New technologies overcoming Gaps, Obstacles, and Technological Challenges in Hypersonic Applications

The era of hypersonic flight had arrived. The large driving force behind hypersonic research emerges from the need to reduce cost to space and faster global transportation for both military and civilian purposes. Countries are developing future hypersonic Spaceplanes , enabling intercontinental travel at very high speeds, that could cut the journey times from the UK to Australia from the current duration of around 20 hours to as little as two hours.

They shall also provide revolutionary military capability like prompt global strike, launch on demand, satellite servicing and antisatellite missions. The Military of United States, Russia and other countries are developing sixth-generation fighters that may be capable of achieving hypersonic speeds. There is global race to develop Hypersonic Missiles such as US HTV-2 and X-51, Chinese WU-14, Russian Yu-71, that travel at least five times the speed of sound (Mach 5) or more. These vehicles can fly along the edge of the space and can glide and maneuver to the targets.

The Hypersonic International Flight Research Experimentation (HIFiRE) program is a hypersonic flight test program executed by the United States AFRL and the Australian DSTO.1,2 Its purpose is to develop and validate technologies critical to next generation hypersonic aerospace systems. Candidate technology areas include, but are not limited to, propulsion,

propulsion-airframe integration, aerodynamics and aerothermodynamics, high temperature materials and structures, thermal management strategies, guidance, navigation, and control, sensors, and system components.

Challenges of Hypersonic Flight

Hypersonic revolution blends the twin stream of space and aeronautics research into a confluence. Halon gives a good description of how the hypersonic flight realm traverses a complex environment as, “ranging from high in the stratosphere to operations into and cross the demarcation of spaceflight, where the laws of aerodynamics cease to apply and the laws of ballistic, Keplerian trajectories, and Hohmann transfers take over.”

Designing a HV often appears daunting and difficult. Numerous attempts have been made in the past with many successes and failures. Only a few programs ever became operational vehicles. Two hurdles which essentially link into a co-hurdle are the extreme hypersonic flight conditions and hypersonic mission objectives.

For example, mission objectives include space access and global transportation. Space access not only requires the attainment of very high vehicle velocities but also must traverse the varying atmospheric layers to reach an orbital path. Global access missions also benefit from hypersonic speeds but do not require the large orbital altitudes. Therefore, HV systems provide the desired speeds but demand complexity.

NASA categorizes speeds between Mach 5 (6125 kilometers per hour) to 10 Machs as Hypersonic. Aerodynamic drag roughly scales with the square of airspeed; double the speed, and the drag goes up four times. Streamlined shapes have partly overcome this problem, but the solution then, as it is now, is more thrust. However, hypersonic speeds speeds are frequently limited not by available thrust or drag, but by the heat buildup caused by atmospheric friction.

When moving at such velocity the heat generated by air and gas in the atmosphere is extremely hot and can have a serious impact on an aircraft or projectile’s structural integrity. That is because the temperatures hitting the aircraft can reach anywhere from 2,000 to 3,000 °C. The structural problems are primarily caused by processes called oxidation and ablation. This is the when extremely hot air and gas remove surface layers from the metallic materials of the aircraft or object traveling at such high speeds.

The hypersonic regime introduces a number of flow attributes such as: extremely high turbulence, pressure, temperature, density, vorticity, and energy, thin shock layers, viscous interactions, entropy layers, changes in vehicle stability and control; and physical-chemical gas changes such as ionization, dissociation, equilibrium effects, and other molecular phenomena.

Studies have uncovered some of the lingering elements that continue to plague vehicle aerodynamics, viz. Limited capabilities of ground testing facilities for the simulation of hypersonic flows. Other challenges are the limited aerothermodynamic flight test database. The stringent access restrictions to existing databases and the limited verification efforts of computational fluid dynamics (CFD) aerothermodynamic codes against ground test data.

The need for improved, cost effective instrumentation hardware and interpretive techniques seems to be essential for advancing hypersonic flight technology. Furthermore, collaboration through CFD, ground testing, and analytical modeling will greatly assist in data interpretation.

In addition to database creation, fundamental fluid dynamics analysis of hypersonic flow motions constitutes another essential aspect of aerodynamic research. Specific topics include boundary layer transition in hypersonic flight and boundary layer effects around vehicles that directly impact surface heating.

In addition, the hypersonic designer must remain aware of the other flow regimes since a hypersonic vehicle will have to transition from rest to the designed hypersonic flight Mach number and transition throughout the various characteristics of the atmosphere. The need to operate in several flight regimes can lead to unforeseen aerodynamic conditions, especially in air-breathing propulsion systems. While a certain shape or lift-to-drag (L/D) configuration may be efficient at low hypersonic Mach numbers (say 4-8), it may exhibit a severe degradation in aerodynamic performance outside this envelope. This would be the case, for example, during the takeoff and landing phases of a space plane.

Other relevant areas that fall under this category consist of control surfaces such as fins, elevons, tailerons, flaperons, etc. The technological factors associated with these control surfaces include:

- The requirement to employ thin structures that reduce drag.
- The need to overcome the thermal protection barriers imposed by the thin surface requirement
- The need to design for longer life cycles and mitigate oxidation.
- The need to integrate both hot and cold structures (e.g., in actuators).

Technology Breakthroughs for Hypersonic Flight

Lockheed is working on a number of innovative technologies to enable long-duration, maneuverable, hypersonic flight, company CEO Marillyn Hewson told reporters. These breakthroughs include new thermal protection systems, innovative aerodynamic shapes, navigation guidance and control improvements, and long-range communication capabilities, she said.

Ultra High Temperature Materials

Hypersonic platforms are ultimately limited by the capacities of the materials available.

The Airframe of Hypersonic Vehicles like SR-72 (Lockheed Martin reconnaissance drone with strike capability) , must include advanced materials to stay intact while subjected to high dynamic loads, and to withstand the extreme aerodynamic heating of hypersonic flight, as air friction alone would melt conventional materials, writes Dora E. Musielak, Ph.D. University of Texas at Arlington.

There is growing interest in developing ultrahigh temperature materials (UHTM). These are materials with temperature capability greater than 1650 °C and able to withstand extreme erosive / corrosive environments. UHTM should possess high strength at high temperatures, oxidation resistance, ablation resistance, thermal shock resistance.

These materials will be required for hypersonic air breathing vehicles, hyper speed cruise missile, hypersonic aircrafts, re-usable launch vehicles to protect leading edges and nose cones that experience very high temperatures (> 2000 °C). Refractory diboride composites like ZrB2, HfB2 etc and multilayer coatings of HfC, SiC on C-C composites are most promising UHTM candidates.

Scramjet Technologies

Solid, liquid, and hybrid rockets, in conjunction with turbine, ramjet, and scramjet engines, embody some of the available propulsion concepts that are capable of hypersonic flight. Two branches emerge as the dominant hypersonic engine mechanisms, the rocket motor and the air-breather.

Ramjets become less efficient at higher Mach numbers due to the ramjet’s subsonic combustion. Scramjets potentially hold the capability to realize the objective of a long range airliner at hypersonic speeds and, complement the traditional rocket in space launchers.

The Air Force, in collaboration with DARPA, NASA, and the Navy, is developing scramjet—supersonic combustion ramjet—technologies that may contribute to the long-range strike mission in the future. In this type of vehicle, the engine gets the oxygen it needs for combustion from the atmosphere passing through the vehicle, instead of from a tank onboard. This eliminates the need for heavy reservoir oxygen tanks, and makes the vehicle far smaller, lighter, and faster than a conventional rocket.

3D Printing Key to Hypersonic Weapons: Raytheon

“But when it comes to making hypersonic systems, which require exotic materials and strangely shaped components that conventional methods can’t handle, 3D printing may be essential,” says Raytheon’s head of advanced missile systems, Tom Bussing. “Growing” parts in a 3D printer allows you to make much more complex shapes than the traditional process – used since before the Bronze Age – of casting the basic shape in a mold and then cutting it to the final desired form.

He gave example of design of cooling system for hypersonic jet moving through the air, at Mach 5-plus, that generate extreme friction and heating of hypersonic air vehicle. “But if you want cooling vents in a traditionally manufactured component, you have to drill a bunch of holes in it (and hope you didn’t weaken it too much). If you want cooling vents in a 3D-printed component, you just program the printer to make a shape that has openings in it from the start. What’s more, if you drill out your cooling channels, they’re going to be pretty much straight; but if you grow the channels in a 3D printer, they can be helixes or other elaborate shapes that vent heat much more efficiently.“If it’s more efficient, it means you can make it smaller, [with] less cooling,” said Bussing. “[It] lasts longer, flies farther.”

Tactical Boost-Glide is the approach already tested by both Russia and China: a rocket motor boosts the missile up to hypersonic speed, after which it glides to the target. The goal is to “skip” off the atmosphere like a skipping stone over water, allowing it to go vast distances at extreme speeds. Getting this to work requires progress in aerodynamics, stability, and controls, as well as materials, Bussing said. Getting this to work requires progress in aerodynamics, stability, and controls, as well as materials, Bussing said. 3D printing can help in all these areas

An “air-breathing” hypersonic vehicle, by contrast, flies under its own jet power the whole way. This approach allows less range than boost-glide but greater maneuverability. Air-breathers can also be significantly smaller. A rocket has to carry large amounts of oxidizer to burn its fuel. A jet just sucks in oxygen from the atmosphere. But normal jets don’t have to suck in air moving at Mach 5-plus. A jet that works at hypersonic speeds will require some breakthroughs – and, again, 3D printing can help grow the exotic components.

Orbital and Nasa 3D printed scramjet engine part survives critical wind tunnel tests

Orbital ATK has successfully tested a 3D printed hypersonic engine combustor at Nasa Langley Research Centre in Virginia. The breakthrough could lead to planes that can travel 3,425mph (5,500km/h) – 4.5 times the speed of sound.

The combustor was created through a manufacturing process known as powder bed fusion (PBF). In this, a layer of metal alloy powder is printed and a laser fuses areas of together based on the pattern fed into the machine by a software program.

As each layer is fused, a second is printed until the final product is complete. Any additional powder is removed and the product is polished. The combustor was successfully put through a range of hypersonic flight conditions over the course of 20 days, including one of the longest duration propulsion wind tunnel tests ever recorded.

Orbital says one of the most challenging parts of the propulsion system, scramjet combustion. This houses and maintains stable combustion within an extremely volatile environment.

References and Resources also include:

https://www.nextbigfuture.com/2017/07/breakthrough-high-temperature-ceramic-for-hypersonic-planes-and-much-more.html

http://trace.tennessee.edu/cgi/viewcontent.cgi?article=2315&context=utk_gradthes