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Advanced development in Hypersonic Cruise Missile – Inertial Guidance System, Universal launch Platform & Ramjet Engine

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Abstract: **This paper is mainly proposed about the recent research trends in the missile development strategy of India. The updated technical development in Ballistic and cruise missiles are proposed in this paper. The brief discussion about the major systems of a missile such as the controls and guidance system, warhead chamber and fuel chamber are presented here. Hypersonic missile is considered to be as the fastest missile ever designed. In addition to the above mentioned stages history of Brahmos, Missile control regime, Target attacking ability, aerial fast strike capability, two- stage propulsion system, Performance and results are also proposed in this paper.**

History of Ballistic missiles: **From the great epics of "Mahabharata" and "Ramayana" we came to know that warriors had used "Astras" which were controlled by 'Mantras'. The deadly weapons are discovered nowadays from the scriptures of 'Idikasa'. But the deadly weapons are now controlled by missile control system. India had mastered in missile technology in the olden days, but under the British ruling period it was suppressed. After that India decided to go with (IGMDP) Integrated Guided Missile Development Programme. Under this large number of host missiles such as Agni, Surface-to-air missiles, Ballistic missiles, Anti-tank guided missiles were developed. Today, India is one of the few countries in the world to have indigenously developed missile system.**

Introduction to BrahMos: BrahMos is a supersonic cruise missile that can be launched from submarines, land, or aircraft. It is a joint venture of between Republic of India's Defence Research and Development (DRDO) and Russian Federation's NPO Mashinostroeyenia. These two have together formed BrahMos Aerospace private Limited. The name BrahMos is formed from the names of Brahmaputra of India and Moskva of Russia. The hypersonic version of BrahMos namely BrahMos-II is under the developing stage. Approximately 15 billion will be invested in the facility to make the BrahMos components. Out of the total share India's is about 50.5%.

Specifications of BrahMos- high speed Ballistic and Cruise missile: BrahMos is a two-stage missile with liquid propellant ramjet engine. The first stage of the missile brings it to supersonic speed. The second stage or the Liquid Ramjet stage takes the missile to the speed in cruise phase. Its range is up to 290 Kms with a supersonic speed. It operates on "fire and forget policy". Compared to other sub sonic missiles BrahMos has 9 times increased in kinetic energy. The components used in BrahMos are designed with very complicated techniques. The airframes of BrahMos are developed by the national Chemical laboratory (NCL). Polymers such as Polymerisable monometric reactant (PMR) type polymer resin, and other new non-metallic components were used in it. About 200 non-metallic components were used in it.

Technical Specifications

S. No	Specifications	Range
1.	Maximum Range	290 Km
2.	Maximum Velocity	Mach 2.8
3.	Cruise Altitute	15 Km
4.	Terminal Altitute–	10-15 metres
5.	Warhead weight	200-300 Kg
6.	Dimensions	9000mm(L), 700mm(D)

Principle of Operation: BrahMos missile works under the "*Fire and Forget*" principle. Fire and Forget is an type of guidance system used in Ballistic and cruise missiles in which no control or guidance is necessary after the launch of the missile. It have the ability to hit its target without the launcher being in line-of-sight of the target. For this the missile system uses laser designator. The missile is designed in a manner that it guide itself after it is fired, by the combination of gyroscopes, organis Radar, accelerometers and infraredoptics GPS. This missile can be operated under three platforms in air, land and water. In this module the guidance used by BrahMos is little bit similar to the guidance system used by Lockheed Martin. In AGTM it is controlled by two means such as Semi-

Automatic Command to Line of Sight (SACLOS) and Manual Command to Line of Sight (MALOS).

Technical Aspects in BarhMos: The major themes that are going to be discussed in this paper are given below:

- Inertial Guidance system
- Liquid Ramjet Engine
- Onboard computer and special algorithm
- Universal Launch system for multiple platform
- Hydraulics and Fabrication

Inertial Guidance system: Inertial guidance system is an electronic guidance system that is used to monitor the velocity, acceleration and position of the missile in air continously. The main advantage of this type of guidance system is that no navigational data or control communication is to be provided from the data base. There are three main components for this type of guidance system and they are:

Gyroscopes: Acts as position sensor by calculating with fixed reference point.

Accelerometers: Acts as motion sensor to measure the velocity of missile.

Computer: The process the critical velocity, acceleration and direction of the missile.

Inertial navigation system is a self-contained navigation system in which the rotation and the motion sensors are used to track the relative position and orientation of the missile. This system uses three accelerometers and gyroscopes that are used to measure the angular velocity and linear acceleration of the missile respectively. An INS can detect even a small change in its geographic position and change in its velocity with reference to Global Positioning System (GPS).

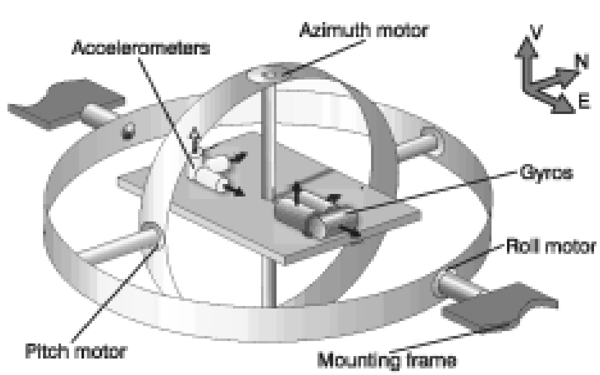


Fig 1: Systematic view of Inertial Navigation System

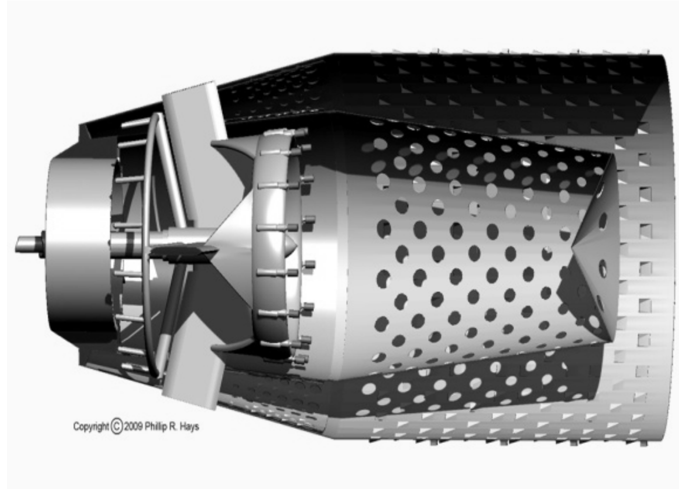


Fig 2: Systematic view of Liquid Ramjet Engine

Initially the Gyroscope measure the angular velocity of the system in the inertial reference frame. Accelerometers measure the linear acceleration of the system in the inertial frame. The accelerometer sensors are fixed with the system and rotate when the system rotates and they are not beware of the orientation. So based on the information provided from the computer of the INS the orientation of the system is calculated and the navigation changes to the predefined direction of the missile. By tracking the current linear acceleration and the current angular velocity of the system, it is possible to determine the linear acceleration, inertial acceleration and inertial velocities of the system. This can be obtained by integrating them.

Error: The INS system provides an error of about 0.6 nautical miles per hour in position due to the integration drift.

Liquid Ramjet Engine:

A ramjet engine is a turbine less engine from which useful thrust can be obtained by creating a velocity difference between the atmosphere entering and the same quantity of air leaving the body. This velocity difference between entrance and exit air is accomplished by the addition of heat to that portion of the air streamflowing through the ramjet body.

- A body structure : It is composed of a divergent nozzle, a combustion chamber and a convergent nozzle.

Rotor Tip Velocity(ft/sec) = pi X diameter X RPM / 60
Entrance Diameter(m) = Area X 4
Exit Diameter (m) = Area X 4

- Fuel injection system : The fuel injection system stores and delievers to the airstream entering the engine shell a sufficient quantity of fuel efficient operation. A fuel regulator is a device which regulates the flow of fuel for change in engine velocity, changes in altitute. The design of a rotor is complicated by unavoidable high centrifugal force created due to rotation. This force boosts the fuel pressure at the nozzle to approximately 3000 psi.

- Flame stabilization system : In order to maintain flame in high velocity airstream some means of shielding the flame source is necessary. Such a shielding device is called as flameholder.

Algorithm Used in Ballistic Missiles: The 3DOF modelling of the Ballistic missile is presented by using series of MATLAB function. Four files are used to accomplish the modelling:

- BRFlight3.m – Integrates each time step to determine the current position, altitute and aerodynamics forces acting on the missile.

$$X = V \cos\theta \cos\Psi \quad \ldots\ldots\ldots\ldots\ldots.. \quad (1.1)$$

$$Y = V \cos\theta \sin\Psi \quad \ldots\ldots\ldots\ldots\ldots.. \quad (1.2)$$

$$Z = V \sin\theta \quad \ldots\ldots\ldots\ldots\ldots.. \quad (1.3)$$

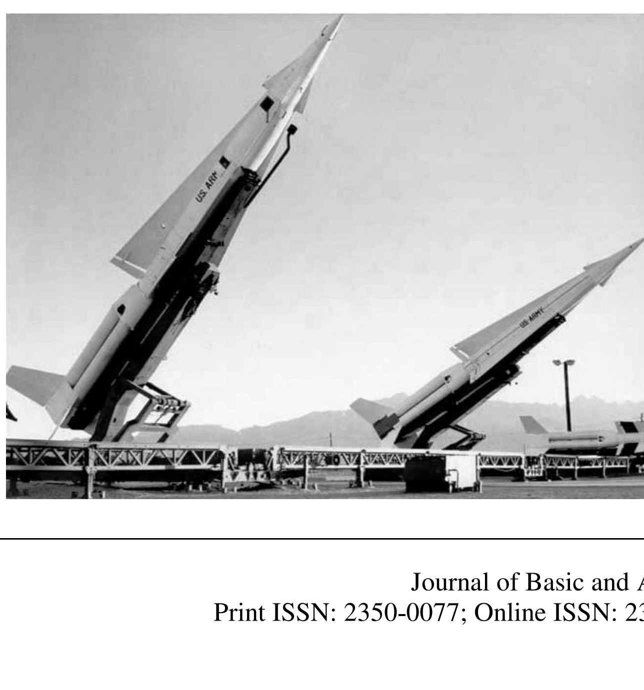
- BRParams3.m – Determines the mass and surface area of the missile.
- ZLDragC.m – Determines the drag coefficient
- STatmos.m – Determines the properties of local atmosphere.

From the derivation the axial acceleration is given as:

$$n_x = (T - D) / mg$$

Universal launch Platform: BrahMos missile is designed to operate in three universal launch pad on all platforms. It can be fired from land, water and air medium. But the design of the missile varies for each platforms and the command used to control and launch the BrahMos missile. The control regime for the BrahMos under varies platforms are given by:

1). Water Medium – "Out of Water Command" 2). Air Medium --"Dassault Aviation Rafale" 3). Surface Medium -- "Fire & Forget"



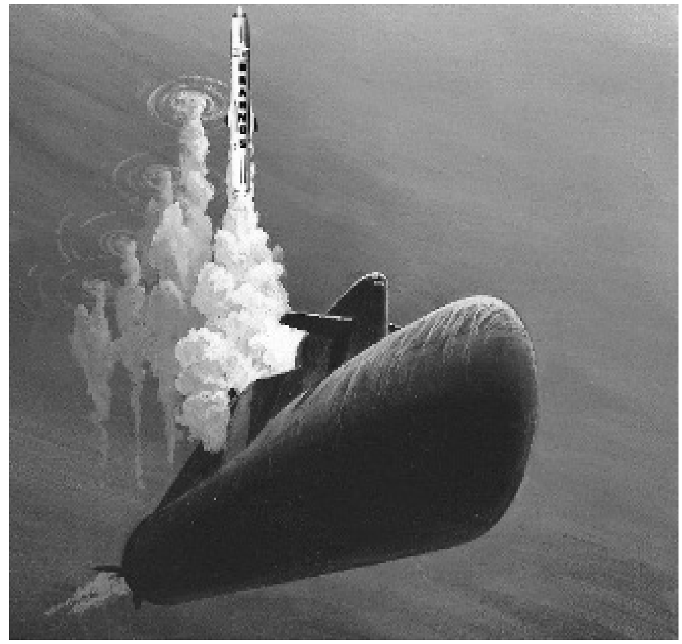
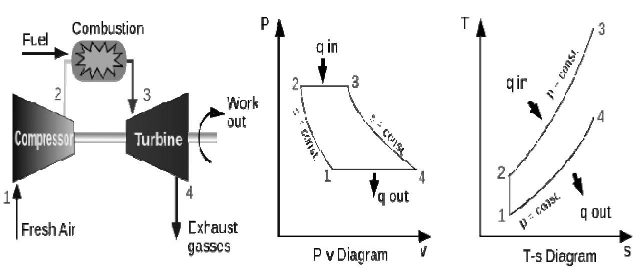


Fig 3: Surface Launch Platform Fig 4: Under water Luanch Platform

8. RESULT AND EFFICIENCY ANALYSIS

Liquid Fuel Ramjet: To increase the efficiency of the engine liquid propulsion technology is applied for Ramjet engine. The fuel used for the engine is liquid Hydrocarbon. The liquid hydrocarbon has high specific impulse than the solid propellant. The flow rate of the liquid is limites by controlling the valves, but the storage of the fuel is difficult and complex. Ramjet engine is a self-sustaining engine, which is completely based on Brayton cycle.It is designed on basis of Aero Thermodynamic Duct. The maximum efficiency of the engine is Mach2-3.



Simulation Results of BrahMos: The simulation ran as expected, testing about 80 iterations and different flight paths before arriving in the neighbourhood of the final value, and testing about 160 iterations and different flight paths before arriving at the optimal solution. The three coordinate axes were independently optimized. The flight paths generated and the first and second derivatives of those flight paths in each of the coordinate axes. It is clear that each flight path is smooth, continuous, and satisfies the initial and final boundary conditions. It is important to note that the derivatives of the flight path are not the velocity and acceleration in a time-frame sense, but instead are the spatial derivatives. They represent the rate of change of the motion of the flight path. In an abstract sense, the interceptor missile could travel along this optimum path at any chosen speed (though in this case the velocity history is defined), and still be flying along the optimum path. The velocity history is introduced after the optimum path has been derived to determine the flight time and test the boundary conditions.

Mat Lab Simulation Part for BRParams3.m

%% Variable List
% BR_mass =total rocket mass
% BR_nose =total mass of nosecone section
% BR_st1_bt =burntime for stage 1
% BR_st1_fcr =consumption rate of stage 1 fuel
% BR_st1_fuel =remaining stage 1 fuel based on time and
% consumption rate
% BR_st1_str =total mass of stage 1 structural material
% BR_st1_tfm =total mass of stage 1 fuel
% BR_st2_bt =burntime for stage 2
% BR_st2_fcr =consumption rate of stage 2 fuel
% BR_st2_fuel =remaining stage 2 fuel based on time and consumption rate
function [path]=SMTrajectory(free, const)
% Written by LT John A. Lukacs IV, Naval Postgraduate School, June 2006
% this function proposes a trajectory based on the input parameters
% "free" and "const". This is a sub-function of the SMGuidance.m
% function's fminsearch. This function creates a 7th order set of
% equations and evaluates that equation at the boundary conditions
% supplied by the inputs. It then calculates the time history of all
% the flight vehicle variables, including controls and reactions,

Simulation Results:

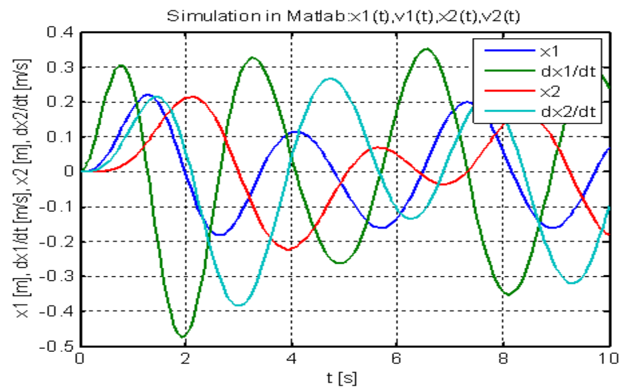


Fig 4. Overall efficiency of BrahMos – Mat lab simulation

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