Testing and Analytical Challenges on the Path to Hypersonic Flight

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**Flight Regimes**

**Subsonic**
- Mach < 1
- Boeing 787 600 mph

**Sonic**
- Mach = 1
- Bell X-1 700 mph

**Supersonic**
- Mach > 1
- F-15 1650 mph

**Hypersonic**
- Mach > 5
- X-15 4520 mph
Seventy Years of Flight Experience

First hypersonic flight
WAC-Corporal 1948

X-15 - fastest manned powered flight: Mach 6.7

Galileo at Jupiter - fastest entry: Mach 65

X-43A – fastest aircraft: Mach 9.8

X-51A – Mach 5 209 seconds

ASSET winged Glider: Mach 6

Apollo 10 – fastest manned entry: Mach 37

UQ HyShot- H2 scramjet: Mach 7.6

Stardust – fastest Earth entry: Mach 43
Future Hypersonic Concepts

- Weapons
- Aircraft
- Space Launch
The U.S. Is Not Alone in the Field

- **China**: Major presence in research community
- **Russia**: Building on 1990's, Deputy PM focus
- **India**: BrahMos missile, ties to Russia
- **France**: LEA flight program, ties to Russia
- **Italy**: High temperature materials
- **Germany**: Academic research, flight
- **Japan**: Ground test facilities, access to space
- **Australia**: First scramjet flight, close U.S. partner
- **Iran**: Academic interests

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**ASIA DEFENSE**

**China Tests New Weapon Capable of Breaching US Missile Defense Systems**

Beijing has successfully tested a new hypersonic missile.

By Franz-Stefan Gady
April 28, 2016

Last week, China has yet again successfully tested the experimental DF-ZF (previously known as WU-14) hypersonic vehicle (HGV), Bill Gertz over at *The Washington Free Beacon*.

The test of the high-speed maneuvering warhead took place at the Zhuhai missile test center in central China’s Shanxi Province, some 800 miles (400 kilometers) southwest of Beijing.

The maneuvering glider, traveling at several thousand miles per hour, "is to an impact area in the western part of the country," Gertz

**MILITARY — APR 26, 2016**

**Russia's Putting Hypersonic Missiles on Its Battlecruisers**

The blisteringly fast Zircon missile will give old battlecruisers new striking power.
Papers Presented at the AIAA Hypersonics Conference
Hypersonics is Difficult

- Very high drag forces
- Surfaces get very hot
- Chemistry of air is important
- Standard engines don’t work
- “Fully integrated” vehicles complicate design

Testing challenges:
- Difficult to simulate conditions on the ground
- Difficult to simulate conditions with computers
- Flight test is expensive
Advancing The Field

- Analysis
- Computation
- Ground Test
- Flight Test

USAF Hypervelocity Tunnel 9
White Oak, MD

Involving government, industry, and academia
Analysis

- Seven decades of work
- Fundamentals not understood
- Physics very complicated
- Fluid equations not always valid
Advancing The Field

• Analysis

• Computation
  • Governing equations stiff
  • Continuum vs. rarefied
  • Inclusion of chemistry
  • Shock resolution
  • Navier-Stokes fluid equations not always valid

USAF Hypervelocity Tunnel 9
White Oak, MD
Advancing The Field

• Analysis

• Computation

• Ground Test
  • Aging/diminishing facilities
  • Aging workforce
  • Instrumentation is difficult at high temperatures, timescales
  • No single facility can replicate all flight conditions
  • Most facilities are transient

USAF Hypervelocity Tunnel 9
White Oak, MD
Advancing The Field

- Analysis
- Computation
- Ground Test

**Flight Test**

- Aging infrastructure
- EXPENSIVE!
- Risk Aversion

USAF Hypervelocity Tunnel 9
White Oak, MD
Reagan’s X-30 NASP 1986

As Conceived...

- duPONT SUPPLIED GOVERNMENT BASELINE DESIGN 1983
- 50,000 POUND TOGW CLASS
- EXISTING MATERIALS
  - NICKEL ALLOYS
  - GRAPHITE COMPOSITE TANK
  - CARBON LEADING EDGES

- SCRAMJET
  - PERFORMANCE SUPPORTED BY ANALYSIS AND SHOCK TUNNEL

- RAMJET
  - PERFORMANCE SUPPORTED BY HYPersonic Research ENGINE TEST DATA

- ACCELERATION ENGINE
  - U.S. PATENT
  - PERFORMANCE VERIFIED BY GASL AND PW TESTS

- DRAG LEVEL VERIFIED
  - NASA WIND TUNNEL TESTS
  - BOEING SUPPLIED MODEL
X-30 NASP Cancelled 1993

At program cancellation

~450,000 lbs TOGW
X-30 NASP Cancelled 1993

At program cancellation

An analysis failure after $1.2B was spent

~450,000 lbs TOGW
More Recent Setbacks

- **DARPA HTV-2**
  - $600M, 0 for 2 flights

- **ONR HyFly**
  - $153M, 0 for 3 flights

- **Army AHW**
  - $300M, 1 for 2 flights
  - Navy/CPS follow-on
**But Significant Successes**

HyShot  
Mach 7.6  30 July 2002

X-43 A  
Mach 6.8  27 Mar. 2004  
Mach 9.7  16 Nov. 2004

AHW/FE-1  
18 Nov. 2011  
30 October 2017
First Practical Airbreather: X-51

Flight program between May 2010 and May 2013, two successes
Four X-51 Flight Tests

- **Flight 1:** 5/26/10: \( M = 4.87 \)
  143 seconds powered: The “Kitty Hawk Moment”

- **Flight 2:** 6/13/11: Failure at ignition
  Resulted in refined fuel injection system

- **Flight 3:** 8/14/12: Fin failure at boost
  Loss unrelated to hypersonic technology

- **Flight 4:** 5/1/13: \( M = 5.10 \)
  209 seconds powered: The “Lindbergh Moment”
Continuing Fits and Starts

In the 1960’s we flew 3 X-15 aircraft on 199 flights, to maximum speed of Mach 6.7 with pilot Pete Knight

Since then:
• 1960’s Aerospace Plane
• NASP X-30
• U.S. Navy Hyfly
• DARPA HTV-2
• NASA Hybolt
• U.S. Army AHW

• NASA X-43 – 2 successful flights
• USAF X-51 – 2 successful flights
• USAF/Australia HIFiRE
Fits and Starts

In the 1960’s we flew 3 X-15 aircraft on 199 flights, to maximum speed of Mach 6.7 with pilot Pete Knight

Since then:

- 1960’s Aerospace Plane – cancelled
- NASP X-30 – cancelled
- U.S. Navy Hyfly – failed 3x, cancelled
- DARPA HTV-2 – failed 2x, discontinued
- NASA Hybolt – failed, cancelled
- U.S. Army AHW – successful flight, cancelled, but reborn as CPS FE-1
- NASA X-43 – 2 successful flights, discontinued
- USAF X-51 – 2 successful flights, discontinued
- USAF/Australia HIFiRE – successful, winding down
Current Status

• **Significant focus of this Administration**
  
  • "the U.S. has to be better than any other challengers in the hypersonics arena, and anyone who doesn’t see it that way, I have no time for you” USD(R&E) Michael Griffin, 6 March 2018

  • “…hypersonic gliders are threats both Russia and China are building now” Gen John Hyten, USSTRATCOM, 21 March 2018

• **Air Force, DARPA, Navy, Missile Defense Agency all involved, including planned flight tests.**

• **NASA had cut its spending, is now climbing back**

• **Focus on T&E, workforce, academia**