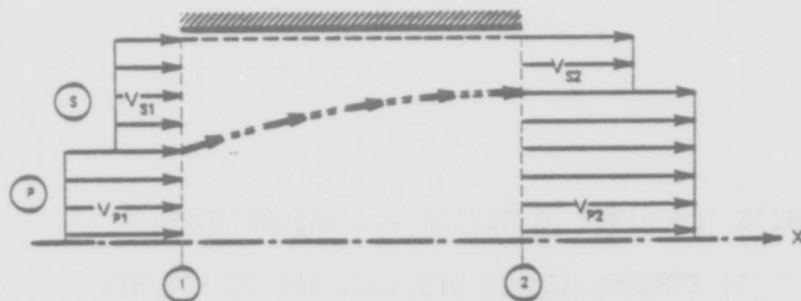


----- Control volume

P, ρ, A, V, T, M , etc. are defined for each stream at sections 1 and 3.

*If "choking" exists

Constant-area mixing section control volume



----- Control volume

Control volume for Fabri "choking" analysis

CONSTANT-AREA EJECTOR ANALYSIS ASSUMPTIONS:

- (1) STEADY FLOW
- (2) PIECEWISE UNIFORM FLOWS AT SECTIONS 1 AND 2, AND UNIFORM FLOW AT SECTION 3
- (3) PRIMARY AND SECONDARY GASES OBEY THE PERFECT GAS RELATIONSHIPS
- (4) PRIMARY AND SECONDARY FLOWS ARE ISENTROPIC FROM THEIR RESPECTIVE STATES AT SECTION 1

CONSTANT-AREA EJECTOR ANALYSIS ASSUMPTIONS (Continued):

- (5) PRIMARY AND SECONDARY STREAMS MIX TO FORM A UNIFORM STREAM AT SECTION 3
- (6) NEGLIGIBLE SHEAR STRESSES AT THE WALL
- (7) ADIABATIC FLOW BETWEEN SECTIONS 1 AND 3
- (8) NO SHAFT/SHEAR WORK BETWEEN SECTIONS 1 AND 3

FABRI'S "CHOKING" CRITERION --- ASSUMPTIONS:

- (1) STREAMS REMAIN DISTINCT AND DO NOT MIX BETWEEN SECTIONS 1 AND 2.
- (2) FLOW IS ISENTROPIC FOR EACH STREAM BETWEEN SECTIONS 1 AND 2.
- (3) AVERAGE PRESSURE OF THE STREAMS CAN BE DIFFERENT AT EACH CROSS-SECTION.
- (4) THE MACH NUMBER OF THE SECONDARY FLOW AT SECTION 2 IS $M_{S2} = 1$.
- (5) THE STATIC PRESSURES ARE SUCH THAT $P_{P1} > P_{S1}$.

CONSERVATION OF MASS:

$$\oint_{CS} \rho \vec{v} \cdot d\vec{A} = 0$$

$$\rho_P V_P A_P + \rho_S V_S A_S = \rho_M V_M A_M$$

$$w = \rho AV, w_P + w_S = w_M$$

$$\mu = w_S/w_P$$

CONSERVATION OF MOMENTUM:

$$\rightarrow \sum F_x = \oint_{CS} v_x (\rho \vec{v} \cdot d\vec{A})$$

$$P_P A_P + P_S A_S - P_M A_M =$$

$$\rho_M A_M V_M^2 - (\rho_P A_P V_P^2 + \rho_S A_S V_S^2)$$

CONSERVATION OF ENERGY:

$$\oint_{CS} h_0 (\rho \vec{v} \cdot d\vec{A}) = 0$$

$$w_P h_{P0} + w_S h_{S0} = w_M h_{M0}$$

$$\frac{T_{M0}}{T_{P0}} = \frac{1}{(1+\mu)} \left[\frac{(C_p)_P}{(C_p)_M} \right] \left[1 + \mu \frac{(C_p)_S}{(C_p)_P} \cdot \frac{T_{S0}}{T_{P0}} \right]$$

CONSTANT-AREA EJECTOR OPERATING REGIMES:

- "MIXED" REGIME ... BACK-PRESSURE DEPENDENT
- "SUPERSONIC" AND "SATURATED SUPERSONIC" REGIME ... BACK-PRESSURE INDEPENDENT
- TRANSITION BETWEEN REGIMES OCCURS ALONG THE "BREAK-OFF" CURVE

"MIXED" FLOW REGIME:

- $M_{S1} < 1$
- $P_{S1}/P_{P1} \leq 1$
- $M_{S2} < 1$
- $w_S/w_P = f(P_{S0}/P_{P0}, P_{M3}/P_{P0}, \dots)$

"SUPERSONIC" FLOW REGIME:

- $M_{S1} < 1$
- $P_{S1}/P_{P1} < 1$
- $M_{S2} = 1$
- $w_S/w_P = f(P_{S0}/P_{P0}, \dots)$

"SATURATED-SUPERSONIC" FLOW REGIME:

- $M_{S1} = 1$
- $P_{S1}/P_{P1} \geq 1$
- $w_S/w_P = f(P_{S0}/P_{P0}, \dots)$

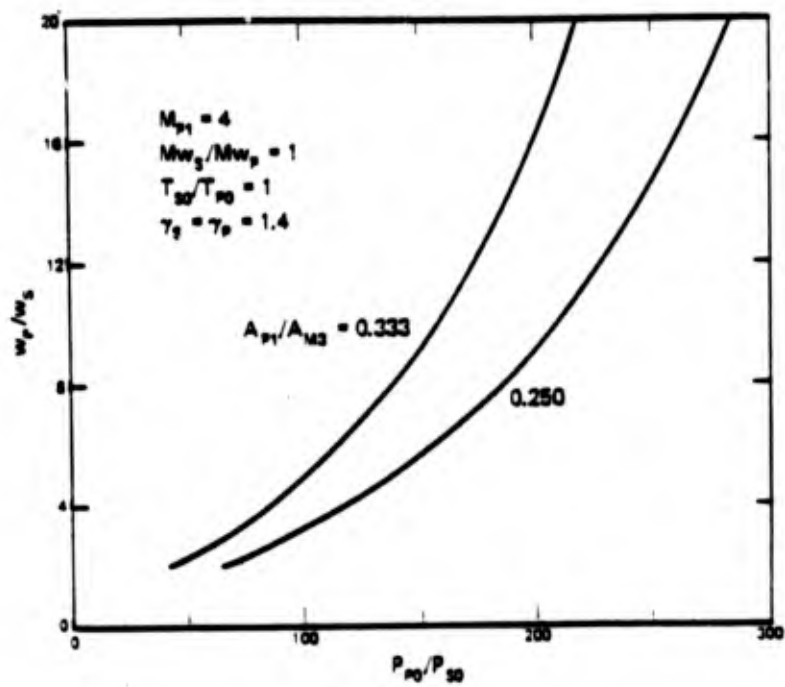
INVISCID INTERACTION CHARACTERISTICS AND CRITERIA:



- SUBSONIC/SUPERSONIC ENTRANCE FLOWS
 - SECONDARY FLOW ACCELERATES TO FORM AN AERODYNAMIC THROAT
 - "CHOKING" AT AERODYNAMIC THROAT
 - UNEQUAL AVERAGE STATIC PRESSURES AT AERODYNAMIC THROAT

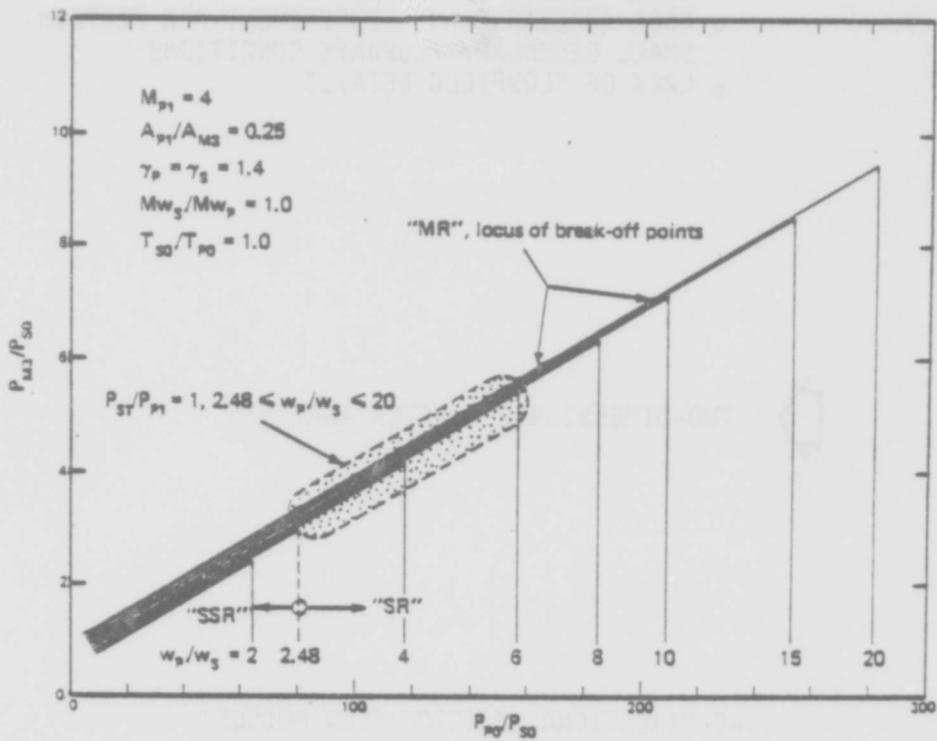
INVISCID INTERACTION CHARACTERISTICS AND CRITERIA (CONT'D)

- SUPERSONIC/SUPERSONIC ENTRANCE FLOWS
 - SECONDARY FLOW DECELERATES TO FORM AN AERODYNAMIC THROAT
 - "LIMITING" MACH NUMBER OF ONE AT AERODYNAMIC THROAT
 - UNEQUAL AVERAGE STATIC PRESSURES AT AERODYNAMIC THROAT
 - INDUCED FLOW SEPARATION MAY LIMIT PERFORMANCE



(a) Mass flowrate characteristics

Constant-area ejector characteristics



(b) Compression characteristics

CONSTANT-AREA EJECTOR FLOW MODEL

- POSITIVE FEATURES:
 - INCLUDES EXPERIMENTALLY OBSERVED FLOW REGIMES
 - INCLUDES "CHOKING" PHENOMENA
 - CONVENIENT AND RAPID ANALYSIS
- NEGATIVE FEATURES:
 - CONSTANT-AREA RESTRICTION
 - "LONG" MIXING SECTIONS
 - POOR AGREEMENT WITH EXPERIMENT FOR CERTAIN SMALL SECONDARY FLOWRATE CONDITIONS
 - LACK OF FLOWFIELD DETAILS



TWO-DIMENSIONAL EJECTOR ANALYSES

TWO-DIMENSIONAL EJECTOR FLOW MODELS:

- "ZERO" AND "SMALL" SECONDARY FLOWRATES
 - TURBULENT MIXING
 - FLOW-WALL INTERACTION
 - FLOW RECOMPRESSION
- "HIGHER" SECONDARY FLOWRATES
 - INVISCID PRIMARY-SECONDARY INTERACTION
 - TURBULENT MIXING
 - SOLUTION CRITERIA AND BOUNDARY CONDITIONS
 - FLOW DIFFUSION

TWO-DIMENSIONAL INVISCID INTERACTION:

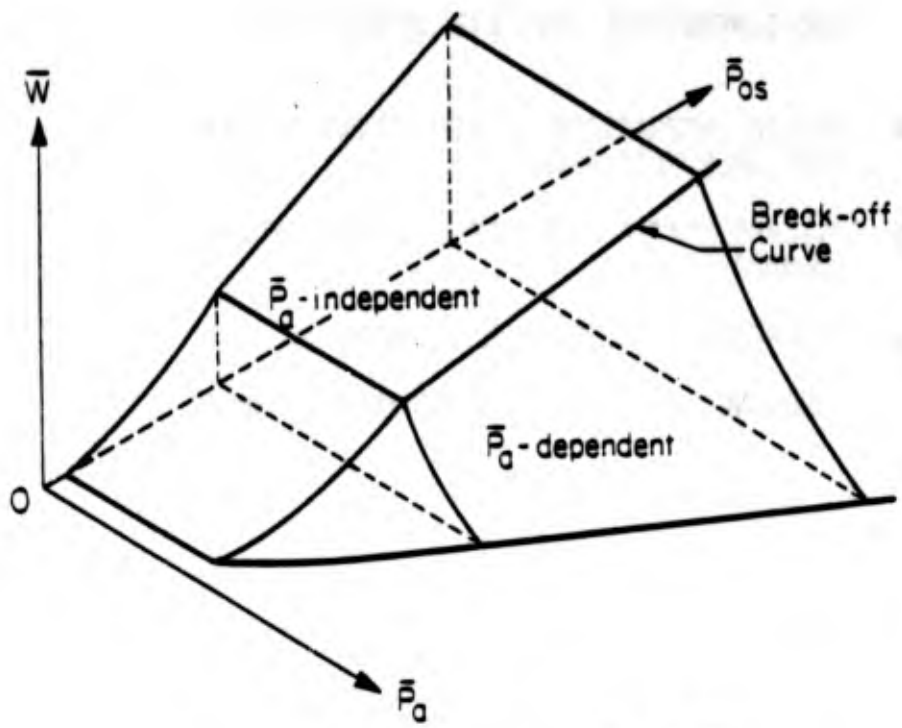
- MUTUAL INTERACTION BETWEEN FLOWS WITHIN AVAILABLE FLOW AREA
- MATCHED STATIC PRESSURE AT MUTUAL FLUID BOUNDARY
- FORMATION OF AERODYNAMIC THROAT
- "CHOKING" CRITERIA AT AERODYNAMIC THROAT

TWO-DIMENSIONAL MIXING COMPONENT:

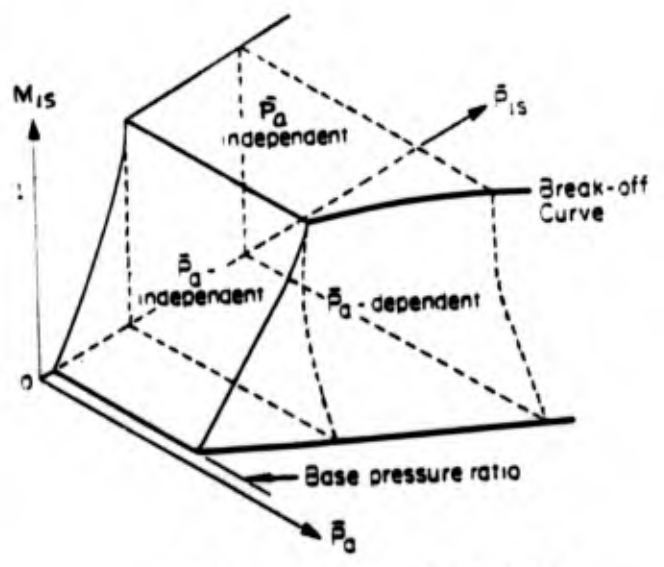
- INVISCID VELOCITIES AT FLUID SLIPLINE BOUNDARY
- SUPERIMPOSE FULLY DEVELOPED MIXING PROFILE
- ESTIMATE ENTRAINMENT AND DISPLACEMENT EFFECTS

EJECTOR OPERATING REGIMES:

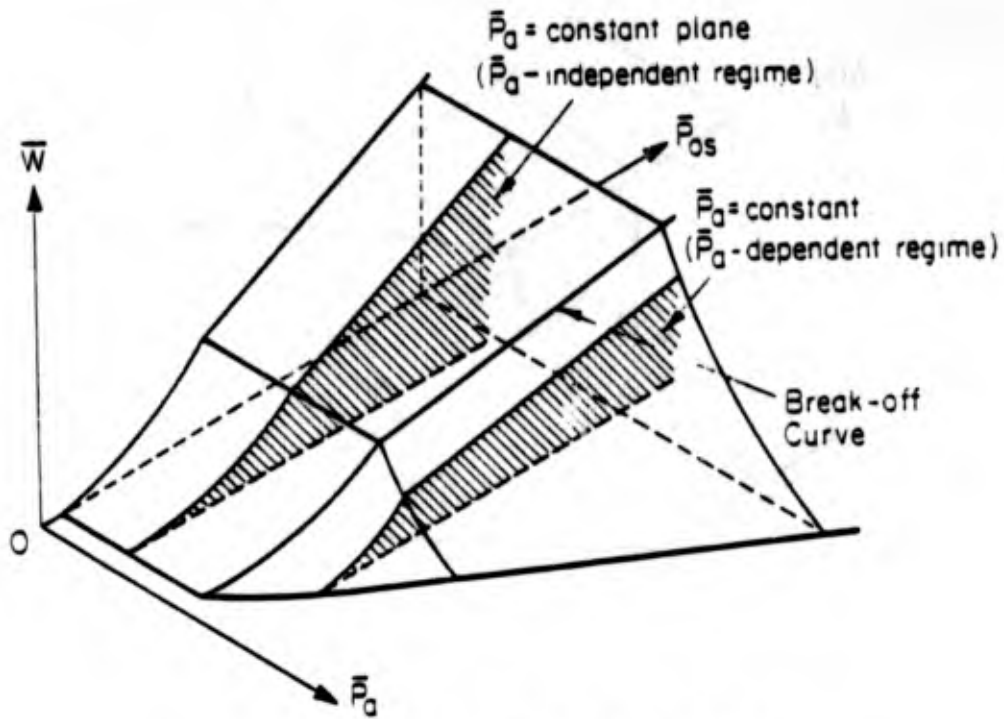
- "MIXED" REGIME...BACK-PRESSURE DEPENDENT
- "SUPERSONIC" AND "SATURATED-SUPERSONIC" REGIME...BACK-PRESSURE INDEPENDENT
- TRANSITION BETWEEN REGIMES OCCURS ALONG THE "BREAK-OFF" CURVE



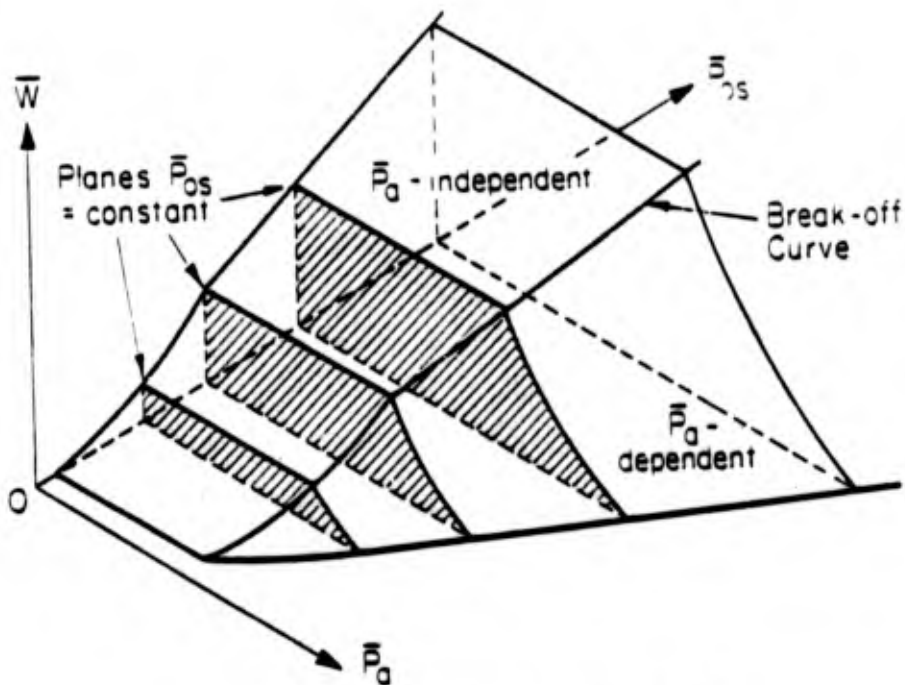
Ejector mass flow characteristic surface, $w = f(P_{0s}, P_a)$



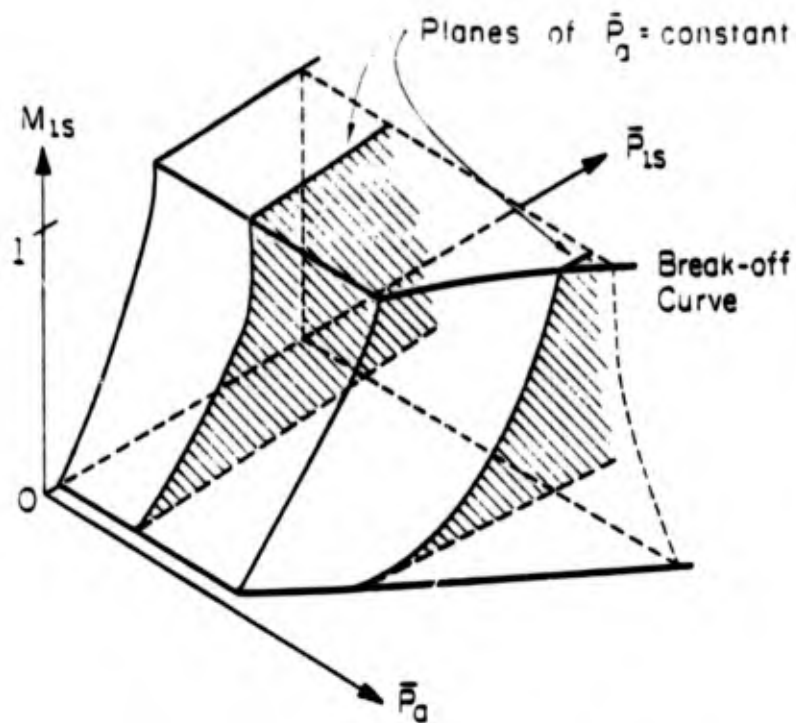
Ejector characteristic surface $M_{1s} = f(P_{1s}, P_a)$



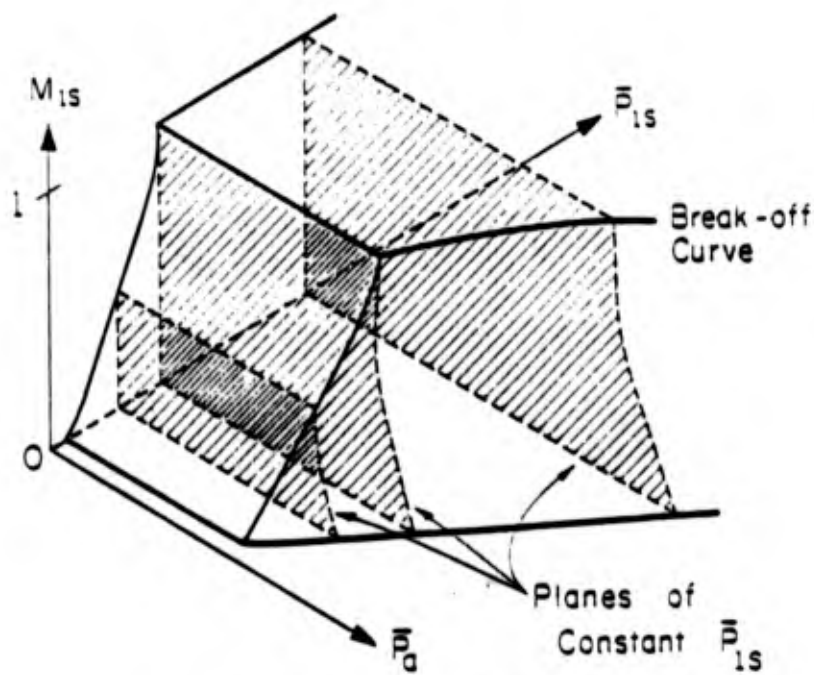
Intersection of the \bar{W} -surface with planes of constant \bar{P}_a



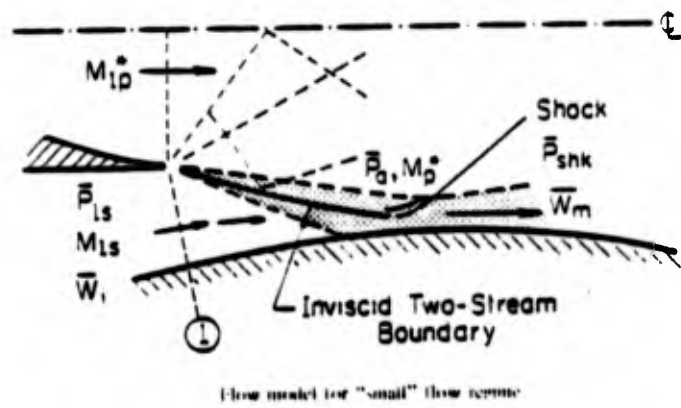
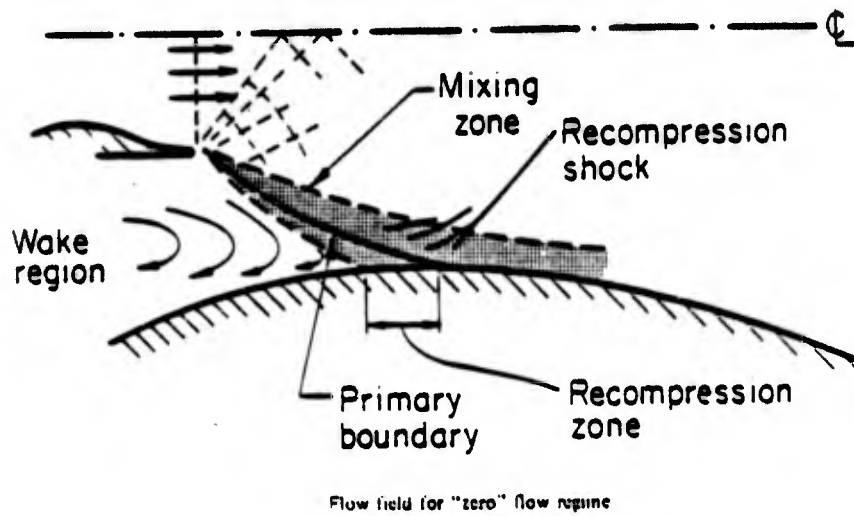
Intersection of the \bar{W} -surface with planes of constant \bar{P}_{os}

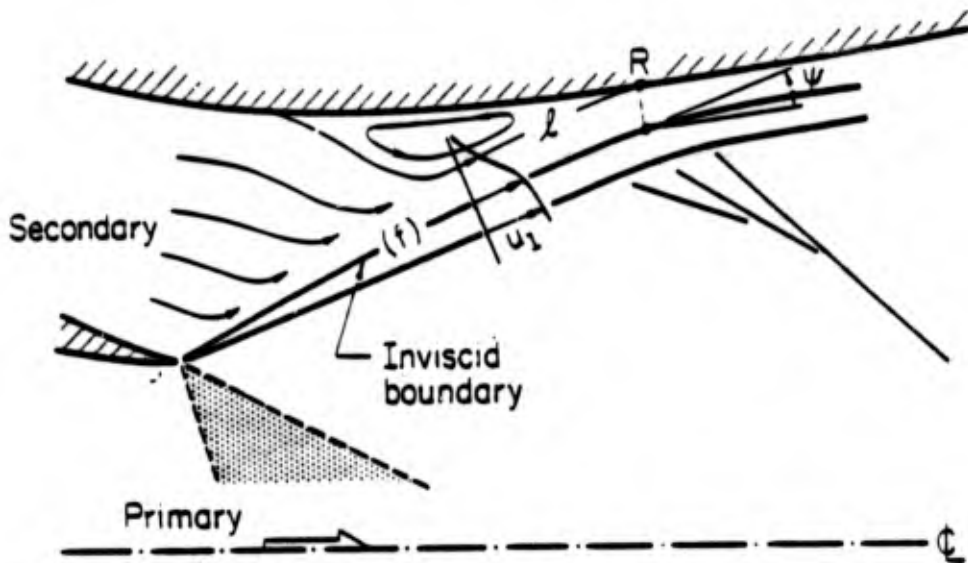


Intersection of the M_{1s} -surface with planes of constant p_a .

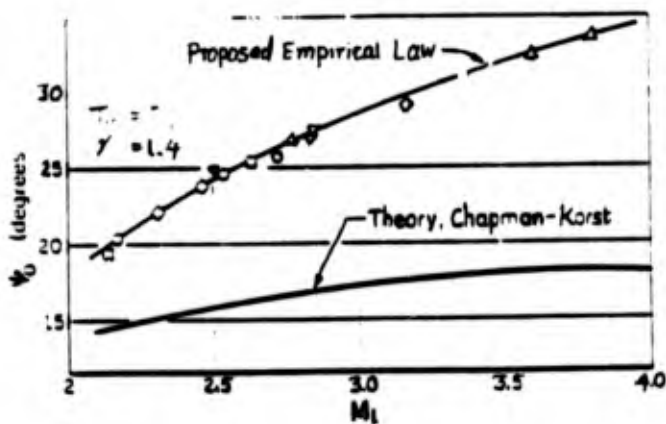


Intersection of the M_{1s} -surface with planes of constant p_{1s} .

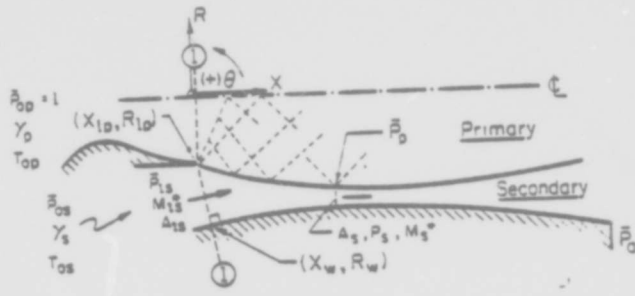




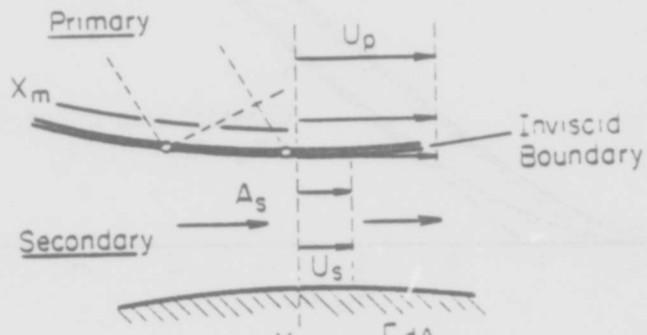
Schematic of theoretical reattachment ONERA



Empirical law of angular reattachment ONERA

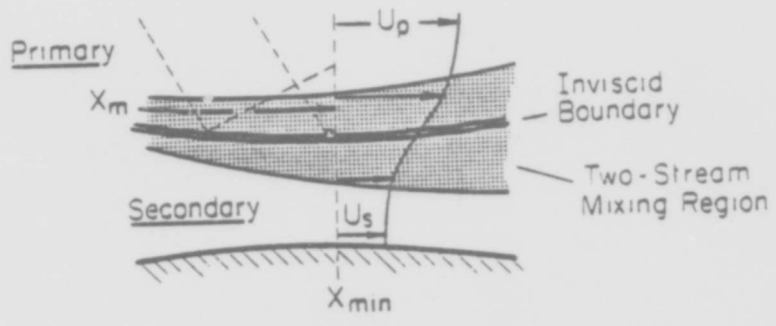


Two-stream inviscid flow model

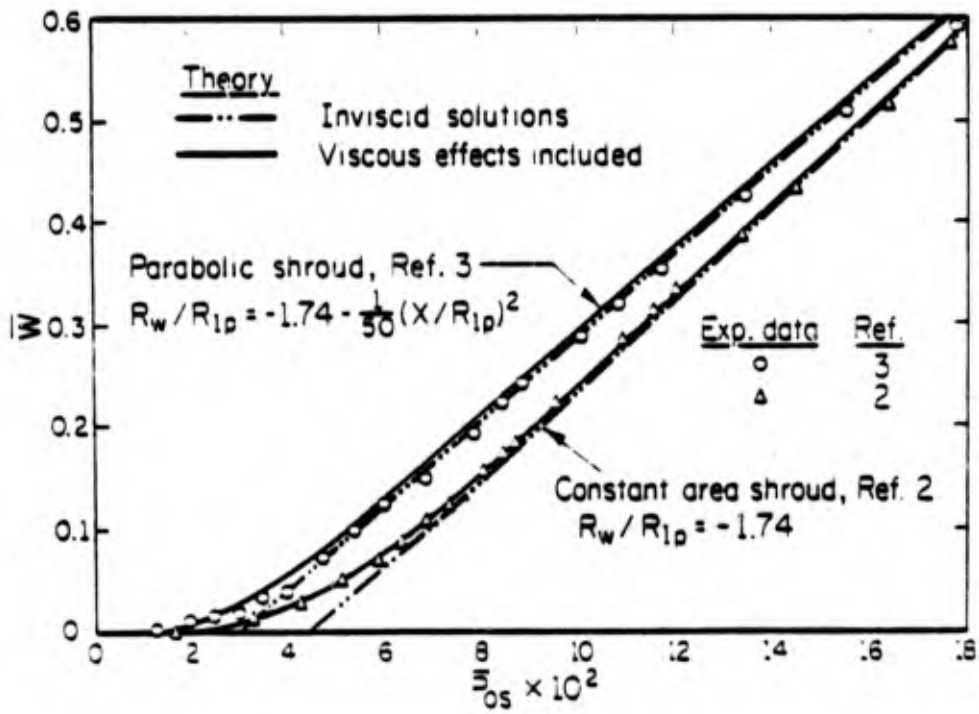


$$\left. \begin{aligned} \frac{dA_s}{dX} &= 0 \\ \text{where } (M_s^*)_{\min} &\leq 1 \\ (A/A^*)_s &= \text{minimum} \end{aligned} \right\}$$

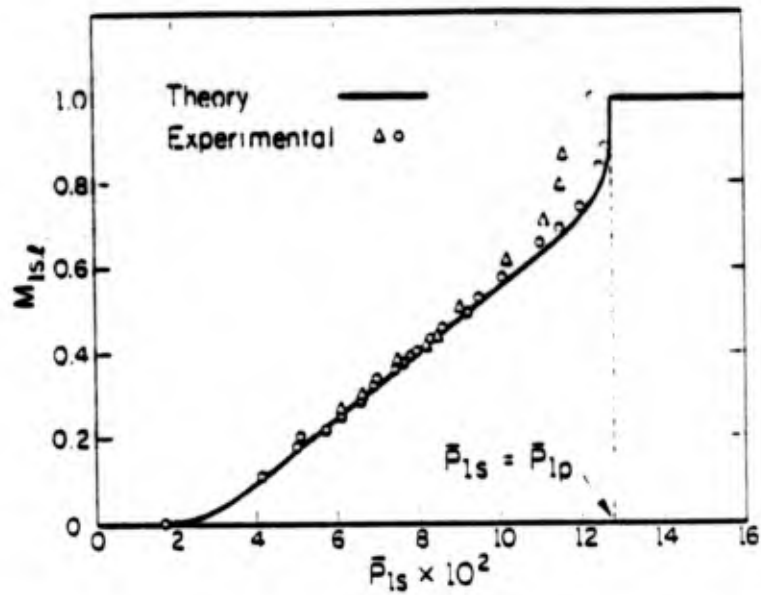
Inviscid velocity profile at the "choking" point



Viscid approximation at the "choking" point



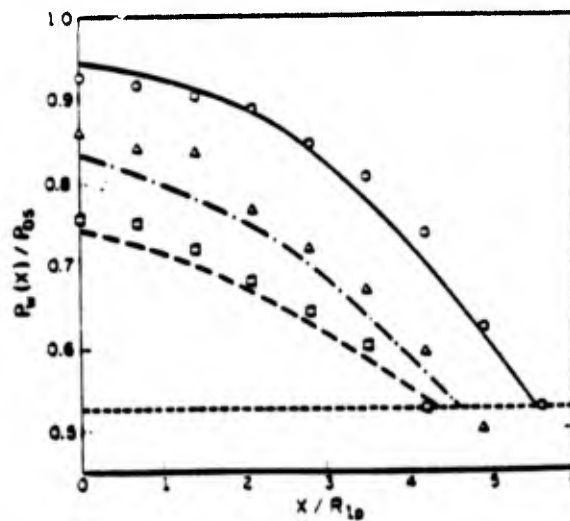
Comparison of theory and experiment for the pumping characteristics of two reactor systems (After References 2 and 3)



Comparison of theory and experiment for the "limiting initial secondary Mach number" for a constant throat area ejector system. ($M_{1p} = 2$, $A_w/A_{1p} = 3.06$ (Ref. 2))

β_{1s} Table

Inviscid Theory		Experimental	
Line	Value	Symbol	Value
—	0.06374	o	0.0658
- · - ·	0.090	△	0.092
- - - -	0.110	□	0.111



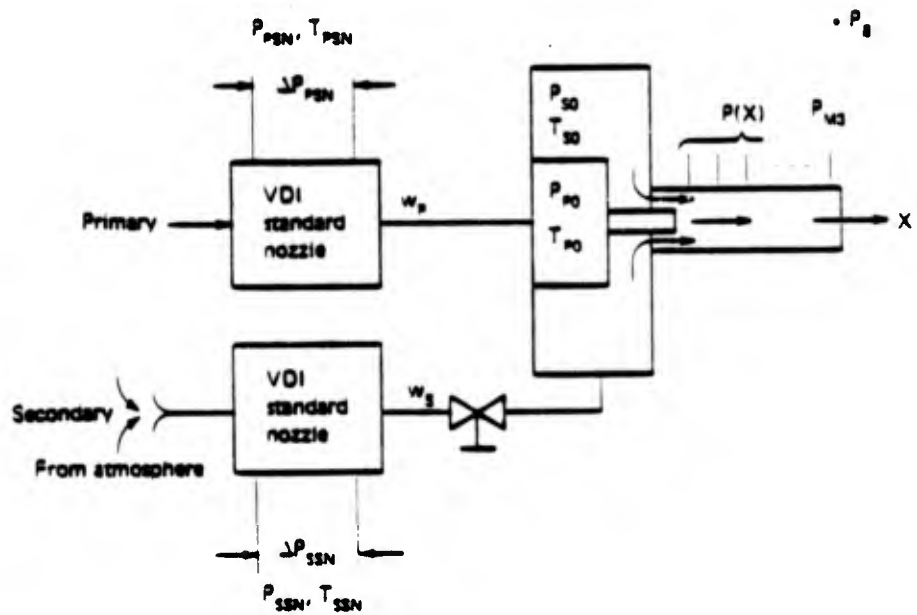
Comparison of theory and experiment for the pressure distribution up to the "choking" point ($M_{1p} = 2$, $A_w/A_{1p} = 3.06$ (Ref. 2))

TWO-DIMENSIONAL INTERACTION MODEL

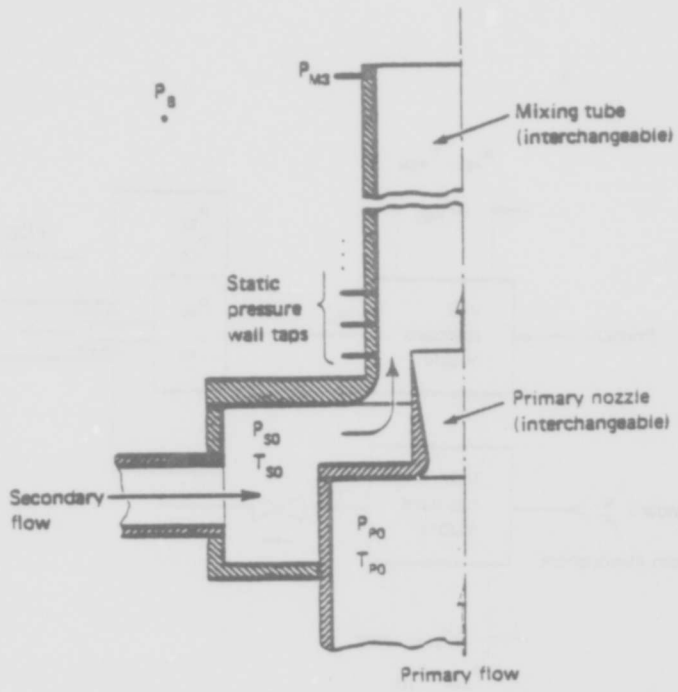
- POSITIVE FEATURES:
 - INCLUDES EXPERIMENTALLY OBSERVED FLOW REGIMES
 - INCLUDES "CHOKING" PHENOMENA
 - ANALYZE NON-CONSTANT AREA MIXING DUCTS
 - AGREES WELL WITH EXPERIMENTS THROUGHOUT OPERATIONAL REGIME
- NEGATIVE FEATURES:
 - TEDIOUS SOLUTION PROCEDURE
 - TIME-CONSUMING COMPUTATIONS
 - NOT APPLICABLE TO "LONG" NON-CONSTANT AREA MIXING DUCTS



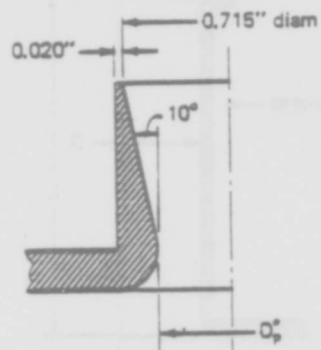
EXPERIMENTAL EJECTOR RESULTS



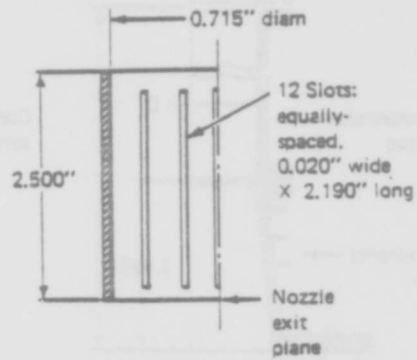
Experimental ejector set-up and notation



Schematic of axisymmetric ejector configuration



(a) Basic conical nozzle.



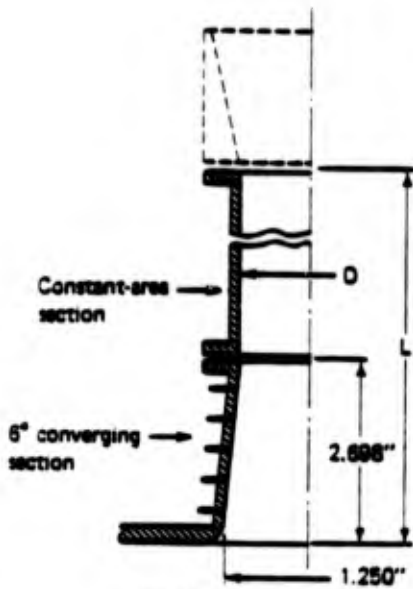
(b) Slotted extension for nozzle.

Nozzle	$M_{p,1}$	D_p^* in.
1	2.0	0.550
2	2.5	0.440
3*	2.5	0.440

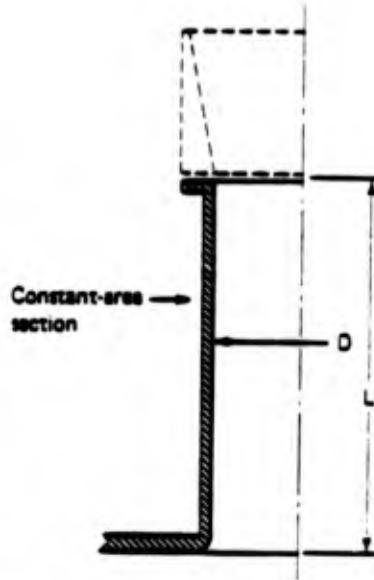
*Slotted nozzle

(c) Nozzle specifications.

Schematics and specifications of ejector primary nozzles



(a) Variable-area mixing section.

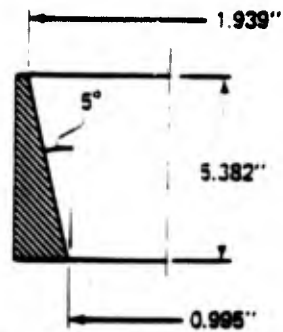


(b) Constant-area mixing section.

Mixing tube	D in.	L in.
1	0.995	12.500
2	1.245	13.000
3*	0.995	12.882

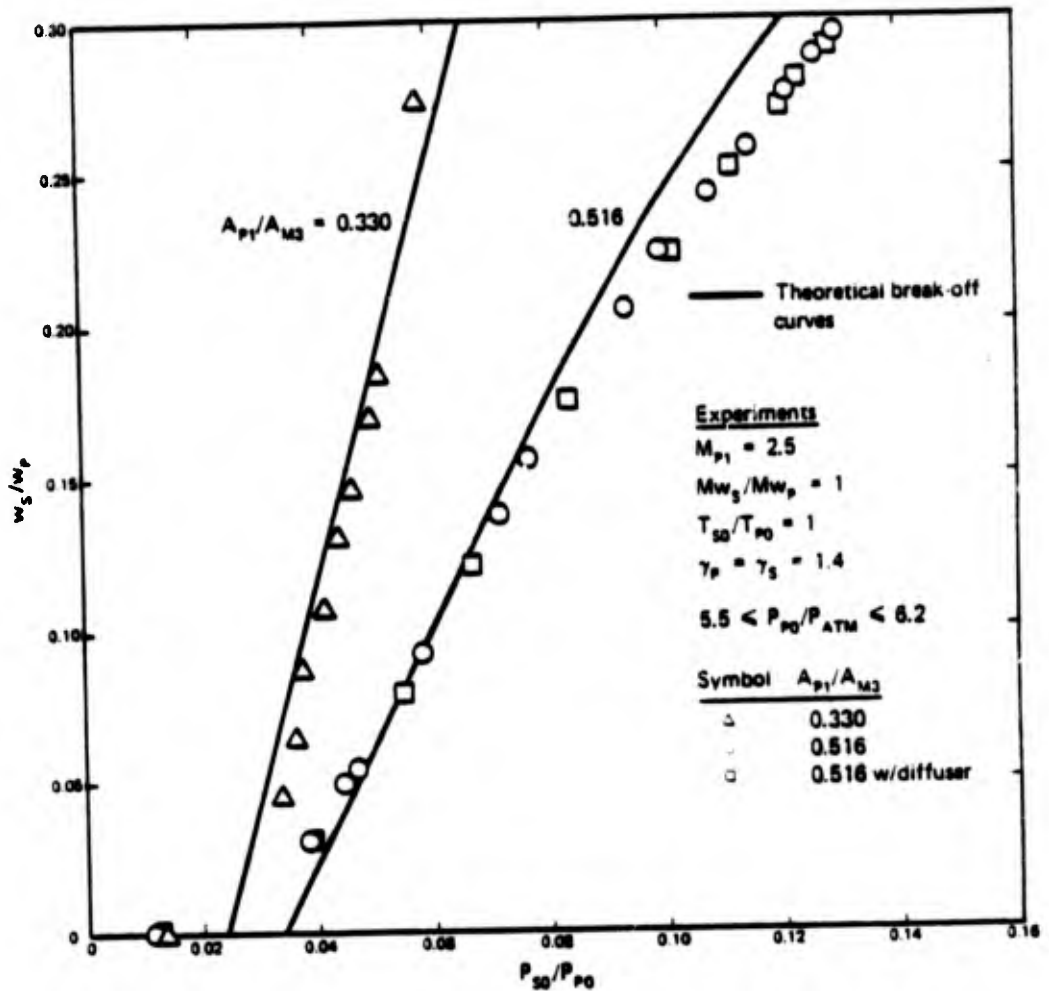
*With 6° converging section

(c) Mixing section specifications.

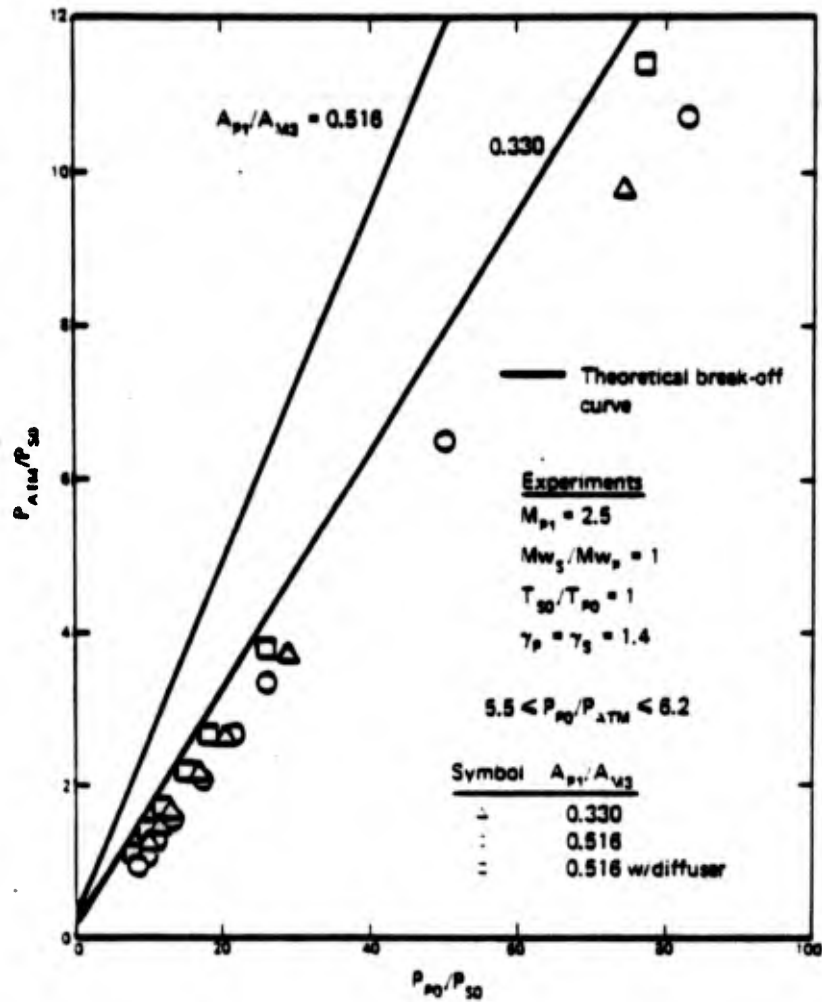


(d) Subsonic diffuser section.

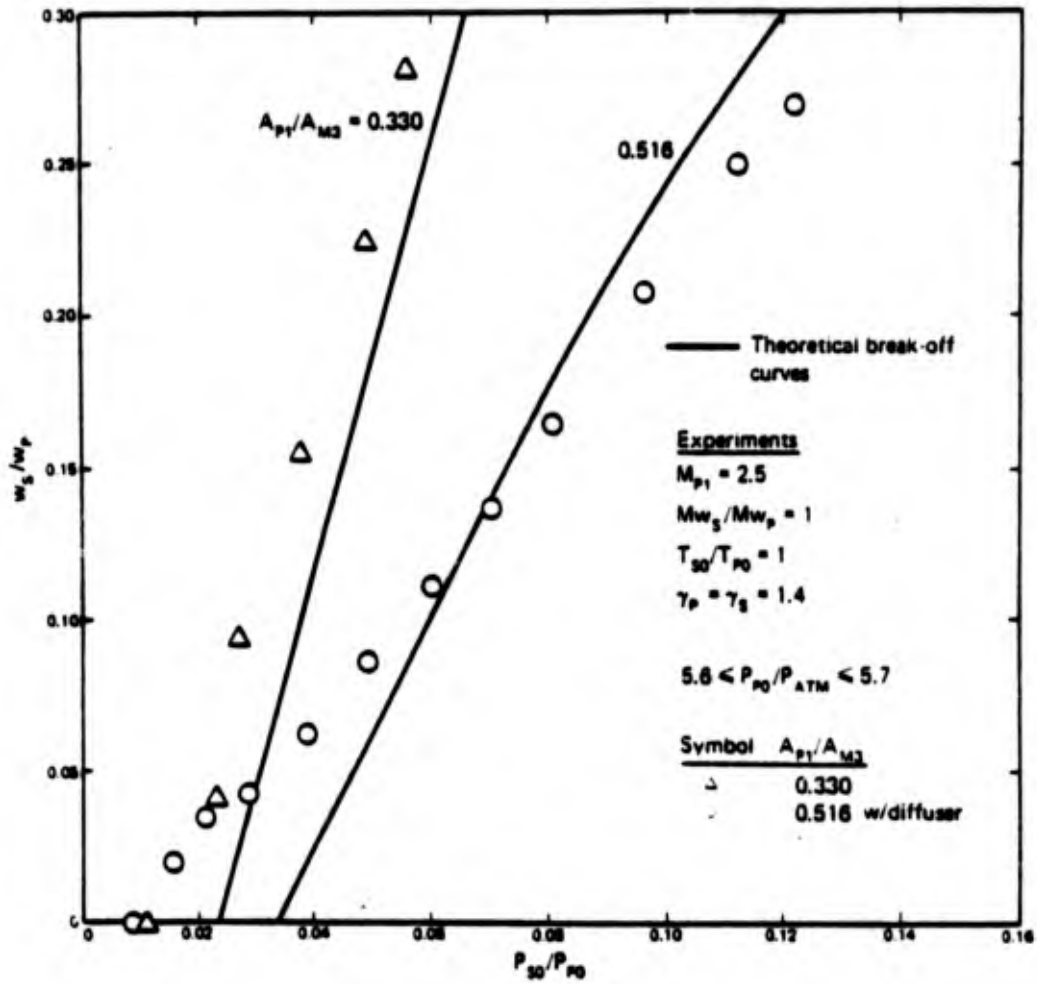
Schematics and specifications of ejector mixing sections



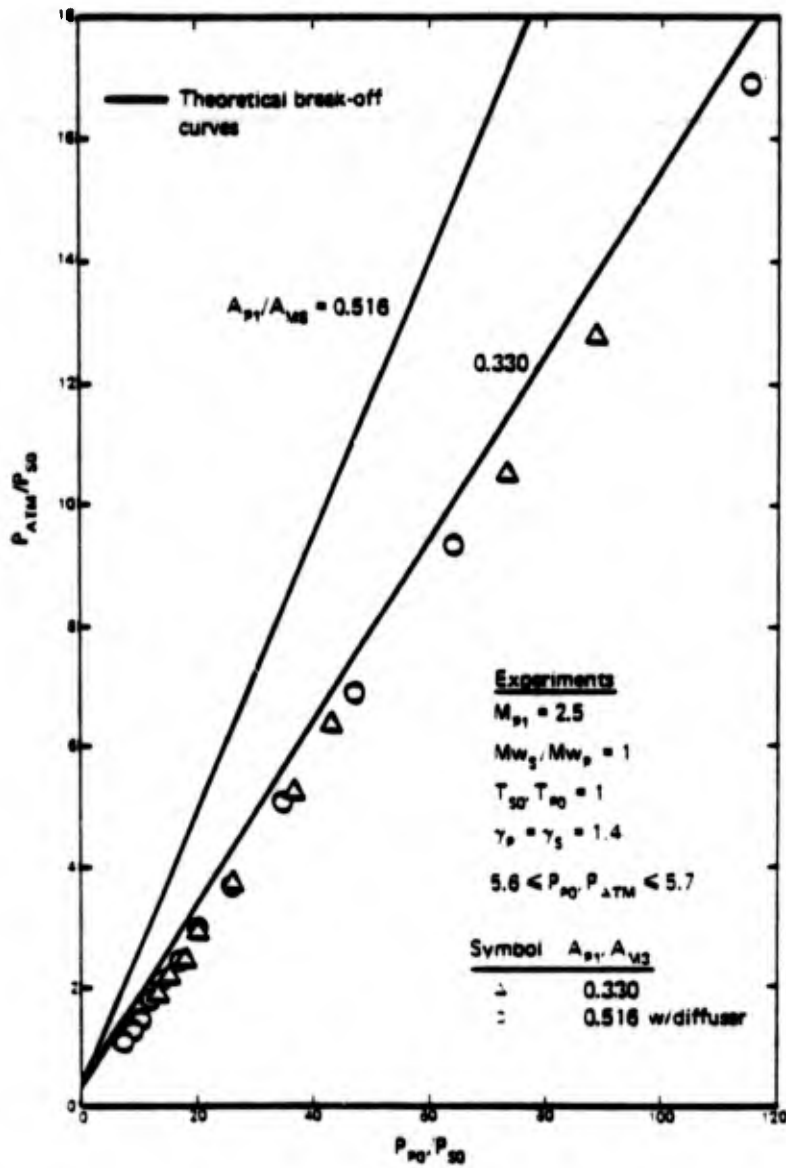
Constant-area ejector mass flow characteristics
 ($A_{p1}/A_{M3} = 0.330, 0.516$ and $M_{p1} = 2.5$)



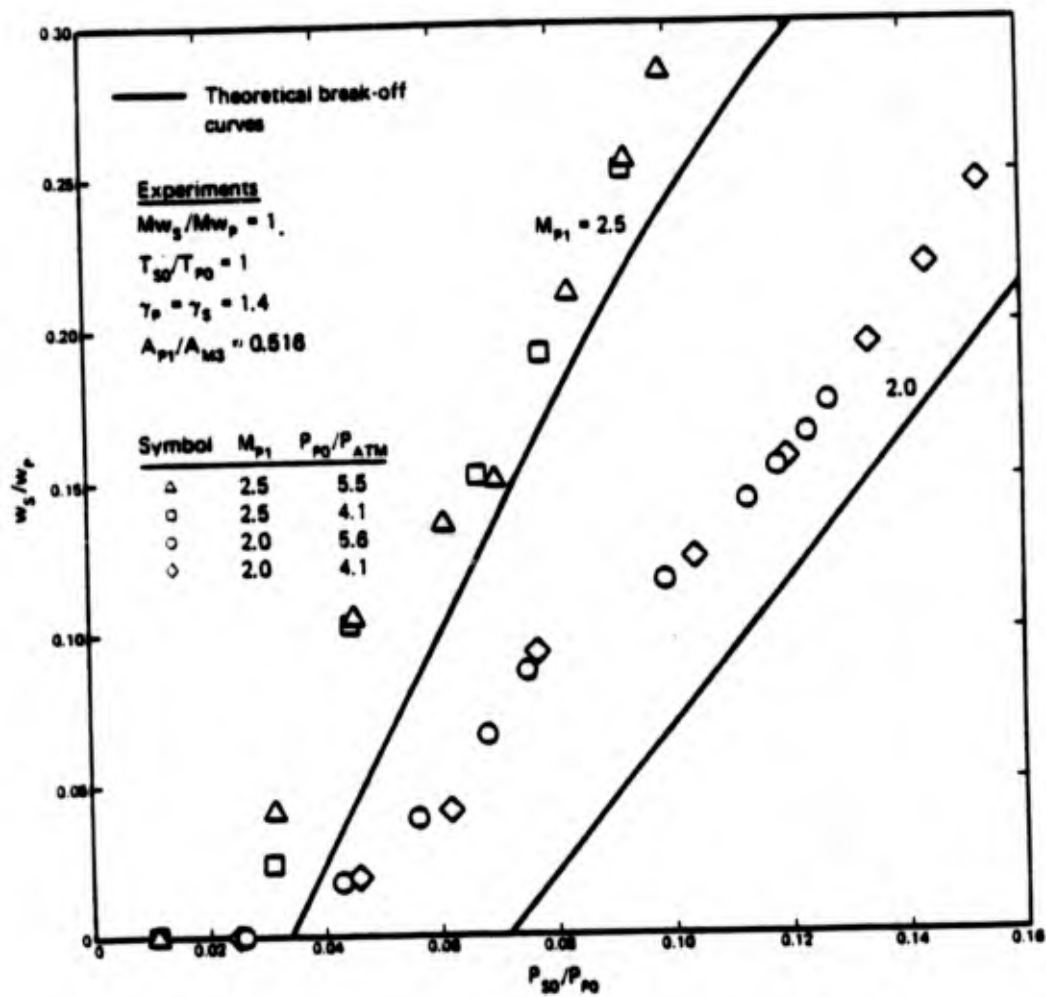
Constant-area ejector compression characteristics
 $(A_{21}/A_{123} = 0.330, 0.516 \text{ and } M_{21} = 2.5)$



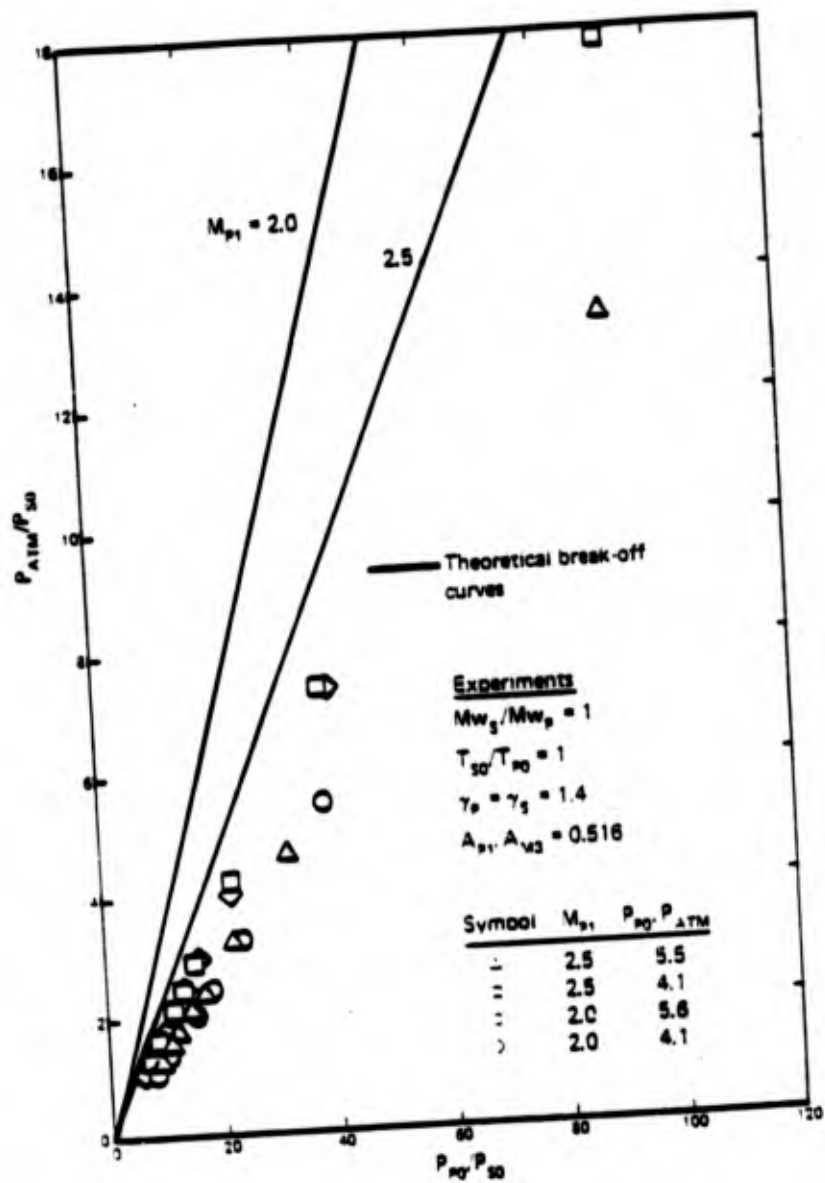
Constant-area, slotted-nozzle ejector mass flow characteristics
 ($A_{p1}/A_{M2} = 0.330, 0.516$ and $M_{p1} = 2.5$)



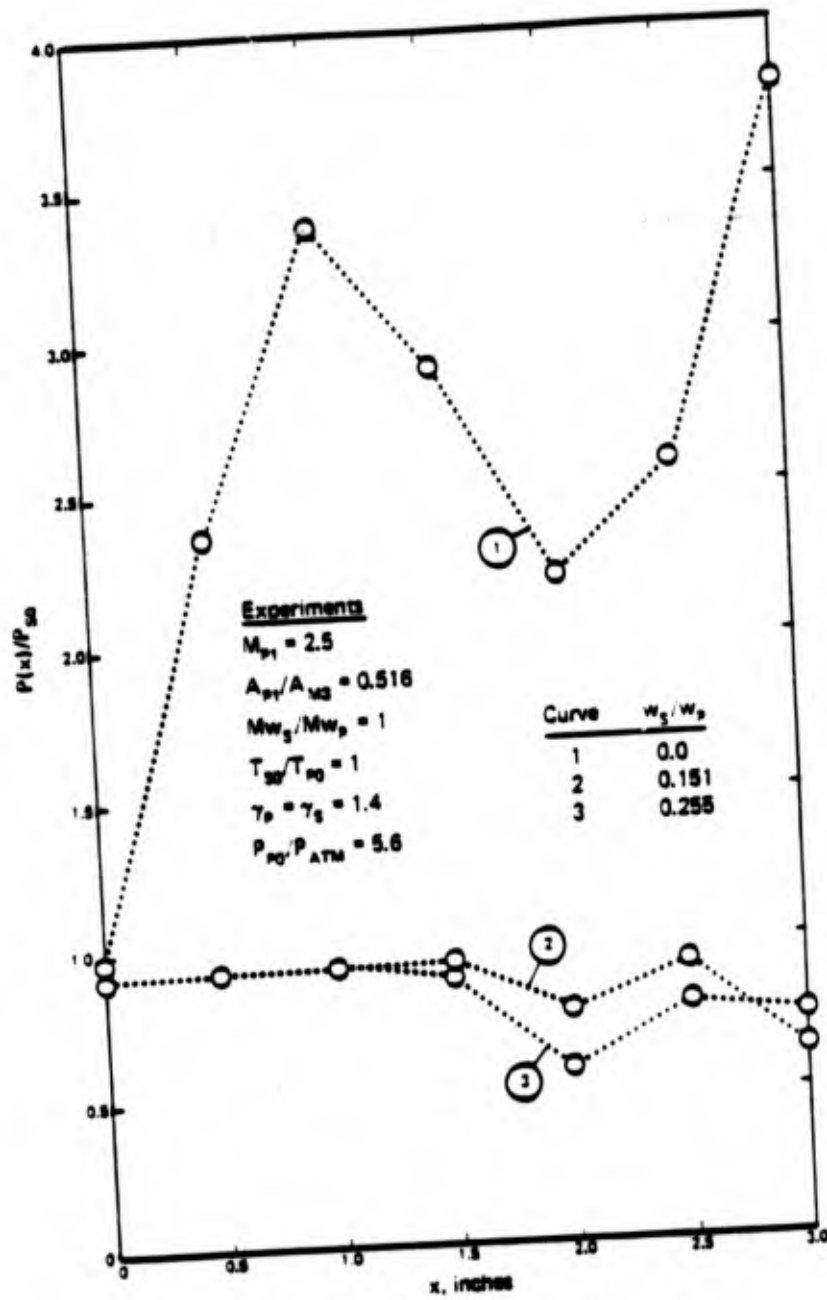
Constant-area, slotted-nozzle ejector compression characteristics ($A_{21}/A_{12} = 0.330, 0.516$ and $M_{21} = 2.5$)



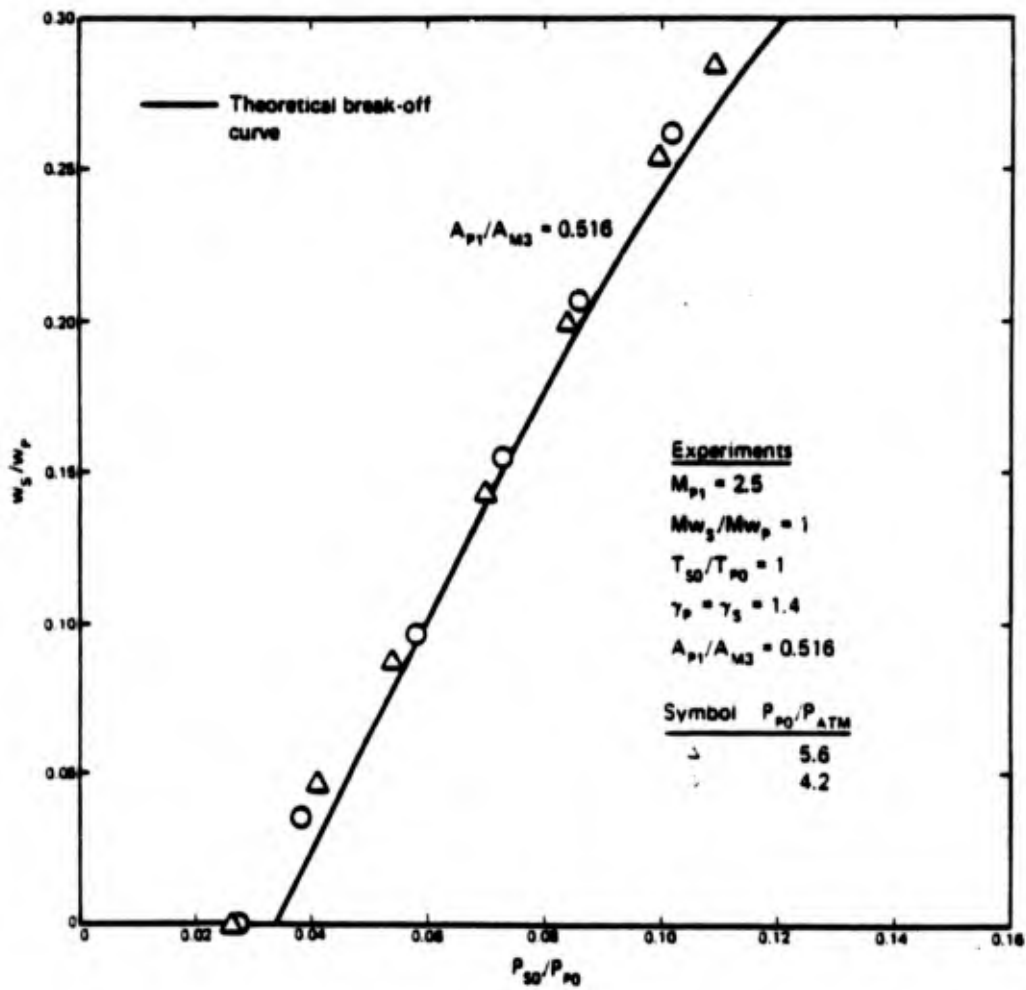
Variable-area ejector mass flow characteristics
 $(A_{p1}/A_{30} = 0.516 \text{ and } M_{p1} = 2.0, 2.5)$



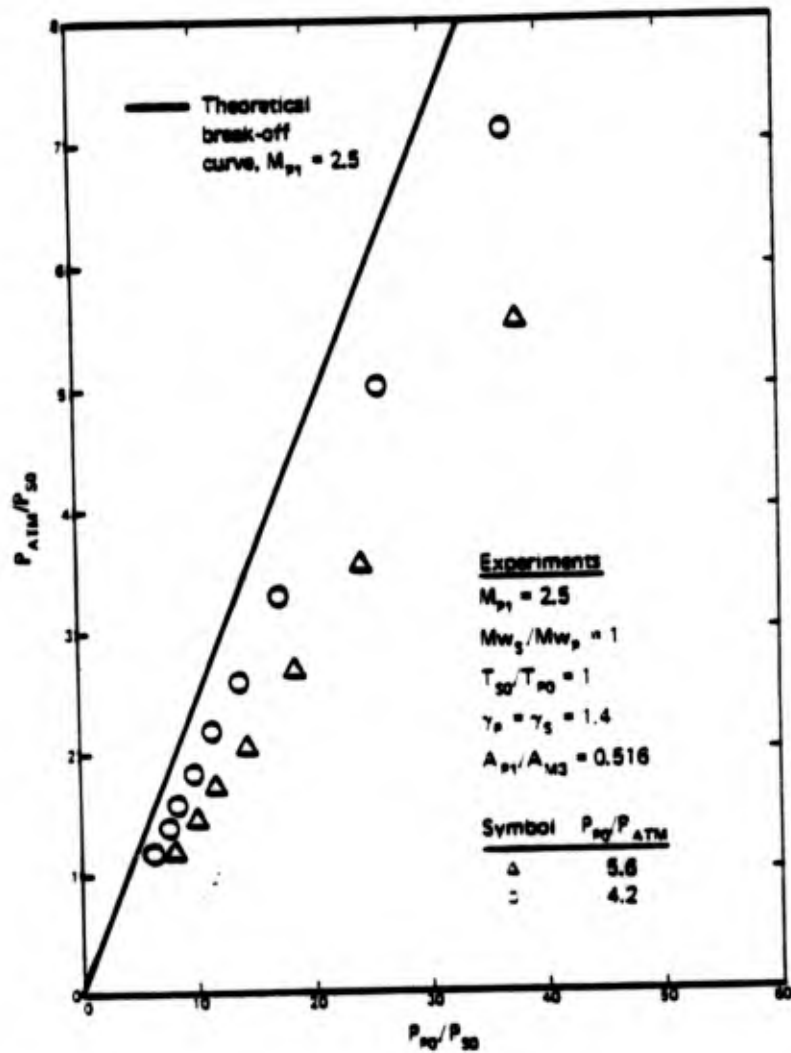
Variable-area ejector compression characteristics
 ($A_{21}/A_{23} = 0.516$ and $M_{21} = 2.0, 2.5$)



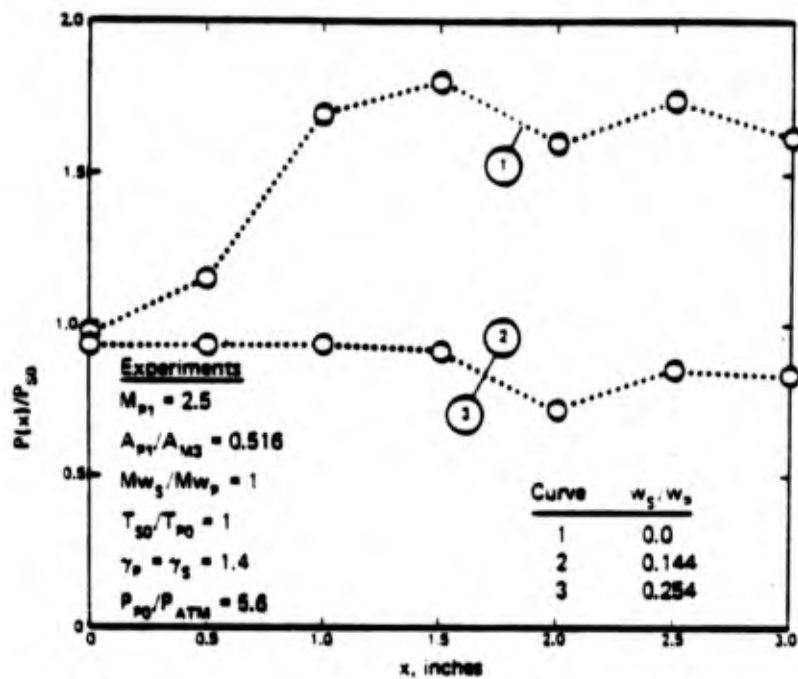
Variable-area ejector wall pressure distributions
 $(A_{p1}/A_{s2} = 0.516, M_{p1} = 2.5, P_{p0}/P_{ATM} = 5.6)$



Variable-area, slotted-nozzle ejector mass flow characteristics
 ($A_{p1}/A_{M3} = 0.516$ and $M_{p1} = 2.5$)



Variable-area, slotted-nozzle ejector compression characteristics ($A_{p1}/A_{M3} = 0.516$ and $M_{p1} = 2.5$)



Variable-area, slotted-nozzle ejector wall pressure distributions ($A_{p1}/A_{133} = 0.516$, $M_{p1} = 2.5$, and $P_{p0}/P_{ATM} = 5.6$)



NEW DIRECTIONS IN EJECTOR FLOW MODELS

- COMBINED INVISCID-VISCID MODEL
- IMPROVED MODEL(S) FOR MIXING PHENOMENA
- IMPROVED "CHOKING" CRITERION
- IMPROVED "DOWNSTREAM" DIFFUSER MODELS
- INTEGRATED BOUNDARY-LAYER ANALYSIS

NEW DIRECTIONS IN EJECTOR SYSTEM DESIGN

- MULTIPLE-STREAM PRIMARY FLOW
- LONGITUDINALLY DISTRIBUTED PRIMARY FLOW
- UNSTEADY PRIMARY FLOW
- SEGMENTED DIFFUSER (MIXING SECTION)
- SUPERSONIC-SUPERSONIC SYSTEMS

NEW DIRECTIONS IN EJECTOR DESIGN -- PRIMARY FLOW

- STEADY-STATE NOZZLE SYSTEM
 - (1) NOZZLE DISTRIBUTION
 - (2) LONGITUDINAL NOZZLE DISTRIBUTION
- UNSTEADY OR PERIODIC NOZZLE SYSTEM
 - (1) PULSATING FLOW
 - (2) OSCILLATING FLOW
 - (3) STRONG ACOUSTIC EXCITATION OF MIXING REGIONS

SELECTED LITERATURE

Fabri, J., and Paulon, J., "Theory and Experiments on Supersonic Air-to-Air Ejectors," NACA TM 1410 (1958).

Fabri, J., and Siestrunk, R., "Supersonic Air Ejectors," Advances in Applied Mechanics, New York, N.Y., Academic Press, Vol. V, pp. 1-34 (1958).

Chow, W. L., and Addy, A. L., "Interaction between Primary and Secondary Streams of Supersonic Ejector Systems and their Performance Characteristics," AIAA Journal, 2(4):686-695 (1964).

Chow, W. L., and Yeh, P. S., "Characteristics of Supersonic Ejector Systems with Non-Constant Area Shroud," AIAA Journal, 3(3):525-527 (1965).

Korst, H. H., Addy, A. L., and Chow, W. L., "Installed Performance of Air-Augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," Journal of Aircraft, 3(6): 498-506 (1966).

Addy, A. L., "The Analysis of Supersonic Ejector Systems," Supersonic Ejectors, AGARDograph No. 163, pp. 31-101 (1972).

Ginoux, J. J., Editor, Supersonic Ejectors, AGARDograph No. 163, 1972, 5 Papers.

Addy, A. L., and Mikkelsen, C. D., "An Investigation of Gas-Dynamic Flow Problems in Chemical Laser Systems," Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, Report No. UIIU-ENG-74-4009 (1974).

Addy, A. L., "The Analysis of Supersonic Ejector Systems," Ejectors, von Karman Institute, Lecture Series 79 (1975).

Delery, J., "Methods d'étude des éjecteurs supersonique Application aux tuyères double-flux," Ejectors, von Karman Institute, Lecture Series 79 (1975).

