# Scramjet - World's Fastest Aircraft Technology

Akshoy Ranjan Paul.
Lecturer, Department of Mechanical Engineering

**Abstract:**
The high-risk, high-payoff X-43A flights are the first actual flight test of an aircraft powered by a Scramjet engine capable of cruising at hypersonic speeds (above Mach 5, or five times the speed of sound). The X-43A is powered by a revolutionary air-breathing Supersonic-combustion ramjet or 'Scramjet' engine. This technology raises the possibility of New York to Tokyo flights within two hours. Today, Scramjet is not a concept, as it has become reality. Within a decade or two, hyperplanes and such sophisticated aircraft cruising at Mach 10 will become a part of our routine life. Even the dream of 'space tourism' is likely to come true, thanks to hypersonic passenger airlines that are in the offing.

**Introduction:**

The aviation era for humankind started 100 years ago, when the Wright brothers from America first successfully piloted the aeroplane with a sustained power flight. Since then, man has been involved in the development of still higher and faster flying machines like jet-planes and rockets. As improved versions of aeroplane were designed, an entirely new concept engine came into existence- the Scramjet engine. Although based on a 40 years old concept of the 'ramjet engine', the scramjet engine can attain hypersonic speed that is five times the sped of sound. In technical parlance, an aircraft traveling at the speed of sound is said to have attained 'Mach 1' speed. The Mach number is, in fact, the ratio of the speed of an object to that of sound in any given medium under the same temperature and pressure.

Today a Boeing 747 or Jumbo jet is the aeroplane, which can carry 570 passengers at a speed of Mach 0.9. Concorde was the only passenger airliner, which could fly at a supersonic speed, that is, Mach 2.02. Besides, unpiloted spy-plane Sr-71 or Blackbird flies at Mach 3+ (Fig. 1). But in a most emerging development fifty-seven years after U.S test pilot Chuck Yeager broke the sound barrier, NASA (National Aeronautics & Space Administration, U.S.A) launched the unpiloted Scramjet on March 27, 2004 that reached a record velocity of just over Mac 7.0. It is the first time, a Scramjet, which burns hydrogen mixed with oxygen from the atmosphere had traveled so fast in the aviation history.

**What is Scramjet:**

'Scramjet' is an acronym for 'supersonic combustion ramjet'. The concept of ramjet was developed four decades ago when a need was felt to develop new cost-effective, reusable space launch vehicles. Such an aircraft, therefore, requires to be accelerated to a certain initial speed by some other vehicle before switching over to scramjet.

Taking a glance of the familiar technology reveals that most commercial and military aircrafts uses turbojet or afterburning turbofan engines, in which axial compressor compresses the intake air, ignites with gasoline in combustor and expands through gas turbine and then exhausts through nozzle to produce thrust (Fig. 2). In contrast with the turbojet or turbofan, there are no moving parts like compressor or turbine in ramjet engine. A ramjet operates by subsonic combustion of fuel in a stream of air compressed by the forward speed of the aircraft itself, as opposed to normal jet engine, in which a compressor compresses the air. The resulting combustion creates thrust. Ramjets operate from Mach 3 to Mach 5, but it cannot power an aircraft past that range. That required the development of the Scramjet, in which the airflow through the whole engine remains supersonic.

A Scramjet operates by supersonic combustion of fuel in a stream of air compressed by the high forward speed of he aircraft similar to ramjet engine. Scramjets start operation at about Mach 6, or six times the speed of sound. There are no moving part in a scramjet engine, but achieving proper ignition and combustion in a matter of milliseconds proved to be an engineering challenge of the highest order.

Both the ramjet and Scramjet consist of four basic components- an inlet, a diffuser, a variable geometry combustor and a nozzle (Fig. 3). Scramjet differs from ramjet in the sense that in scramjet the diffuser is merged with inlet. Also combustion takes place at supersonic speeds in Scramjet. The inlet and nozzle become a part of an aircraft in a |Scramjet (Fig. 4).

Although Scramjet technology seems mechanically simple, it is vastly more complex aerodynamically than a jet engine. The aircraft had to be designed in a way so that the front end of the Scramjet-its flat nose-helps compress the oxygen before it enters the copper-alloy chamber, where it mixes with hydrogen and burn, creating pressure from the expanding gas to propel the plane forward. Improvements made in ramjet have led to the development of the Scramjet model. Basically, in order to achieve the initial required speed, a second engine is integrated in the Scramjet model. The second engine may be a rocket engine or a turbojet engine. As the aircraft is brought to the initial speed by the second engine, the latter is turned off and the Scramjet engine takes over.

**Working of Scramjet:**

Though a Scramjet has a simple mechanism, it is technically the most complex engine. A Scramjet requires intake of large mass of air so the front part below the aircraft forms the inlet. Further, the shape of he aircraft is also such that it helps in gathering more air. Indeed, successful working of this engine solely depends upon the airflow. Any error that changes the airflow could seriously affect the performance of the engine, so much so that the engine may even fail to work. Consequently, this engine requires careful designing and construction with negligible tolerance (Fig. 5).For understanding the working of Scramjet, let us take a virtual ride on an aircraft fitted with rocket engine is integrated in the combustor of Scramjet. Initially, as the aircraft attains some altitude, the rocket engine is ignited, accelerating the Scramjet to a hypersonic speed (Mach >7). After attaining a certain speed, the rocket engine is switched on. Due to the special shape and design of this aircraft, air enters the engine at high speed through the inlet. The air gets hotter as its speed is slowed down. At this moment, the fuel is injected in the combustor where it mixes with the incoming air. The fuel-air mixture burns within a millisecond inside the combustor at a supersonic speed. The combustion products are released from the nozzle creating a positive thrust. An external nozzle is also used for this purpose. Due to the shape of the aircraft, high pressure is developed below the aircraft, which provides it an additional lift.

**Four Basic Modes of Flight:**

In an actual single-stage-to-orbit aircraft, there are four basic modes for specific altitude and Ma number. A rocket engine or a turbojet is used for take-off stage. These engines accelerate the aircraft to a speed of Mach 2 or 3 at an altitude of about 40 km (Fig. 6). Then the aircraft is shifted over to ramjet and then to Scramjet. At a speed of Mach 10 or 12, at an altitude o 75 km, the rocket engine is used to provide supplementary thrust to assist the Scramjet engine. Above Mach 18, the aircraft is propelled solely by the rocket engine for its final entry and propulsion into space. Thus, both rocket-based combined cycle engines and dual mode Scramjet engines are used where former can switch over from rocket to Scramjet and back to rocket an the latter can operate either on Scram or ram mode.

**Recent Developments:**

Some of the interesting developments in the Scramjet technology are discussed here in brief.

**1. Avatar:** Avatar stands for 'Aerobic Vehicle for Advanced Trans-Atmospheric Research'. Air Commodore Raghavan Gopalaswami publicly announced in July 2001 that *Avatar* is the hyperplane concept that has been developed in Defence Research and Development Organization (DRDO), India. The hyperplane weighs only 25 tons, 60% of which is liquid hydrogen fuel. In can enter into a 100 km orbit in a single stage and can launch satellites weighing up to 1 ton. It can be used as a missile launcher as well. More interestingly, it can be converted into an aircraft for carrying passengers into space. This hyperplane would, however, use a combination of turbojet, ramjet and Scramjet engines to reach an altitude of 100 km. After that a cryogenic rocket engine needs to be employed to provide a final push into space.

**2. HyShot** : The University of Queensland (UQ) in Australia conducted the World's first test flight of a Scramjet, HyShot on July 30, 2002. This launch was held at the Department of Defence's Woomera instrumented range, 500 km north of Adelaide in the south Australian desert. The Scramjet payload designing for a speed of Mach 7.6 was mounted at the nose of the two-staged Terrier Orion MK-70 rocket. The rocket and payload reached an altitude of 314 km before the rocket was configured to fly in a new trajectory pointing the payload back down to earth (Fig. 7). The flight experiment took place within only the last few seconds of the flight, lasting almost 10 minutes. After the Terrier booster had finished its work and subsequently fell 5 km downrange, the Orion continued on with the Scramjet payload and impacted some 370 km downrange of the launch-site, very close to the nominal impact point predicted by the scientists. Radar and four sets of telemetry (radio) tracked the flight. During The HyShot flight, several pressure measurements was made to validate the experiments made of supersonic combustion in the UQ's T4 shock tunnel.

**3. Hyper-X Programme:** The Hyper-X programme is conducted jointly by the Langley Research Centre, Hampton, Va., and the NASA Dryden Flight Research Centre, Edwards, Calif, U.S.A. Langley is the lead centre and is responsible for hypersonic technology development, whereas Dryden is responsible for flight research and testing. The US$ 250 million programme began with conceptual deign and wind tunnel work in early 1996. A team lead by A2l2 (formerly MicroCraft Inc.) had built three unpiloted X-43A research aircraft in support of the Hyper-X programme. The three lifting body of X-43A aircraft were identical in appearance but are engineered with slight differences simulating engine inlet variable geometry, generally a function of Mach number. Each vehicle was designed to fly once. The first and second were designed to fly at Mach 7 and the third at Mach 10 (Fig. 8).

Vehicle and engine ground tests and analyses were performed prior to each flight n order to reduce technical risk and to compare with in-flight results. The model testing of Scramjet engine was performed Langley's 8-foot high temperature wind tunnel to verify the Scramjet propulsion system operability and performance at Mach 7 flight conditions.

The first flight of the 3.65 metre long X-43A was in June 2001 with help of Pegasus booster rocket, but unfortunately, the rocket failed and had to be destroyed early in flight. For the reflight,several subtle changes were made. On March 27, 2004, reminiscent of the notable hyperplane experiments during the mishap of first flight, a modified B-52 bomber took off with the 3.65 metre long X-43A experimental craft riding atop a Pegasus booster rocket- about the same size as a F-16 (Falcon) fighter jet-attached to its wings at 643 km. off the coast of southern California over the Pacific ocean (Fig. 9). Two F-18B chase planes flowed the B-52 and transmitted live video images to nervous NASA officials watching from a flight operations room at Dryden. As the B-52 neared San Nicolas Island, the booster detached from the wing and began a five second free fall from an altitude of 12.2 km. before the rocket engines ignited (Fig. 10). The booster rocket with X-43A accelerated to a speed of Mach 7 and climbed to an altitude of 29 km (Fig. 11). Ninety seconds after ignition, the booster rocket sent commands to the X-43A, causing it to separate from the booster (Fig. 12). After separation, the X-43A, zipping at Mach number 7 high above the Pacific Ocean, burnt its onboard fuel of liquid hydrogen and air from the atmosphere for 10 seconds- the first time in aviation history that an air-breathing hyperplane flew freely at a speed of just over Mach 7 (Fig. 13). At the end of its 10 seconds sensational flight, the scramjet turned off automatically, letting the hyperplane glide for about six minutes before plummeting into the ocean 640 km. from where it had separated from its B-52 mother plane (Fig. 14). The 10 seconds of powered flight at over Mach 7 (8 km/hour) covered about 24 km. By comparison, the Wright Brothers plane flew for 12 seconds and covered about 36.36 metres when it mad aviation history in 1903.

**Future of Scramjet:**

Hydrocarbon-fueled based scramjet engine has been developed by the famous aero-engine manufacturer Pratt & Whitney, which is integrated into an air-vehicle built by Boeing Phantom Works and the test flight of this aircraft is expected to take place around 2007/2008. Even the bigger size like 12.17 m. long Scramjet is expected to fly around 2010.

Researchers believe these technologies may someday offer more aeroplane-like operations and other benefits compared to traditional rocket systems. Rockets provide limited throttle control and must carry heavy tanks filled with liquid oxygen necessary for combustion of fuel. An air-breathing engine, like X-43A, on the other hand, scoops oxygen from the air as it flies. The weight savings could be used to increase payload capacity, increase range or reduce vehicle size for the same payload. Some aerospace engineers hope that combining hypersonic air-breathing engines with conventional rocket engines would help reducing the cost of space launches. The hyperplane would work in the atmosphere and the rockets would boost the aircraft into spaces.

However, since the Scramjet technology is still in its infancy more demonstration flights are needed before NASA, the military, or a commercial company commits money to it. Even the penalty for a hypersonic vehicle is a dramatic decrease in cruise efficiency- a much larger amount of fuel is required to travel the same distance as existing subsonic aircraft. For all the hopes it has raised bout commercial hypersonic travel, NASA officials said that it could be two decades or more before a piloted air-breathing vehicle is flown. In a nutshell, it can be said that Scramjet technology has explored the possibilities ranging from inter-continental flight within hours to the space-tourism to be happened in the days to come.

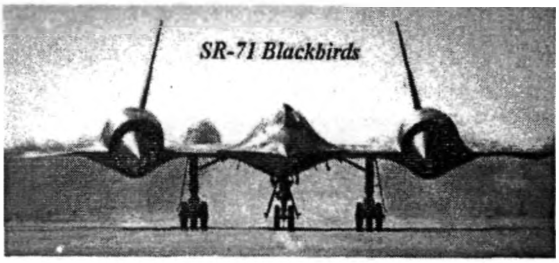


Fig. 1: Sr-71/Blackbird

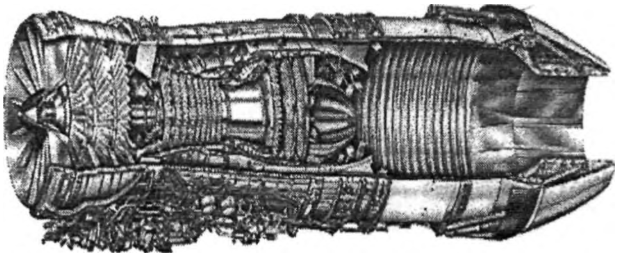

Fig. 2: Turbofan

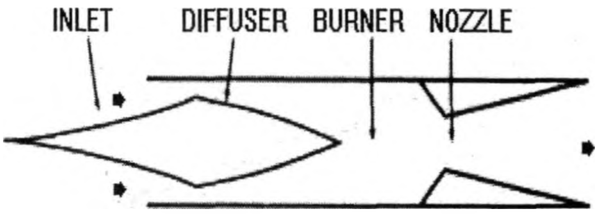


Fig. 3: Ramjet (Schematic)

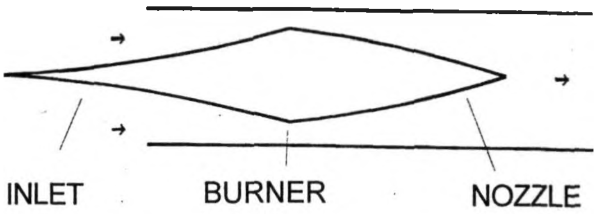


Fig. 4: Scramjet (Schematic)

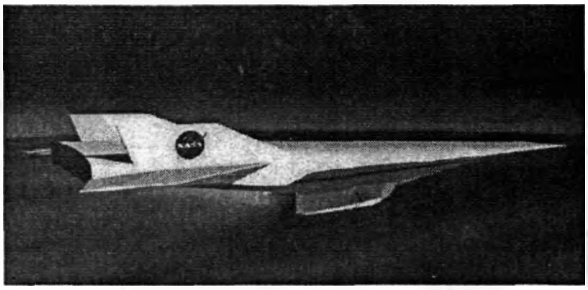

Fig. 5: Scramjet (X-43 A)

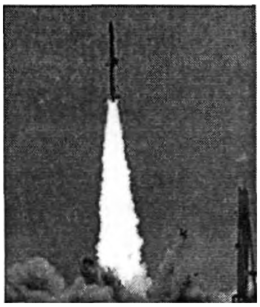

Fig. 7: HyShot launch


Fig. 9: Take off

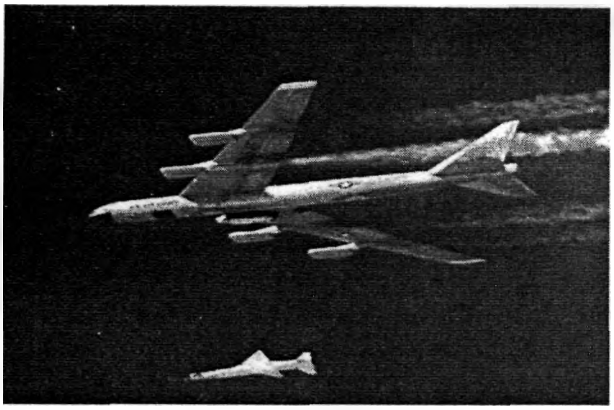

Fig. 10: Separation of Booster rocket

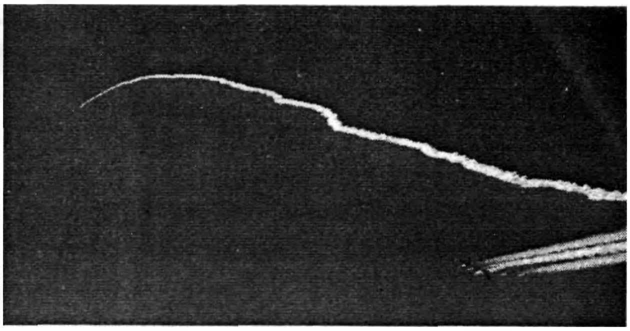

Fig. 11: Accereation of Booster rocket

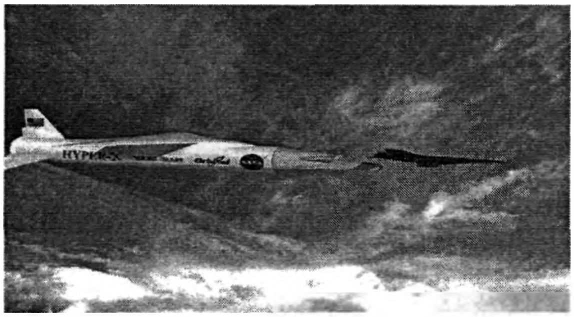

Fig. 12: Separation of (X-43 A)

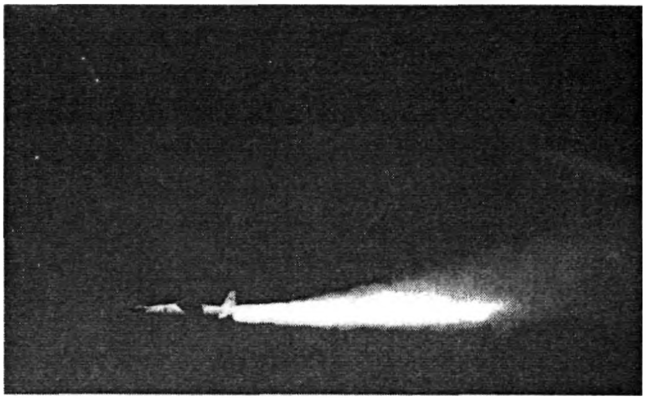

Fig. 13: Free flight of X-43 A

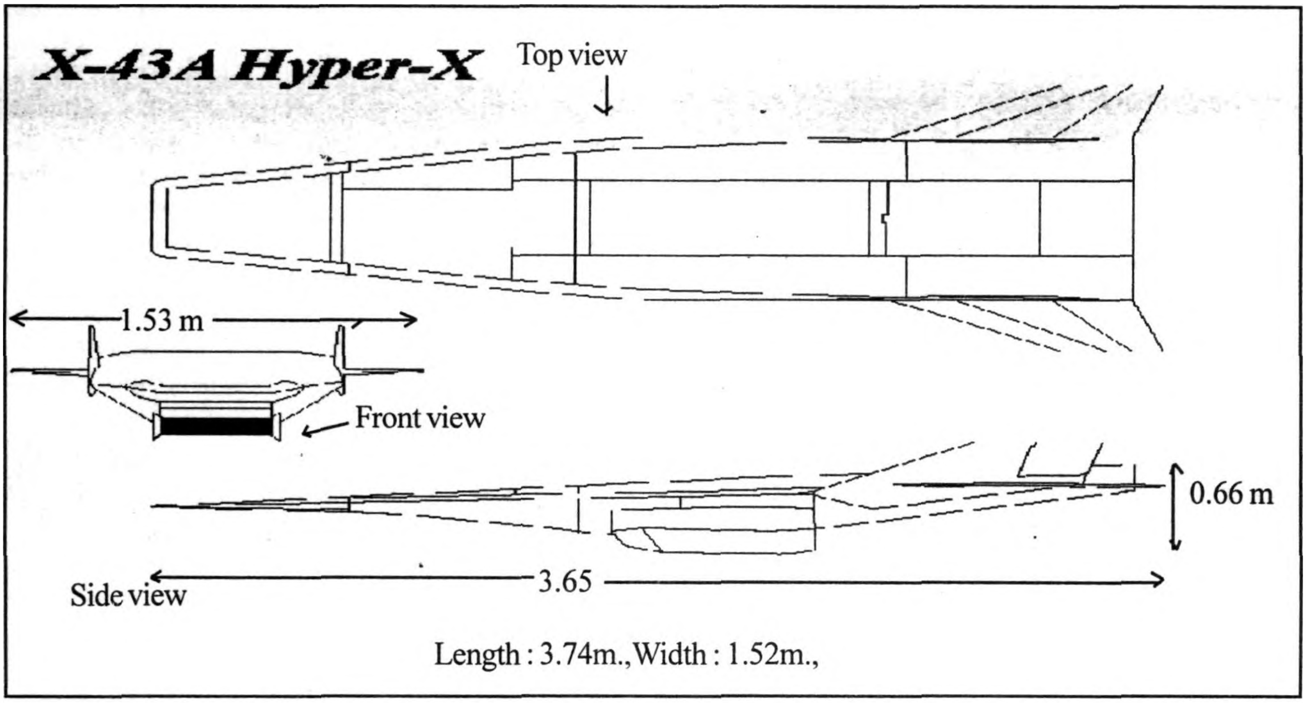


Fig. 8 : X-43 A (Schematic)

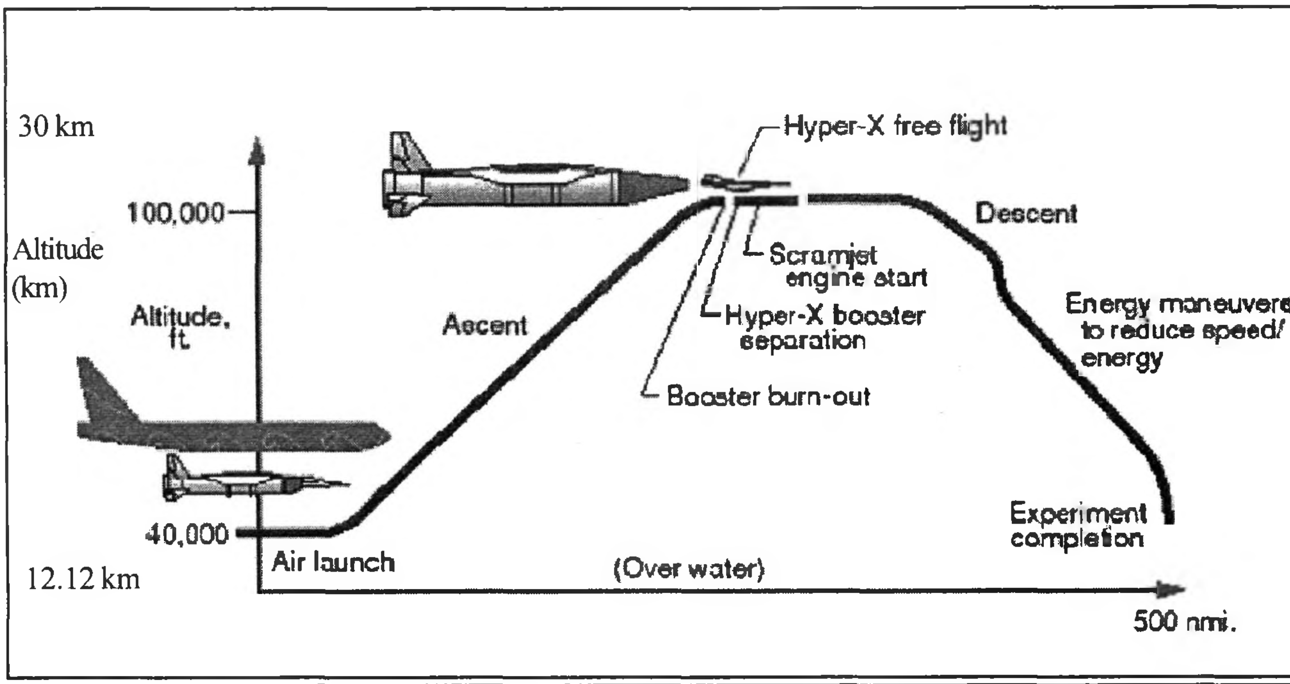


Fig. 14: Total flight path of X-43 A

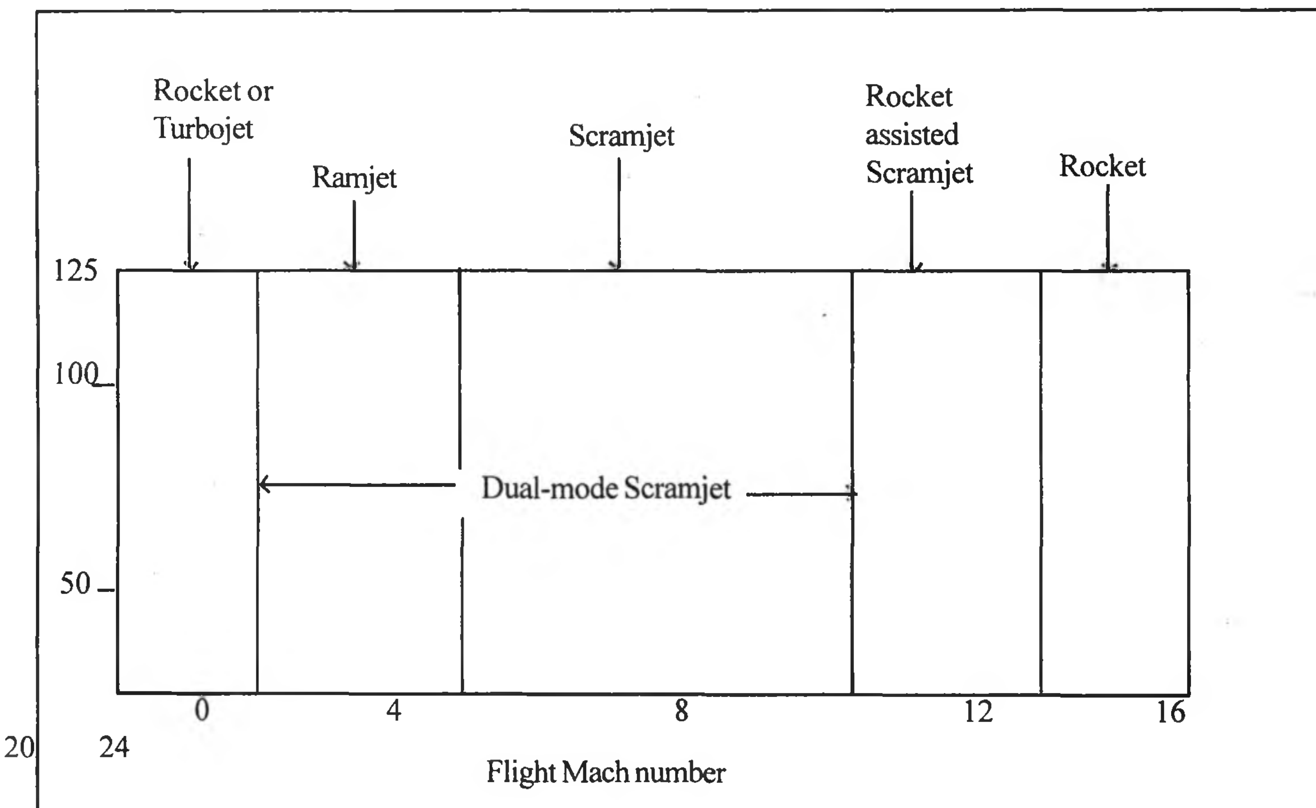


Fig. 6 : Basic modes of flight