UK Hypersonic Glide Vehicle Concept and Performance Assessment

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Aims

• UK Hypersonic Glide Vehicle study
  – To understand the factors effecting the design and performance of a key emerging missile technology and highlight major challenges

• To illustrate potential vehicle performance – including maximum range and divert capability
Caveat

• This is purely a concept ‘What if’ study
  – To inform and develop expertise
  – To exercise tools and techniques in order to better understand the area
  – To present at this conference
  – Only open source information used to guide design and constraints of vehicle
  – Focused on weapon/ missile – not whole system
HGV Basics

• What is an HGV?
  – Vehicle that flies at speeds of anywhere from ~Mach 5 to ~Mach 20 using aerodynamic lift for the majority of its flight
  – Boosted up to speed using a Ballistic Missile booster before being deployed

• HGV Benefits
  – Flies below the radar horizon for much of its flight reducing warning times
  – Ambiguous targeting / flight plan making the defence’s task complex
  – High atmospheric flight (~30km to ~50km) - challenging for current Missile Defence systems
Dave’s HGV Concept Requirements

- Use – Tactical weapon system for use against high value/ well defended targets
- Warhead
  - ~350kg High Explosive (Tomahawk/ StormShadow class)
- Affordable – Use of existing technology and supporting systems/ infrastructure where possible
- Medium-Range ~ 2,500km – 3,000km
- Deployable into conflict theatres
- Survivable
  - High Speed > M5 for majority of flight
  - Manoeuvrable – High lateral accelerations >10g
- Accurate
  - <10m accuracy
HGV Concept Rough Specs – Iteration Zero!

- Launch Mass ~ 10 – 20 tonnes
- Length ~ 10m – 20m
- Diameter ~ 1.0 – 1.5m

- Doesn’t fit in standard Navy Vertical Launch tubes
  - E.g. Mk41 Tube – available diameter ≈ 0.64m
- Too heavy for RAF Fast Jets
  - E.g. Storm Shadow weighs ≈ 1,300kg
UK HGV Deployment Options

Land


Sea

http://www.defenceimagery.mod.uk

Air


https://www.amc.af.mil/News/Article-Display/Article/785964

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Vehicle Design Process

- Requirements
- Constraints

Design

Model/ Test

Assess

Iterate

Typically start with multiple parallel competing Designs
HGV Key Performance Drivers

- High Lift to Drag Ratio (L/ D)
- High Weight to Drag Ratio (Ballistic Coefficient)
- High Max Lift Capability (Manoeuvrability)
  - Lift Curve vs Angle of Attack (Alpha)
  - Maximum achievable Alpha
- Controllable airframe
  - Centre of Pressure vs Centre of Gravity (Static Margin)
  - Control Surfaces/ Systems
- Thermal management/ protection system
- Internal Volume available (Volume Efficiency)
- Many more…
HGV Options

Conical
- Peak Lift/ Drag ~ 2
- Good controllability

[Image: commons.wikimedia.org/w/index.php?curid=36840799]

Blended Body
- Peak Lift/ Drag ~ 4
- Challenging controllability

[Image: commons.wikimedia.org/w/index.php?curid=10160895]

Fuselage/ Delta Wing
- Peak Lift/ Drag ~ 3.5
- Good controllability

[Image: commons.wikimedia.org/w/index.php?curid=36840799]

Choice – Blended body concept
- High Risk/ High Reward option

[Image: commons.wikimedia.org/w/index.php?curid=10160895]
Key Characteristics

- Aim to achieve high Lift/ Drag ratio of 3.5 – 5
  - Use of small nose radius (only ~ 10 mm)
- Mass ≈ 900 kg (Sufficient for our 350kg warhead)
- Materials - Use of Existing materials already used in Re-entry Vehicles
  - Carbon-Carbon nose-tip and control surfaces, Carbon or Silica Phenolic Heatshield
- Navigation using GPS+ Inertial Nav + Synthetic Aperture Radar (SAR)
- Direct insertion from boost into glide – No Reaction Control System or Post Boost Vehicle
  - Reduces cost/ complexity
Dstl CAD Representation

CAD created to feed aerodynamic prediction codes (CFD)

<table>
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<tr>
<th>Length (m)</th>
<th>Base Width (m)</th>
<th>Base Height (m)</th>
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<tr>
<td>3.61</td>
<td>1.22</td>
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Aerodynamic Results

Pressure field (Pa):
M7.5, 5° Alpha,
30km Altitude

Lift

Drag

Lift / Drag
Booster Design

- Two stage solid rocket
- Protective shroud around HGV
- Launch from commercial vehicle
  - Boeing-747

<table>
<thead>
<tr>
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<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>All Up</th>
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<tr>
<td>Diameter (m)</td>
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<tr>
<td>Mass (kg)</td>
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<td>3,000</td>
<td>1,300</td>
<td>16,300</td>
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</table>
HGV Performance/ Flight Constraints

- Max (possible) Lift acceleration contours shown for HGV
  - Limited manoeuvre above ~40km
  - High-g manoeuvres possible at lower altitudes
- Constraints
  - Nose-tip (Stagnation) heat limit = 6 MW/m²
  - Dynamic pressure limit (mechanical load) = 900 k.Pa
  - Aim to maintain impact speed > Mach 2 to evade intercept
Trajectory Modelling Results - Nominal Trajectory

- Trajectories generated using Dstl TABSys model
  - Pseudo Six DoF
  - Oblate Rotating Earth (WGS-84)
- HGV flown with Bank To Turn steering
- HGV limited to 20° Alpha (assumed control limit)
Nominal Trajectory (2)

- **Glide angle of attack**
  - ~5-10°
  - Optimum L/D region
- **50° Bank turns during glide**
  - Make’s trajectory harder to predict
  - Bleeds some speed to stay within terminal constraints
- **Steep & Lateral ~15g dive in terminal phase**
Max Range/ Divert Capability

- Trajectories flown due East along equator
- Re-target system 1,600km into flight
- Find max reach whilst maintaining impact speed >M2 (680 m/s)
- Max Down Range 3,200km
- Max Cross Range 600km
- Can change heading by ~90°
Max Divert Capability (2)

- Divert start 2,000km
- Divert start 2,400km
- Footprint from 1,600km
- Footprint from 2,000km
- Footprint from 2,400km

- Footprint shrinks the later the divert is initiated
  - Less time and energy to divert
Key Challenges

• Solid Rocket Motors
  – UK doesn’t make large solid rockets - would need assistance from international partners

• Hypersonic Aerodynamics/ Controllability
  – Need high quality predictions across a broad range of high Mach numbers (M2 – 13)
  – Poor aero understanding massively reduces ability to control vehicle
  – Need access to appropriate wind tunnels

• Heating
  – Need good understanding of aerothermal environment/ management
  – Manufacture and integration of Thermal Protection System materials

• Cost!
Conclusions

- Given the postulated requirements - Preferred option for the HGV concept is air launched
- UK HGV assessed as ‘possible’ but significant challenges would include
  - Acquiring suitable rocket booster technology
  - Aerodynamic prediction and control systems
  - Thermal Protection System
- Weapon would be highly capable in terms of range, speed and divert capability
  - But whole system operation not considered
- Most importantly – Dstl is developing the tools and expertise to model/ understand this new class of system
Questions?