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| N202-107 | TITLE: Radio Communication with Hypersonic Aerial Vehicle |

RT&L FOCUS AREA(S): Hypersonics, Network Command, Control and Communications

TECHNOLOGY AREA(S): Electronics

OBJECTIVE: Develop an effective radio frequency communication system solution for communicating through the plasma sheath surrounding a hypersonic aerial vehicle. ITAR: The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with section 3.5 of the Announcement. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws.

DESCRIPTION: When a vehicle is traveling at hypersonic speed through the atmosphere, a plasma sheath envelops the aerial vehicle because of the ionization and dissociation of the atmosphere surrounding the vehicle [Refs 1-3]. The plasma sheath prevents radio communication, telemetry, and Global Positioning System (GPS) signal reception for navigation [Ref 4]. This radio “blackout” period poses a serious challenge that hinders the use of hypersonic aerial vehicles for future naval applications. Development of an appropriate mitigation method to allow uninterrupted aerial vehicle to control station and control station to vehicle communications through the plasma sheath during the entire hypersonic flight is required. Develop and demonstrate an effective blackout mitigation solution that enables continuous communication between a stationary or mobile platform and a hypersonic vehicle during hypersonic flight. Many mitigation techniques have been proposed, including but not limited to, aerodynamic shaping, magnetic windows, and liquid injection. Any innovative solution capable of eliminating any radio frequency communication disruptions due to the plasma sheath [Ref 4] will be considered.

PHASE I: Develop concepts for communication directly through the plasma sheath of a hypersonic aerial vehicle in the frequency band between 1.1 to 5.6 GHz for error-free GPS and radio communication for a separation distance up to 20,000 km. Perform modeling and simulation of the proposed concepts in the hypersonic environment to validate their feasibility. Complete design tradeoffs to predict the performance, size, weight, and power requirement of the most promising design. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop a hardware prototype based on the Phase I design. Demonstrate the prototype’s radio frequency communication capability and characterize its communication performance in a terrestrial plasma chamber to establish proof of concept.

PHASE III: Fully develop and transition the radio frequency communication system based on the final design from Phase II for Naval applications in the areas of reliable and error-free radio communication with hypersonic aerial vehicles. The commercial sector would benefit from this research and development in the area of radio communication with hypersonic re-entry space vehicles.

REFERENCES:

1) 1. Chadwick, K.M., Boyer, D.W. and Andre, S.S. “Plasma and Flowfield Induced Effects on Hypervelocity Reentry Vehicles for L-Band Irradiation at Near Broadside Aspect Angles.” 27th AIAA Plasmadynamics and Lasers Conference, New Orleans, LA, June 1996. https://arc.aiaa.org/doi/10.2514/6.1996-2322 2. Norris, G. “Plasma Puzzle: Radio Frequency-Blocking Sheath Presents a Hurdle to Hypersonic Flight.” Aviation Week & Space Technology, March 2009, p. 58. 3. Blottner, F.G. “Viscous Shock Layer at the Stagnation Point with Nonequilibrium Air Chemistry.” AIAA Journal, vol. 7, no. 12, December 1969, pp. 2281-2288. https://arc.aiaa.org/doi/abs/10.2514/3.5528?journalCode=aiaaj 4. Hartunian, R.A. et al. “Implication and Mitigation of Radio Frequency Blackout during Reentry of Reusable Launch Vehicles.” AIAA Atmospheric Flight Mechanics Conference, Hilton Head, South Carolina, Aug 20-23, 2007

KEYWORDS: Radio Frequency, Communication, Plasma, Hypersonic, Black-Out, GPS

TPOC USERS: None

We need a small hole ( low density plasma region) in the high conductivity plasma sheath to couple to the outside, that is used for a plasma antenna.  I have an idea.  I read the first chapter of an aerodynamics book once and I remember something (note- a little knowledge is dangerous).   The velocity of the air always goes to zero (stagnation) on the leading perpendicular edge of a wing (or any surface).  Suppose we make a small cup (e.g. 1-2 cm diameter by 1-2 cm deep, probably out of a ceramic) in the nose of the missile.  There would be zero velocity high pressure air in this small cup, with no air friction inside to make plasma.  The edge of the cup would generate intense plasma (good for a PA), but possibly with a plasma hole in front. This is assuming that the mean free path is small compared to the size of the cup, which should true in this high pressure air.  We put a small probe, loop, fractal antenna, etc. in this stagnant air cup that couples to the plasma ring that is the leading edge of the plasma sheath antenna.

    Air against air friction in front of the cup might generate enough plasma to plug the hole.  If we can show that the plasma density is low enough to not plug the hole then the major physics problem is solved.  We might inject SF6 gas in the cup to suppress plasma and improve the hole.  A strong magnet might help too.  If successful to make a plasma hole the rest is engineering the coupling to the plasma sheath, calculating radiation patterns, measuring noise figure, etc.   A longer probe that protrudes beyond the cup, through the plasma hole, might work too and would also be a plasma antenna as it would be covered in a plasma sheath.

     We need access to a simulation code  that can handle this aerodynamic-plasma problem.  Apparently they exist as Ive seen simulations of plasma around a re-entry vehicle (maybe you sent to me- send again).   Id be surprised if it can also handle the E&M problems but if we can show a plasma hole then we have a possible solution.

    How would we physically test this theory in Phase 2?  Would need access to a hypersonic wind tunnel.  NASA has them, and also AEDC only a few miles from me.

    This is an interesting problem but we would not be able to publish, or talk about, our great solution.

This would not work in a "terrestrial plasma chamber" as required in Phase II, as it requires fast moving neutral air to make the plasma hole, and to generate the intense plasma at the edge of the hole for the plasma antenna  A plasma jet would not work.  I think it would require hypersonic neutral air to the same velocities that generates the sheath in the first place.  Im not sure that neutral air can be generated in a hypersonic wind tunnel.  The whole volume may be plasma.

     So how to test?   Maybe only on a hypersonic missile.  That would cost $M's per test.  The military would spend that kind of money but the simulations would have to be convincingly accurate.

     Perhaps a lower velocity (supersonic) easier to ionize neutral gas would work for scaled tests.  Cesium and sodium have ionization energies of less than a third of oxygen, nitrogen and argon (air).  An ion engine with neutralized gas?

It turns out that ion engines have been around a long time, can be easily bought, utilize Cesium, and have a neutralized high velocity gas output!

    So not that difficult for an experiment!!

It turns out that ion engines have been made, and used in deep space missions, using Xenon which has an ionization energy similar to Argon (a component of air), but very heavy compared to air (aerodynamics would be very different).

    Argon is very similar to air.  So we buy/make an Argon ion engine.

Or even an oxygen/nitrogen/air ion engine.  With a test facility like that (ion engine in a large glass chamber with a large vacuum pump) we could easily experiment with a lot of ideas.

    I think we could do this.

I'd start at 6 GHz first (or even higher to show the principle of a plasma hole) and work down.  1.1 GHz would be the most difficult as it would require an almost zero density hole.

   Another thought.  If we use a surface wave launcher in the cup, then as the plasma decayed the wave would probably launch into free space.

Another idea:  Inject cesium into the rocket exhaust and use the long plasma trail, 100's of meters long, as a giant plasma antenna.  This might be better for the low freq GPS.

    They wont like it because a large part of the trajectory is free fall.