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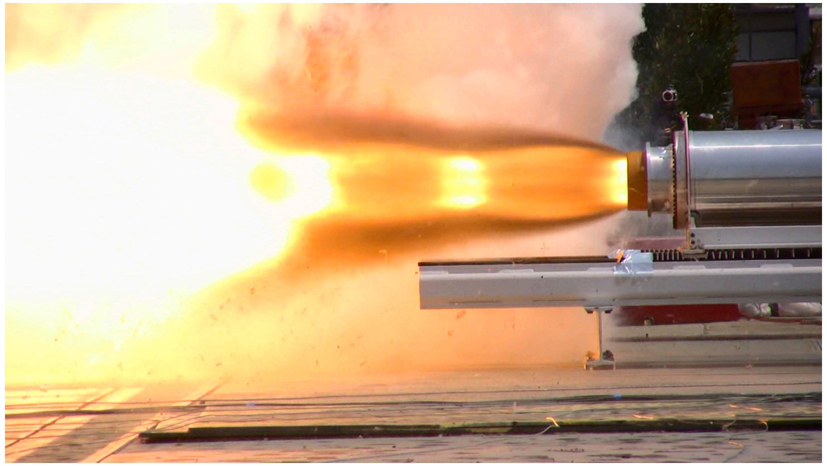
AERONAUTICS & ASTRONAUTICS

AA103 Air and Space Propulsion

Course Introduction



Instructor: Brian Cantwell – Department of Aeronautics and Astronautics, Stanford University, cantwell@stanford.edu

Course assistant: Matt Subrahmanyam – PhD student, Department of Aeronautics and Astronautics, Stanford University, msubrahm@stanford.edu

Course Reference Material

AA210 and 284 Texts: Course Readers for Fundamentals of Compressible Flow and Aircraft and Rocket Propulsion – These are my course notes and can be downloaded in pdf format from my web site.

Recommended References

Hill and Peterson, Mech. and Thermo. of Propulsion, 2nd Edition, Addison-Wesley

Kerrebrock, Aircraft Engines and Gas Turbines, MIT Press.
(Available online through Stanford Libraries)

Mattingly, Elements of Propulsion: Gas Turbines and Rockets, Mc Graw-Hill
(Available online through Stanford Libraries)

Oates, G., Aerotherm. of Gas Turbine and Rocket Propulsion-AIAA Education Series.
(Available online through Stanford Libraries)

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

Sutton, G.S. Rocket Propulsion Elements, Sixth Edition, Wiley Interscience.
(Available online through Stanford Libraries)

Whittle, Frank, Gas Turbine Aero-thermodynamics
(Available online through Stanford Libraries)

To access the full text put “Stanford University Libraries” into Google and enter the book title in the search box. Click on the resulting link.

TENTATIVE LIST OF TOPICS

THERMODYNAMICS, FORCES IN FLUIDS, GASDYNAMICS

1. Rocket and aircraft propulsion systems
2. Review of thermodynamics of ideal gases, enthalpy, isentropic flow, atmospheric models
3. Forces in fluids, viscosity, pressure, turbulence, drag
4. Drag due to lift, altitude for aircraft minimum drag
5. Introduction to gasdynamics I, stagnation enthalpy, stagnation temperature, stagnation pressure
6. Introduction to gasdynamics II, shock waves, nozzle flow

ROCKET PROPULSION

7. Conservation of momentum, generation of thrust
8. Rocket performance parameters
9. The rocket equation
10. Multistage launch systems
11. Liquid rocket propulsion, mission analysis, delta-V budgets
12. Combustion fundamentals
13. Solid rockets
14. Hybrid rockets

AIRBREATHING ENGINES

15. Performance parameters of aircraft engines
16. Ramjets, scramjets, Turbojets, turbofans
17. Turboprops, modern trends in aircraft design

ADVANCED CONCEPTS

18. Electric propulsion
19. Space exploration missions, the legends of Mars, missions to the outer planets
20. Nuclear propulsion
21. Space sailing, propulsion from light, interstellar flight

AA103 - Useful Web Site – fluid mechanics videos

This is my web site where the AA 103 course material can be found along with 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

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 – Software for Combustion Calculations

http://www.grc.nasa.gov/WWW/CEAWeb/ceaHome.htm

This is a NASA Glenn web site where you can download free software for the application CEA (CHEMICAL EQUILIBRIUM WITH APPLICATIONS). Click on the "request form" button and follow the instructions. The pc and linux object files should execute with no problem. The software for MacOSX requires that your Mac be equipped with the software developer tools "Xcode tools" that came with your system softwareCD and it requires the latest version of the free fortran compiler g77. The Glenn site provides instructions for getting the software running on the Mac and the website where g77 can be obtained. If your Mac is PowerPC based then the g77 for PowerPC compiler will work. The data used by CEA is the data compiled in the report by McBride et al. If you have an intel based Mac, the g77 for intel compiler will not compile the CEA fortran source codes. There are instructions developed by Jonah Zimmermann on my web site for installing CEA on an Intel-based Mac.

http://cearun.grc.nasa.gov

This is a web-based interface for running CEA. You need a browser with cookies enabled. The cookies go away when you close your browser. In addition you need two passwords both six letters, both lower case. The first is 'rocket', the second is 'combus'. Any problems with this site should be reported to michael.j.zehe@nasa.gov.

https://www.grc.nasa.gov/WWW/CEAWeb/ceaThermoBuild.htm

This link takes you to a site with an application called ThermoBuild which is an interactive tool that allows you to access the NASA Glenn thermodynamic database to select species and to obtain tables of thermodynamic properties and data sets for use in CEA, or any other computer program.

http://software.lpre.de/index.htm

This link takes you to a site with a downloadable (for a price) application called RPA - Tool for Rocket Propulsion Analysis. The capabilities are very similar to CEA. Downloads are available for a variety of Windows, Linux and Intel-based Mac based operating systems.

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.

Grading/Homework Policies

Homework - Homework problems will be assigned each tuesday and will be due the following tuesday. 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.

Term paper – Part of your final grade will be determined by your own creation in the form of a term paper on a topic related to propulsion. 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 propulsion. 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 June 4 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%

Rubric for grading the term paper

The term paper is worth 30 points.

Item 1 - 10 points - formatting and presentation
a) Is the report presented using an AIAA template or something comparable?
b) Grammar and spelling
c) Are footnotes, quotes and references used appropriately?
d) Are figures clear and understandable?

Item 2 - 20 points - technical content
a) Is the technical subject of the paper framed well, including the history, background and challenges of the field?
b) Is the current state-of-the -art described fully? What are the unresolved issues?
c) If the paper addresses a scientific/engineering problem quantitatively is the solution and/or conclusion reasonable?

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 AA103* includes a folder containing a bookmarked pdfs of the reference course texts for AA210 and AA283, 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 AA103 site on CANVAS.

Some suggested topics for your article.

1) History and development of bipropellant liquid rocket engines
2) The Cold War and the Space Race between the US and Soviet Union, first to orbit, first to the Moon
3) Comparative study of modern heavy lift launch systems
4) The commercial launch market; past, present and future
5) Alternative propulsion technologies for deep space exploration, electric, nuclear, photonic
6) Propulsion technologies supporting NASA and ESA roadmaps for solar system exploration
7) The development of the jet engine, its role in the dawn of high speed flight
8) Development of the turbofan engine, low to high bypass ratio
9) Impact of modern turbofan engines on aircraft noise
10) The role of CFD on modern turbofan design
11) Ramjets and scramjets, propulsion for extended hypersonic flight
12) The role of advanced materials in improving turbine performance, ceramic coatings

Suggested viewing

National Science Foundation
Fluid Mechanics Films

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

Fluid Dynamics of Drag, Parts I to IV

Fundamental Boundary Layers

Turbulence

Channel flow of a Compressible Fluid

Waves in Fluids

Pressure Fields and Fluid Acceleration

Some of the historical figures in rocket propulsion

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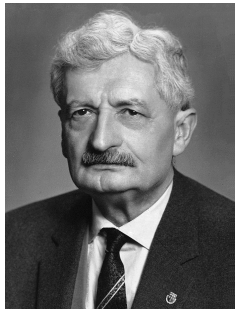
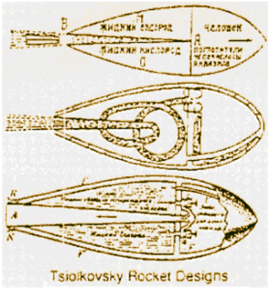
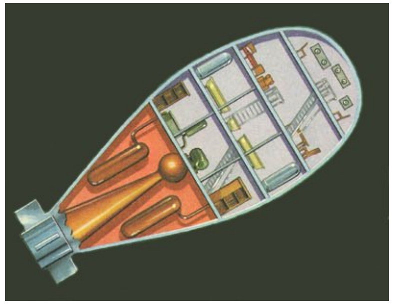
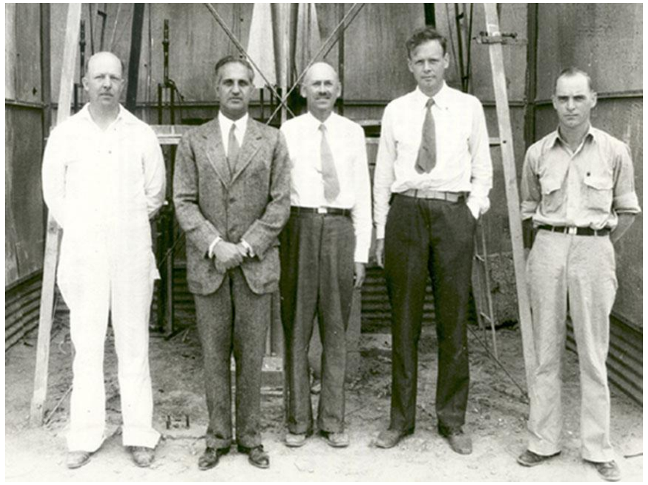


Hermann Oberth





Konstantin Tsiolkovsky



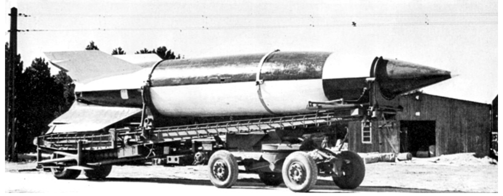
Pioneers - Early Rocket Scientists

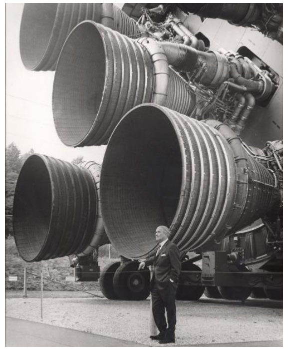
Standing in front of the rocket in the launch tower on Sept. 23, 1935, are (left to right) Albert Kisk, Robert H. Goddard's brother-in-law and machinist; Harry F. Guggenheim; Robert H. Goddard; Col. Charles A. Lindbergh; and N.T. Ljungquist, machinist. Lindbergh was an advocate for Goddard and his research. He helped secure a grant so Goddard could conduct research and launch rockets.

Robert Goddard

Sergie Korolev

Mary Sherman Morgan
"Rocket Girl"
Creator of Hydyne fuel





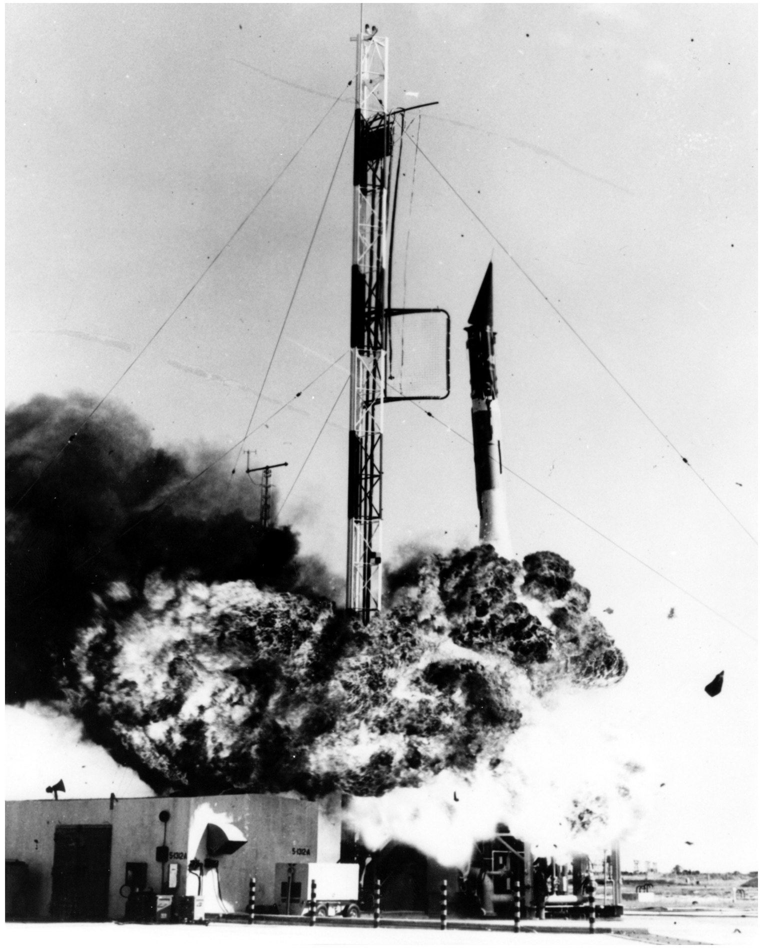
Wernher Von Braun

Katherine Johnson

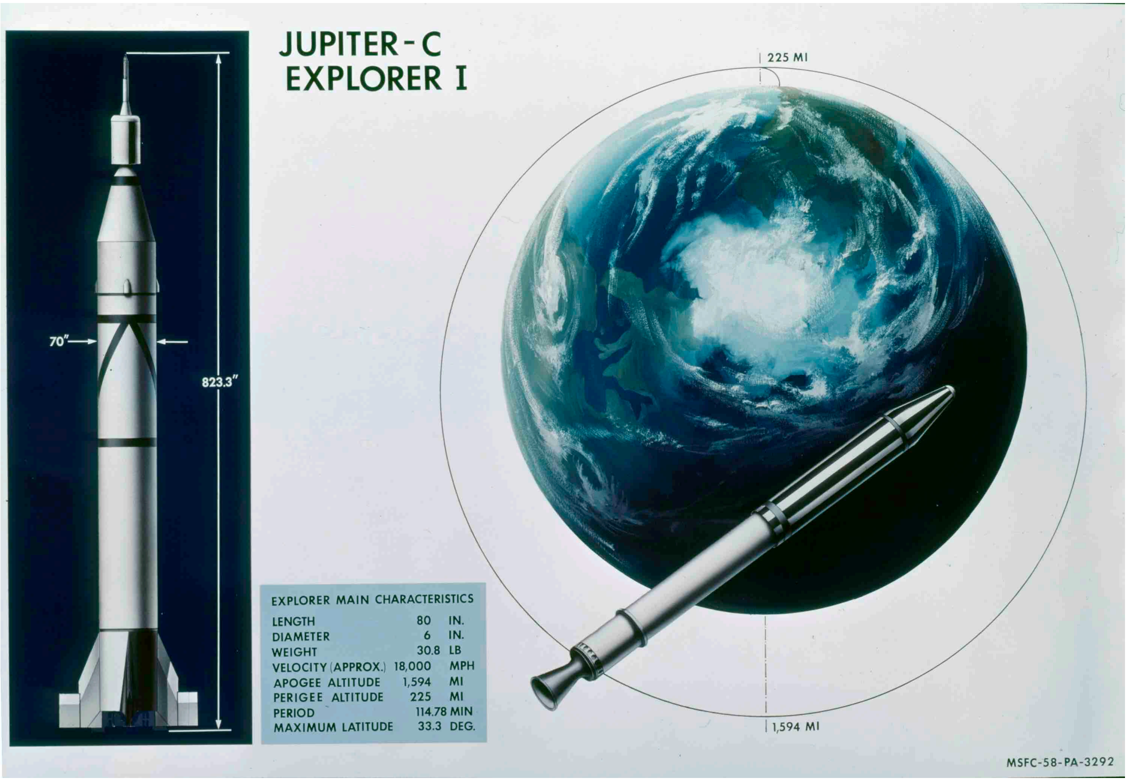
Melba Roy

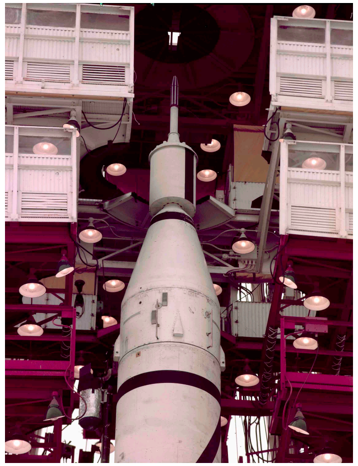
"Hidden Figures"

Vanguard



Explorer I





The story of Mary Sherman Morgan creator of Hydyne fuel and subject of the play "Rocket Girl"

https://www-chemistryworld-com.stanford.idm.oclc.org/culture/mary-sherman-morgan-the-best-kept-secret-in-the-space-race/4013329.article

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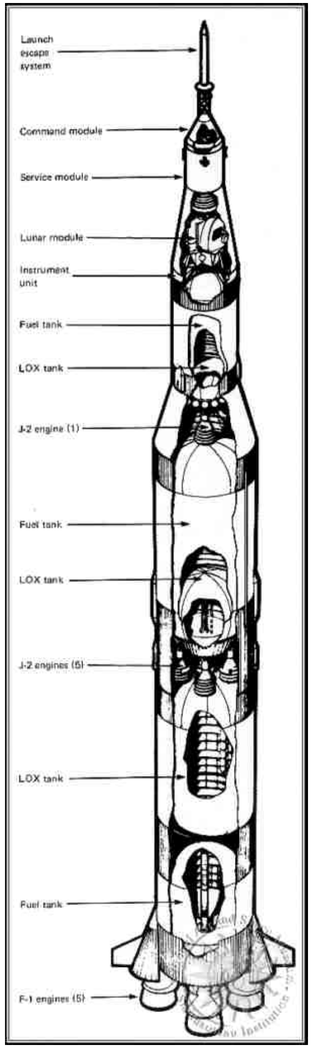
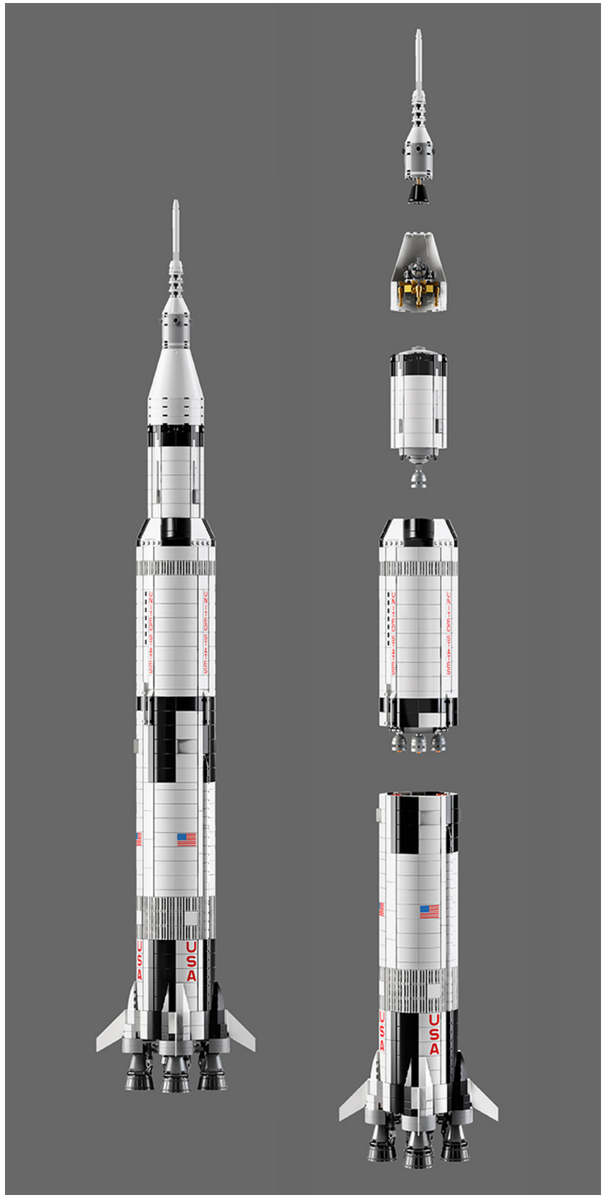
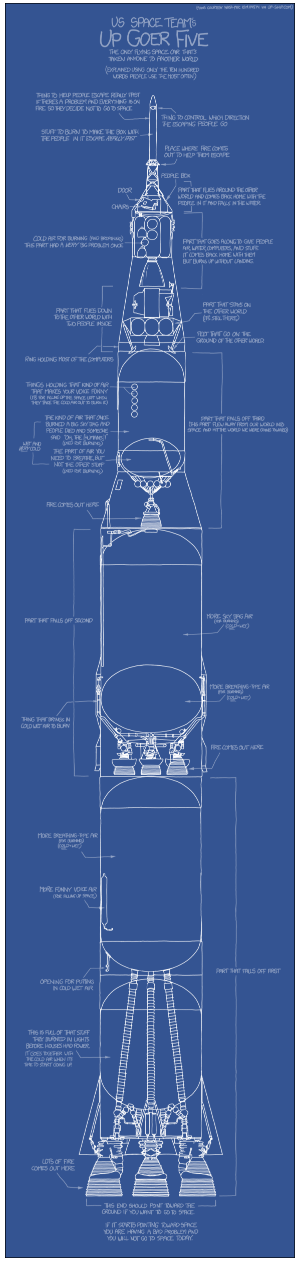
Saturn V







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All modern launch systems use conventional solid and/or liquid rocket propulsion systems

Liquid Main Engines

High performance and throttle-able but complex, expensive, explosion hazard.

Worldwide both liquid and solid rocket propulsion systems fail at a rate of about 2.5 per 100 launches. The US failure rate is about 1.5 per 100. No other industry accepts this rate of failure.

Reference: I-Shih Chang and Edmardo Joe Tomei of the Aerospace Corp. AIAA paper 2005-3793

Solid Rocket Booster

Mechanically simple but difficult to throttle, expensive, explosion hazard, environmental hazard.

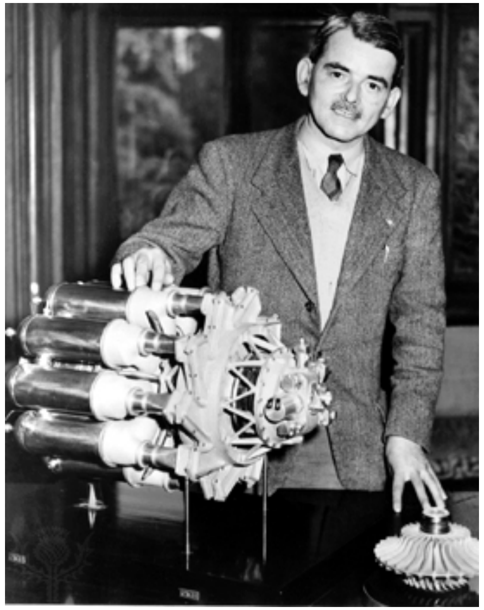
Oxidizer is Ammonium Perchlorate

There are Increasing concerns about groundwater contamination by perchlorates produced in the manufacture of solid rocket propellants. Even very low levels of contamination are correlated with reduced iodine intake in women.

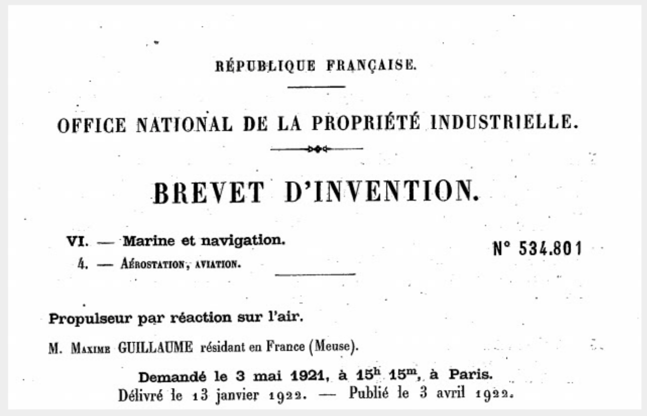
Reference: CDC Report doi:10.1289/ehp.9466 October 5, 2006. Available at http://dx.doi.org/

Some of the historical figures in jet propulsion

Inventors of the jet engine



Frank Whittle - UK



RÉPUBLIQUE FRANÇAISE.

OFFICE NATIONAL DE LA PROPRIÉTÉ INDUSTRIELLE.

BREVET D'INVENTION.

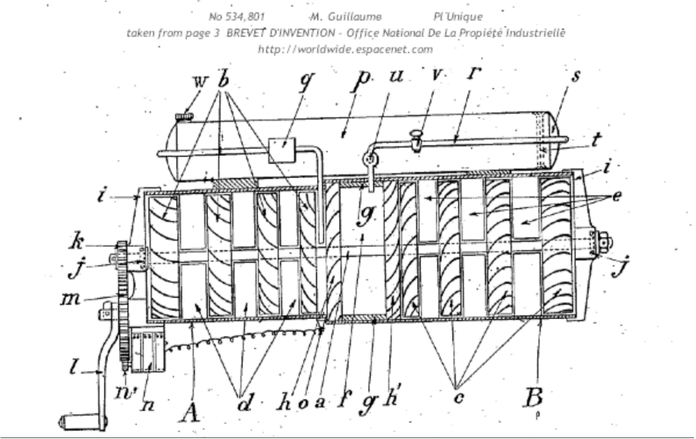
VI. — Marine et navigation.
4. — Aérostation, aviation.

N° 534.801

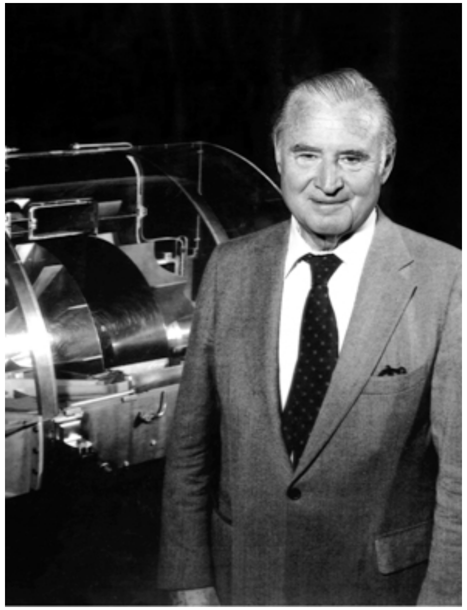
Propulseur par réaction sur l'air.

M. Maxime GUILLAUME résidant en France (Meuse).

Demandé le 3 mai 1921, à 15h 15m, à Paris.
Délivré le 13 janvier 1922. — Publié le 3 avril 1922.



Maxime Guillaume – France 1921 patent



Hans Von Ohain

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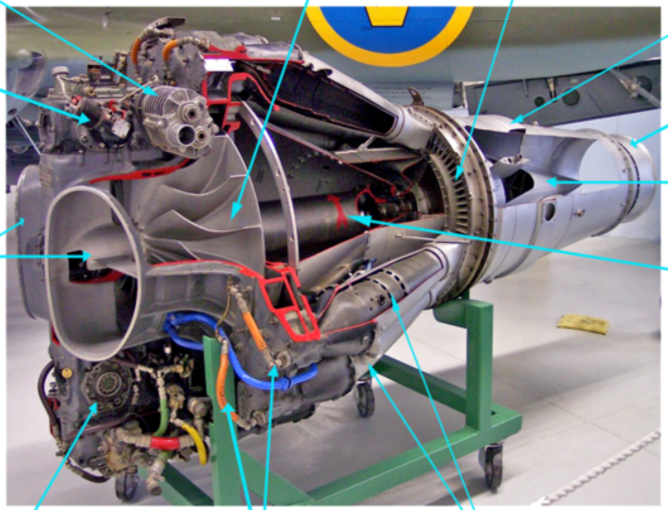
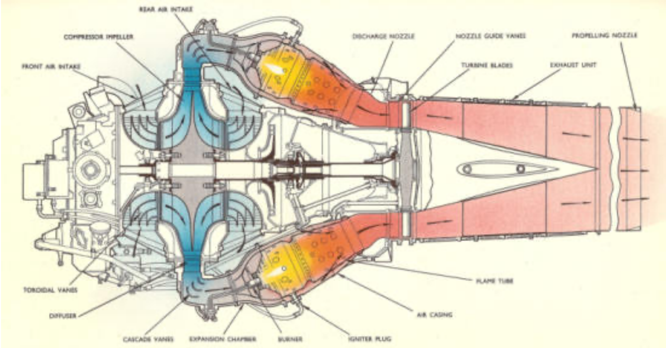
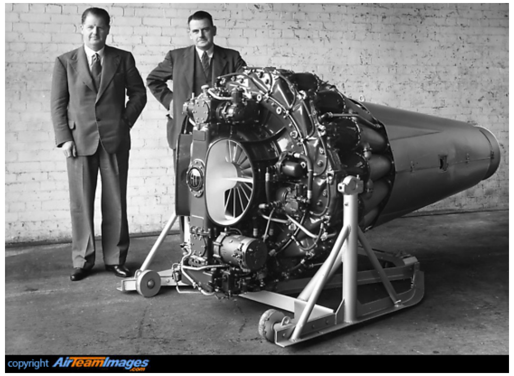
de Haviland Goblin with radial compressor





de Haviland Vampire



Frank Halford and Frank Whittle

Specifications (D.H Goblin II D.Gn 27) [edit]

Data from Smith[7][8]

General characteristics

- **Type:** Turbojet
- **Length:** 107 in (2,718 mm)
- **Diameter:** 50 in (1,270 mm)
- **Dry weight:** 1,550 lb (703 kg)

Components

- **Compressor:** Single sided, centrifugal flow
- **Combustors:** 16 chambers
- **Turbine:** Single stage axial flow
- **Fuel type:** Kerosene (R.D.E. / F / KER)
- **Oil system:** metered pressure spray at 50 psi (344.7 kPa) dry sump, 40 S.U. secs (13 cs) (Intavia 620) grade oil

Performance

- **Maximum thrust:** 3,000 lbf (13.34 kN) at 10,200 rpm at sea level
- **Overall pressure ratio:** 3.3:1
- **Air mass flow:** 60 lb (27.22 kg) /sec at 17,000 rpm
- **Turbine inlet temperature:** 1,472 °F (800 °C)
- **Fuel consumption:** 3,720 lb/hr (465 imp.gal/hr), (1,687 kg/h) or (2,114 l/h)
- **Specific fuel consumption:** 1.18 lb/lbf/hr (120.285 kg/kW/h)
- **Thrust-to-weight ratio:** 1.9 lbf/lb (0.0186 kN/kg)

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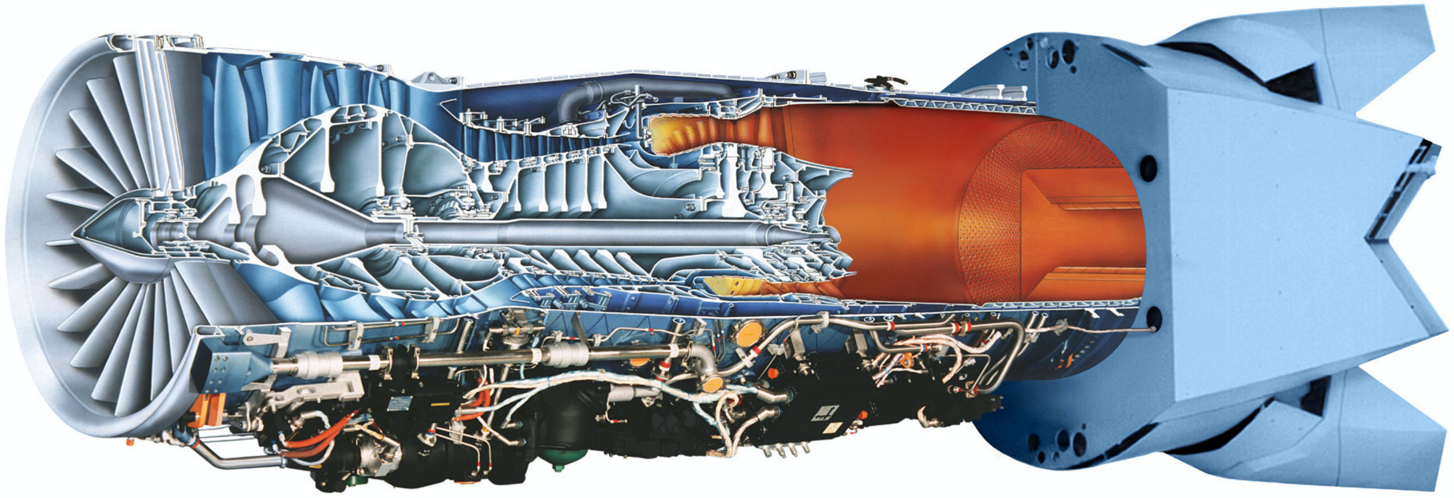
General Electric GE 90

PW4077 fan front view – Denver accident

GE90 fan blade
4ft long
50 lbs

GE90 fan front view

Pratt and Whitney F119



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

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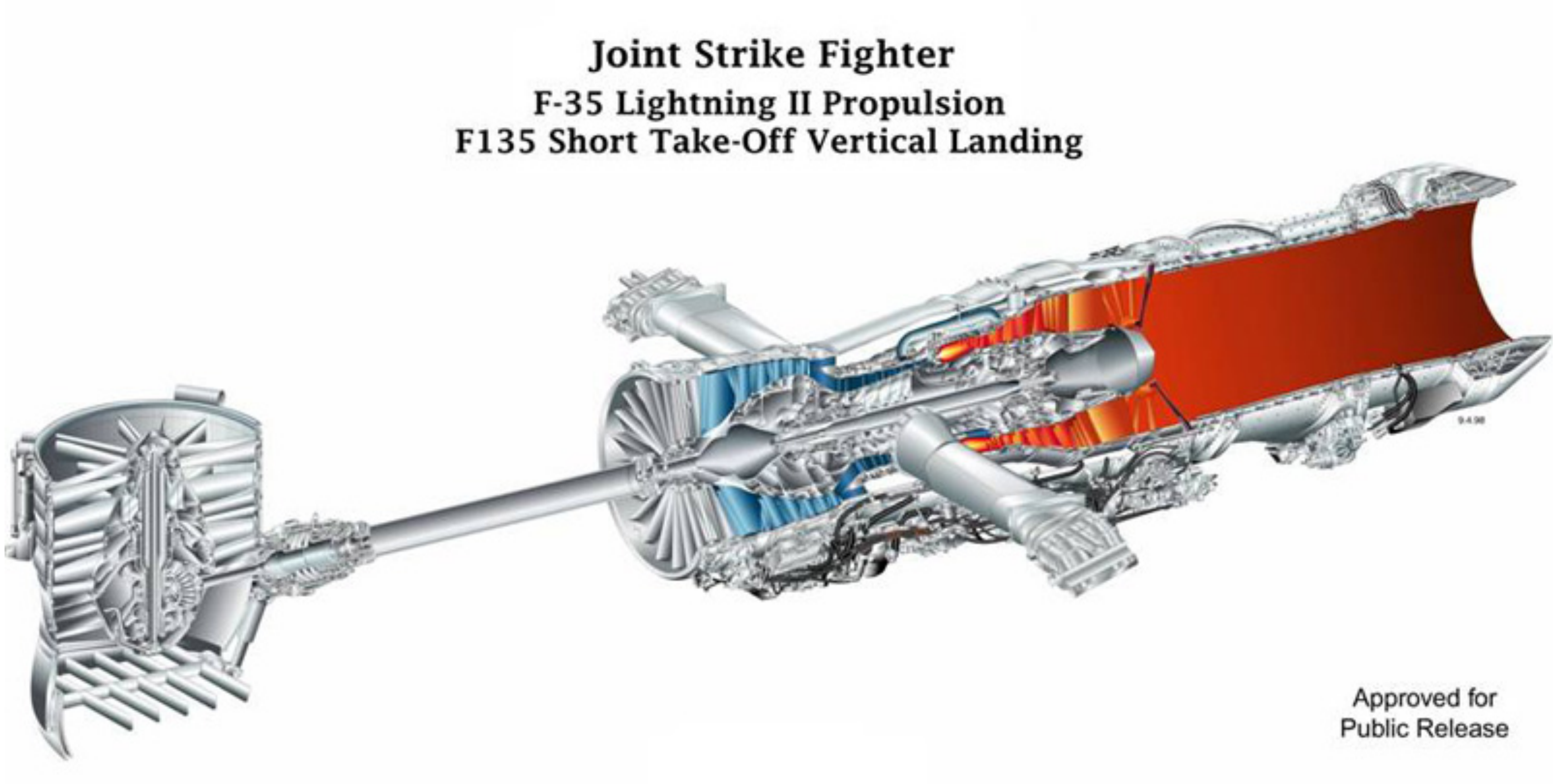
Pratt and Whitney F135



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