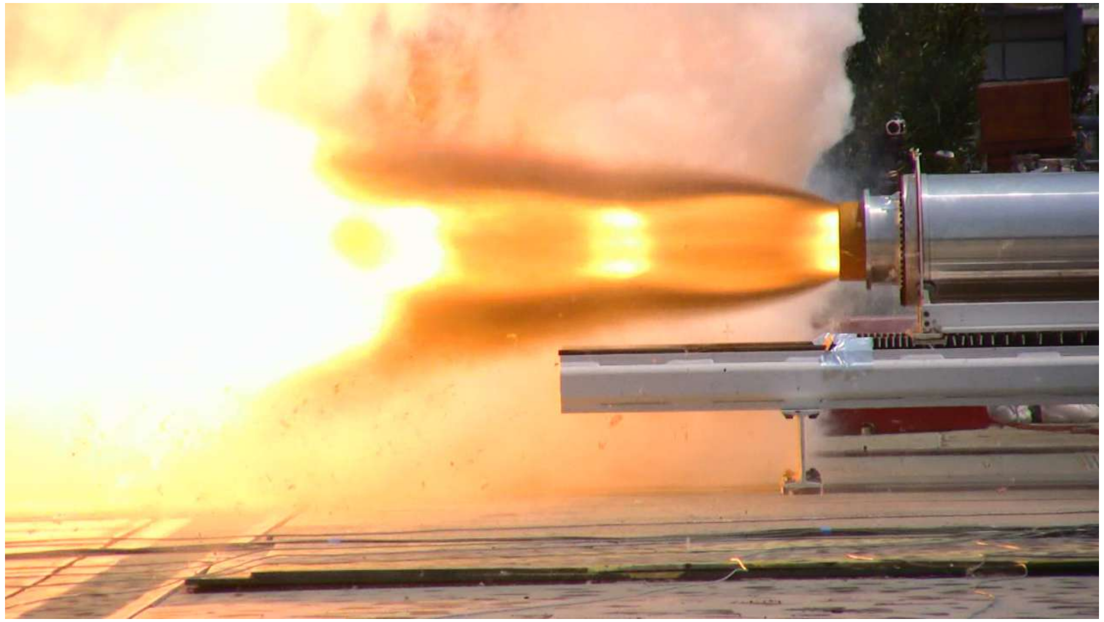
AA210A

Fundamentals of Compressible Flow

Course Introduction



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Course Reference Material

Required Text: Course Reader, *Fundamentals of Compressible Flow.*
These are my course notes and can be downloaded in pdf format from my web site.

Recommended reference: Van Dyke, *An Album of Fluid Motion*, Parabolic Press.
This book is filled with great flow pictures. I often use it to illustrate the concepts developed in the course.

Also recommended

Liepmann and Roshko, *Elements of Gasdynamics*, Dover

Anderson, *Modern Compressible Flow*, McGraw Hill

Thompson, *Compressible-Fluid Dynamics*, Rensselaer Polytechnic Institute Press

Shapiro, *The Dynamics and Thermodynamics of Compressible Fluid Flow*, Ronald Press.

Aris, *Vectors, Tensors, and the Basic Equations of Fluid Mechanics*, Prentice-Hall

Schlichting and Gersten, *Boundary Layer Theory*, Springer

Course Contents

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Useful Web Sites - pictures and videos

This is my web site where the AA 210A notes can be found in pdf format along with the course summary and homework assignments.

http://www.stanford.edu/~cantwell/

This Virginia Tech web site has a useful app for calculating the properties of a one-dimensional compressible flow as well as several other apps.

http://www.engapplets.vt.edu

Lots of interesting flow pictures.

http://www.efluids.com/efluids/pages/gallery.htm

This MIT site has the Fluid Mechanics Films produced for the National Science Foundation in the 1960's available in streaming video. You need Real Player to view the films. Highly recommended.

http://web.mit.edu/fluids/www/Shapiro/ncfmf.html

Useful Web Sites – Khan Academy short video lectures

One of the most interesting developments in recent years has been the creation of new, free websites dedicated to online teaching. Perhaps the best of these is the amazingly extensive set of lectures put up by Sal Khan who lives in Los Altos just south of Stanford. While there are really no lectures on the site directly connected to compressible flow, there are several on calculus and thermodynamics that might be useful.

Links to a few suggested lectures are below. They typically run ten minutes or less. I am suggesting these as a means of review if you feel you are rusty on these subjects. I would like to get your feedback as to whether you find the lectures useful. Feel free to suggest others you might like.

Integrating Factors
http://www.khanacademy.org/video/integrating-factors-1?playlist=Differential%20Equations

Second Order differential Equations
http://www.khanacademy.org/video/2nd-order-linear-homogeneous-differential-equations-1?playlist=Differential%20Equations

Carnot Cycle
http://www.khanacademy.org/video/carnot-cycle-and-carnot-engine?playlist=Chemistry

Enthalpy
http://www.khanacademy.org/video/enthalpy?playlist=Chemistry

Thermodynamic Entropy Definition, Clarification
http://www.khanacademy.org/video/thermodynamic-entropy-definition-clarification?playlist=Chemistry

Recently these links were working but several others that I had listed before had stopped working. I suspect the above links will also stop working eventually. To get the most out of the site you will probably have to set up an account on the Khan Academy website.

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Grading/Homework Policies

Homework - Homework problems will be assigned each wednesday and will be due the following wednesday. The understanding gained through solving problems is absolutely crucial to learning the course subject matter. You are not expected to work on homeworks in total isolation; seek out your peers, the course assistants and the instructor when you need help on the problems. This is a fundamental part of the learning experience. Just be sure that whatever you hand in, is your own work. Homeworks that are turned in by 5:00 PM on the date due will be carefully examined, graded and returned. There is a considerable effort required to grade the homeworks. Please be considerate of the course assistants and make every effort to turn your homework in on time. Late homeworks will not be graded. They will be assigned up to 3/5 credit depending on effort and returned without examination.

Academic paper – Part of your final grade will be determined by your own creation in the form of a scholarly paper on a topic related to compressible flow. The purpose of the paper is to give you an opportunity to do an in-depth study on a topic of your choosing related to compressible flow. I will suggest a number of possible topics, but I am very open to your suggestions. The paper must be new, original work but not necessarily a new contribution to knowledge. The paper could be expository or educational in nature. It could be related to your research but must be clearly independent of any other papers you might be preparing for a conference or journal and any other paper you have written in the past unless that paper serves as a reference for a new effort. You can see from the list of suggested topics below, that I expect the paper to include your perspective on the history and background of your subject. The paper should be prepared using the template from the AIAA website for a paper submitted to the SciTech conference and be of a quality that you would feel comfortable publishing as an article in a journal or conference. Conferences often have sessions devoted to papers of the type you will be producing. The length should be between 10 and 20 pages although you can consider those limits flexible. The paper is due friday November 20 at 5:00 pm. As with the homework, a late paper will be assigned up to 3/5 credit based on effort.

Grading: Homework - 70% ; Academic paper - 30%

Resources

e-Resources – If you need free access to journal articles through the Stanford system this link, https://library.stanford.edu/using/connecting-e-resources, will help you set that up on your home computer.

Course material – Materials for all my courses are available at my website at https://web.stanford.edu/~cantwell/. The folder *Course Material for AA210A* includes a folder containing a pdf of the course text, *Fundamentals of Compressible Flow*, a folder where pdfs of the lectures will be posted a day or so before the lecture, and a folder where homework assignments will be posted. In addition, selected papers related to the course material are also included in a resources folder. Videos of the lectures will be placed on the AA210a site on CANVAS.

Some suggested topics for your article.

1) The development of high-speed flight, breaking the sound barrier
2) High speed commercial flight, the transition from piston to jet power
3) The issue of jet noise and its impact on commercial air travel
4) The development of CFD and the problem of computing transonic flow
5) The challenge of extended hypersonic flight
6) Turbulence modeling of compressible wall flows
7) Solving the re-entry heating problem
8) The challenge of landing on Mars and other planets
9) The history and current status of high-speed test facilities; transonic, supersonic, hypersonic tunnels, shock tunnels
10) Meteor and comet impacts, shock waves in liquids and solids
11) Compressibility effects in volcanos, geysers, stellar explosions and heavy element creation
12) Safety of gas, liquid and powder storage facilities, LNG safety, the Beirut explosion, grain elevator explosions

Compressible flows play a crucial role in a vast variety of man-made and natural phenomena.

Propulsion and power systems

High speed flight

Star formation, evolution and death

Geysers and geothermal vents

Earth meteor and comet impacts

Gas processing and pipeline transfer

Sound creation and propagation

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Let's look at some examples of compressible flows.

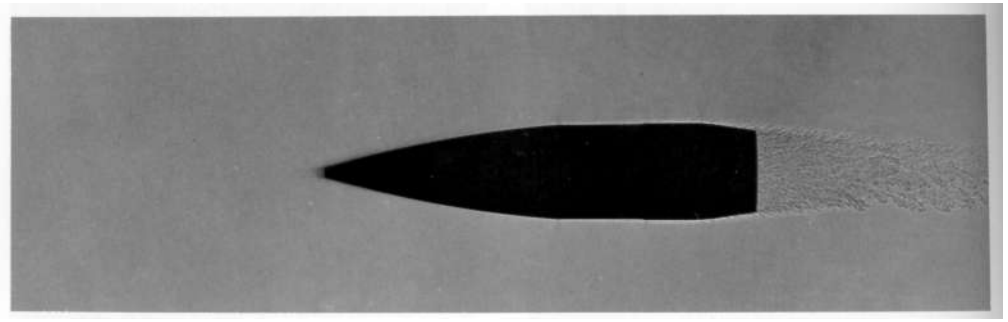
I will often refer to the Mach number. This key parameter is defined as:

$$M = \frac{\text{Flow Velocity}}{\text{Speed of Sound}}$$

Often compressible flows involve the formation of shock waves.

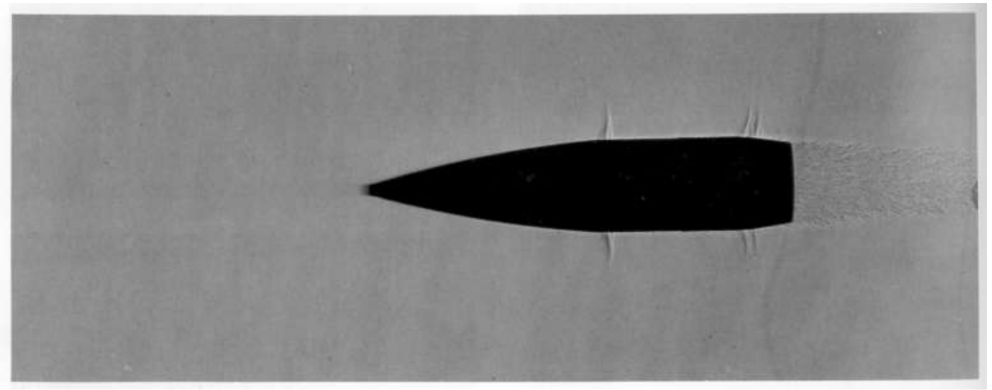
A shock wave is a very thin region of the flow where flow properties change <u>very</u> rapidly.

Transonic Projectile (1 of 5)



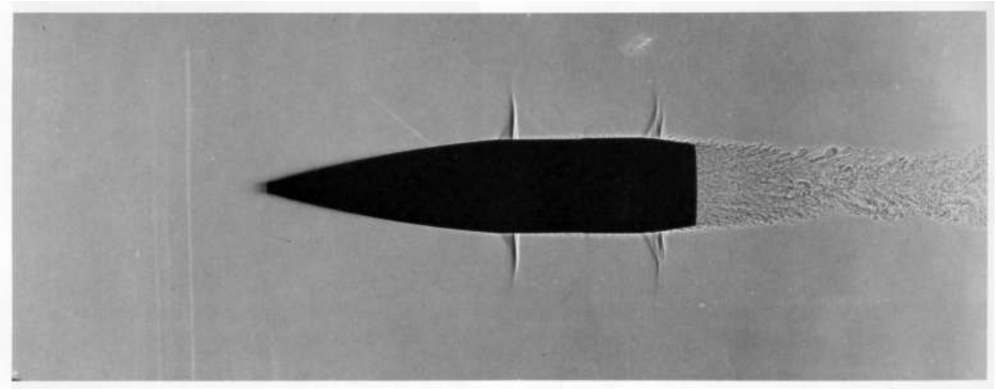
M = 0.840

Note the formation of weak shock waves on the projectile



M = 0.885

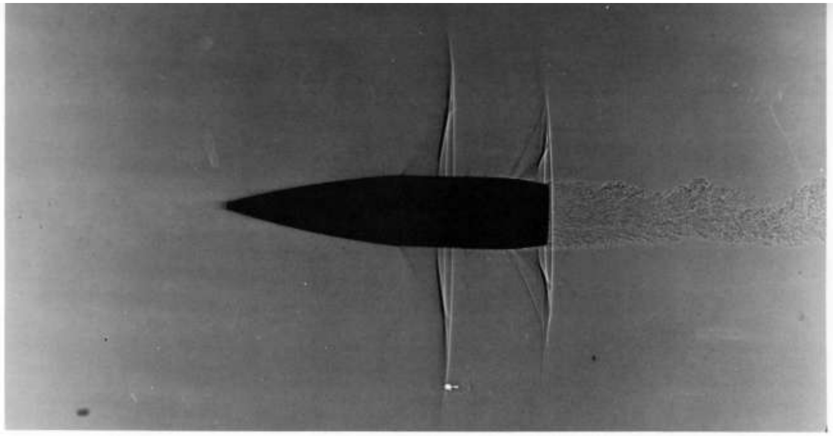
As the Mach number increases, the shocks become stronger and extend farther from the projectile.



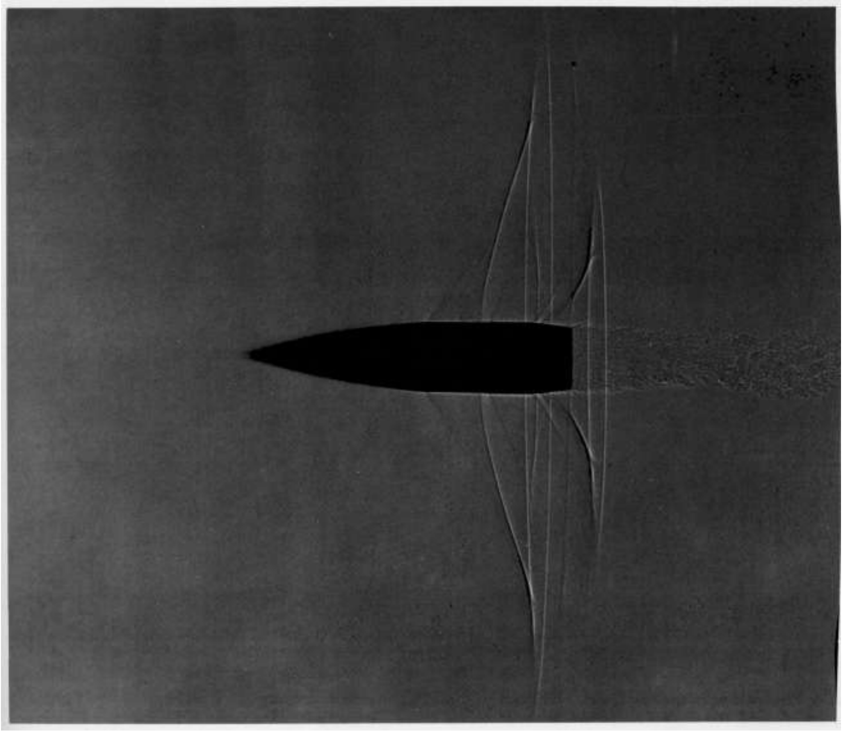
M = 0.900

Picture ref: Van Dyke, *An Album of Fluid Motion*

Transonic Projectile (2 of 5)



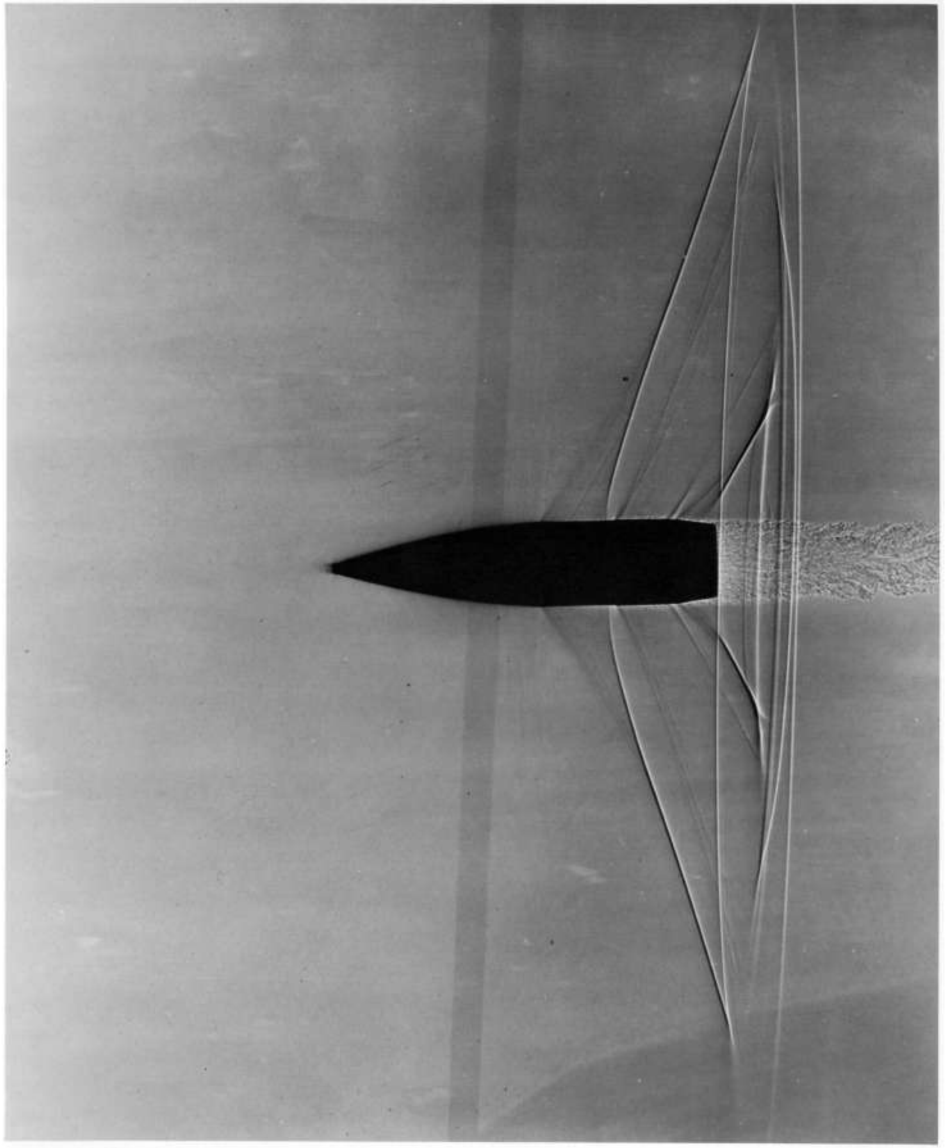
M = 0.946



M = 0.971

Picture ref: Van Dyke, *An Album of Fluid Motion*

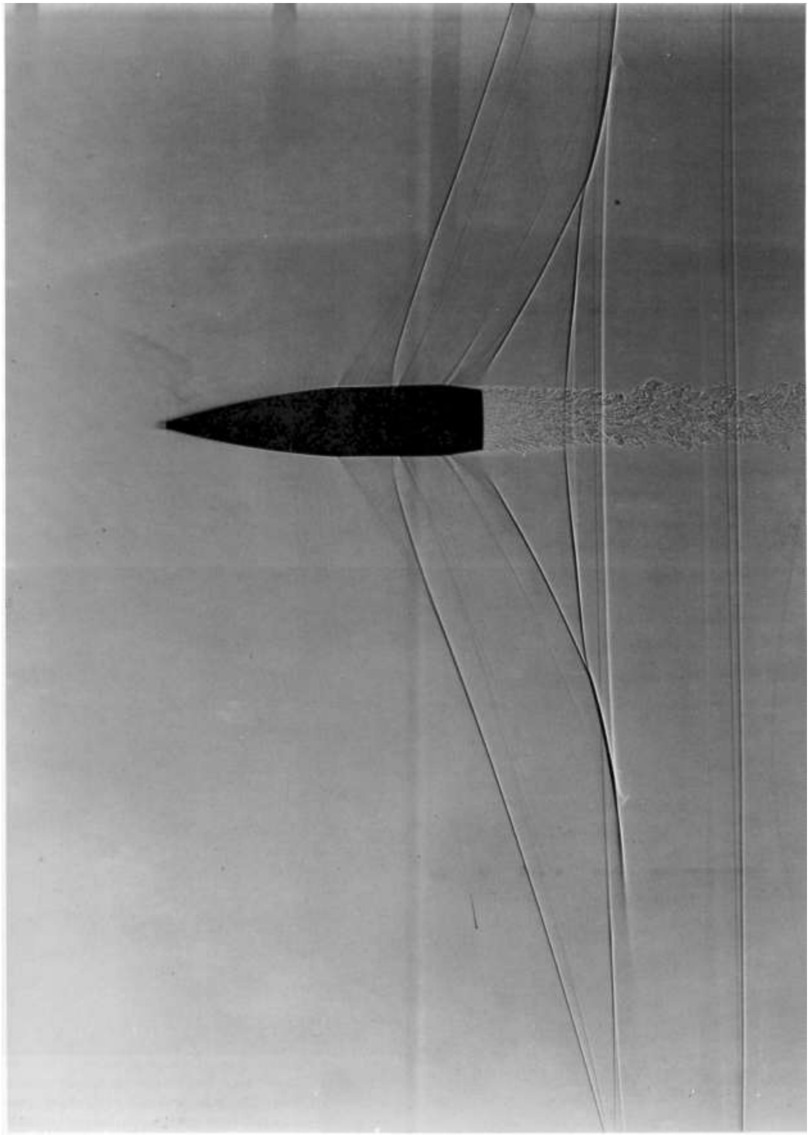
Transonic Projectile (3 of 5)



M = 0.978

Picture ref: Van Dyke, *An Album of Fluid Motion*

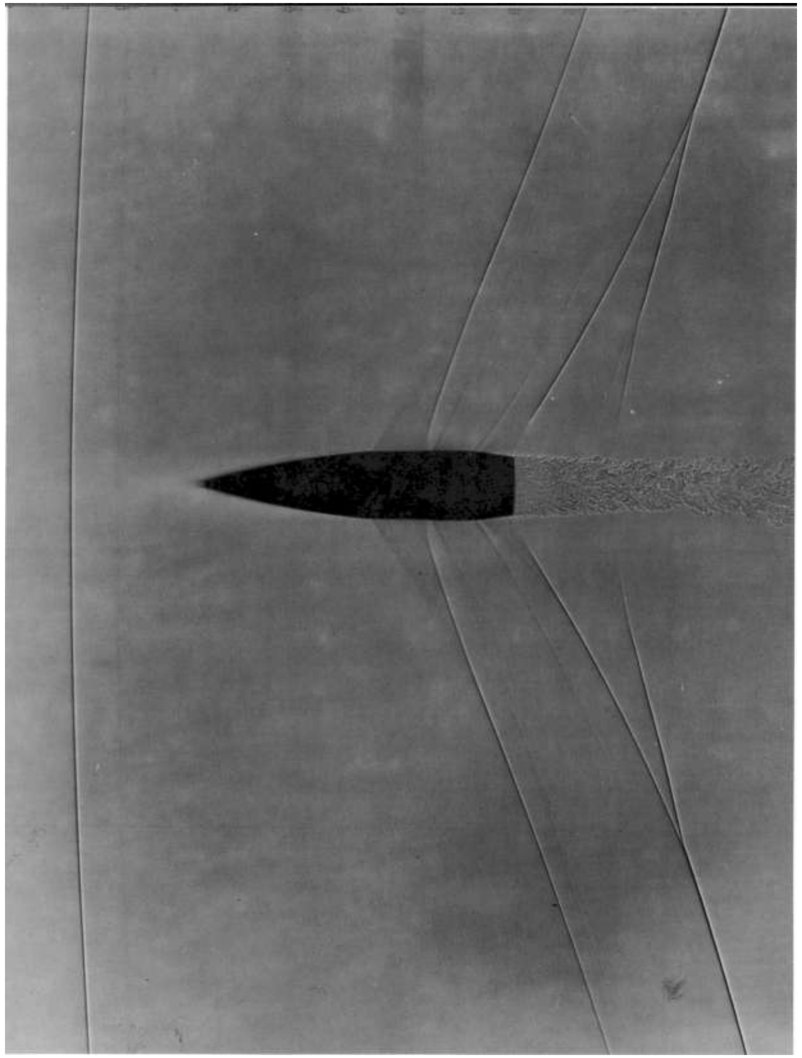
Transonic Projectile (4 of 5)



M = 0.990

Picture ref: Van Dyke, *An Album of Fluid Motion*

Transonic Projectile (5 of 5)



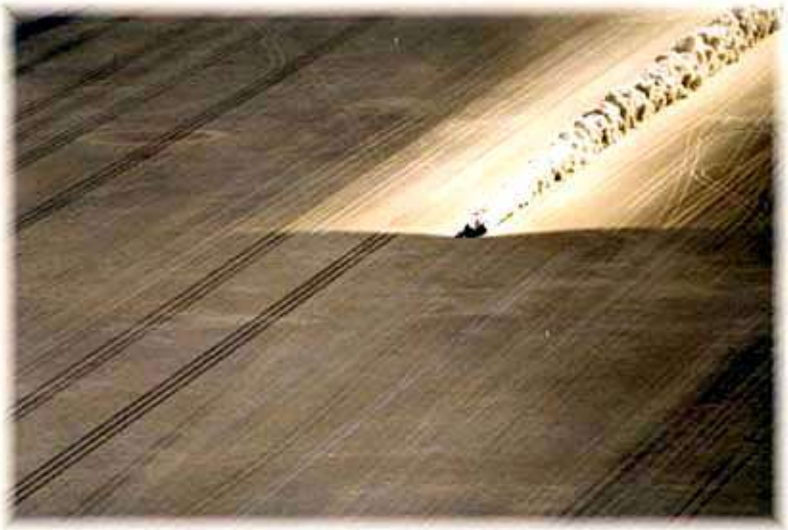
M = 1.015

Picture ref: Van Dyke, *An Album of Fluid Motion*

Shock Waves About Transonic Aircraft Visualized by Condensation.

Shock Waves on the World’s Fastest “Automobile”

Black Rock
Desert, Nevada,
October 15, 1997

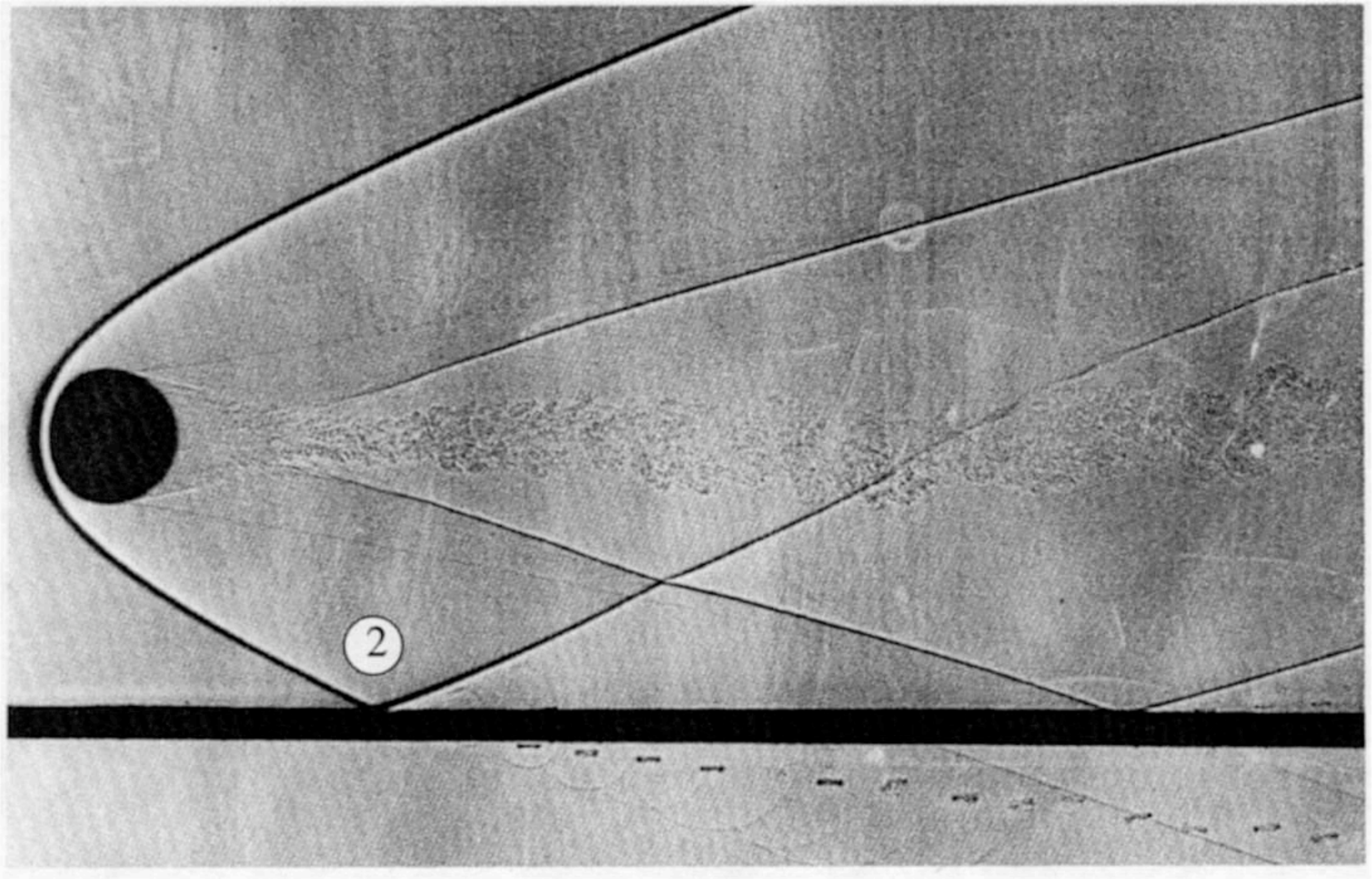


763 miles per hour

Artillery fire - USS Iowa

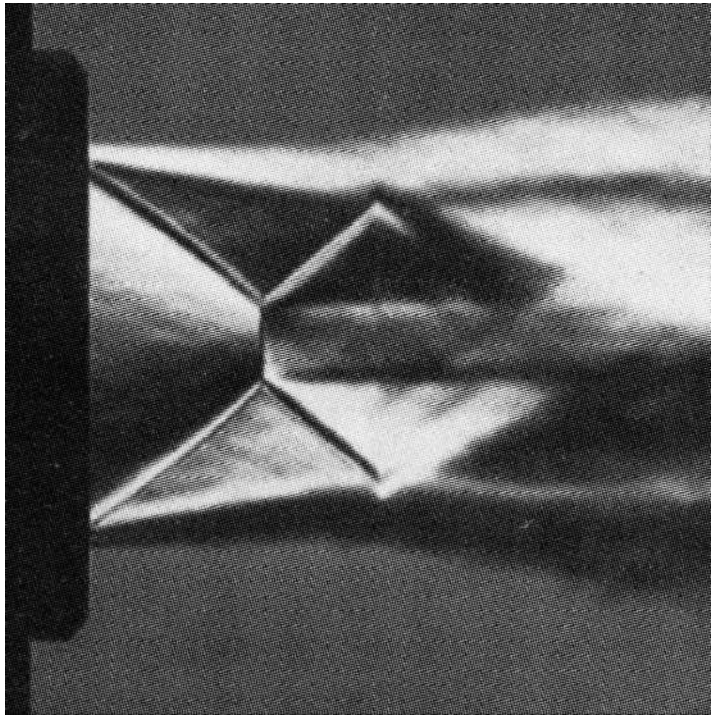
Papua New Guinea Volcano Eruption 2014

Sphere in High Speed Flow



Picture ref: Van Dyke, *An Album of Fluid Motion*

Supersonic Nozzle Flow (1 of 2)



Picture ref: Van Dyke, *An Album of Fluid Motion*

Space Shuttle Main Engine

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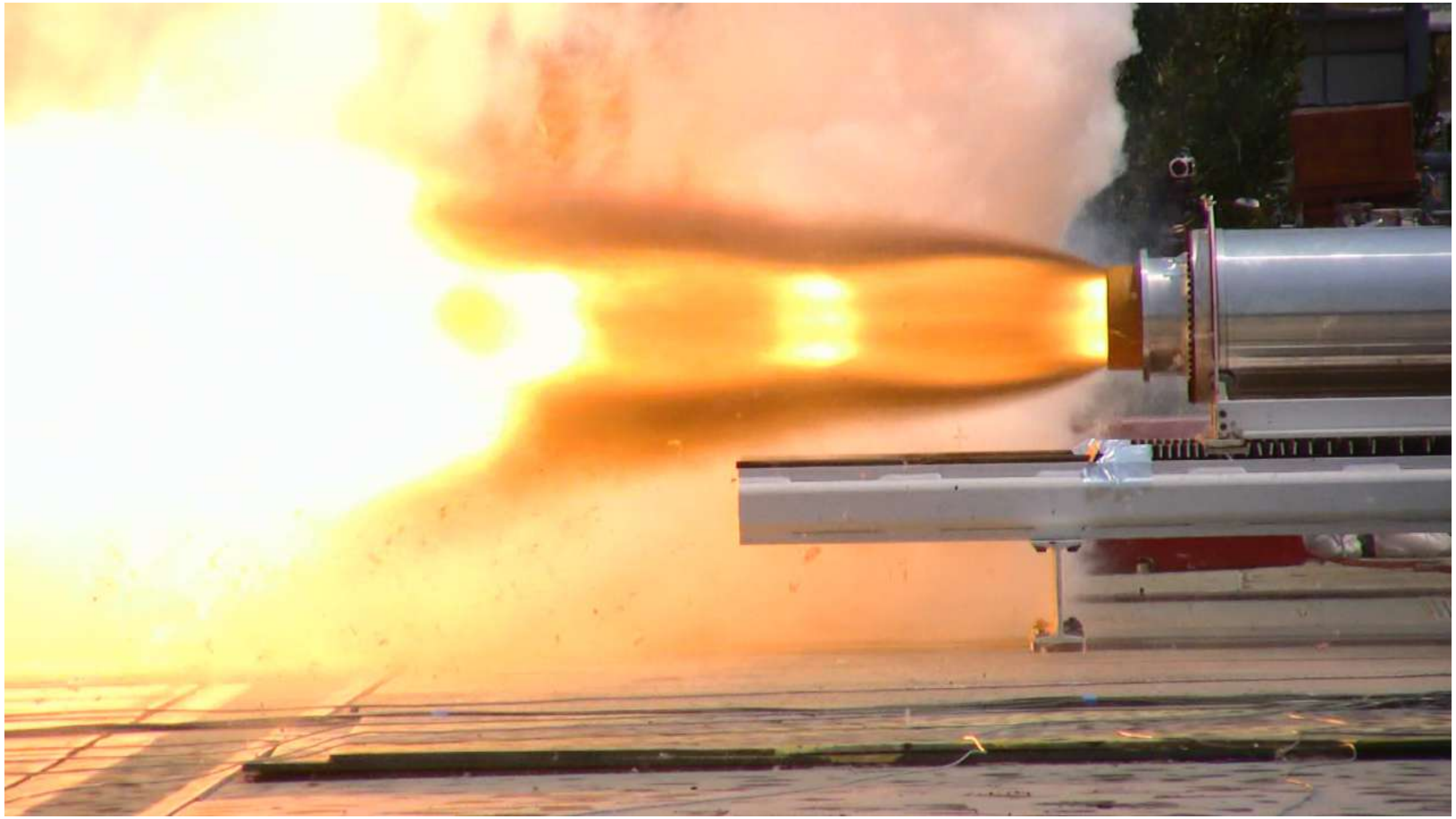
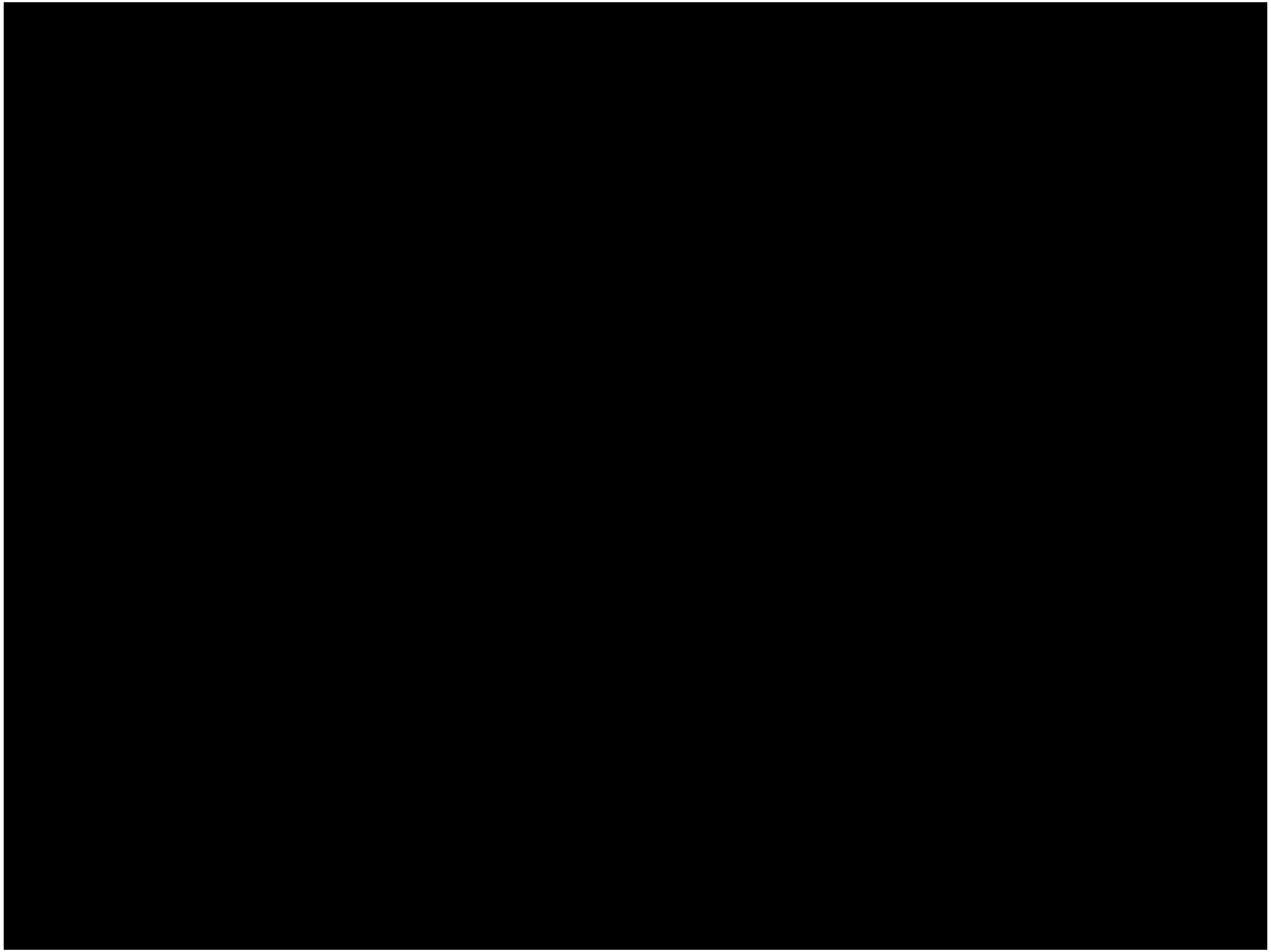
Supersonic Nozzle Flow (2 of 2)

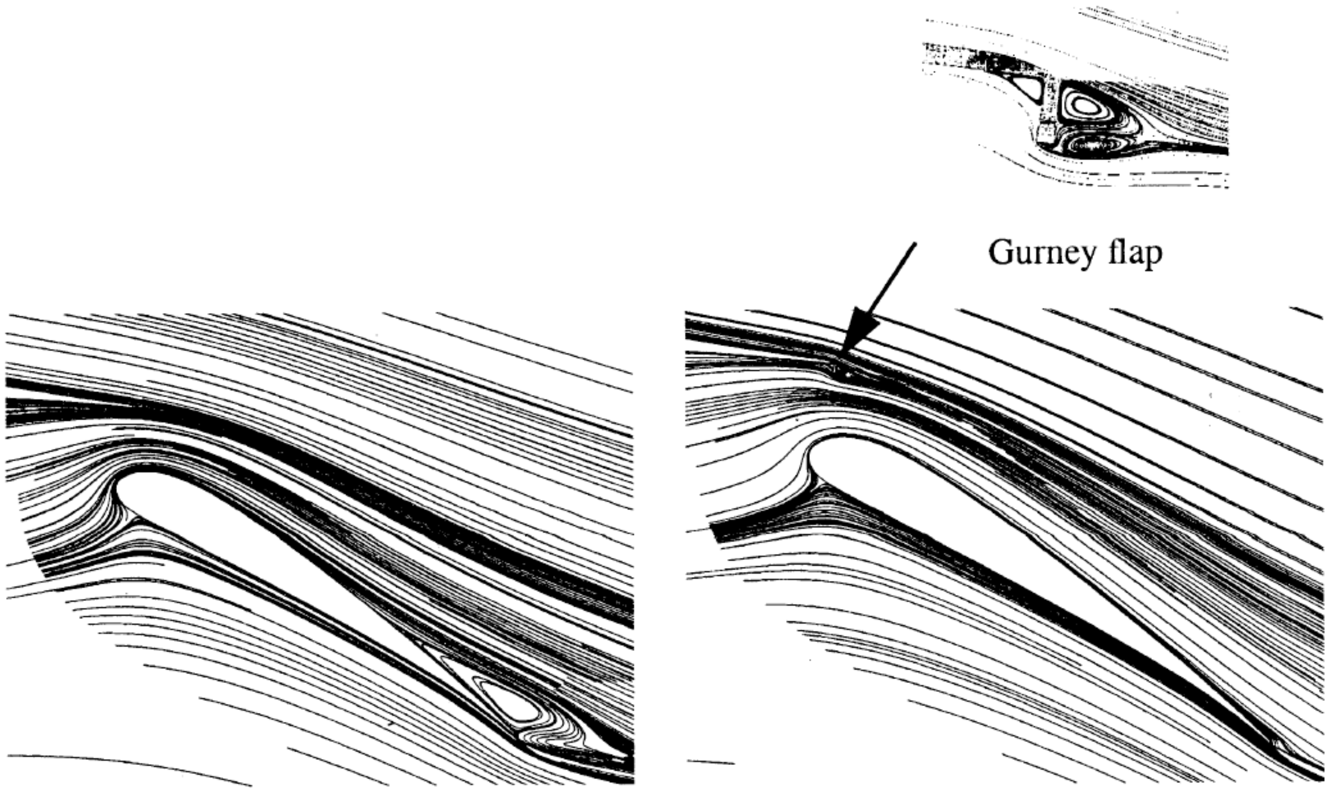


Hybrid Rocket Motor Test at NASA Ames

2-D Supersonic Nozzles:
The US Air Force's new fighter the F-22

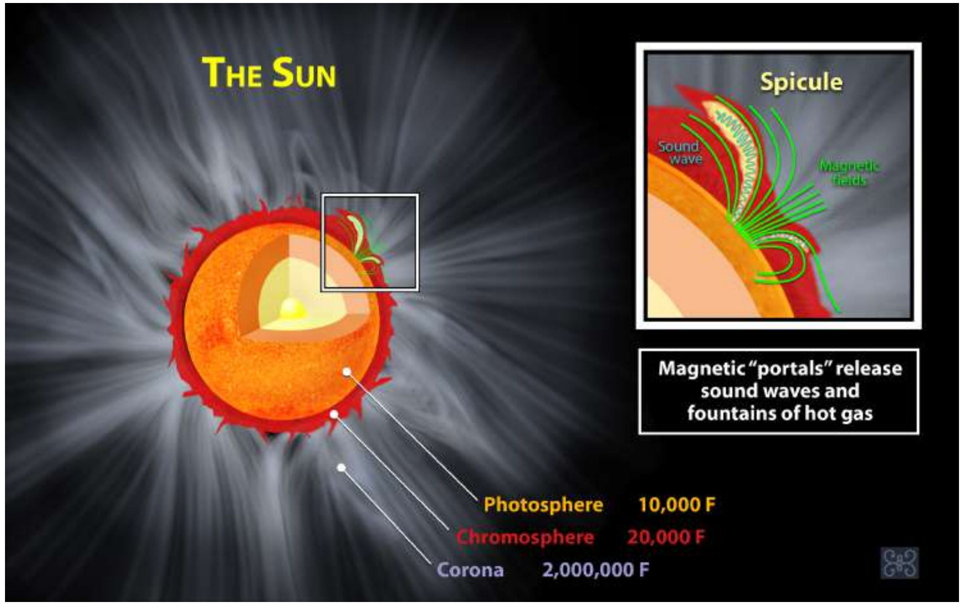


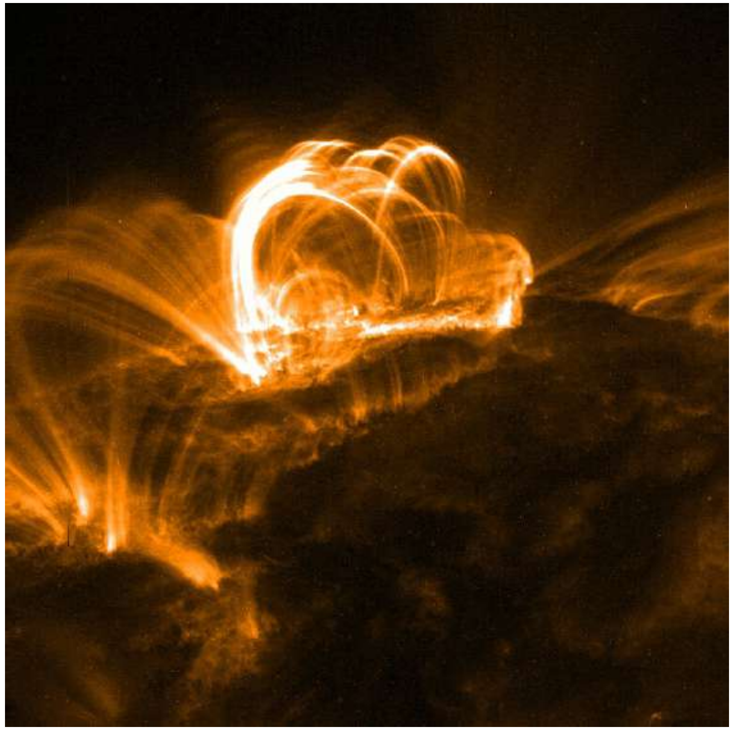
A weakly compressible example:
flow over a wing flap.



Computed streamlines over a wing flap.

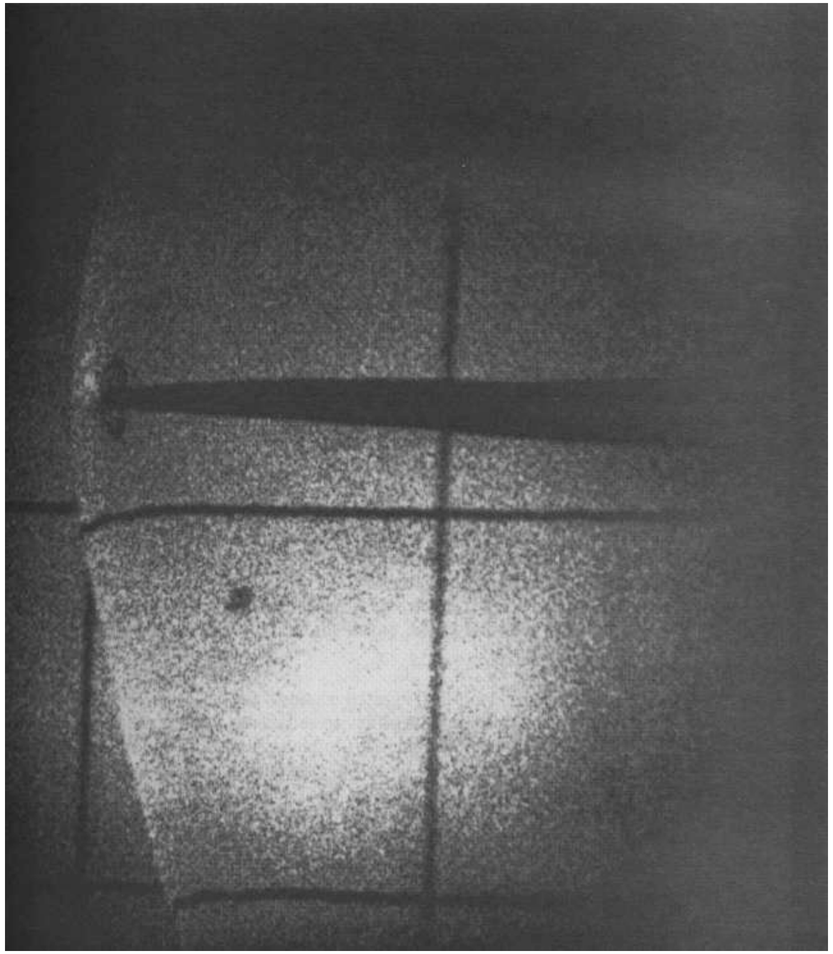
Sound Waves on the Sun

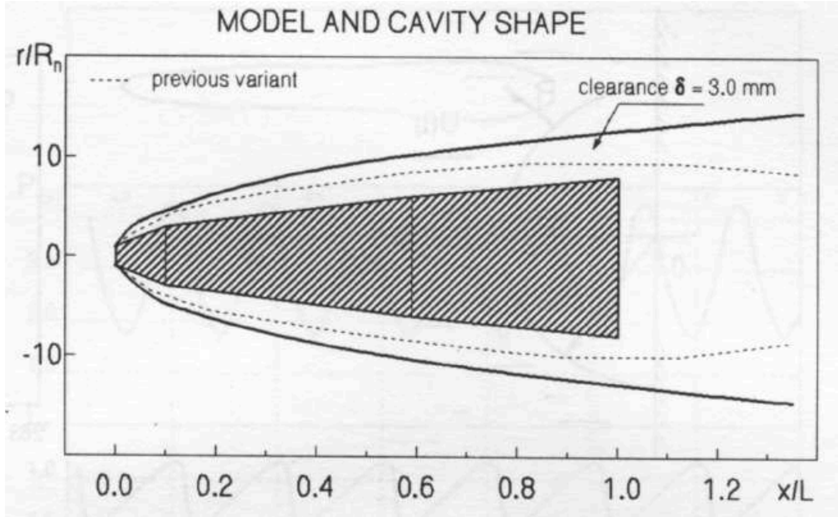


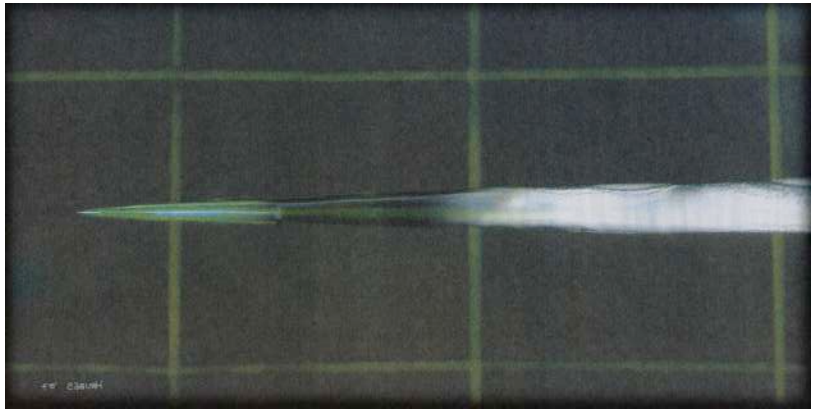


The Cat's Eye Nebula produced by a dying star

Supersonic projectile in water 1220 m/sec







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Questions?