FOBS and SWERVE
As Exemplified by Some Recent Chinese Tests?

by

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URL (live link): https://rlg.fas.org
Please search in any browser with the green text, e.g., site:rlg.fas.org "fractional orbit"

An introduction to technical discussion
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(Typo corrected at p. 6.8)

I give a simple introduction to this topic, to encourage discussion by other participants.

I view the recent tests that have attracted so much attention as a significant demonstration based on decades-old technology of fractional orbit bombardment systems, teamed with a modern evolution of the maneuvering re-entry vehicle – MaRV. This newly relevant capability has now been effectively demonstrated by China in flights that began in China and ended with "targets" in China, having flown round the world, using rocket propulsion to LEO, followed by planned de-orbit of a hypersonic glide vehicle able to maneuver for complex precision attack on a target. A precursor mission may have occurred on September 4, 2020, but without impact on a target.

China has fielded many shorter-range boost/glide vehicles, BGV, which, perforce, are hypersonic boost/glide vehicles -- HBGV -- and has now put that technology together with a long-range ballistic delivery vehicle, as did the Sandia Corporation in the 1980s in its SWERVE program-- Sandia Winged Energetic Reentry Vehicle Experiment. The text of the 2008 NAS Report,

"U.S. Conventional Prompt Global Strike" Issues for 2008 and Beyond (2008)[1]

mentioned such capabilities, as described below. In the recent tests, the reentry system could have been launched to very low orbit, not intended to complete a full 40,000 km circuit of the Earth (40 megameters – 40 Mm) but de-orbited for reentry as it reached China almost 90 minutes later.

Remaining with the technology for the moment, and leaving implications for the discussion, I'll try to illustrate by some of my own publications and observations over the years some simple approaches to understanding the HGV dynamics, such as loss of speed caused by maneuver.

I think my first open publication of some relevance is the March 1968 paper with Hans Bethe, which has long been available on the Garwin Archive. In that paper,

"Anti-Ballistic-Missile Systems," by R.L. Garwin and H.A. Bethe in *Scientific American*, Vol. 218, No. 3, pp. 21-31, March 1968.

one of the figure captions notes: "… *On a fractional orbit trajectory the missile would stay so close to the earth that it would not cross the radar horizon until it was about 1,400 kilometers, or about three minutes, away*." and the text points out, "*Worse, the possibility that reentry vehicles can be built to maneuver makes it dangerous to ignore objects even 100 kilometers off target."*

In the series, *Foreign Relations of the United States,* maintained by the U.S. Department of State,

[1] This is a live link. Ctrl-LeftClick on the blue text to be able to download a free copy of the PDF to your computer for convenient searching, printing, etc.

https://history.state.gov/historicaldocuments/frus1969-76v34/d14

are many formerly SECRET references to potential Soviet FOBS, and also to U.S. preparations for dealing with such a threat, e.g.,

> *b.* ***Description***
>
> *The Sentinel system as designed would be rearranged to provide for the above objectives. Complete radar coverage against ICBMs, SLBMs, and FOBS would be provided, and the MSR/Spartan sites would be moved away from large cities to locations that provide the best protection of our bomber bases against surprise attack and SLBMs.*

HERE IS HOW I LOOK AT BOOST/GLIDE VEHICLES AT HYPERSONIC SPEEDS.

For details, I point to Appendix G, *"The Why and How of Boost-Glide Systems"* of the 2008 NAS *"Prompt Global Strike"*report. As part of my contribution as an author, I wrote Appendix G, which has a simple model of an HBGV, especially of its glide and maneuver. On the assumption of a constant L/D (lift-to drag ratio), one can estimate ranges, speed loss during turns, and the like. Appendix G begins with this paragraph,

> *"Given the prominence of the boost-glide technology in some of the options under consideration in this report, it is useful to include an appendix explaining semi-quantitatively what the technology can and cannot accomplish, its relation to the fractional orbit bombardment systems (FOBSs) technology discussed during the 1960s and 1970s, and some of the technical challenges involved. Another issue is the extent to which such vehicles can be expected to defeat "garden--variety" and advanced air defenses.*
>
> *"A boost-glide vehicle (BGV), or "lifting body" without propulsion, can be used to extend the range of a ballistic-missile payload beyond the purely ballistic range. It can also be used for out-of-plane or "dogleg" maneuvers to avoid overflight of certain areas or to allow the dropping of initial rocket stages into the sea or into another body of water not under the ballistic path. The space shuttle on reentry is an example of a hypersonic lifting body."*

China's tests may be the first to link a FOBS to a MaRV in the form of an HGV; it is clearly an outstanding example.

[From Appendix G, p. 215 (page 234 of the PDF)]

"A simple terminal maneuver for a ballistic missile will allow it to deny sanctuary to structures and locations shielded by a near-vertical bluff. At intermediate range this can require a 45º maneuver that with an L/D = 2.2 would (according to the example following Equation G-2) result in a reduction of warhead speed to 0.6998 of the initial speed. If performed at 10-g transverse acceleration (0.098 km/s^2), the maneuver could take on the order of 30 s; an alternative would be to have a high-drag RV to greatly reduce speed to, say, Mach 3 (1 km/s), so that a 45º maneuver could be accomplished in a few seconds (slowdown to turn). The simple kinematic considerations of this appendix indicate the value of the engineering design of a variable-geometry RV, and the competition between the longer-term 'better' and the earlier and perhaps 'good enough.'"

Speed loss by an HGV due to maneuver by an angle Δθ,

U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond

APPENDIX G 209

$$(V_f/V_i) = exp((D/L) \times \Delta\theta) = exp -((1/2.2) \times (\pi/4)), \quad \text{(Eq. G-2)}$$

where V_i is the vehicle initial speed at the beginning of the transition, and V_f is the speed at the end of the transition and the beginning of the glide portion of flight.

(At this point of Appendix G, I used an L/D = 2.2. Elsewhere an L/D = 2.6)

HOW FAR CAN A FOBS-LAUNCHED HGV FLY? The approximate answer is trivial to estimate.

Assume a hypothetical HBGV with a lift-to-drag ratio L/D = 2.6 at initial cruise altitude, which, for a velocity of 2.75 km/s (about Mach 8.1 relative to a standard sound speed of 340 m/s), might be 30 km. This does not represent any existing HBGV, so far as I know.

In the spirit of Appendix G, the approximate range can be calculated trivially from the observation that for a given L/D, the lift, L, is equal to the weight multiplied by the acceleration of gravity (g= 0.0098 km/second-squared), and the Drag therefore gives a deceleration V-dot = g/(L/D) , so the HBGV will reach zero speed in the atmosphere in a time Tg = Vo x (L/D)/g and will traverse a distance Tg x Vo/2 in that time.

The resulting HGV glide distance, Dg = Vo^2 x (L/D)/2g = 7.56 x 2.6/(2x0.0098) = 1003 km for an HGV starting from Mach 8.1 (2.75 km/s). Ordinary ICBM reentry vehicles sustain an axial peak deceleration of about 60 g, so a simple "variable geometry" reentry from FOBS orbit can be achieved by deployment of an air brake or parachute-equivalent that slows the HGV to the desired speed or Mach number and is then jettisoned, leaving a clean HGV at, say, Mach 8.1

Greater "range extension" is achieved at glide speeds above 3 km/s on a round Earth.

Appendix G expands the consequences of this longest-range glide, maintaining the appropriate, declining, altitude for the same L/D and "angle of attack" (nose-up angle) as the vehicle loses kinetic energy and speed and must therefore glide at lower altitude and greater air density. Appendix G provides also analytic insight into inevitable speed loss resulting from maneuver, not of importance in estimating straight range extension.

At a speed of Mach 8 within the atmosphere, the vehicle is not stealthy to infrared sensors, which might be in orbit, on balloons, or on small high-altitude drones. The airborne IR sensor need only view a narrow angular range above the horizon for the most distant HBGV threat. A recent paper[2] from which I show several figures, illustrates the considerations of Appendix G with actual integration of the equations of motion, and also considers the detection of the HGV in normal flight by detection of the intense infrared radiation emitted by the lifting body in level flight, intensified in maneuver.

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[2] "Modeling the Performance of Hypersonic Boost-Glide Missiles", by Cameron L. Tracy and David Wright, *Science and Global Security*, https://scienceandglobalsecurity.org/archive/sgs28tracy.pdf

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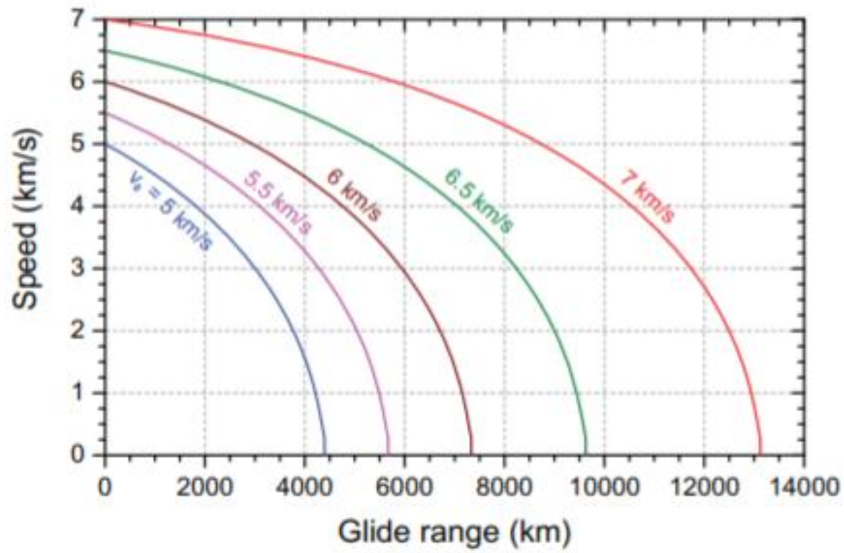

Figure 3. Hypersonic vehicle speed as a function of glide range for various initial glide speeds, illustrating how atmospheric drag slows the vehicle throughout the glide phase.

Fig. 3 shows a residual range from *any* of these curves of about 1300 km from a glide speed of 2.75 km/s, and Fig. 4 an altitude of some 32 km – not far from the 2008 estimates of Appendix G.

As demonstrated both in Appendix G and in Ref. 2, the great range extension at initial speeds greater than 6 km/s comes from the contribution of "centrifugal-force" to reducing the aerodynamic lift required for constant-altitude flight in the atmosphere of a centrifugal earth, so that at orbital speed, no aerodynamic lift is required. ~~For orbital speed of 8 km/~~s[3] For slightly sub-orbital speed of 7 km/s, only 23% of the weight is borne by aerodynamic lift.

[3] Error corrected verbally in presentation. Now documented here.

As a result, the maneuvering capability of an HGV is impaired at high speeds, and quickest maneuver might be achieved by a complex maneuver to quickly reduce altitude by as much as 8 km, make a turn there, and regain some of the altitude later, all of which costs kinetic energy according to an analogue of Eq. G-2.

10 C. L. TRACY AND D. WRIGHT

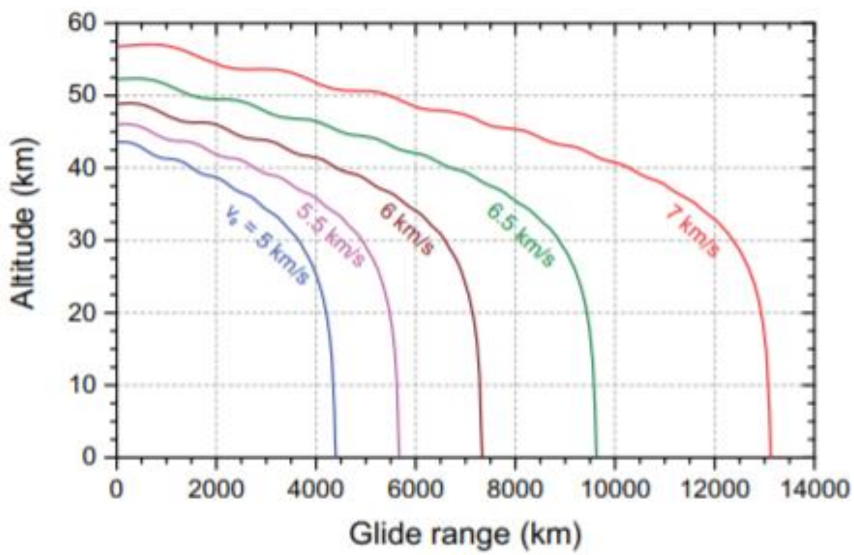

Figure 4. Hypersonic vehicle altitude as a function of glide range for various initial speeds. As drag slows the vehicle, the lift it generates (at a constant angle of attack) decreases. The glider therefore drops to lower altitude, at which increased atmospheric density yields a greater lift force for the same velocity. Minor oscillations about the equilibrium flight altitude, called phugoid motion, result from the dynamics of this process. These could be damped by active control of the vehicle.

Although the Press comments on the difficulty of detecting HGV by defensive radars, there is almost no comment of the intense infrared signal radiated by the HGV – the subject of Figure 13 of the Tracy/Wright paper. This IR signal can readily be detected by small-aperture imaging sensors on small drone aircraft, on balloons or satellites, and also serves as an intense beacon for a homing interceptor.

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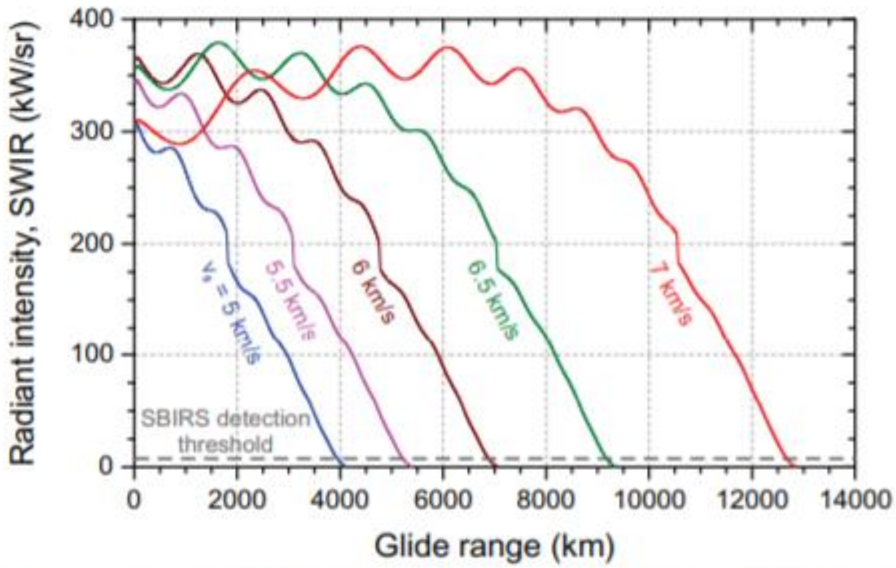

Figure 13. Glider overhead radiant intensity in the SWIR band (1.4–3.0 µm) as a function of glide time for various initial speeds. In all cases glider radiance remains above the approximate 6 kW/sr SBIRS detection threshold for essentially the entire glide phase. Oscillations arise from the altitude variation shown in Figure 4. The discontinuities seen at $I \approx 200$ kW/sr are caused by the switch from Equation (9) to Equation (10) when the vehicle slows to $v \leq 4$ km/s.

To give some indication of the origin of the intense infrared radiation I provide Fig. 14 from Chinese authors analyzing a nominal HGV[4] in level flight.

[4] Liu et al., "Infrared Radiation Characteristics of a Hypersonic Vehicle Under Time-Varying Angles of Attack,"(2019) p. 869

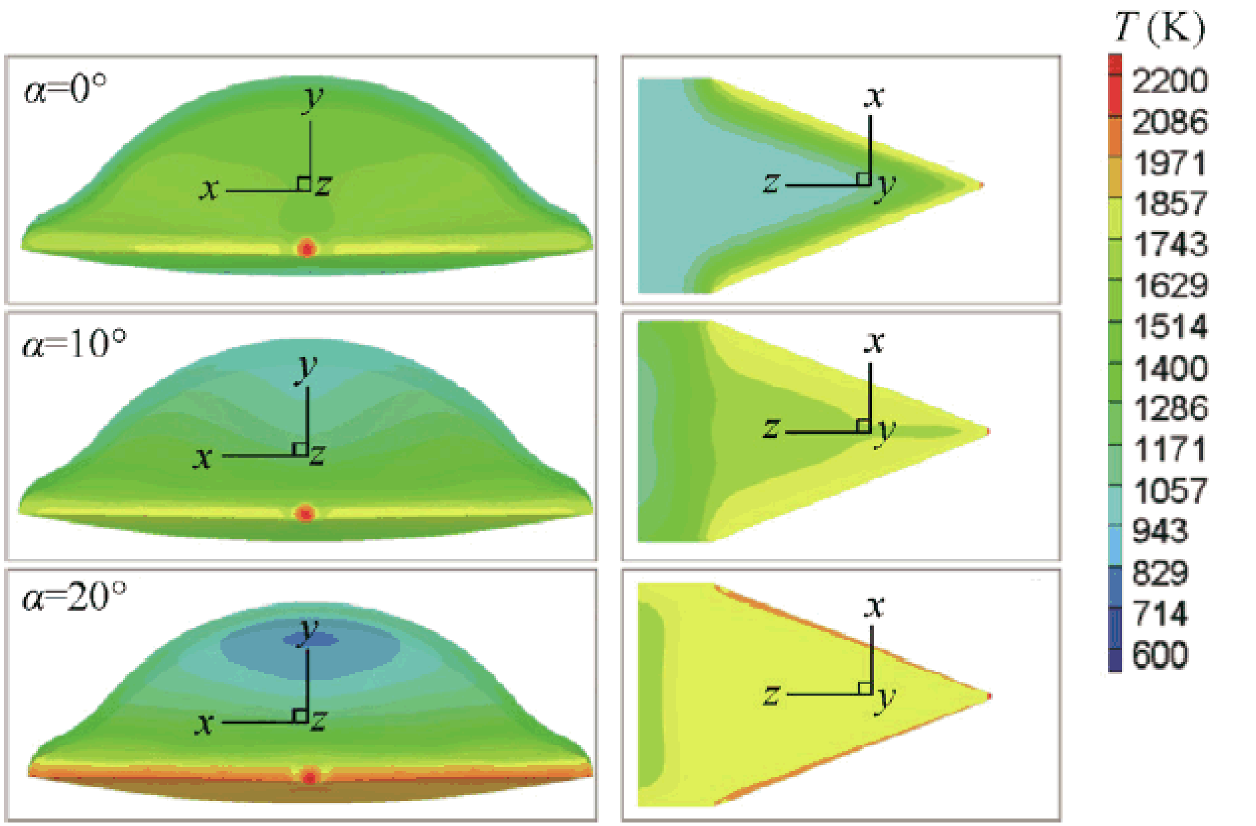

Fig. 14 Surface temperatures at different angles of attack.

The views on the left are from the front of the vehicle, and those on the right are looking up from below.

THANK YOU FOR YOUR ATTENTION. I look forward to another introductory presentation and to the discussion by participants.