NASA/TM—2006-214086

User Guide for Compressible Flow Toolbox

Version 2.1 for Use With MATLAB® Version 7

Kevin J. Melcher
Glenn Research Center, Cleveland, Ohio

January 2006

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at 301–621–0134

- Telephone the NASA Access Help Desk at 301–621–0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/TM—2006-214086

User Guide for Compressible Flow Toolbox

Version 2.1 for Use With MATLAB® Version 7

Kevin J. Melcher
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center

January 2006

Acknowledgments

The author acknowledges the significant contribution of Jonathan DeCastro, QSS Group, Inc. Mr. DeCastro conducted comprehensive testing of the algorithms comprising the Compressible Flow Toolbox, and completed the tedious task of reviewing this document in detail prior to publication.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at http://gltrs.grc.nasa.gov

Contents

User Guide for Compressible Flow Toolbox

Version 2.1 for Use With MATLAB® Version 7

Kevin J. Melcher
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

This report provides a user guide for the Compressible Flow Toolbox, a collection of algorithms that solve almost 300 linear and nonlinear classical compressible flow relations. The algorithms, implemented in the popular MATLAB® programming language, are useful for analysis of one-dimensional steady flow with constant entropy, friction, heat transfer, or shock discontinuities. The solutions do not include any gas dissociative effects. The toolbox also contains functions for comparing and validating the equation-solving algorithms against solutions previously published in the open literature. The classical equations solved by the Compressible Flow Toolbox are: isentropic-flow equations, Fanno flow equations (pertaining to flow of an ideal gas in a pipe with friction), Rayleigh flow equations (pertaining to frictionless flow of an ideal gas, with heat transfer, in a pipe of constant cross section.), normal-shock equations, oblique-shock equations, and Prandtl-Meyer expansion equations. At the time this report was published, the Compressible Flow Toolbox was available without cost from the NASA Software Repository.

1. Introduction

Description

This paper provides a User Guide for the Compressible Flow Toolbox, a collection of algorithms that solve almost 300 linear and nonlinear classical compressible flow relations. The algorithms, implemented in the popular MATLAB® programming language, are useful for analysis of one-dimensional steady flow with constant entropy, friction, heat transfer, or shock discontinuities. The solutions do not include any gas dissociative effects. The toolbox also contains functions for comparing and validating the equation-solving algorithms against solutions previously published in the open literature. The classical equations solved by the Compressible Flow Toolbox are:

- The isentropic-flow equations,
- The Fanno flow equations (pertaining to flow of an ideal gas in a pipe with friction),
- The Rayleigh flow equations (pertaining to frictionless flow of an ideal gas, with heat transfer, in a pipe of constant cross section.)
- The normal-shock equations,
- The oblique-shock equations, and
- The Prandtl-Meyer expansion equations.

The user should note that the scope of this guide is limited to documenting the individual functions and providing instruction in using them to solve simple compressible flow examples. Functions in the toolbox can be used together to solve more complex compressible flow problems—that is why they were created. However, instructing the user in the broader context of compressible flow is not the intended purpose of this guide.

Background

Algorithms included in the Compressible Flow Toolbox were originally developed to support controls and dynamics research under the NASA's High Speed Research Program. They were inspired by NACA Report 1135 "Equations Tables, and Charts for Compressible Flow" (ref. 1) which the author studied extensively as part of that research. Early implementations were first published as part of the author's Masters Thesis in 1996. They were subsequently made publicly available via a MATLAB® third party software web site hosted by the Mathworks, Inc. After several years, the toolbox was removed from the web site for a variety of reasons, including the need to upgrade the algorithms for compatibility with newer versions of MATLAB®. Finally, to appease a number of recent requests for the software, the toolbox has been updated, expanded, and made available to the general public via the NASA Software Repository.

All of the numerical and graphical results shown in this report were generated using functions included in the Compressible Flow Toolbox version 2.1and running MATLAB® version 7.04 on an MS Windows XP, 2.2 GHz Intel Pentium 4 processor-based personal computer. Results may vary slightly based on the precision of the floating point processor used to perform the calculations.

Organization

This User's Guide is organized in five sections. Introduction, Nomenclature, Quick Reference Guide, Function Reference Guide, and References. **Section 1. Introduction** provides a general description of the User Guide along with historical information on the origin of the toolbox and availability of the software. **Section 2. Nomenclature** describes the symbols and special formatting conventions used throughout the text. **Section 3. Quick Reference Guide** provides a comprehensive list of the functions contained in the toolbox and provides a brief description of each function listed. **Section 4. Function Reference Guide** provides a detailed description of each function in the toolbox including its purpose, syntax, a discussion of how the algorithm works, and examples demonstrating its use. Finally, **Section 5. References** contains a list of references used in developing and documenting the toolbox.

Availability

At the time this report was published, the Compressible Flow Toolbox was available to the general public without cost through the NASA Software Repository.

https://technology.grc.nasa.gov/software/

2. Nomenclature

Formats and Convensions

`Monospace`	MATLAB® commands, functions names and screen output are displayed in this font. For example: `rayleigh`.
Italics	Book titles and names of book sections, mathematical symbols and notation, and the introduction of new terms. For example: *Introduction*.
Bold Initial Caps	Key names, menu names, and items that are selected from menus. For example: the **File** menu.

Symbols

This document uses the following symbols and notations:

Roman Symbols	Description
A	Cross-sectional area of stream tube or channel
D_H	Hydraulic diameter of the flow cross-sectional area
I	Impulse function
M	Mach number, V/a
P	Static Pressure
P_t	Total Pressure
T	Static Temperature
T_t	Total Temperature
V	Velocity
$\bar{f}$	Average friction factor
q	Dynamic pressure, $\rho V^2/2$

Greek Symbols	Description
β	$\sqrt{\lvert M^2 - 1\rvert}$
γ	Ratio of specific heats of the working fluid (default = 1.4)
δ	Turning angle (degrees)
θ	Oblique shock angle (degrees)
μ	Mach Angle (degrees)
ν	Prandtl-Meyer angle (degrees)
ρ	Static mass density
ρ	Mass density

Subscripts	Description
*	Critical flow condition (i.e., conditions where the local fluid velocity is equal to the local speed of sound)
1	Upstream flow property
2	Downstream flow property

3. Quick Reference Tables

PROPERTIES OF ISENTROPIC FLOW, PRANDTL-MEYER FLOW, AND NORMAL SHOCKS	
`ames`	Solves the equations for isentropic flow, Prandtl-Meyer flow, and normal shocks to obtain flow properties.
`amesplt`	Plots the properties for isentropic flow, Prandtl-Meyer flow, and the normal shocks as a function of Mach number.
`ameserr`	Consistency check for function `ames`. Computes and plots, as a function of Mach number, errors in `ames` calculations.
`isentbl`	Generates text file containing a table of the isentropic flow properties.
`nshktbl`	Generates text file containing a table of Prandtl-Meyer flow and normal shock properties.

PROPERTIES OF OBLIQUE SHOCKS	
`oblqshck`	Solves the oblique shock equations for both weak and strong shock angles.
`oblqw12`	Solves the oblique shock equations to obtain downstream flow properties as a function of upstream flow properties.
`oblqw21`	Solves the oblique shock equations to obtain upstream flow properties as a function of downstream flow properties.
`deltason`	Computes the theoretical deflection angle that reduces supersonic flow to sonic conditions.
`deltamax`	Computes the theoretical maximum angle through which supersonic flow may be deflected or turned without separation.

PROPERTIES OF FANNO-LINE FLOW	
`fanno`	Solves the Fanno line equations to obtain properties of flow with friction.
`fannoplt`	Plots the Fanno line flow properties as a function of Mach number.
`fannoerr`	Consistency check for function `fanno`. Computes and plots, as a function of Mach number, errors in `fanno` calculations.
`fannotbl`	Generates text file containing a table of the Fanno-line flow properties.

PROPERTIES OF RAYLEIGH-LINE FLOW	
`rayleigh`	Solves the Rayleigh-line equations to obtain properties of flow heating or cooling.
`raylplt`	Plots the Rayleigh-line flow properties as a function of Mach number.
`raylerr`	Consistency check for function **rayleigh**. Computes and plots, as a function of Mach number, errors in **rayleigh** calculations.
`rayltbl`	Generates text file containing a table of the Rayleigh-line flow properties.

4. Function Reference Guide

ames

Purpose

Solve the equations for isentropic flow, both subsonic and supersonic, Prandtl-Meyer expansion, and normal shocks.

Synopsis

```
ames
Properties=ames(VarIn,ValuesIn,VarsOut)
Properties=ames(VarIn,ValuesIn,VarsOut,Gamma)
[Properties,PltLbls]=ames(VarIn,ValuesIn,VarsOut,Gamma)
```

Description

`ames` by itself calls `amesplt` which plots normalized versions of the isentropic flow, Prandtl-Meyer, and normal shock functions versus Mach number.

`Properties=ames(VarIn,ValuesIn,VarsOut)`, given a number designating one of the flow properties listed in **Table 4.1** and a value or vector of values for that flow property, `ames` computes corresponding values for isentropic flow, Prandtl-Meyer flow, and normal shock functions. `VarIn` is a scalar that specifies the property used as the input (independent variable). `ValuesIn` may be a scalar or vector and contains values of the independent variable for which the other properties will be computed. `VarsOut` contains a list of Indices corresponding to the flow properties listed in **Table 4.1**. Indices specified in `VarsOut` may be in any order and may be repeated as desired by the user. Results are returned in the `Properties` matrix. Columns in this matrix correspond to indices specified in `VarsOut`. Rows of the `Properties` matrix contain results corresponding to the elements of `ValuesIn`.

Note that, when properties 5, 6, or 7 are used as the independent variable, the solution is double-valued. The double-valued solution is provided by making `Properties` a cell array. `Properties{1}` contains values of the solution associated with the smaller Mach number, while `Properties{2}` contains the solution associated with the larger Mach number.

`Properties=ames(VarIn,ValuesIn,VarsOut,Gamma)` provides a mechanism for specifying values for the ratio of specific heats of the working fluid via `Gamma`. `Gamma` is optional. If unspecified, a value of 1.4, the value of the ratio of specific heats of air at standard temperature and pressure, is used. If specified, `Gamma` may be defined as either a scalar or a vector. If it is a vector, it must have the same length as `ValuesIn`.

`[Properties,PltLbls]=ames(VarIn,ValuesIn,VarsOut,Gamma)`, in addition to returning the properties of the fluid at user specified conditions, also returns a cell array, `PltLbls`, containing text strings that may be used when plotting the results.

Table 4.1—Description of Flow Properties Computed by Function `ames`

REF. INDEX	PROPERTY	REF. 1	DESCRIPTION
ISENTROPIC FLOW PROPERTIES (VALID FOR ALL M):			
1.	M or M_1		Mach number
2.	P/P_t	Eq. 44	Ratio of static to total pressure
3.	ρ/ρ_t	Eq. 45	Ratio of static to total density
4.	T/T_t	Eq. 43	Ratio of static to total temperature
5.	β	pg. 1	$\sqrt{\left\lvert M^2 \quad 1\right\rvert}$
6.	q/P_t	Eq. 48	Ratio of dynamic to total pressure
7.	A/A^*	Eq. 80	Ratio of flow area to critical flow area
8.	V/V^*	Eq. 50	Ratio of flow velocity to critical flow velocity
PRANDTL-MEYER FLOW (VALID FOR M≥1):			
9.	ν	Eq. 171	Prandtl-Meyer angle (degrees)
10.	μ	pg. 1	Mach Angle (degrees), $\sin^{-1}(1/M)$
NORMAL SHOCK PROPERTIES (VALID FOR M≥1):			
11.	M_2	Eq. 96	Mach number downstream of a normal shock
12.	P_2/P_1	Eq. 93	Static pressure ratio across a normal shock
13.	ρ_2/ρ_1	Eq. 94	Static density ratio across a normal shock
14.	T_2/T_1	Eq. 95	Static temperature ratio across a normal shock
15.	$P_{t,2}/P_{t,1}$	Eq. 99	Total pressure ratio across a normal shock
16.	$P_1/P_{t,2}$	Eq. 100	Ratio of static pressure upstream of a normal shock to total pressure downstream of the same shock

Algorithm

`ames` determines the desired flow properties by first obtaining a Mach number solution for each value, `ValuesIn`, of the user specified flow property, `VarIn`. These Mach numbers are then used to compute the other properties, `VarsOut`, specified by the user. Most of the flow equations may be manipulated analytically to obtain Mach number as a function of the other properties. However, some nonlinear relationships exist which have no simple analytical solution. In these cases, MATLAB’s `fminbnd` function is used determine an approximate solution for Mach number from the nonlinear equations. The search is arbitrarily constrained to Mach numbers less than 100. Solutions associated with Mach numbers larger than 100 are returned as `NaN` (i.e., not a number).

See Also

`ameserr`, `amesplt`, `isentbl`, and `nshcktbl`

Example 4.1:

Determine the properties of air at Mach 2.

```
>> ames(1,2,1:16)
ans =
  Columns 1 through 5
    2.0000    0.1278    0.2300    0.5556    1.7321
  Columns 6 through 10
    0.3579    1.6875    1.6330   26.3798   30.0000
  Columns 11 through 15
    0.577    44.5000    2.6667    1.6875    0.7209
  Column 16
    0.1773
```

Example 4.2:

Given a normal shock with downstream Mach number of 0.85, determine the Mach number upstream of the shock.

```
>> ames(11,0.85,1)
ans =
  1.1876
```

Example 4.3:

Determine the properties of air when $A/A_* = 3.007$.

```
>> properties=ames(7,3.007,1:16)
properties =
    [1x16 double]    [1x16 double]

>> properties{1}
ans =
  Columns 1 through 5
    0.1970    0.9733    0.9809    0.9923    0.9804
  Columns 6 through 10
    0.0264    3.0070    0.2149       NaN       NaN
  Columns 11 through 15
       NaN       NaN       NaN       NaN       NaN
  Column 16
       NaN

>> properties{2}
ans =
  Columns 1 through 6
    2.6399    0.0471    0.1128    0.4177    2.4432
  Columns 6 through 10
    0.2299    3.0070    1.8691   42.3049   22.2597
  Columns 11 through 15
    0.5005    7.9638    3.4935    2.2796    0.4453
  Column 16
    0.1058
```

Example 4.4:

Plot the Mach number downstream of a normal shock as a function of the Mach number upstream of the shock.

```
M1=1:0.1:10;
[M2,Lbls]=ames(1,M1,11);
plot(M1,M2);
xlabel('M_1'); ylabel(Lbls{1});
```

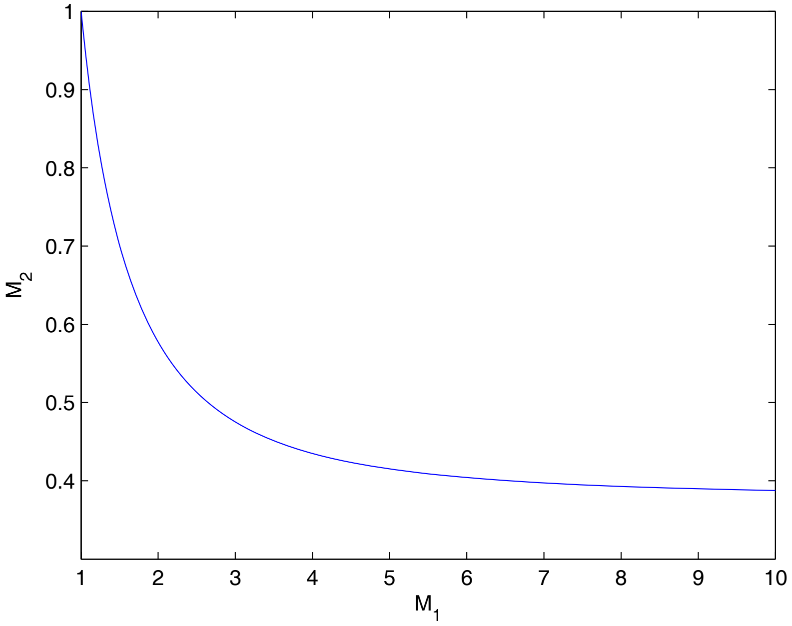


Figure 4.1.—Result of using function `ames` to compute Mach number variations across a normal shock.

ameserr

Purpose

Show the computational errors that result when using function `ames` to solve the equations for isentropic flow, Prandtl-Meyer expansion, and normal shocks.

Synopsis

```
ameserr
[error,M1]=ameserr
```

Description

`ameserr` computes the error between Mach numbers used as inputs to function `ames` and Mach numbers calculated from the output of function `ames`. The results are plotted as absolute and percent errors versus Mach number for each of the flow functions shown in **Table 4.1**.

`[error,M1]=ameserr` returns the computed error in `error`. If specified, `M1` contains the initial vector of Mach numbers.

Algorithm

`ameserr` first generates a logarithmically spaced vector of 250 Mach numbers from 0.01 to 10. This vector also includes critical Mach number values where numerical stability is important, such as saddle points. `ameserr` then uses function `ames` to calculate each of the isentropic flow properties and the normal shock properties corresponding to those Mach numbers. The functions of Mach number, obtained from `ames`, are then used as input to the `ames` function in order to obtain a Mach number which corresponds to the function value. Theoretically, the initial and computed Mach numbers should be the same. In general, they are not due to round off, truncation, convergence, and/or optimization errors. The difference in the two Mach numbers is returned as the error in the calculations.

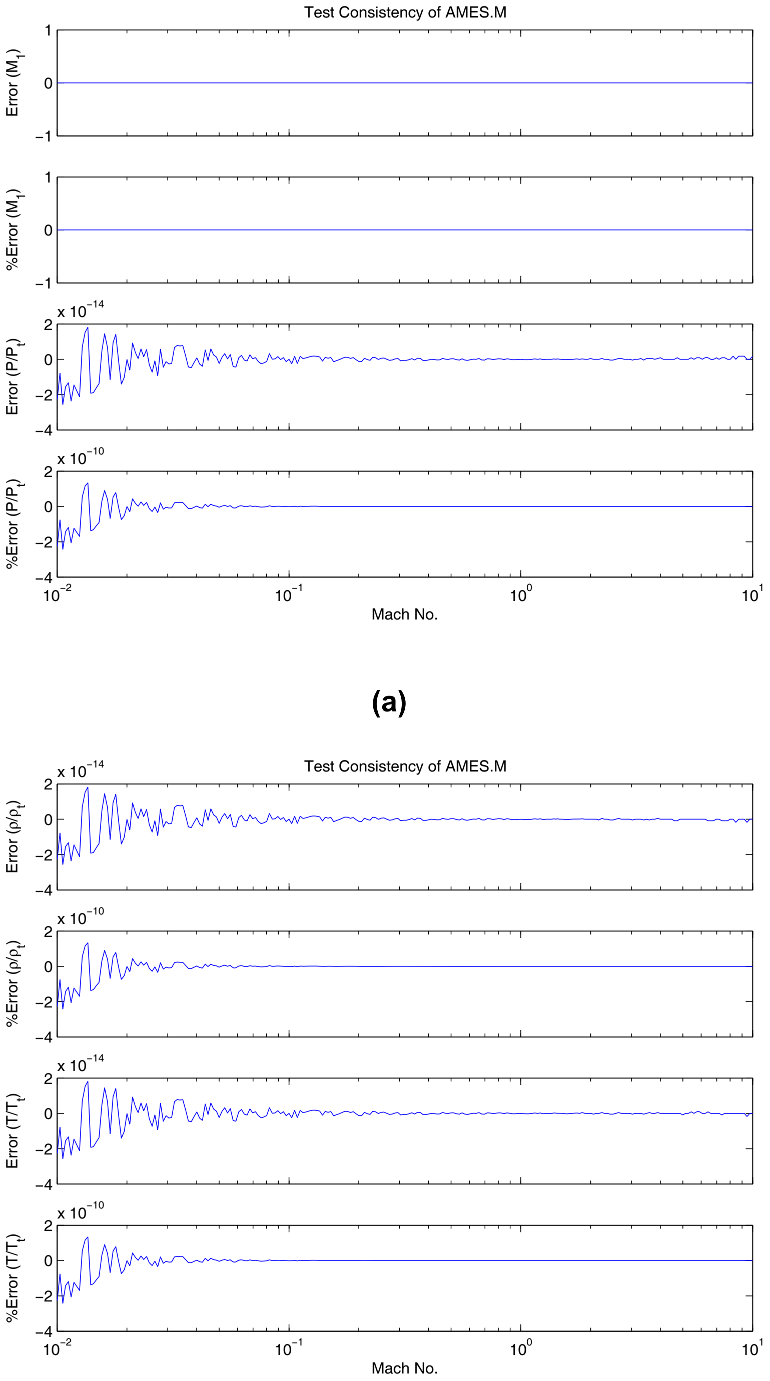
See Also

`ames`, `amesplt`, `isentbl`, and `nshcktbl`

Example 4.5:

Compute and plot the errors the errors that result from running `ameserr`. Plots are shown in Figure 4.2(a to g).

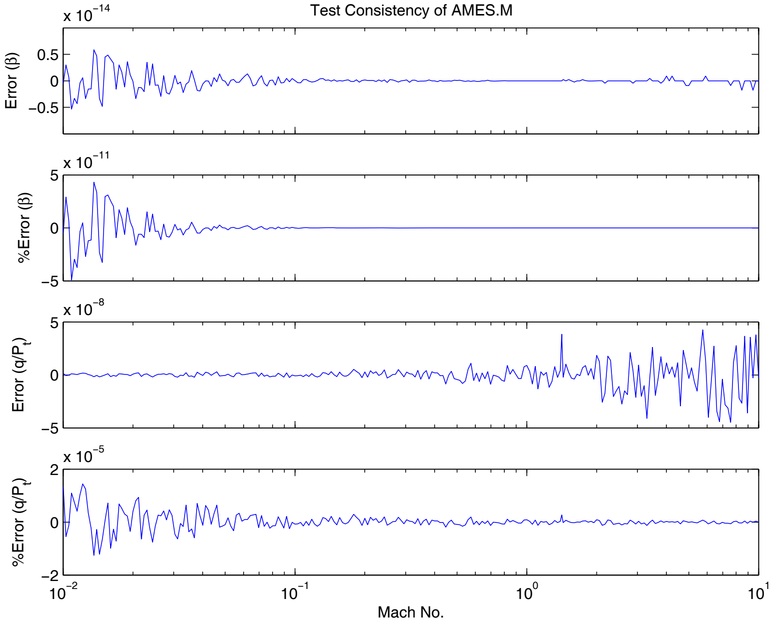
```
>> ameserr
```



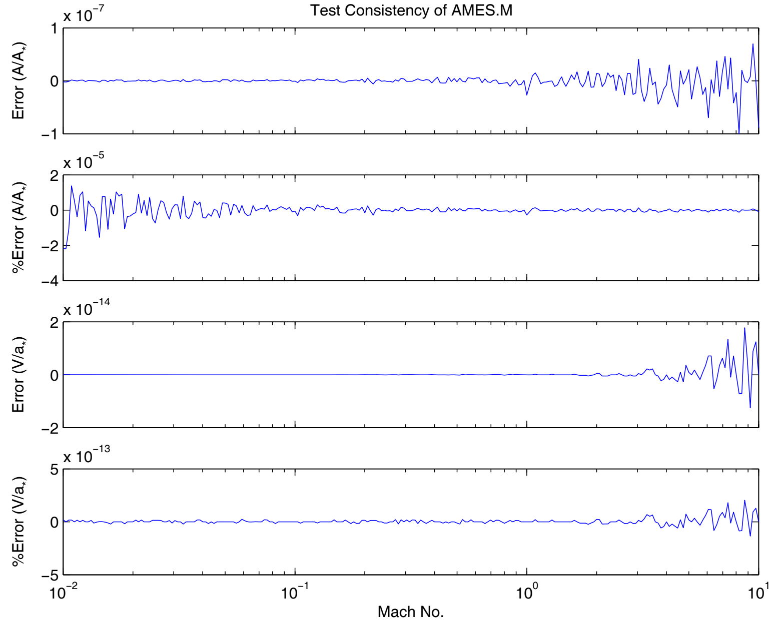
(a)

(b)

Figure 4.2.—Output of function `ameserr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7.

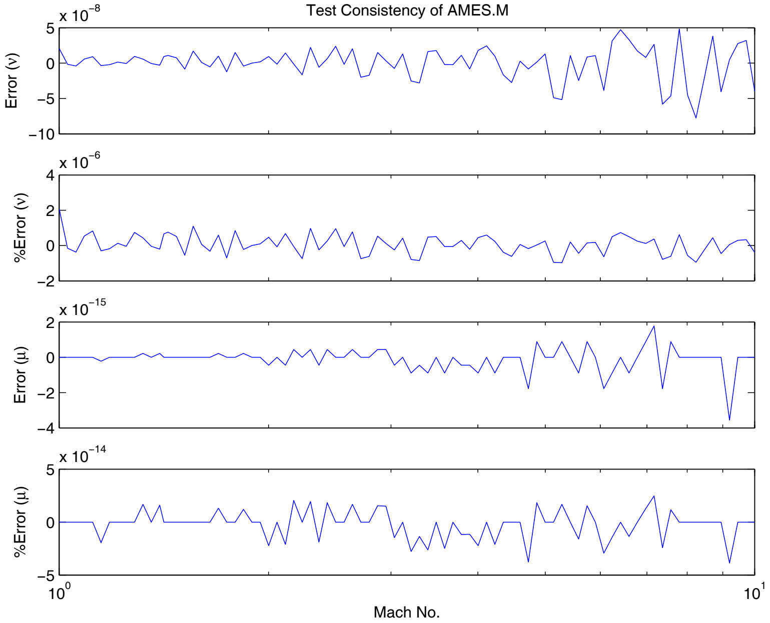


(c)

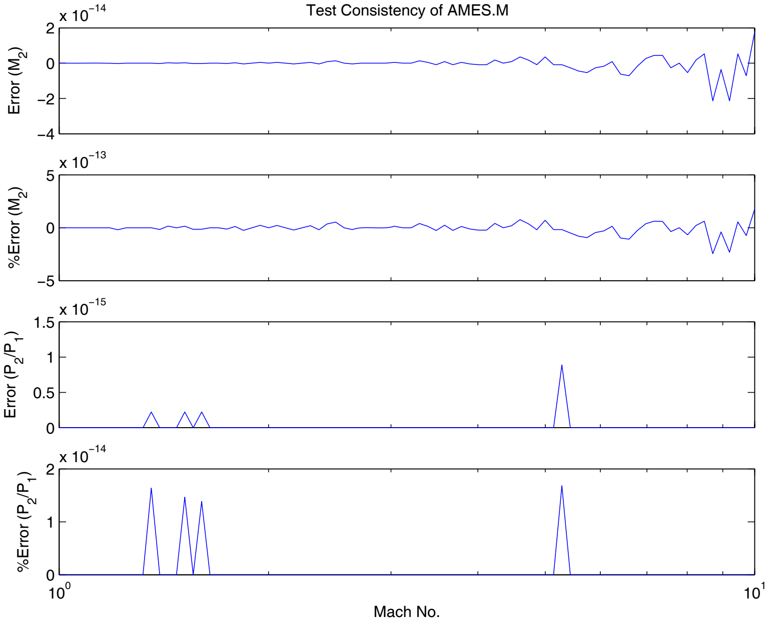


(d)

Figure 4.2.—Output of function `ameserr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7 (continued).

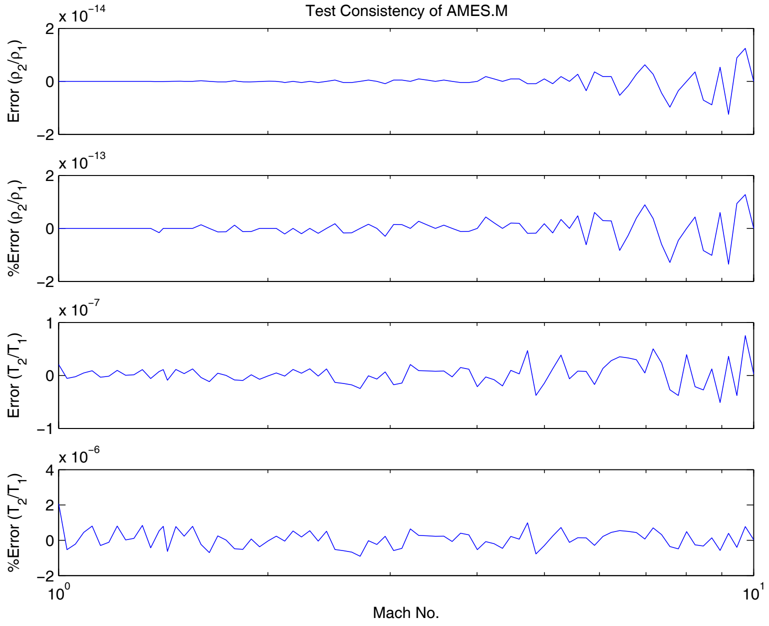


(e)

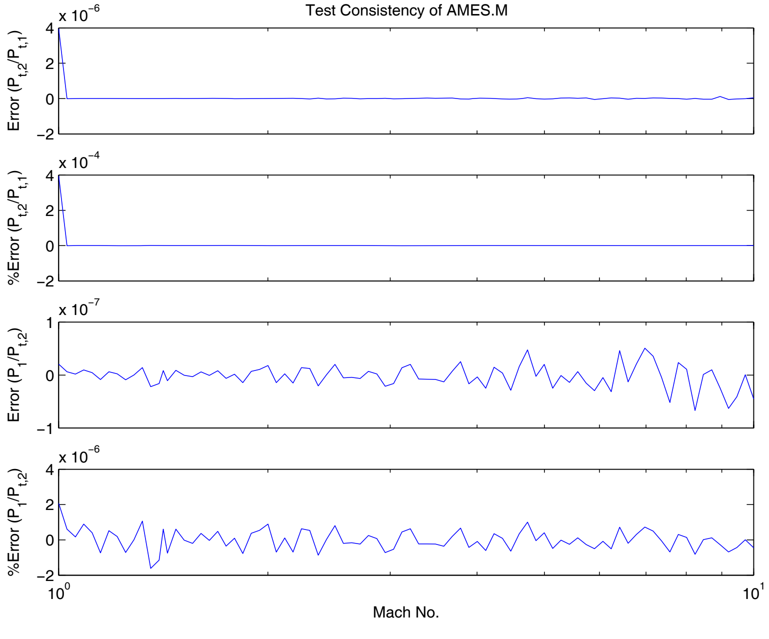


(f)

Figure 4.2.—Output of function `ameserr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7 (continued).



(g)



(h)

Figure 4.2.—Output of function `ameserr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7 (continued).

amesplt

Purpose

Plots normalized properties for isentropic flow, Prandtl-Meyer expansion, and normal shocks as a function of Mach number.

Synopsis

```
amesplt
amesplt(MNmin,MNmax)
amesplt(MNmin,MNmax,Npts)
amesplt(MNmin,MNmax,Npts,Gamma)
```

Description

`amesplt` uses function `ames` to compute and plot the isentropic and normal shock flow properties at 250 points between Mach 0.01 and Mach 10 when the ratio of specific heats of the fluid is 1.4.

`amesplt(MNmin,MNmax)` plots results for a range of user specified Mach numbers where: `MNmin` is the minimum Mach number; and `MNmax` is the maximum Mach number.

`amesplt(MNmin,MNmax,Npts)` in addition to allowing the user to specify the range of Mach numbers used, this form allows the user to specify the number of data points, `Npts`, used to plot each curve.

`amesplt(MNmin,MNmax,Npts,Gamma)` in addition to allowing the user to specify Mach number. and number of points per curve, this form also allows the user to specify a scalar value for the ratio of specific heats, `Gamma`, of the fluid.

Algorithm

`amesplt` first generates a logarithmically spaced vector of 250 Mach numbers from 0.01 to 10. This vector also includes critical Mach number values where numerical stability is important, such as solution saddle points. `amesplt` then uses this vector as inputs to function `ames` which is used to calculate each of the isentropic flow properties and the normal shock properties corresponding to those Mach numbers. The resulting values are normalized and plotted versus Mach number to provide the user a graphical understanding of the relationship between flow properties and Mach number.

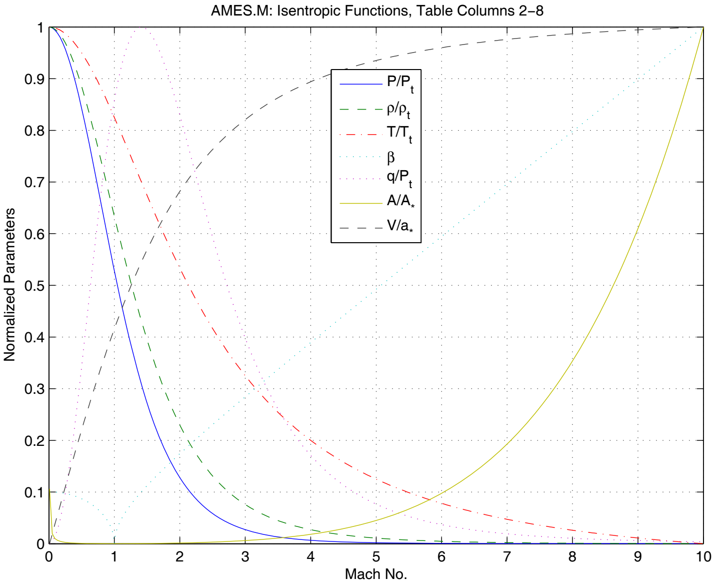
See Also

`ames`, `amesplt`, `isentbl`, and `nshcktbl`

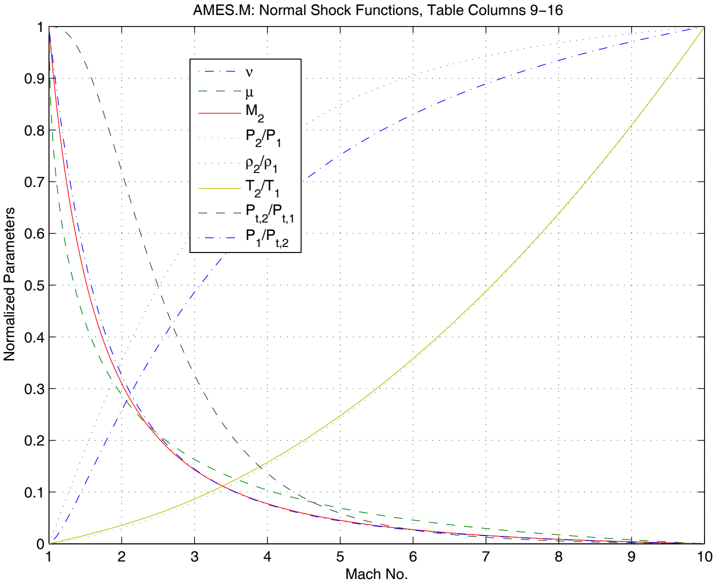
Example 4.6:

Plot normalized isentropic flow and normal shock properties as a function of Mach number. The resulting plots are shown in Figure 4.3 (a and b).

```
>> amesplt
```



(a)



(b)

Figure 4.3.—Normalized isentropic and normal shock functions as generated by function `amesplt`.

deltamax

Purpose

For steady state supersonic flow with compressive turning, `deltamax` computes the maximum flow deflection angle (δ) that can occur without producing separation of the flow from the turning surface. Also, optionally calculates the angle of the oblique shock (θ) that results from turning the flow. Both angles have units of degrees. See Figure 4.4 for a graphical representation of the flow situation.

Synopsis

```
deltamax
Delta=deltamax(M1)
[Delta,Theta]=deltamax(M1,Gamma)
```

Description

`deltamax` by itself, computes and plots the maximum flow deflection and resulting oblique shock angle for a range of Mach numbers from 1.0 to 15.

`Delta=deltamax(M1)` computes and returns the maximum flow deflection angle, `delta`, in degrees for user specified Mach numbers, `M1`. `M1` may be a scalar, vector, or matrix.

`[Delta,Theta]=deltamax(M1,Gamma)` uses optional input `Gamma`, the ratio of specific heats for the working fluid, to calculate the turning angle `Delta` and additionally the angle, `Theta`, of the oblique shock that results from turning the flow. `Gamma` has a default value of 1.4 and must be a scalar or have dimensions equivalent to `M1`. The dimensions of `Delta` and `Theta`, and the values therein, correspond to the dimensions of `M1`.

Algorithm

If no input parameters are specified by the user, `deltamax` first generates a vector of upstream Mach numbers. The function then uses the Mach number(s) to calculate the maximum angle, θ_{max}, of an oblique shock that can occur without separation. The shock angle is then used with the Mach number(s) to calculate the associated flow deflection angle, δ_{max}.

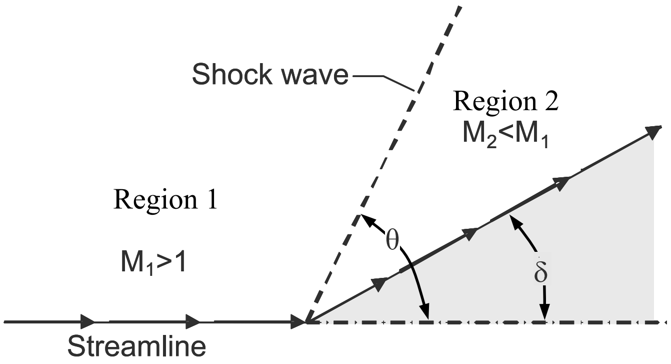


Figure 4.4.—Oblique shock diagram.

The equation used to calculate $\theta_{\max}$ is:

$$\theta_{\max} = \sin^{-1}\sqrt{\frac{1}{\gamma M_1^2}\left\{\frac{(\gamma+1)}{4}M_1^2 + \sqrt{(\gamma+1)\left[1+\frac{(\gamma-1)}{2}M_1^2+\frac{(\gamma-1)}{16}M_1^4\right]}-1\right\}} \tag{4.1}$$

The equation used to calculate $\delta_{\max}$ is:

$$\delta_{\max} = \tan^{-1}\frac{\left(M_1^2\sin^2\theta_{\max}-1\right)\cot\theta_{\max}}{\frac{1}{2}(\gamma+1)M_1^2 - M_1^2\sin^2\theta_{\max}+1} \tag{4.2}$$

Similar equations may be found in reference 1, pp. 9 and 12; (ref. 2), p. 586; and (ref. 4), pp. 315 to 316.

See Also

`deltason`, `oblqshck`, `oblqw12`, and `oblqw21`

Example 4.7:

Calculate and plot the maximum compressive turning angle and oblique shock angle for airflow over a range of Mach numbers from 1 to 15.

```
>> deltamax
```

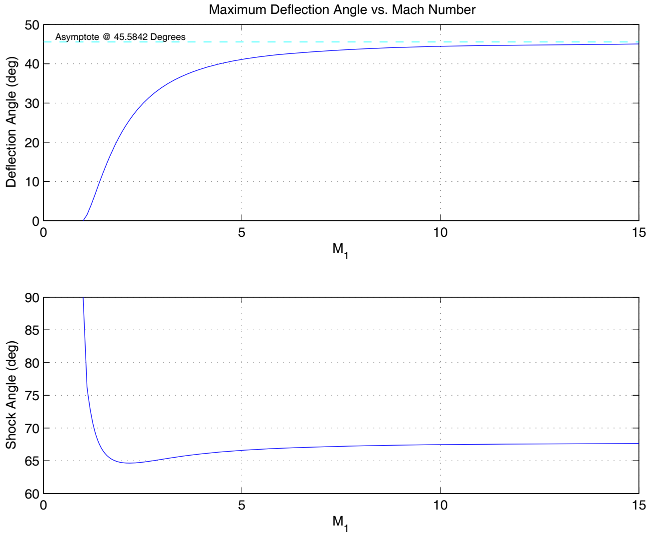


Figure 4.5.—Results of function `deltamax` showing maximum turning angle and the angle of the resulting oblique shock as a function of upstream Mach number.

Example 4.8:

Calculate the maximum compressive turning angle and oblique shock angle for steam flowing at Mach numbers from 1.5 to 3.0. The ratio of specific heats for steam is 1.327 at standard temperature.

```
>> [Delta,Theta]=deltamax(1.5:0.1:3.0,1.327)
Delta =
  Columns 1 through 5
   12.6726   15.3598   17.8660   20.1780   22.2960
  Columns 6 through 10
   24.2282   25.9869   27.5862   29.0404   30.3634
  Columns 11 through 15
   31.5684   32.6673   33.6712   34.5896   35.4314
  Column 16
   36.2042

Theta =
  Columns 1 through 5
   66.7820   66.0774   65.6264   65.3536   65.2072
  Columns 6 through 10
   65.1509   65.1587   65.2116   65.2959   65.4013
  Columns 11 through 15
   65.5206   65.6483   65.7803   65.9137   66.0466
  Column 16
   66.1772
```

deltason

Purpose

For steady state supersonic flow with compressive turning, `deltamax` computes the flow deflection angle (δ) that results in sonic flow downstream of the resulting oblique shock (i.e., $M_2 = 1$). Also, optionally calculates the angle of the oblique shock (θ) that produces sonic flow. Both angles have units of degrees. See Figure 4.4 (pp. 19) for a graphical representation of the flow situation.

Synopsis

```
deltason
Delta=deltason(M1)
[Delta,Theta]=deltason(M1,Gamma)
```

Description

`deltason` by itself, computes and plots the sonic flow deflection angle and the resulting oblique shock angle for a range of Mach numbers from 1.0 to 15.

`Delta=deltason(M1)` computes and returns the flow deflection angle, `Delta`, that results in sonic flow downstream. Values of `Delta` are in degrees for user specified Mach numbers, `M1`. `M1` may be a scalar, vector, or matrix.

`[Delta,Theta]=deltason(M1,Gamma)` uses optional input `Gamma`, the ratio of specific heats for the working fluid, to calculate the turning angle `Delta` and additionally the angle, `Theta`, of the oblique shock that results from turning the flow. `Gamma` has a default value of 1.4 and must be a scalar or have dimensions equivalent to `M1`. The dimensions of `Delta` and `Theta`, and the values therein, correspond to the dimensions of `M1`.

Algorithm

If no input parameters are specified by the user, `deltason` first generates a vector of upstream Mach numbers. The function then uses the Mach number(s) to calculate the angle, θ_*, of an oblique shock that produces sonic flow downstream of the shock. The shock angle is then used with the Mach number(s) to calculate the associated flow deflection angle, δ_*.

The equation used to calculate θ_* is:

$$\theta_* = \sin^{-1}\sqrt{\frac{1}{\gamma M_1^2}\left\{\frac{(\gamma+1)M_1^2-(3-\gamma)}{4}+\sqrt{(\gamma+1)\left[\frac{9+\gamma}{16}-\frac{3-\gamma}{8}M_1^2+\frac{(\gamma+1)}{16}M_1^4\right]}\right\}} \quad (4.1)$$

The equation used to calculate δ_* is:

$$\delta_* = \tan^{-1} \frac{\left(M_1^2 \sin^2 \theta_* - 1\right)\cot\theta_*}{\frac{1}{2}\left(\gamma + 1\right)M_1^2 - M_1^2 \sin^2 \theta_* + 1} \tag{4.2}$$

Similar equations may be found in reference 1, pp. 9 and 12; (ref. 2), p. 586; and (ref. 4), pp. 315 to 316.

See Also

`deltamax`, `oblqshck`, `oblqw12`, and `oblqw21`

Example 4.9:

For airflow over a range of Mach numbers from 1 to 15, calculate and plot the compressive turning angle and associated oblique shock angle that results in sonic flow downstream of the shock.

```
>> deltason
```

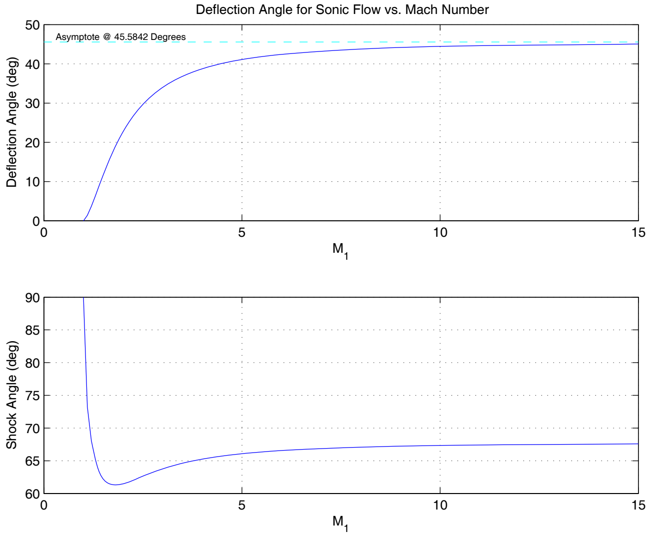


Figure 4.6.—Results of function `deltason` showing sonic turning angle and the angle of the resulting oblique shock as a function of upstream Mach number.

Example 4.10:

Given a flow of hydrogen gas at a several Mach numbers from 1.0 to 2.0, at each Mach number, calculate the compressive turning angle that produces sonic flow and the associated oblique shock angle. The ratio of specific heats for hydrogen is 1.667 at standard temperature.

```
>> format short e
>> [Delta,Theta]=deltason(1.0:0.1:2.0,1.667)
```

```
Delta =
  Columns 1 through 4
 -1.4216e-022  1.2526e+000  3.2647e+000  5.5235e+000
  Columns 5 through 8
  7.8286e+000  1.0071e+001  1.2192e+001  1.4161e+001
  Columns 9 through 11
  1.5967e+001  1.7612e+001  1.9103e+001

Theta =
  Columns 1 through 4
  9.0000e+001  7.3209e+001  6.7949e+001  6.4868e+001
  Columns 5 through 8
  6.2929e+001  6.1691e+001  6.0910e+001  6.0434e+001
  Columns 9 through 11
  6.0164e+001  6.0034e+001  5.9998e+001
```

fanno

Purpose

Solve the equations for one-dimensional steady adiabatic flow in a constant area duct with friction.

Synopsis

```
Properties=fanno(VarIn,ValuesIn,VarsOut)
Properties=fanno(VarIn,ValuesIn,VarsOut,Gamma)
[Properties,PltLbls]=fanno(VarIn,ValuesIn,VarsOut,Gamma)
fanno
```

Description

`Properties=fanno(VarIn,ValuesIn,VarsOut)`, given a number designating one of the flow properties listed in **Table 4.2** and a value or vector of values for that flow property, `fanno` computes corresponding values for adiabatic frictional flow. `VarIn` is a scalar that specifies the property used as the input (independent variable). `ValuesIn` may be a scalar or vector and contains values of the independent variable for which the other properties will be computed. `VarsOut` contains a list of Indices corresponding to the flow properties listed in **Table 4.2**. Indices specified in `VarsOut` may be in any order and may be repeated as desired by the user. Results are returned in the `Properties` matrix. Columns in this matrix correspond to indices specified in `VarsOut`. Rows of the `Properties` matrix contain results corresponding to the elements of `ValuesIn`.

Note that, when properties 4, 6, or 7 are used as the independent variable, the solution is double-valued. The double-valued solution is provided by making `Properties` a cell array. `Properties{1}` contains values of the solution associated with the smaller Mach number, while `Properties{2}` contains the solution associated with the larger Mach number.

`Properties=fanno(VarIn,ValuesIn,VarsOut,Gamma)` provides a mechanism for specifying values for the ratio of specific heats of the working fluid via `Gamma`. `Gamma` is optional. If unspecified, a value of 1.4, the value of the ratio of specific heats of air at standard temperature and pressure, is used. If specified, `Gamma` may be defined as either a scalar or a vector. If it is a vector, it must have the same length as `ValuesIn`.

`[Properties,PltLbls]=fanno(VarIn,ValuesIn,VarsOut,Gamma)`, in addition to returning the properties of the fluid at user specified conditions, also returns a cell array, `PltLbls`, containing text strings that may be used when plotting the results.

`fanno` by itself calls `fannoplt` which plots the Fanno-line flow properties versus Mach number.

Table 4.2.—Description of Flow Properties Computed by Function `fanno`

REF. INDEX	PROPERTY	REF. 4	DESCRIPTION
1.	M or M_1		Mach number
2.	T/T_*	Eq. 5.31	Ratio of static temperature at M_1 to static temperature at sonic conditions.
3.	P/P_*	Eq. 5.30	Ratio of static pressure at M_1 to static pressure at sonic conditions.
4.	$P_t/P_{t,*}$	Eq. 5.34	Ratio of total pressure at M_1 to total pressure at sonic conditions.
5.	V/V_* ρ_*/ρ	Eq. 5.29	Ratio of flow velocity at M_1 to flow velocity at sonic conditions. Also, ratio of static density at sonic conditions to static density at M_1.
6.	I/I_*	Eq. 3.42	Ratio of the impulse function at M_1 to the impulse function at sonic conditions.
7.	$4\bar{f}L_*/D_H$	Eq. 5.35	Friction factor

Algorithm

`fanno` determines the desired flow properties by first obtaining a Mach number solution for each value, `ValuesIn`, of the user specified flow property, `VarIn`. The resulting Mach numbers are then used to compute the other properties, `VarsOut`. Some of the flow equations may be manipulated analytically to obtain Mach number as a function of the other properties. However, some nonlinear relationships exist which have no simple analytical solution. In these cases, MATLAB's `fminbnd` function is used determine an approximate solution for Mach number from the nonlinear equations. The search is arbitrarily constrained to Mach numbers less than or equal to 100. Solutions associated with Mach numbers larger than 100 are returned as `NaN` (i.e., not a number).

See Also

`fannoerr`, `fannoplt`, and `fannotbl`

Example 4.11:

For air flowing at Mach 3.5, determine the Fanno-line flow properties.

```
>> fanno(1,3.5,1:7)
ans =
  Columns 1 through 5
   3.5000    0.3478    0.1685    6.7896    2.0642
  Columns 6 through 7
   1.2743    0.5864
```

Example 4.12:

For a range of friction factors from 0.5 to 1.0, determine the static pressure ratio (P/P_*) and upstream Mach number of air flowing adiabatically through a constant area duct.

```
>> fric=[0.5:0.1:1.0]'; properties=fanno(7,fric,[3,1])
```

```
properties =
    [6x2 double]    [6x2 double]

>> [fric properties{1}]
ans =
    0.5000    1.7706    0.5977
    0.6000    1.8459    0.5748
    0.7000    1.9154    0.5551
    0.8000    1.9804    0.5378
    0.9000    2.0416    0.5225
    1.0000    2.0996    0.5087

>> [fric properties{2}]
ans =
    0.5000    0.2359    2.8603
    0.6000    0.1583    3.6302
    0.7000    0.0850    5.1405
    0.8000    0.0148   12.7693
    0.9000       NaN       NaN
    1.0000       NaN       NaN
```

Here, `properties{1}` is the subsonic solution, and `properties{2}` is the supersonic solution. Also, column 1 of `ans` contains values for friction factor. Column 2 and 3 contain corresponding solutions for pressure ratio and Mach number, respectively. Note that `NaN` results imply solution has exceeded internal limit for intermediate Mach number calcualtion (i.e., M > 100).

fannoerr

Purpose

Show the computational errors that result when using function `fanno` to solve equations for one-dimensional steady adiabatic flow in a constant-area duct with friction.

Synopsis

```
fannoerr
[error,M1]=fannoerr
```

Description

`fannoerr` computes the error between Mach numbers used as inputs to function `fanno` and Mach numbers calculated from the output of function `fanno`. The results are plotted as absolute and percent errors versus Mach number for each of the flow functions shown in **Table 4.2**.

`[error,M1]=fannoerr` returns the computed error in `error`. If specified, `M1` contains the initial vector of Mach numbers.

Algorithm

`fannoerr` first generates a logarithmically spaced vector of 250 Mach numbers from 0.01 to 10. This vector also includes critical Mach number values where numerical stability is important, such as saddle points. `fannoerr` then uses function `fanno` to calculate each of the Fanno-line flow properties corresponding to those Mach numbers. The functions of Mach number, obtained from `fanno`, are then used as input to the `fanno` function in order to obtain a Mach number which corresponds to the function value. Theoretically, the initial and computed Mach numbers should be the same. In general, they are not due to round off, truncation, convergence, and/or optimization errors. The difference in the two Mach numbers is returned as the error in the calculations.

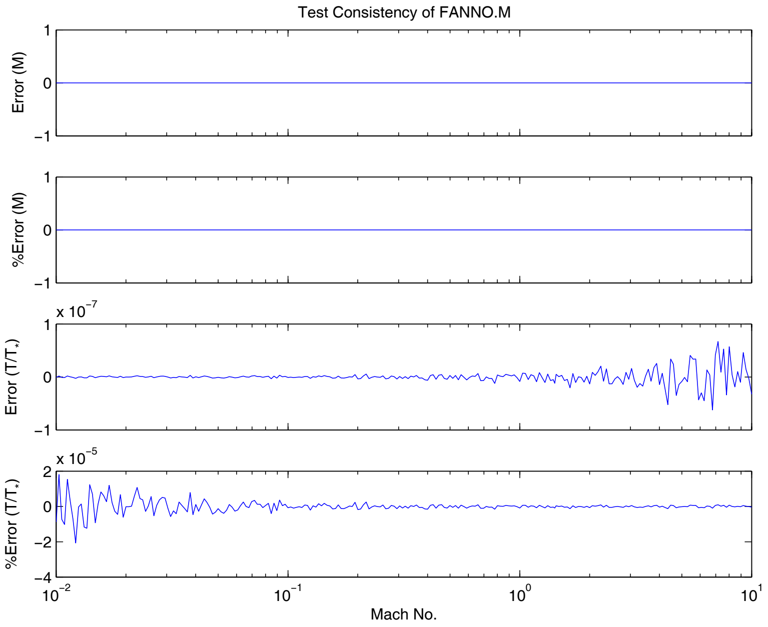
See Also

`fanno`, `fannoplt`, and `fannotbl`

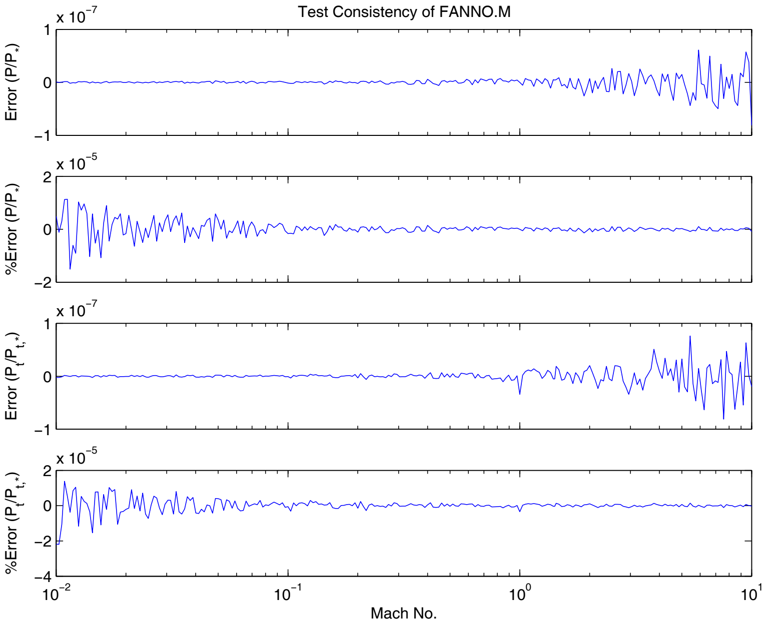
Example 4.13:

Compute and plot the errors the errors that result from running `fannoerr`. Plots are shown in Figure 4.7(a to d)

```
>> fannoerr
```

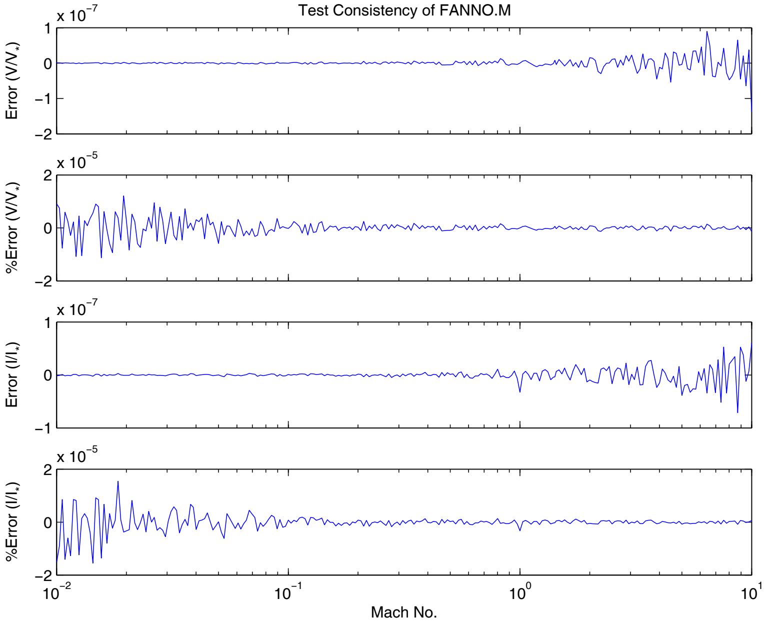


(a)

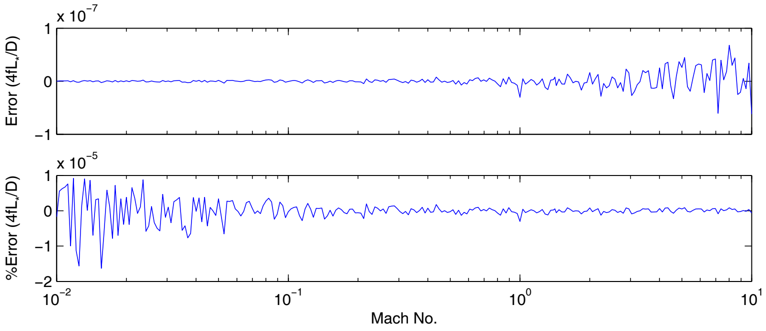


(b)

Figure 4.7.—utput of function `fannoerr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7.



(c)



(d)

Figure 4.7.—utput of function `fannoerr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7 (continued).

fannoplt

Purpose

Plot properties for Fanno-line flow, i.e., one-dimensional steady adiabatic flow in a constant-area duct with friction.

Synopsis

```
fannoplt
fannoplt(MNmin,MNmax)
fannoplt(MNmin,MNmax,Npts)
fannoplt(MNmin,MNmax,Npts,Gamma)
```

Description

`fannoplt` uses function `fanno` to compute and plot the Fanno-line flow properties at 250 points between Mach 0.05 and Mach 2.5 when the ratio of specific heats of the fluid is 1.4. This plot resembles Figure 5.4 in (ref. 4).

`fannoplt(MNmin,MNmax)` plots results for a range of user specified Mach numbers where: `MNmin` is the minimum Mach number; and `MNmax` is the maximum Mach number.

`fannoplt(MNmin,MNmax,Npts)` in addition to allowing the user to specify the range of Mach numbers used, this form allows the user to specify the number of data points, `Npts`, used to plot each curve.

`fannoplt(MNmin,MNmax,Npts,Gamma)` in addition to allowing the user to specify Mach No. and number of points per curve, this form also allows the user to specify a scalar value for the ratio of specific heats, `Gamma`, of the fluid.

Algorithm

`fannoplt` first generates a logarithmically spaced vector of 250 Mach numbers from 0.05 to 2.5. This vector also includes critical Mach number values where numerical stability is important, such as solution saddle points. `fannoplt` then uses this vector as inputs to function `fanno` which is used to calculate each of the isentropic flow properties and the normal shock properties corresponding to those Mach numbers. The resulting values are plotted versus Mach number to provide the user a graphical understanding of the relationship between flow properties and Mach number.

See Also

`fanno`, `fannoerr`, and `fannotbl`

Example 4.14:

Plot Fanno-line flow properties over a range of Mach numbers from 0.05 to 2.5. The resulting plot is shown in Figure 4.8.

```
>> fannoplt
```

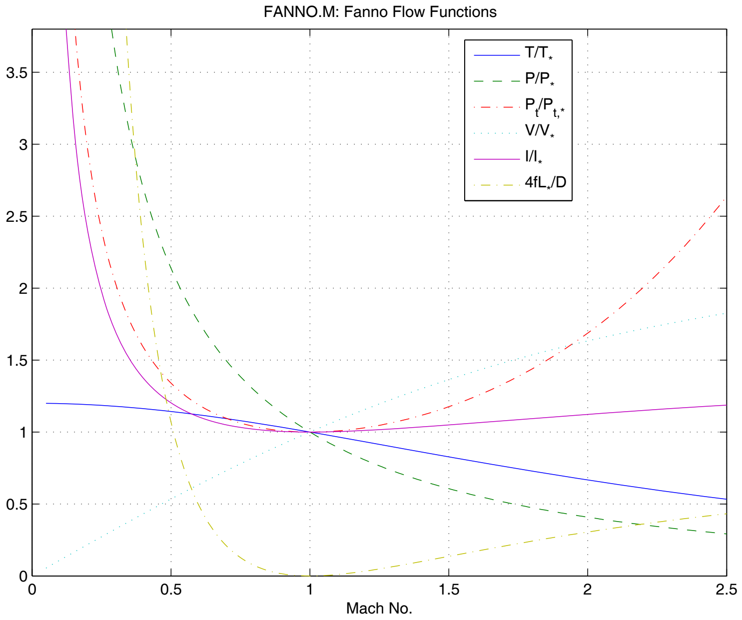


Figure 4.8.—Fanno-line flow properties as generated by function `fannoplt`.

fannotbl

Purpose

Generate a text file containing tables of Fanno-line flow properties. The tables generated by this function may be useful when computational solution of the equations is not practical.

Synopsis

```
fannotbl
fannotbl(Filename,Mn,Gamma)
```

Description

`fannotbl` uses function `fanno` to generate a table of values for Fanno-line flow properties as a function of Mach numbers from 0.01 to 10. Properties 2 through 7 of **Table 4.2** are written to the text file, `fannotbl.txt`.

`fannotbl(Filename,Mn,Gamma)` computes the flow functions and writes the ASCII data to the file specified by the string variable, `Filename`. Functions are evaluated at Mach numbers specified in `Mn`. `Gamma` is an optional scalar variable specifying the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used for `Gamma`.

See Also

`fanno`, `fannoplt`, and `fannotbl`

Example 4–15:

Create a table containing values for Fanno-line flow functions over a range of Mach numbers from 0.50 to 0.70 in increments of 0.01. Results are shown in **Table 4.3** on the following page.

```
>> fannotbl('fannotbl.txt.',0.5:0.01:0.7)
```

Table 4.3.—Output of function `fannotbl` for a range of Mach numbers from 0.5 to 0.7

```
                     Fanno-line Flow Properties for Gamma=1.400000
      M            T/T*         P/P*         P0/P0*        V/V*         I/I*         4fL*/D
5.00000e-001 1.14286e+000 2.13809e+000 1.33984e+000 5.34522e-001 1.20268e+000 1.06906e+000
5.10000e-001 1.14066e+000 2.09415e+000 1.32117e+000 5.44689e-001 1.19030e+000 9.90414e-001
5.20000e-001 1.13843e+000 2.05187e+000 1.30339e+000 5.54826e-001 1.17860e+000 9.17418e-001
5.30000e-001 1.13617e+000 2.01116e+000 1.28645e+000 5.64934e-001 1.16753e+000 8.49624e-001
5.40000e-001 1.13387e+000 1.97192e+000 1.27032e+000 5.75011e-001 1.15705e+000 7.86625e-001
5.50000e-001 1.13154e+000 1.93407e+000 1.25495e+000 5.85057e-001 1.14715e+000 7.28053e-001
5.60000e-001 1.12918e+000 1.89755e+000 1.24029e+000 5.95072e-001 1.13777e+000 6.73571e-001
5.70000e-001 1.12678e+000 1.86228e+000 1.22633e+000 6.05055e-001 1.12890e+000 6.22874e-001
5.80000e-001 1.12435e+000 1.82820e+000 1.21301e+000 6.15006e-001 1.12050e+000 5.75683e-001
5.90000e-001 1.12189e+000 1.79525e+000 1.20031e+000 6.24925e-001 1.11256e+000 5.31743e-001
6.00000e-001 1.11940e+000 1.76336e+000 1.18820e+000 6.34811e-001 1.10504e+000 4.90822e-001
6.10000e-001 1.11688e+000 1.73250e+000 1.17665e+000 6.44664e-001 1.09793e+000 4.52705e-001
6.20000e-001 1.11433e+000 1.70261e+000 1.16565e+000 6.54483e-001 1.09120e+000 4.17197e-001
6.30000e-001 1.11175e+000 1.67364e+000 1.15515e+000 6.64269e-001 1.08484e+000 3.84116e-001
6.40000e-001 1.10914e+000 1.64556e+000 1.14515e+000 6.74020e-001 1.07883e+000 3.53299e-001
6.50000e-001 1.10650e+000 1.61831e+000 1.13562e+000 6.83737e-001 1.07314e+000 3.24591e-001
6.60000e-001 1.10383e+000 1.59187e+000 1.12654e+000 6.93419e-001 1.06777e+000 2.97853e-001
6.70000e-001 1.10114e+000 1.56620e+000 1.11789e+000 7.03066e-001 1.06270e+000 2.72955e-001
6.80000e-001 1.09842e+000 1.54126e+000 1.10965e+000 7.12677e-001 1.05792e+000 2.49775e-001
6.90000e-001 1.09567e+000 1.51702e+000 1.10182e+000 7.22252e-001 1.05340e+000 2.28204e-001
7.00000e-001 1.09290e+000 1.49345e+000 1.09437e+000 7.31792e-001 1.04915e+000 2.08139e-001
```

isentbl

Purpose

Generate a text file containing tables of isentropic flow properties. The tables generated by this function may be useful when computational solution of the equations is not practical.

Synopsis

```
isentbl
isentbl(Filename,Mn,Gamma)
```

Description

`isentbl` uses function `ames` to generate a table of values for isentropic flow properties as a function of Mach numbers from 0.01 to 10. Properties 2 through 8 of **Table 4.1** are written to the text file, `isentbl.txt`.

`isentbl(Filename,Mn,Gamma)` computes the flow functions and writes the ASCII data to the file specified by the string variable, `Filename`. Functions are evaluated at Mach numbers specified in `Mn`. `Gamma` is an optional scalar variable specifying the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used for `Gamma.`

See Also

`ames`, `fannotbl`, `nshcktbl`, and `rayltbl`

Example 4–16:

Create a table containing isentropic functions for a range of Mach numbers from 0.9 to 1.1 in increments of 0.01. Results are shown in **Table 4.4** on the following page.

```
>> isentbl('isentbl.txt.',0.9:0.01:1.1);
```

Table 4.4.—Output of function `isentbl` for a range of Mach numbers from 0.9 to 1.1

```
                          Isentropic Flow Table for Gamma=1.400000
   M or M1         P/Pt          p/pt          T/Tt          Beta          q/Pt          A/A*          V/V*
9.00000e-001  5.91260e-001  6.87044e-001  8.60585e-001  4.35890e-001  3.35244e-001  1.00886e+000  9.14598e-001
9.10000e-001  5.84858e-001  6.81722e-001  8.57913e-001  4.14608e-001  3.39025e-001  1.00713e+000  9.23323e-001
9.20000e-001  5.78476e-001  6.76400e-001  8.55227e-001  3.91918e-001  3.42735e-001  1.00560e+000  9.32007e-001
9.30000e-001  5.72114e-001  6.71079e-001  8.52529e-001  3.67560e-001  3.46375e-001  1.00426e+000  9.40650e-001
9.40000e-001  5.65775e-001  6.65759e-001  8.49820e-001  3.41174e-001  3.49943e-001  1.00311e+000  9.49253e-001
9.50000e-001  5.59460e-001  6.60443e-001  8.47099e-001  3.12250e-001  3.53439e-001  1.00215e+000  9.57814e-001
9.60000e-001  5.53170e-001  6.55130e-001  8.44366e-001  2.80000e-001  3.56861e-001  1.00136e+000  9.66334e-001
9.70000e-001  5.46905e-001  6.49822e-001  8.41623e-001  2.43105e-001  3.60208e-001  1.00076e+000  9.74813e-001
9.80000e-001  5.40669e-001  6.44520e-001  8.38870e-001  1.98997e-001  3.63481e-001  1.00034e+000  9.83250e-001
9.90000e-001  5.34460e-001  6.39225e-001  8.36106e-001  1.41067e-001  3.66677e-001  1.00008e+000  9.91646e-001
1.00000e+000  5.28282e-001  6.33938e-001  8.33333e-001  0.00000e+000  3.69797e-001  1.00000e+000  1.00000e+000
1.01000e+000  5.22134e-001  6.28660e-001  8.30551e-001  1.41774e-001  3.72840e-001  1.00008e+000  1.00831e+000
1.02000e+000  5.16018e-001  6.23391e-001  8.27760e-001  2.00998e-001  3.75806e-001  1.00033e+000  1.01658e+000
1.03000e+000  5.09935e-001  6.18133e-001  8.24960e-001  2.46779e-001  3.78693e-001  1.00074e+000  1.02481e+000
1.04000e+000  5.03886e-001  6.12887e-001  8.22152e-001  2.85657e-001  3.81502e-001  1.00131e+000  1.03300e+000
1.05000e+000  4.97872e-001  6.07653e-001  8.19336e-001  3.20156e-001  3.84233e-001  1.00203e+000  1.04114e+000
1.06000e+000  4.91894e-001  6.02432e-001  8.16513e-001  3.51568e-001  3.86884e-001  1.00291e+000  1.04925e+000
1.07000e+000  4.85952e-001  5.97225e-001  8.13683e-001  3.80657e-001  3.89456e-001  1.00394e+000  1.05731e+000
1.08000e+000  4.80047e-001  5.92033e-001  8.10846e-001  4.07922e-001  3.91949e-001  1.00512e+000  1.06533e+000
1.09000e+000  4.74181e-001  5.86856e-001  8.08002e-001  4.33705e-001  3.94362e-001  1.00645e+000  1.07331e+000
1.10000e+000  4.68354e-001  5.81696e-001  8.05153e-001  4.58258e-001  3.96696e-001  1.00793e+000  1.08124e+000
```

nshktbl

Purpose

Generate a text file containing tables of supersonic flow and normal shock properties. The tables generated by this function may be useful when computational solution of the equations is not practical.

Synopsis

```
nshktbl
nshktbl(Filename,Mn,Gamma)
```

Description

`nshktbl` uses function `ames` to generate a table of values for supersonic flow and normal shock properties as a function of Mach numbers from 1 to 10. Properties 9 through 16 of **Table 4.1** are written to the text file, `nshktbl.txt`.

`nshktbl(Filename,Mn,Gamma)` computes the flow functions and writes the ASCII data to the file specified by the string variable, `Filename`. Functions are evaluated at Mach numbers specified in `Mn`. `Gamma` is an optional scalar variable specifying the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used for `Gamma`.

See Also

`ames`, `isentbl`, `fannotbl`, and `rayltbl`

Example 4–17:

Create a table containing supersonic flow and normal shock functions for a range of Mach numbers from 1.0 to 2.5 in increments of 0.1. Results are shown in **Table 4.5** on the following page.

```
>> nshktbl('nshktbl.txt.',1.0:0.1:2.5);
```

Table 4.5.—Output of function `nshktbl` for a range of Mach numbers from 1.0 to 2.5

```
                                 Supersonic Flow & Normal Shock Properties for Gamma=1.400000
      M1              Nu              Mu              M2             P2/P1           p2/p1           T2/T1          PT2/PT1          P1/PT2
 1.00000e+000    0.00000e+000    9.00000e+001    1.00000e+000    1.00000e+000    1.00000e+000    1.00000e+000    1.00000e+000    5.28282e-001
 1.10000e+000    1.33620e+000    6.53800e+001    9.11770e-001    1.24500e+000    1.16908e+000    1.06494e+000    9.98928e-001    4.68857e-001
 1.20000e+000    3.55823e+000    5.64427e+001    8.42170e-001    1.51333e+000    1.34161e+000    1.12799e+000    9.92798e-001    4.15368e-001
 1.30000e+000    6.17029e+000    5.02849e+001    7.85957e-001    1.80500e+000    1.51570e+000    1.19087e+000    9.79374e-001    3.68515e-001
 1.40000e+000    8.98702e+000    4.55847e+001    7.39709e-001    2.12000e+000    1.68966e+000    1.25469e+000    9.58194e-001    3.27951e-001
 1.50000e+000    1.19052e+001    4.18103e+001    7.01089e-001    2.45833e+000    1.86207e+000    1.32022e+000    9.29787e-001    2.92974e-001
 1.60000e+000    1.48604e+001    3.86822e+001    6.68437e-001    2.82000e+000    2.03175e+000    1.38797e+000    8.95200e-001    2.62814e-001
 1.70000e+000    1.78099e+001    3.60319e+001    6.40544e-001    3.20500e+000    2.19772e+000    1.45833e+000    8.55721e-001    2.36752e-001
 1.80000e+000    2.07251e+001    3.37490e+001    6.16501e-001    3.61333e+000    2.35922e+000    1.53158e+000    8.12684e-001    2.14155e-001
 1.90000e+000    2.35861e+001    3.17569e+001    5.95616e-001    4.04500e+000    2.51568e+000    1.60792e+000    7.67357e-001    1.94485e-001
 2.00000e+000    2.63798e+001    3.00000e+001    5.77350e-001    4.50000e+000    2.66667e+000    1.68750e+000    7.20874e-001    1.77291e-001
 2.10000e+000    2.90971e+001    2.84369e+001    5.61277e-001    4.97833e+000    2.81190e+000    1.77045e+000    6.74203e-001    1.62196e-001
 2.20000e+000    3.17325e+001    2.70357e+001    5.47056e-001    5.48000e+000    2.95122e+000    1.85686e+000    6.28136e-001    1.48888e-001
 2.30000e+000    3.42828e+001    2.57715e+001    5.34411e-001    6.00500e+000    3.08455e+000    1.94680e+000    5.83295e-001    1.37105e-001
 2.40000e+000    3.67465e+001    2.46243e+001    5.23118e-001    6.55333e+000    3.21190e+000    2.04033e+000    5.40144e-001    1.26632e-001
 2.50000e+000    3.91236e+001    2.35782e+001    5.12989e-001    7.12500e+000    3.33333e+000    2.13750e+000    4.99015e-001    1.17286e-001
 2.60000e+000    4.14147e+001    2.26199e+001    5.03871e-001    7.72000e+000    3.44898e+000    2.23834e+000    4.60123e-001    1.08917e-001
 2.70000e+000    4.36215e+001    2.17385e+001    4.95634e-001    8.33833e+000    3.55899e+000    2.34289e+000    4.23590e-001    1.01395e-001
 2.80000e+000    4.57459e+001    2.09248e+001    4.88167e-001    8.98000e+000    3.66355e+000    2.45117e+000    3.89464e-001    9.46129e-002
 2.90000e+000    4.77903e+001    2.01713e+001    4.81380e-001    9.64500e+000    3.76286e+000    2.56321e+000    3.57733e-001    8.84780e-002
 3.00000e+000    4.97573e+001    1.94712e+001    4.75191e-001    1.03333e+001    3.85714e+000    2.67901e+000    3.28344e-001    8.29121e-002
```

oblqshck

Purpose

For steady state supersonic flow, `oblqshck` computes the angle of the oblique shock that results from compressively turning the flow through angle (δ). One of two solutions will occur for each Mach number specified, a weak shock solution, or a strong shock solution. Angles have units of degrees. The flow situation is similar to that depicted in Figure 4.4 (pp. 19).

Synopsis

```
oblqshck
ThetaW=oblqshck(M1,delta)
[ThetaW,ThetaS]=oblqshck(M1,delta,gamma)
```

Description

`oblqshck` by itself generates a plot showing shock angle vs. deflection angle for lines of constant Mach from 1 to 20. This plot is a representation of Chart 2 in (ref. 1).

`[ThetaW,ThetaS]=oblqshck(M1,delta)` computes both the weak oblique shock angle, `ThetaW`, and the strong oblique shock angle, `ThetaS`, that are the result of compressively turning supersonic flow at Mach number, `M1`, through angle `delta`. `M1` and `delta` may be either scalars or vectors. If both are vectors, they must have identical dimensions.

`[ThetaW,ThetaS,DELmax,DELson]=oblqshck(M1,delta,gamma)` uses optional **scalar** input `Gamma` to specify the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used for `Gamma`. In addition to returning the oblique shock angles, this form also returns the maximum flow deflection angle, `DELmax`, and the flow deflection angle that results in sonic flow downstream of the oblique shock, `DELson`.

Algorithm

`oblqshck` uses the upstream Mach number, the flow deflection angle, and the ratio of specific heats to calculate the solution of the cubic equation for both weak and strong oblique shock angles using the method given in (ref. 5). If flow deflection angles are specified as outputs, `oblqshck` uses functions `deltamax` and `deltason` to compute values for those parameters at Mach number(s), `M1`.

See Also

`deltason`, `deltamax`, `oblqw12`, and `oblqw21`

Example 4–18:

Replicate the results in Chart 2 of (ref. 1).

```
>> oblqshck
```

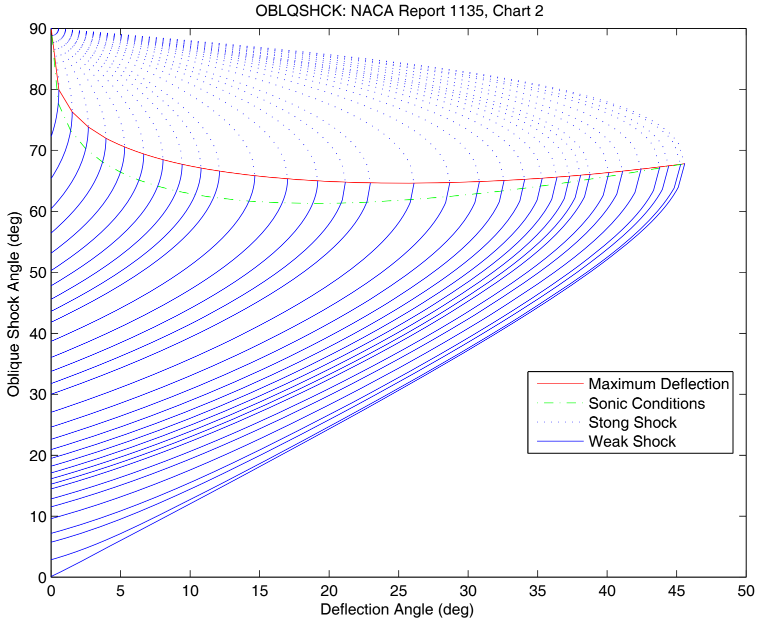


Figure 4.9.—Oblique shock angle versus deflection angle for lines of constant Mach number.

Example 4–19:

Given freestream airflow at Mach 2.2, calculate the shock angle that results from turning the flow through a range of deflection angles from zero to the maximum deflection possible without separating the flow.

```
>> M1=2.2, DELmax=deltamax(M)
M1 =
    2.2000

DELmax =
   26.1028

>> delta=DELmax*[0:10]'/10; M1=M1*ones(size(delta));

>> ThetaW=oblqshck(M1,delta); [delta ThetaW]
ans =
         0   27.0357
    2.6103   29.0843
    5.2206   31.2899
    7.8308   33.6666
   10.4411   36.2338
   13.0514   39.0200
   15.6617   42.0707
   18.2719   45.4660
   20.8822   49.3676
   23.4925   54.2056
   26.1028   64.6203
```

oblqw12

Purpose

For steady state supersonic flow, `oblqw12` uses the upstream fluid properties to compute properties of the flow downstream of a weak oblique shock. The flow situation is similar to that depicted in Figure 4.4 (pp. 19).

Synopsis

```
oblqw12
M2=oblqw12(M1,delta)
[M2,Theta,PTratio]=oblqw12(M1,delta,gamma)
```

Description

`oblqw12` by itself generates a series of plots showing properties of oblique shocks for lines of constant Mach from 1 to 20. Figure 4.9(a and b) replicates the weak shock portions of Charts 2 and 4 in (ref. 1). Figure 4.9(c) shows variations in total pressure across and oblique shock as a function shock angle. In these figures, the solid lines represent lines of constant Mach number.

`M2=oblqw12(M1,delta)` computes the Mach number, `M2`, downstream of an oblique shock that results from compressively turning supersonic flow at Mach number, `M1`, through angle `delta`. `M1` and `delta` may be either scalars or vectors. If both are vectors, they must have identical dimensions.

`[M2,Theta,PTratio]=oblqw12(M1,delta,gamma)` uses optional **scalar** input `Gamma` to specify the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used. In addition to returning the downstream Mach number, this form also returns the resulting oblique shock angle as `Theta`, and the total pressure ratio across the shock, $P_{t,2}/P_{t,1}$, as `PTratio`.

Algorithm

`Oblqw12` uses the upstream Mach number, the flow deflection angle, and the ratio of specific heats to calculate the solution of the cubic equation for both weak and strong oblique shock angles using the method given in reference 5. It then uses equation 131 and 142 from reference 1—alternatively, equation 7.31 and 7.25 from reference 4—to calculate the downstream Mach number and total pressure ratio across the oblique shock.

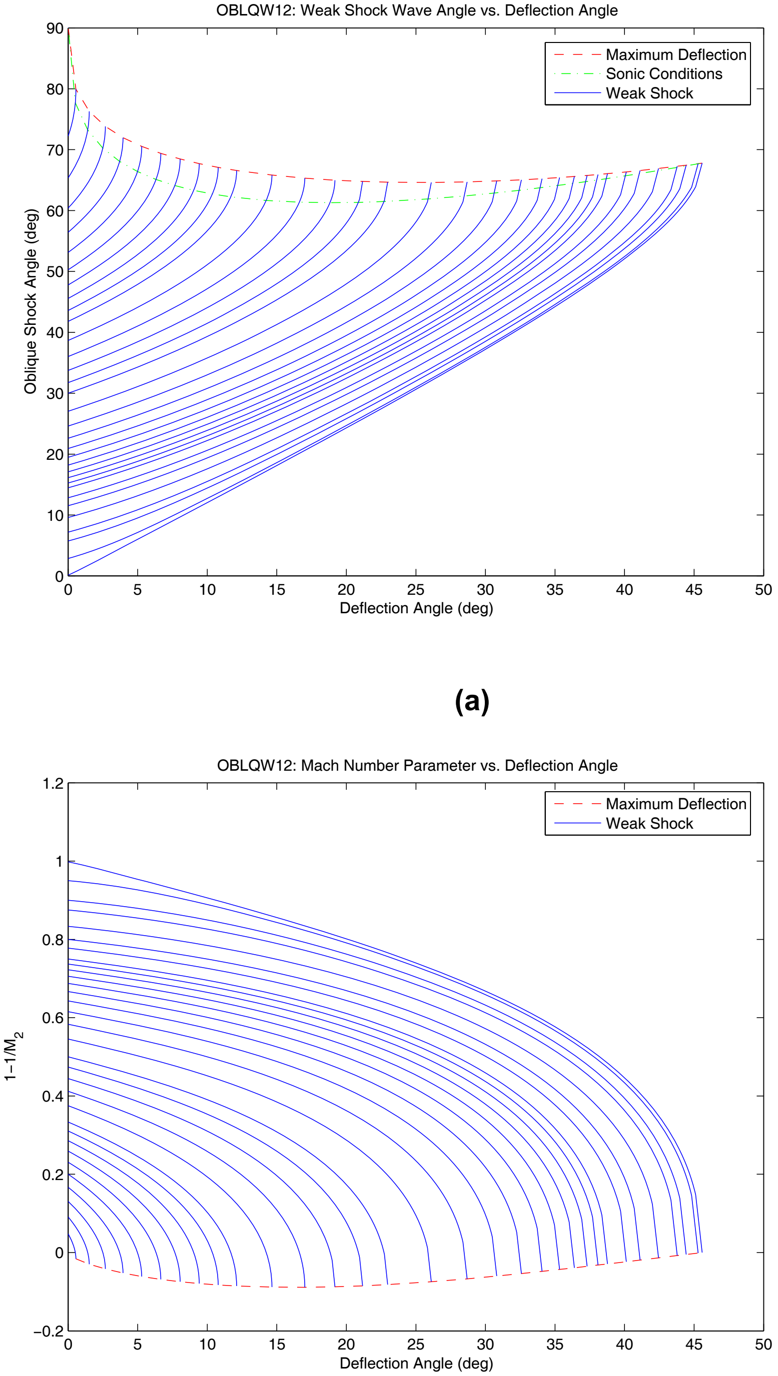
See Also

`deltason`, `deltamax`, `oblqshck`, and `oblqw21`

Example 4–20:

Replicate the results in Chart 2 and 4 of reference 1. Results are shown in Figure 4.10.

```
>> oblqshck
```



(a)

(b)

Figure 4.10.—Plots generated by function `oblqw12`.

Example 4–21:

Given flow deflection of freestream airflow at Mach 2.2, calculate the shock angle that results from turning the flow through a range of deflection angles from zero to the maximum deflection possible without separating the flow.

```
>> M1=2.2, DELmax=deltamax(M)
M1 =
    2.2000
DELmax =
   26.1028

>> delta=DELmax*[0:10]'/10; M1=M1*ones(size(delta));

>> ThetaW=oblqshck(M1,delta); [delta ThetaW]
ans =
         0   27.0357
    2.6103   29.0843
    5.2206   31.2899
    7.8308   33.6666
   10.4411   36.2338
   13.0514   39.0200
   15.6617   42.0707
   18.2719   45.4660
   20.8822   49.3676
   23.4925   54.2056
   26.1028   64.6203
```

oblqw21

Purpose

For steady state supersonic flow, `oblqw21` uses the downstream fluid properties to compute properties of the flow upstream of a weak oblique shock. The flow situation is similar to that depicted in Figure 4.4 (pp. 19).

Synopsis

```
oblqw21
M1=oblqw21(M2,delta)
[M1,Theta,PTratio]=oblqw21(M2,delta,gamma)
```

Description

`oblqw21` generates a consistency check for the oblique shock equations used by functions `oblqshck`, `oblqw12`, and `oblqw21`. The absolute error is plotted as a function of flow deflection angle for lines of constant Mach number.

`M1=oblqw21(M2,delta)` computes the Mach number, `M1`, upstream of an oblique shock that is required to achieve downstream Mach number, `M2`, after compressively turning the flow through angle `delta`. `M2` and `delta` may be either scalars or vectors. If both are vectors, they must have identical dimensions.

`[M1,Theta,PTratio]=oblqw21(M2,delta,gamma)` uses optional **scalar** input `Gamma` to specify the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used. In addition to returning the downstream Mach number, this form also returns the resulting oblique shock angle as `Theta`, and the total pressure ratio across the shock, $P_{t,2}/P_{t,1}$, as `PTratio`.

Algorithm

`oblqw21` uses MATLAB's `fminbnd` function to find a solution to the nonlinear equation for downstream Mach number as a function of upstream Mach number, the flow deflection angle, and the ratio of specific heats. `fminbnd` solves the nonlinear equation by employing an inline function to compute the error between the user specified Mach number, M_2, and a downstream Mach number, $M_{2,\text{Guess}}$, that is calculated using function `oblqw12` and a guess for the upstream Mach number, $M_{1,\text{Guess}}$. The search is arbitrarily constrained to Mach numbers less than or equal to 100. Solutions associated with Mach numbers larger than 100 are returned as `NaN` (i.e., not a number).

See Also

`deltason`, `deltamax`, `oblqshck`, and `oblqw12`

Example 4–22:

Generate the consistency check for the oblique shock functions.

```
>> oblw21
```

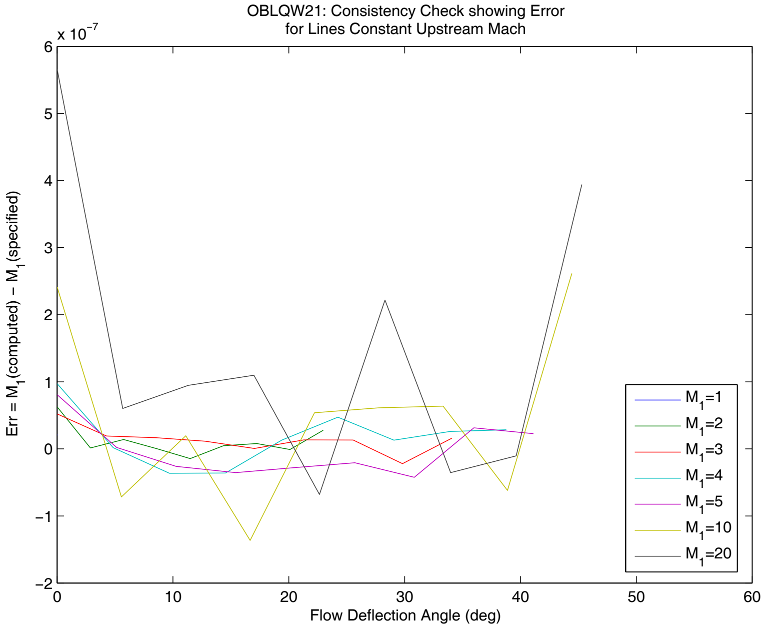


Figure 4.11.—Consistency check for oblique shock functions `oblqshck`, `oblqw12`, and `oblqw21`.

Example 4–23:

Given the values for downstream Mach number, `M2`, shown below, calculate the upstream Mach number required to produce `M2` when the flow deflection angle is 0.5 degrees. Also calculate the oblique shock angle and the total pressure ratio across the oblique shock.

```
>> M2=[ 0.9000  1.0000  1.9819  2.9742  3.9624 …
       61.9798 69.5625 76.8279 83.7768 90.4113];

>> delta=0.5;

>> [M1,Theta,PTratio]=oblqw21(M2,delta);
Warning: FANNO: Some Mach number solutions exceed internal limit (M
> 100).  Solutions set to NaN
> In oblqw21 at 119
```

```
>> [M2(:) M1(:) Theta(:) PTratio(:)]
ans =
    0.9000       NaN       NaN       NaN
    1.0000    1.0490   77.7993    1.0000
    1.9819    2.0000   30.4029    1.0000
    2.9742    3.0000   19.8116    1.0000
    3.9624    4.0000   14.8009    1.0000
   61.9798   70.0000    1.1719    0.9500
   69.5625   80.0001    1.0766    0.9288
   76.8279   90.0000    1.0038    0.9037
   83.7768   99.9999    0.9468    0.8750
   90.4113       NaN       NaN       NaN
```

Note that a weak oblique shock solution does not exist for the case where `M2` = 0.9. Therefore, the associated solutions are defined as `NaN`. Also, because the search space is limited to Mach numbers less than or equal to 100, a solution for `M2` = 90.4113, `M1` = 110, is not computed by `oblqw21`.

rayleigh

Purpose

Solve the equations for one-dimensional steady flow in a constant area duct with heat transfer.

Synopsis

```
Properties=rayleigh(VarIn,ValuesIn,VarsOut)
Properties=rayleigh(VarIn,ValuesIn,VarsOut,Gamma)
[Properties,PltLbls]=rayleigh(VarIn,ValuesIn,VarsOut,Gamma)
rayleigh
```

Description

`Properties=rayleigh(VarIn,ValuesIn,VarsOut)`, given a number designating one of the flow properties listed in **Table 4.6** and a value or vector of values for that flow property, `rayleigh` computes corresponding values for flow though a constant area duct with heat transfer. `VarIn` is a scalar that specifies the property used as the input (independent variable). `ValuesIn` may be a scalar or vector and contains values of the independent variable for which the other properties will be computed. `VarsOut` contains a list of indices corresponding to the flow properties listed in **Table 4.6**. Indices specified in `VarsOut` may be in any order and may be repeated as desired by the user. Results are returned in the `Properties` matrix. Columns in this matrix correspond to indices specified in `VarsOut`. Rows of the `Properties` matrix contain results corresponding to the elements of `ValuesIn`.

Note that, when properties 2, 3, or 5 are used as the independent variable, the solution is double-valued. The double-valued solution is provided by making `Properties` a cell array. `Properties{1}` contains values of the solution associated with the smaller Mach number, while `Properties{2}` contains the solution associated with the larger Mach number.

`Properties=rayleigh(VarIn,ValuesIn,VarsOut,Gamma)` provides a mechanism for specifying values for the ratio of specific heats of the working fluid via `Gamma`. `Gamma` is optional. If unspecified, a value of 1.4, the value of the ratio of specific heats of air at standard temperature and pressure, is used. If specified, `Gamma` may be defined as either a scalar or a vector. If it is a vector, it must have the same length as `ValuesIn`.

`[Properties,PltLbls]=rayleigh(VarIn,ValuesIn,VarsOut,Gamma)`, in addition to returning the properties of the fluid at user specified conditions, also returns a cell array, `PltLbls`, containing text strings that may be used when plotting the results.

`rayleigh` by itself calls `raylplt` which plots the Rayleigh-line flow properties versus Mach number. The resulting plot is similar to figure 6.5 in reference 4.

Table 4.6.—Description of Flow Properties Computed by Function `rayleigh`

REF. INDEX	PROPERTY	REF. 4[*] EQN.	DESCRIPTION
1.	M or M_1		Mach number
2.	$T_t/T_{t,*}$	Eq. 6.22	Ratio of total temperature at M_1 to total temperature at sonic conditions.
3.	T/T_*	Eq. 6.19	Ratio of static temperature at M_1 to static temperature at sonic conditions.
4.	P/P_*	Eq. 6.20	Ratio of static pressure at M_1 to static pressure at sonic conditions.
5.	$P_t/P_{t,*}$	Eq. 6.23	Ratio of total pressure at M_1 to total pressure at sonic conditions.
6.	V/V_*	Eq. 6.21	Ratio of flow velocity at M_1 to flow velocity at sonic conditions.

[*] Similar equations may also be found in reference 2 on p. 196.

Algorithm

`rayleigh` determines the desired flow properties by first obtaining a Mach number solution for each value, `ValuesIn`, of the user specified flow property, `VarIn`. The resulting Mach numbers are then used to compute the other properties, `VarsOut`. Most of the flow equations may be manipulated analytically to obtain Mach number as a function of the other properties. However, in the case of total pressure ratio, a nonlinear relationships exists which has no simple analytical solution. In this case, MATLAB's `fminbnd` function is used determine an approximate solution for Mach number from the nonlinear equation. The search is arbitrarily constrained to Mach numbers less than or equal to 100. Solutions associated with Mach numbers larger than 100 are returned as `NaN` (i.e., not a number).

See Also

`raylerr`, `raylplt`, and `rayltbl`

Example 4.24:

For air flowing at Mach 0.72 and 2.85, determine the Rayleigh-line flow properties.

```
>> rayleigh(1,[0.72 2.85],2:6)
ans =
    0.9221    1.0026    1.3907    1.0376    0.7209
    0.6685    0.3057    0.1940    3.0014    1.5757
```

Example 4.25:

Given sonic conditions at a point in a constant area duct with total temperature of 1000 K and total pressure of 300 kPa, find the Mach number and total pressure as the total temperature decreases to 800, 600, and 400 K.

First, divide duct total temperature by sonic total temperature to obtain the ratio of total temperatures.

```
>> TTratio = [900 750 600]/1000
TTratio =
0.9000    0.7500    0.6000
```

Next, use function `rayleigh` to compute the Mach number (ref. index 1) and total pressure ratio (ref. index 5) for the speficied total temperature ratios.

```
>> Properties=rayleigh(2,TTratio,[1 5])
Properties =
    [3x2 double]    [3x2 double]
```

The solution is double-valued. The subsonic solution is returned as `Properties{1}`, and the supersonic solution is returned as `Properties{2}`. Mach number values are returned in column one of each of the solutions. The subsonic and supersonic solutions for Mach number are shown below in columns one and two, respectively. Here, the rows correspond to the elements of `TTratio`, with the first row corresponding to the element one.

```
>> M1=[Properties{1}(:,1) Properties{2}(:,1)]
M1 =
    0.6884    1.5368
    0.5423    2.2361
    0.4415    3.7749
```

Values for total pressure ratio are returned in column two of each of the cells in `Properties`. The subsonic and supersonic solutions are shown below in columns one and two, respectively. Here, the rows correspond to the elements of `TTratio`, with the first row corresponding to the element one. The total pressure ratios are multiplied by the pressure ratio at sonic conditions (i.e., 300 kPa) to obtain total pressure at the specified total temperature conditions.

```
>> PT=[Properties{2}(:,2); Properties{2}(:,2)]*300
PT =
  1.0e+003 *
    0.3139    0.3421
    0.3291    0.5379
    0.3416    2.0328
```

Note that `NaN` results would imply that the intermediate solution for Mach number exceeded the internal limit (i.e., M > 100).

raylerr

Purpose

Show the computational errors that result when using function `rayleigh` to solve equations for one-dimensional steady adiabatic flow in a constant-area duct with friction.

Synopsis

```
raylerr
[error,M1]=raylerr
```

Description

`raylerr` computes the error between Mach numbers used as inputs to function `rayleigh` and Mach numbers calculated from the output of function `rayleigh`. The results are plotted as absolute and percent errors versus Mach number for each of the flow functions shown in **Table 4.6**.

`[error,M1]=raylerr` returns the computed error in `error`. If specified, `M1` contains the initial vector of Mach numbers.

Algorithm

`raylerr` first generates a logarithmically spaced vector of 250 Mach numbers from 0.01 to 10. This vector also includes critical Mach number values where numerical stability is important, such as saddle points. `raylerr` then uses function `rayleigh` to calculate each of the Rayleigh-line flow properties corresponding to those Mach numbers. The functions of Mach number, obtained from `rayleigh`, are then used as input to the `rayleigh` function in order to obtain a Mach number which corresponds to the function value. Theoretically, the initial and computed Mach numbers should be the same. In general, they are not due to round off, truncation, convergence, and/or optimization errors. The difference in the two Mach numbers is returned as the error in the calculations.

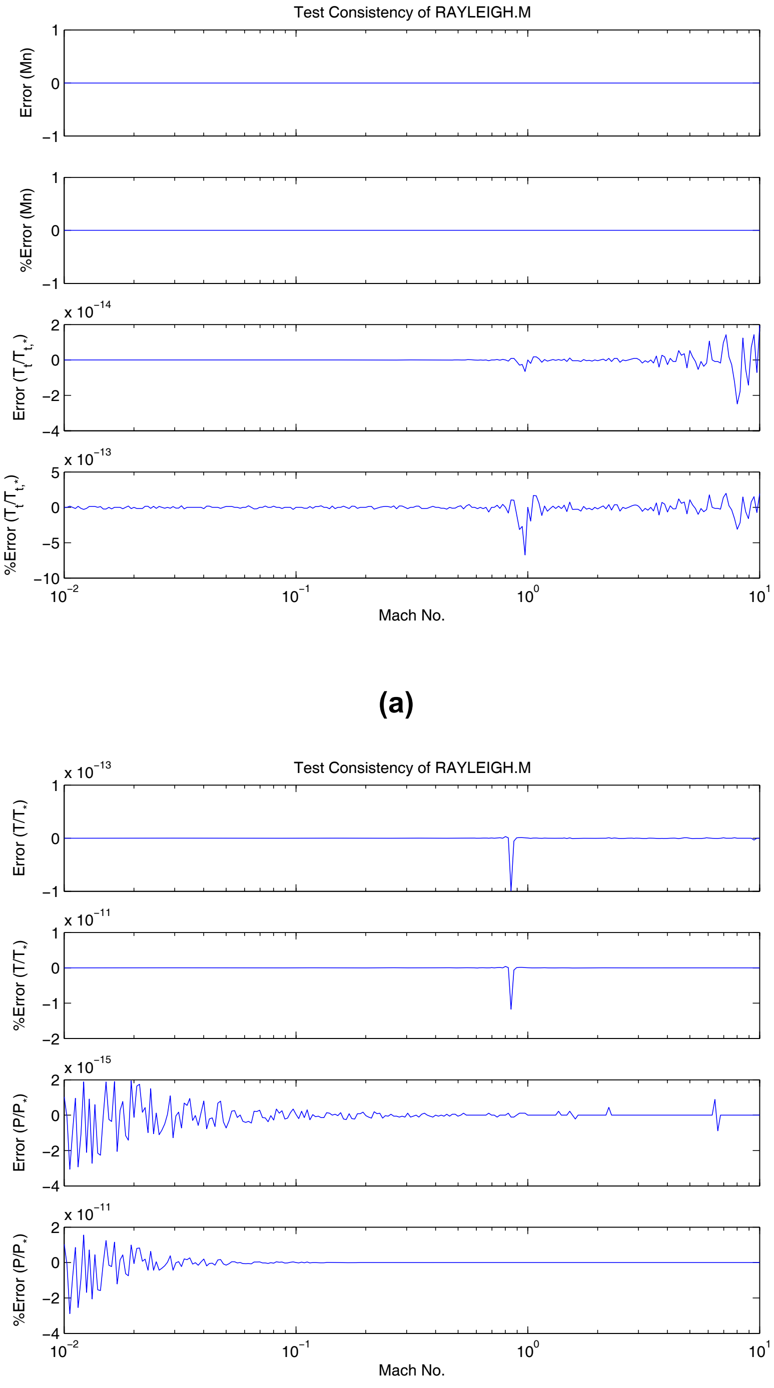
See Also

`rayleigh`, `raylplt`, and `rayltbl`

Example 4.26:

Perform a consistency check on the calculations in function `rayleigh`. Plots are shown in Figure 4.12(a to c).

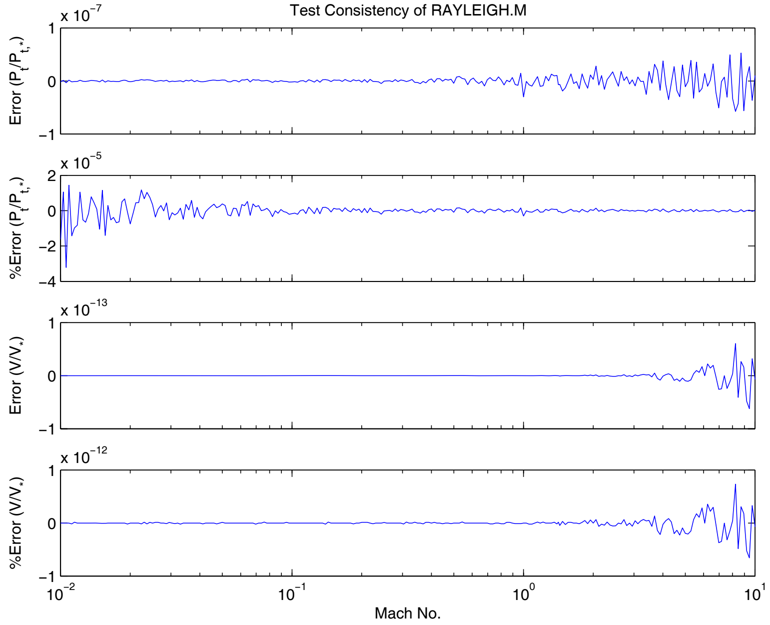
```
>> raylerr
```



(a)

(b)

Figure 4.12.—Output of function `raylerr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7.



(c)

Figure 4.12.—Output of function `raylerr` as computed on an Intel Pentium4 processor-based computer running MATLAB® 7 (continued).

raylplt

Purpose

Plot properties for Rayleigh-line flow, i.e., one-dimensional steady adiabatic flow in a constant-area duct with friction.

Synopsis

```
raylplt
raylplt(MNmin,MNmax)
raylplt(MNmin,MNmax,Npts)
raylplt(MNmin,MNmax,Npts,Gamma)
```

Description

`raylplt` uses function `rayleigh` to compute and plot the Rayleigh-line flow properties at 250 points between Mach 0.05 and Mach 2.5 when the ratio of specific heats of the fluid is 1.4. This plot resembles figure 6.5 in reference 4.

`raylplt(MNmin,MNmax)` plots results for a range of user specified Mach numbers where: `MNmin` is the minimum Mach number; and `MNmax` is the maximum Mach number.

`raylplt(MNmin,MNmax,Npts)` in addition to allowing the user to specify the range of Mach numbers used, this form allows the user to specify the number of data points, `Npts`, used to plot each curve.

`raylplt(MNmin,MNmax,Npts,Gamma)` in addition to allowing the user to specify Mach No. and number of points per curve, this form also allows the user to specify a scalar value for the ratio of specific heats, `Gamma`, of the fluid.

Algorithm

`raylplt` first generates a logarithmically spaced vector of 250 Mach numbers from 0.05 to 2.5. This vector also includes critical Mach number values where numerical stability is important, such as solution saddle points. `raylplt` then uses this vector as inputs to function `rayleigh` which is used to calculate each of the isentropic flow properties and the normal shock properties corresponding to those Mach numbers. The resulting values are plotted versus Mach number to provide the user a graphical understanding of the relationship between flow properties and Mach number.

See Also

`rayleigh`, `raylerr`, and `rayltbl`

Example 4.27:

Plot Rayleigh-line flow properties over a range of Mach numbers from 0.5 to 2.5. The resulting plot is shown in Figure 4.13.

```
>> raylplt
```

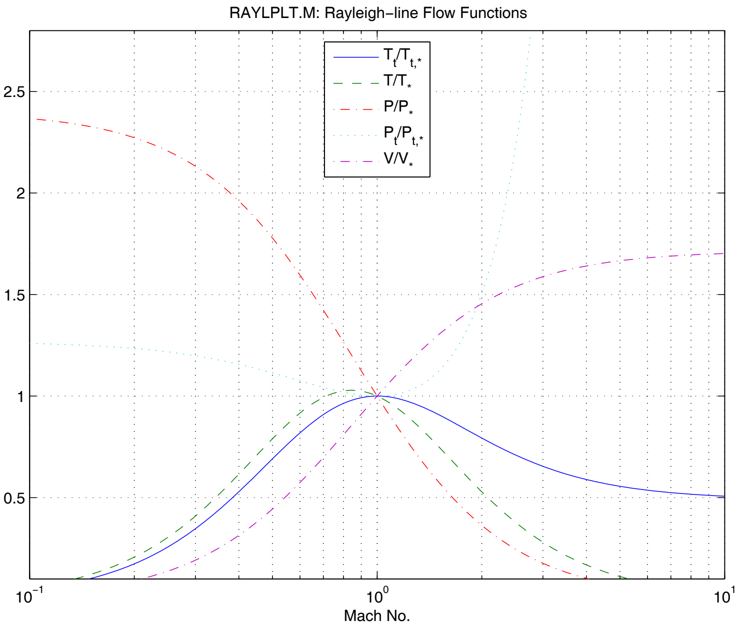


Figure 4.13.—Rayleigh-line flow properties as generated by function `raylplt`.

rayltbl

Purpose

Generate a text file containing tables of Rayleigh-line flow properties. The tables generated by this function may be useful when computational solution of the equations is not practical.

Synopsis

```
rayltbl
rayltbl(Filename,Mn,Gamma)
```

Description

`rayltbl` uses function `rayleigh` to generate a table of values for Rayleigh-line flow properties as a function of Mach numbers from 0.01 to 10. Properties 2 through 6 of **Table 4.2** are written to the text file, `rayltbl.txt`.

`rayltbl(Filename,Mn,Gamma)` computes the flow functions and writes the ASCII data to the file specified by the string variable, `Filename`. Functions are evaluated at Mach numbers specified in `Mn`. `Gamma` is an optional scalar variable specifying the ratio of specific heats of the working fluid. If unspecified, a value of 1.4 is used for `Gamma`.

See Also

`rayleigh`, `raylplt`, and `rayltbl`

Example 4–28:

Create a table containing values for Rayleigh-line flow functions over a range of Mach numbers from 0.55 to 059 in increments of 0.01, and from 2.0 to 2.4 in increments of 0.1. Results are shown in **Table 4.7** on the following page.

```
>> M1=[0.55:0.01:0.59  2.0:0.1:2.4];

>> rayltbl('rayltbl.txt.',M1)
```

Table 4.7.—Output of function `rayltbl` for a range of Mach numbers specified in Example 4.28

```
                Rayleigh-line Flow Properties for Gamma=1.400000
      M            TT/TT*          T/T*           P/P*          PT/PT*          V/V*
5.50000e-001  7.59910e-001  8.59870e-001  1.68599e+000  1.09397e+000  5.10011e-001
5.60000e-001  7.72486e-001  8.72274e-001  1.66778e+000  1.09011e+000  5.23015e-001
5.70000e-001  7.84675e-001  8.84158e-001  1.64964e+000  1.08630e+000  5.35969e-001
5.80000e-001  7.96478e-001  8.95523e-001  1.63159e+000  1.08256e+000  5.48866e-001
5.90000e-001  8.07894e-001  9.06371e-001  1.61362e+000  1.07887e+000  5.61701e-001
2.00000e+000  7.93388e-001  5.28926e-001  3.63636e-001  1.50310e+000  1.45455e+000
2.10000e+000  7.74064e-001  4.93558e-001  3.34541e-001  1.61616e+000  1.47533e+000
2.20000e+000  7.56135e-001  4.61058e-001  3.08642e-001  1.74345e+000  1.49383e+000
2.30000e+000  7.39543e-001  4.31220e-001  2.85510e-001  1.88602e+000  1.51035e+000
2.40000e+000  7.24213e-001  4.03836e-001  2.64784e-001  2.04505e+000  1.52515e+000
```

5. References

1. Ames Research Staff: "Equations Tables and Charts for Compressible Flow," NACA Report 1135, 1953.
2. Melcher, Kevin J.: "A Method for Perturbing the Flow Field in Supersonic Wind Tunnels for Dynamic Analysis of High Speed Inlets," Masters Thesis, Cleveland State University, June 1996.
3. Shapiro, A.: *The Dynamics and Thermodynamics of Compressible Fluid Flow*, John Wiley & Sons, Inc., 1953.
4. Saad, M.: *Compressible Fluid Flow,* Prentice-Hall., 1993.
5. Hartley, T.T., et al.: "Exact and Approximate Solutions to the Oblique Shock Equations for Real-Time Applications," NASA CR–187173, August 1991.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	**2. REPORT DATE** January 2006	**3. REPORT TYPE AND DATES COVERED** Technical Memorandum

4. TITLE AND SUBTITLE

User Guide for Compressible Flow Toolbox
Version 2.1 for Use With MATLAB® Version 7

5. FUNDING NUMBERS

WBS–22–714–92–56

6. AUTHOR(S)

Kevin J. Melcher

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–15423

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—2006-214086

11. SUPPLEMENTARY NOTES

Responsible person, Kevin J. Melcher, organization code RIC, 216–433–3743.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category: 34

Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This report provides a user guide for the Compressible Flow Toolbox, a collection of algorithms that solve almost 300 linear and nonlinear classical compressible flow relations. The algorithms, implemented in the popular MATLAB® programming language, are useful for analysis of one-dimensional steady flow with constant entropy, friction, heat transfer, or shock discontinuities. The solutions do not include any gas dissociative effects. The toolbox also contains functions for comparing and validating the equation-solving algorithms against solutions previously published in the open literature. The classical equations solved by the Compressible Flow Toolbox are: isentropic-flow equations, Fanno flow equations (pertaining to flow of an ideal gas in a pipe with friction), Rayleigh flow equations (pertaining to frictionless flow of an ideal gas, with heat transfer, in a pipe of constant cross section.), normal-shock equations, oblique-shock equations, and Prandtl-Meyer expansion equations. At the time this report was published, the Compressible Flow Toolbox was available without cost from the NASA Software Repository.

14. SUBJECT TERMS

Compressible flow; Supersonic flow; Subsonic flow; Shock waves; Normal shock waves; Oblique shock waves; Isentropic process; Rayleigh equations

15. NUMBER OF PAGES

62

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT**