The Challenges of Hypersonic and Space Flight

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The Challenges of Hypersonic Flight

Overview

- Definition
- Background

- Propulsion Methods
- Aerodynamics
- Aero-thermal Effects
- Industrial Standards

Challenges

- Military
- Civil

Applications

Summary / Questions
Definition

“Almost everyone has their own definition of the term hypersonic. If we were to conduct something like a public opinion poll amongst those present and asked everyone to name a Mach number above which the flow of gas should properly be described as hypersonic there would be a majority of answers round about 5 or 6 but it would be quite possible for someone to advocate and defend numbers as small as three or as high as 12.”

P.L. Roe
Von Karman Institute, Belgium
January 1970
Definition

- Hypersonic flight is generally defined as high speed atmospheric flight where the dissociation of air becomes apparent, which is usually around Mach 5.

Dissociation

“In a hypersonic regime, diatomic or polyatomic begin to dissociate as they come into contact with the bow shock generated by the body.”

\[
\begin{align*}
O_2 & \rightarrow 2O \\
N_2 & \rightarrow 2N
\end{align*}
\]

\[
\begin{align*}
2000K & < T < 4000K \\
4000K & < T < 9000K
\end{align*}
\]
Hypersonic Challenges

Propulsion Methods

Source - http://cdn.c.photoshelter.com/img-get2/l00003dkge9n6sKo/fit=1000x750/machinate-mamal-visura-edit-019.jpg
Propulsion Methods

The Flaws of Conventional Rocket Engines

Expense

“The cost per pound of payload launched into geostationary transfer orbit is currently between $5,000 and $10,000.” (N.Taylor., 2008).

Propellant Storage
- Staging needed to achieve the required delta-V of most missions
- All propellants (including oxidizers) needed to be stored on board

Staging Requirement and Insufficient Reusability
- Despite recent efforts from SpaceX/Blue Origins, effective and sustainable is arguably still yet to be achieved.

Low Specific Impulse
- In comparison to other propulsion methods, the specific impulse of rocket engines is dismal.
Propulsion Methods
Low Specific Impulse

\[ I_{sp} = \frac{T}{\dot{W}_p} \]

Source - http://www.esa.int/Our_Activities/Launchers/Launch_vehicles/Ariane_5_ECA
Propulsion Methods

Alternative Propulsion Methods

**Scramjet**

(supersonic combusting **ramjet**) is a variant of a ramjet air-breathing jet engine in which combustion takes place in supersonic airflow.

**Air-Breathing Rocket Engine**

Developed by Reaction Engines over the last 20 years, **SABRE** (**Synergetic Air-Breathing Rocket Engine**) is a new engine class that can operate in both air-breathing and rocket modes.

Source - www.reactionengines.co.uk/images_library/
Hypersonic Challenges
Aerodynamics
Hypersonic flow is different from supersonic flow in that it is nonlinear, experiences different physical effects and the types of vehicles designed are very different.

**Notable Characteristics**

- Shock Boundary Layer Heating
- Large entropy layer and entropy gradients
- Viscous Interaction Phenomena on boundary layer
Aerodynamics
Waveriders

Maximum Achievable L/D Ratios of various hypersonic aircraft configurations:

Apollo Command Module - 0.6
Winged Body - 2.7
Truncated Cone - 3.7
Flat Delta Wing - 6.0
Waverider - 7-15

Source – The use of hypersonic Waveriders for aero-assisted orbital manoeuvring – M.Lewis
Aerodynamics

Waveriders

The Boeing X-51 (also known as X-51 WaveRider) is an unmanned scramjet demonstration aircraft for hypersonic flight testing.
Aerodynamics

Aero-Thermal Effects

The surface of a vehicle slows the flow velocity down for those molecules close to it by the effect of viscosity in the fluid.

Kinetic energy → Replaced by: Internal heating.

Even at relatively low hypersonic speeds, a Lockheed Martin Test Vehicle reached surface temperatures of nearly 2000 °C.
Aerodynamics Research Cost Implication

USAF X-15 Program - $600,000 (per flight)
NASA Hyper-X Program - $230 million
Lockheed SR-72 Concept Demonstrator Aircraft - $1 billion (target)

Source: http://www.globalsecurity.org/military/systems/aircraft/images/sr-72-image2.jpg
Propulsion Methods
Hypersonic/Space Industry
Standards

Component/Material Cost

Space Standards
- International standards for components
- Allows the benefits of a wide market

Source – Standards in the Space Industry, Mark Hempsell 2015
Propulsion Methods

Hypersonic/Space Industry Standards

- Standards define and create markets
- Bespoke space systems segment the market increasing costs.

Source – Standards in the Space Industry, Mark Hempsell 2015
Military

Primary applications are to use hypersonic capability aircraft and missiles to penetrate defended airspace.

- Aircraft
  - Immediate Surveillance
  - Time Critical Strike Aircraft

- Hypersonic Cruise Missiles
Applications

Commercial

- Routine, Affordable and Reusable Space Access
  - Satellite/Space craft launch and Repair
  - Delivery to space station
- Hypersonic Transport
  - Space Tourism?
Summary

Source - www.reactionengines.co.uk/images_library/