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MP-IDSA Commentary

# India's Scramjet Propulsion Programme

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## Summary

Scramjet combustion tests over the past two years indicate a technological transition towards endurance-oriented propulsion engineering.

## Introduction

The Hyderabad-based Defence Research and Development Laboratory (DRDL) has carried out a sequence of increasingly complex scramjet combustor tests over the past two years that collectively indicate a gradual transition from experimental combustion validation towards sustained propulsion engineering. Each successive test appears to have focused on a different engineering challenge: ignition stability, endurance, scaling complexity and long-duration thermal survivability. This progression is particularly important because scramjet development globally has historically struggled not with achieving initial ignition, but with sustaining stable combustion under prolonged hypersonic conditions while simultaneously managing extreme thermal loads.

The recent tests suggest that India's scramjet programme is moving into a more demanding engineering phase centred on endurance, cooling, structural survivability and propulsion integration. Although these achievements do not imply the existence of operational hypersonic cruise missiles, they do indicate the steady development of an indigenous technological base in advanced propulsion, high-temperature materials, fuels and testing infrastructure.

## Scramjet Propulsion and Challenges

SCRAMJET (Supersonic Combustion Ramjet) engines are required to accelerate airborne vehicles beyond the speed of sound.[1] India's interest in scramjet propulsion predates the recent media attention surrounding scramjet testing. Public references to indigenous scramjet ambitions can be traced back to the late 2000s, when former DRDO chief V.K. Saraswat discussed work underway on the Hypersonic Technology Demonstrator Vehicle (HSTDV) programme.[2] At that time, Saraswat noted that DRDO intended to demonstrate the performance of a scramjet engine at altitudes between 15 and 20 kilometres, signalling India's early interest in air-breathing hypersonic propulsion systems.[3]

Unlike conventional rocket propulsion, a scramjet engine uses atmospheric oxygen for combustion rather than onboard oxidisers.[4] This reduces the vehicle weight and allows sustained hypersonic flight over longer durations. However, the engineering complexity involved is immense. In a scramjet combustor, the incoming airflow

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[1] D. Preller and M. Smart, "**Scramjet Powered Accelerator for Reusable Technology Advancement**", *Proceedings of the 12th Reinventing Space Conference*, Springer, Cham, 27 December 2016.

[2] T.S. Subramanian, "**Focus DRDO Missile Shield**", *Frontline*, Vol. 26, No. 3, 13 February 2009.

[3] Ibid.

[4] Nishant Agarwal, "**Hypersonic Airbreathing Propulsion**", Department of Aerospace Engineering Sciences, University of Colorado Boulder.

continues to move at supersonic speeds, leaving only milliseconds for fuel injection, mixing, ignition and combustion.[5] Maintaining a stable flame under such conditions has often been described as comparable to "keeping a candle lit in a hurricane".[6]

Thermal management of the vehicle presents an equally severe challenge. During a hypersonic flight, the vehicle undergoes intense aerodynamic heating that can structurally degrade the external surfaces, internal systems and microelectronics circuitry on board.[7] Consequently, successful scramjet development depends not only on successful and sustained combustion, but also on advanced designs of its cooling systems, materials science and high-temperature structural engineering.

Over the years, DRDL has gradually built a wider ecosystem supporting scramjet development. This includes computational fluid dynamics (CFD) modelling and simulation tools, thermal barrier coatings, endothermic fuels, specialised ground-testing infrastructure, solid and liquid propellant test facilities, the base for precision manufacturing of gyroscopes, accelerometers, and actuators for missile control and guidance, and a foundry for manufacturing light materials such as magnesium.[8]

The CFD models and simulation tools enable engineers to study the complex aerodynamics and supersonic combustion processes inside the scramjet engine.[9] They also help optimise fuel injection and flame stabilisation, predict thermal loads, and evaluate engine performance under different flight conditions before conducting expensive ground or flight tests.[10] The TBC, or thermal barrier coating, protects the outer vehicle skin and engine components from the extreme temperatures generated during hypersonic flight.[11]

According to official statements, the coatings developed jointly by DRDL and Department of Science and Technology laboratories are capable of operating beyond the melting point of steel.[12] The endothermic fuel has also been developed

5 F. Falempin, "**Ramjet and Dual Mode Operation**", in *Advances on Propulsion Technology for High-Speed Aircraft*, Educational Notes RTO-EN-AVT-150, Paper 7, pp. 7-1–7-36, 2008.

6 "**DRDO Conducts Scramjet Engine Ground Test**", Press Information Bureau, Ministry of Defence, Government of India, 21 January 2025.

7 Ajay Kumar, J. Philip Drummond, Charles R. McClinton and James L. Hunt, "**Research in Hypersonic Airbreathing Propulsion at the NASA Langley Research Center**", Presented at the Fifteenth International Symposium on Airbreathing Engines Bangalore, India, 2–7 September 2001.

8 T.S. Subramanian, "**Focus DRDO Missile Shield**", no. 2; "**DRDO Conducts Scramjet Engine Ground Test**", no. 6.

9 Ryan J. Clark and S.O. Bade Shreshtha, "**A Review of Numerical Simulation and Modeling of Combustion in Scramjets**", *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, Vol. 229, No. 5, 2015.

10 Santosh K. Gogoluthu, "**A Systematic Literature Review Based on Different Fuel Injection Strategies Used in Scramjet Combustors**", *Heat Transfer—Asian Res.*, Vol. 48, pp. 3657–3681, 2019.

11 J. Sankaer, "**Thermal Barrier Coatings (Tbc) for High Temperature (Ht) Applications**", Glimpses of Engineering and Technology in the Modern World, 5 February 2021.

12 Snehesh Alex Philip, "**Boost for India as DRDO Successfully Conducts Scramjet Engine Ground Test for Hypersonic Missiles**", *The Print*, 21 January 2025.

indigenously by the DRDL.[13] It fulfils two purposes: first, since it is endothermic, it absorbs some of the heat generated inside the engine, thereby stabilising the engine temperature; and second, since the fuel absorbs heat, it ignites rapidly during combustion.

In strategic terms, scramjet propulsion research can generate competencies applicable not only to India's cruise missile systems, but also to advanced aerospace engineering more broadly. The DRDL's work in partnership with industry and research institutions reflects the growing integration of India's defence-industrial and scientific ecosystem in advanced propulsion research. The development of specialised facilities such as the Scramjet Connect Pipe Test (SCPT) Facility has further enabled progressive validation of these technologies under controlled ground-test conditions, reducing technological risk before eventual flight testing.[14]

The establishment and use of facilities such as the SCPT rig reduces dependence on foreign countries for technology transfer, as well as cost-intensive testing in foreign labs. It also enables iterative domestic experimentation, which is an essential requirement for any long-term hypersonic research effort. The sequence of successive combustor tests at sub-scale and full-scale thus reflects the maturation of this broader ecosystem. In future, this ecosystem will become the base for India's indigenous Hypersonic Cruise Missile Development Programme.

## The Progression of India's Recent Scramjet Tests

The most significant aspect of India's recent scramjet programme is not any single test, but the cumulative progression visible. Rather than repeating similar demonstrations, each test appears to have addressed a distinct engineering objective.

**Table 1. Recent Progression of India's Scramjet Combustor Tests**

| Test | Duration | Hardware Configuration | Assessed Objective |
|---|---|---|---|
| January 2025 | 120 seconds[15] | Active-cooled combustor | Ignition and flame stability |
| April 2025 | 1000 seconds[16] | Subscale combustor | Long-duration endurance validation |

[13] Ibid.

[14] "**India's Hypersonic Technology Gets Boost with DRDO's 1,000-Second Scramjet Test**", *Newsonair.gov*, 25 April 2025.

[15] "**DRDO Conducts Scramjet Engine Ground Test**", no. 6.

[16] "**DRDO Achieves Significant Milestone in Scramjet Engine Development Conducts Active Cooled Scramjet Subscale Combustor Ground Testing for over 1,000 seconds**", Press Information Bureau, Ministry of Defence, Government of India, 25 April 2025.

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|---|---|---|---|
| January 2026 | 720 seconds+[17] | Full-scale actively cooled combustor | Scaling and thermal survivability |
| May 2026 | 1200 seconds+[18] | Full-scale combustor | Sustained endurance validation |

The January 2025 test was India's first publicly acknowledged demonstration of an actively cooled scramjet combustor. Active cooling enables longer hypersonic flight durations than passive cooling.[19] The official statements highlighted several key advances associated with the trial that are jointly developed by DRDL and industry partners. The combustor reportedly incorporated innovative flame stabilisation techniques designed to maintain combustion under airflow speeds exceeding 1.5 km per second.[20]

However, the hardware configuration visible in images released after the test suggests that the primary objective was combustion validation. The combustor geometry appears relatively compact, with limited cooling infrastructure and dense instrumentation concentrated around the test section. The set-up resembled an experimental combustion rig intended to study ignition behaviour, flame holding and combustion stability under controlled conditions.

The April 2025 subscale combustor test marks an upgrade from the previous test, as the combustor sustained operation for more than 1000 seconds at the SCPT facility in Hyderabad.[21] More importantly, the hardware itself appeared noticeably more complex. Compared to the January 2025 configuration, the subscale combustor shows denser plumbing networks, more elaborate fuel-distribution arrangements and visibly enhanced cooling architecture. Sustaining stable supersonic combustion for over 1000 seconds is challenging because prolonged operation dramatically increases structural and thermal stress within the combustor. In engine testing, the duration is not merely a numerical milestone; it directly reflects progress in cooling effectiveness, flame stability, and the overall structural resilience.

[17] "**DRDO Conducts Successful Ground Test of Full Scale Actively Cooled Long Duration Scramjet Engine for Hypersonic Missile Programme**", Press Information Bureau, Ministry of Defence, Government of India, 9 January 2026.

[18] "**Major Breakthrough in Hypersonic Missile Development: DRDO Conducts Extensive Long-duration Test of Actively Cooled Full Scale Scramjet Combustor**", Press Information Bureau, Ministry of Defence, Government of India, 9 May 2026.

[19] Snehesh Alex Philip, "**Boost for India as DRDO Successfully Conducts Scramjet Engine Ground Test for Hypersonic Missiles**", no. 12.

[20] "**DRDO Conducts Scramjet Engine Ground Test**", no. 6.

[21] "**DRDO Achieves Significant Milestone in Scramjet Engine Development Conducts Active Cooled Scramjet Subscale Combustor Ground Testing for over 1,000 seconds**", no. 16.

The January 2026 test brought another important transition in terms of scale. Although the runtime was shorter than the earlier 1000-second subscale test, the engineering significance of the trial lay in the transition from subscale hardware to a full-scale combustor configuration. The test images reveal a much larger and structurally complex system integrated into a reinforced test stand. The visible increase in plumbing density, cooling channels and instrumentation strongly indicates a focus on full-scale thermal management and structural survivability. Scaling up the dimensions in such systems (as compared to laboratory-level models) is challenging, as it introduces more complex airflow behaviour, higher thermal gradients, and greater structural loads.

The subsequent May 2026 test extended the full-scale combustor operation to a little over 1200 seconds, representing the longest-duration endurance demonstration yet achieved by the programme.[22] This test effectively combined the endurance objectives of the April 2025 trial with the scaling objectives of the January 2026 full-scale configuration, suggesting growing engineering confidence in the combustor's long-duration performance.

The collective significance of these tests indicates a clear technological transition from experimental combustion research towards endurance-oriented propulsion engineering. While the tests validated the capabilities achieved and the infrastructure developed, another important factor is the data generated by these tests. Long-term military research programmes require multiple data points that showcase system behaviour, the impact of modifications on the system and the possibility of future upgrades. Collected and analysed over decades, this 'legacy data' becomes an important input for benchmarking future programmes as well as for providing inputs into ongoing projects.

## Challenges Ahead

Despite the significance of the recent tests, important limitations remain. The ground-based combustor demonstrations do not immediately provide India with an operational scramjet engine or a hypersonic cruise missile. Those milestones are many months away. Studies on hypersonic propulsion development have emphasised that testing and validation remain major challenges because existing facilities cannot fully reproduce operational flight conditions.[23] This necessitates expensive and technically demanding wind tunnel testing and flight-testing

[22] **"Major Breakthrough in Hypersonic Missile development: DRDO Conducts Extensive Long-duration Test of Actively Cooled Full Scale Scramjet Combustor"**, no. 18.

[23] Vinayak Kumbar, **"Redefining Combustion: The Scramjet Surge"**, Issue Brief, Centre for Joint Warfare Studies (CENJOWS), 2023; Wg Cdr Kiran Krishnan Nair, **"India's Scram Jet Test and Implications for Future Space Transportation"**, *CAPS In Focus*, 29 August 2016.

campaigns.[24] First, the transition from ground-tested combustors to an integrated, flightworthy propulsion system is now one of the most difficult stages in India's hypersonic development. Second, given the current geopolitical environment, such critical technologies cannot be obtained through foreign collaboration or imports of systems. Even the jointly developed BrahMos programme has not provided India with such capabilities given Russia’s reluctance to transfer the technology of the scramjet engine and motors. Third, agencies like ISRO have carried out separate programmes from that of the DRDO for development of scramjet technologies, with no visible collaboration.[25] Fourth, India has a relatively limited hypersonic testing infrastructure as compared to countries such as the United States and China.[26] This can slow down the iterative development cycles.

A scramjet combustor represents only one system within a much larger hypersonic vehicle architecture. India’s hypersonic cruise missiles need a successfully integrated combustor and engine apart from guidance and precision navigation mechanisms, aerodynamic structures, hardened warheads, micro-electro mechanical systems (MEMS), nano-sensors, nano-materials, advanced computers with sophisticated software, etc. The development, testing, certification, integration, and trials of these systems will take some time. Thereafter, these systems will be incorporated into India’s indigenous cruise missiles, enabling them to fly at speeds of 6100 km/hr.[27] While the recent tests represent meaningful progress, they should not be interpreted as evidence of immediate operational capability.

## Conclusion

India’s recent scramjet combustor tests should be viewed not as isolated breakthroughs, but as evidence of a gradual transition from experimental combustion validation towards endurance-oriented propulsion engineering. The progress achieved reflects a growing emphasis on thermal management, scaling and structural survivability.

The most important development is therefore not simply the increase in runtime achieved across successive tests, but the visible maturation of the indigenous

[24] Ibid. For testing procedures, see **“Scramjet Testing in Shock Tunnels”**, Indian Institute of Science, Bangalore.

[25] T.V. Venkateswaran, **“SCRAMJET: ISRO’S Futuristic Technology to Reduce Costs of Space Travel”**, *Emerging Trends in Physics*, Azim Premji University.

[26] Vinayak Kumbar, **“Redefining Combustion: The Scramjet Surge”**, no. 23; Wg Cdr Kiran Krishnan Nair, **“India’s Scram Jet Test and Implications for Future Space Transportation”**, no. 23. For country-specific progress, see Varsha Rani and Ayush Passi, **“Scramjet Combustor Design - A Review”**, *Journal of Aeronautics and Aerospace Engineering*, Vol. 9, Issue 3, No. 227.

[27] **“DRDO Achieves Breakthrough in Hypersonic Missile Development with Long-duration Scramjet Test”**, *The Hindu*, 10 January 2026.

engineering ecosystem surrounding the programme. The evolution of the hardware itself, from compact experimental rigs to heavily cooled and structurally integrated full-scale combustors, suggests that India's scramjet effort is entering a more advanced developmental phase centred on sustained propulsion endurance.

Significant challenges nevertheless remain. Ground-test success does not automatically translate into operational hypersonic cruise missile capability, and the transition to integrated flightworthy systems continues to represent a technological hurdle. India also faces limitations in funding, foreign collaborations, testing infrastructure, etc., that could affect the pace of future development. Nevertheless, the recent tests indicate that India is steadily building the technological foundations necessary for sustained hypersonic propulsion. This is a sensitive domain where engineering endurance and data availability matter more than brief experimental success that ultimately determines long-term viability.

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