COPY No 3 (115)

DISSERTATION WORK

ON

UPGUNNING OF ICV BMP

AND

POSSIBILITY OF EMPLOYING

GUN LAUNCHED MISSILE

IN

PARTIAL FULFILMENT

FOR

AWARD OF M. TECH DEGREE

BY

JNU, NEW DELHI

SUBMISSION BY

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GUIDE (S)

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SYNOPSIS

1. At one point of time it was felt that mounting a low pressure 80 mm gun which fired fin stabilised shaped charge projectiles was enough for BMP to defeat enemy armour. However armour penetration was lesser than 100/105 mm Guns. The mass of explosive and shot fired was also less effective in comparison. The firing impulse and trunnion pulls (recoil force) generated by the 100/105mm gun are reduced to a certain level so as to accommodate higher caliber Gun on the BMP.

2. Effective upgunning of BMP has been carried out by Russia in what has been presented during the nineties to the world as BMP - 3. It incorporates a 100 mm fully automatic gun. This gun is of low medium Pressure type capable of firing both the APDS/HE/HEAT rounds and also the missile through the Gun barrel.

3. Although various calibre guns i.e, 90 mm, 100 mm and 105 mm guns have been covered in the dissertation, the 105mm has been covered in maximum detail as it is considered the best choice available for upgunning the BMP. An effort has been made to arrive at a mathematical model for the upgunned BMP for analysis of stability, dynamic response and amphibious capability.

4. Penetrating modern armour requires a cone diameter beyond 100mm or even 105mm. The limitation of chamber volume and catridge length continue to restrict even KE munition performance. Thus the two generic missile systems - either through the tube or strap on systems provide the solution. The alternative of missile through the tube is the most attractive to the user. This system, provides a high probability of kill given a shot, would increase stand off and prevent obsolescence of BMP.

5. Presently the missile cannot be reloaded on the launcher without compromising the NBC protection and in case of BMP-1 requires that the gun be elevated to 3.5deg causing the tgt to disappear from the gunner's view. Also the present missile launching system exposes the crew to enemy fire during loading as learnt by Russsians in Afghanistan. Thus missile firing through the gun barrel overcomes the above short commings of the BMP.

6. The ATGW for gun launched missile will have LOSBR (Line of sight beam riding). The laser beam has the advantage of less attenuation and can avoid jamming. An autopilot located in the missile sends driving signal to canard control surfaces and generates error signal for pitch, roll and yaw acceleration of the missile. The missile is activated after loading in the gun. Pin of the spacer plug pierces the tail of the missile to set the Bty circuit. The fire control computer is integrated to check the missile serviceability by BITS and flash it on board to the gunner.

7. The high level of fire power achieved with the upgunned barrel and increased single shot kill probability with the laser guided gun fired missile would make BMP a " Break through ICV" making it a logical accompaniment to the new forthcoming T-90 tanks.

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INTRODUCTION

1. In the present world Scenario no major army would seriously dispute the tactical, and even strategic, importance of armoured fighting vehs (AFVs). Indeed their role is no longer restricted to giving infantrymen a level of mobility more or less comparable to that of MBTs while protecting them against small arms fire and artillery splinters. AFVs are now expected to actively engage in combat, be it by providing fire support to the dismounted infantry squad and/or by taking care of anti-tank (or at least anti armour) actions and/or of short range AA defence.

2. Looking at the wide range of weapon systems guns or missiles which are, or can be, accommodated on current A FVs, one can measure the design advances made since the first tracked or half-tracked personnel carriers were introduced into western armies (and particularly in the us and Germany) about 50 years ago.

3. Correspondingly worthy of note is the evolution of tactical doctrines concerning A FV employment. During the first post-war modernisation of western armies, which took place in the 1950s and 1960s and which emphasised tracked vehicles, the renewal of western AFV flects followed on two main tracks. These were the parallel development of both new APCs (carrying no armament or being only lightly armed) intended to equip mechanised infantry units on the one side, and of specialised armoured reconnaissance vehicles, armed with more powerful automatic cannon, on the other. We are currently at the end of a second phase, which started in the late 1970s. Reconnaissance missions are (or will be) entrusted to much lighter and faster vehicles (such as the HUMMER or the Panhard VBL), which should not be regarded as simple armoured jeeps. On the other hand, the imperative requirement for enhanced mobility is no longer restricted to armoured units only. All infantry units (including airborne troops and marine infantry) are, or will be, equipped not with simple APCs, but rather with true A FVs (wheeled or tracked) in most cases backed by one or more weapon systems intended to provide direct fire support or fire protection for the infantry squad.

4. An interesting point to note here is that most battle tanks used in Asia have so far been light tanks. To name a few, the American M41 used in the Philippines, Taiwan and Thailand. The British Scorpion is still used by Malaysia and Thailand. The reasons only this category of battle tanks/A FVs are favoured in our region of the globe is as follows:-

(a) The heavy weight of most battle tanks results in high NGP and therefore it is difficulty to operate them in areas where ground is soft.

(b) Inability to cross many light bridges.

(c) Difficulty in transportation by rail or air.

5. At One point of time it was felt that mounting a low pressure 80mm gun which fired fin stabilised shaped charge projectiles was enough for BMP to defect enemy armour. However armour penetration was lesser than that of 100/105mm guns. Also the mass of explosive and shot fired was less and hence less effective in comparison. The firing impulse and trunnion pulls generated by the 100/105mm gun on firing were too high to absorb. Studies proved that these recoil forces and firing impulses could be reduced to a certain level so as to accommodate than on the BMP. This was achieved by the use of longer recoil strokes in combination with baffled muzzle brakes.

AIM

6. The aim of this dissertation is to ascertain the feasibility of " Upgunning of BMP and possibility of employing gun launched missile".

PRE FEASIBILITY ANALYSIS

Requirement

7. There is a requirement for over matching the penetration against armour. In addition up gunning also results in increased effective range. The effect of increased range in any tank vs tank duel is extremely favourable for the tank with the longer range. A terrain study carried out in Germany gave that it would be possible to open fire in excess of 3000 meters, of which 8-9% targets could be engaged beyond 4000 meters. The tank experts concluded that 3000meters could no longer be considered as the maximum combat range for design of AFVs and gave the new figure of 4000 meters. [14]

8. There is also a requirement of placing missiles on tanks/ICVs to enhance its capability. The increasing use of missile systems on other battle field carriers increases the requirement of integrating the missile systems on the BMP. There are three basic reasons for considering missile armament for BMPs.

(a) To counter an increasing threat.

(b) To avoid losing the existing missile system on BMP through obsolescence.

(c) To provide significant advantage in the tank anti tank role.

Since these goals are not mutually exclusive, a missile system must be examined to determine how well it can fulfill these objectives.

9. It should be expected that tank battles will occur at ranges of 3km and beyond. Many computer tank battle scenarios conducted at the Directorate of combat developments at fort know indicate that tank forces need to initiate engagements at ranges in excess

CERTIFICATE : GUIDE(S)

1. It is Certified that the Dissertation work on "Up gunning of ICV BMP and possibility of employing Gun launched missile " by MAJ I S RATHORE has been carried out under my guidance and supervision.

2. The Dissertation work is recommended for submission and presentation.

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CERTIFICATE

1. I hereby certify that my Dissertation work on "Up gunning of ICV BMP and Possibility of employing gun launched missile " has been carried out under the guidance and directions of my guide(s).

2. The thesis duly certified is submitted herewith for consideration and presentation of the Dissertation work.

MAJ I S RATHORE

ACKNOWLEDGES

1. It has indeed been a life time opportunity given to us by MCEME to do MTech after successfull completion of our Advanced course (OAME-40). Two of my instructors on advance course - Col T V Sadavisan and Lt Col S S Malik willingly associated themselves as guide(s) in the preparation of this dissertation. I am thankful for the guidance and directions that they gave me from time to time without which this work would not have been completed.

2. In the preparation of this dissertation, sources of information were innumerable. The salient ones are listed in the Bibliography but this in no way diminishes my gratitude to various officers and men of my unit in particular who promptly provided me the details that I sought to fill some gaps.

3. My thanks are also due to Maj A K Sharma, Maj Jitendra Jain and Col S C Jain whose help has been invaluable. My thanks are also due to my wife Seema who assited me in drafting of various chapters and encouraged me to explore different libraries.

4. For compilation and printing I had the whole hearted support from Cfn Padam Singh and Sub J N Singh belonging to the 7004 Combined Workshop and 4 Corps Headquarters printing press resp.They worked cheerfully and endlesslessly that led to the production of this dissertation.

of 2,400 metres and break off engagement when close to within 1200 metres if they are to avoid decisive engagements against numerically superior forces, obtaining this stand off is not possible with cannon/munition technology. This situation can be over come by application of missile technology to the tank.

10. Penetrating modern armour requires a cone diameter beyond 100mm or even 105mm. For some time kinetic energy munitions have provided an answer, but the limitation of chamber volume and cartridge length continue to restrict even kinetic energy performance. Thus the two generic missile systems, either through the tube or strap-on-systems may be the solution. The alternative of missile through the tube is the most attractive to the user. This system, providing a high probability of kill given a shot, would both increase standoff and prevent obsolescence of BMP. It should be noted that recently during a test of 15 shillelagh missiles, the functioning rate was excellent, scoring 15 of 15.[19]

Mechanics of Perforation

11. The mechanics of perforation are complex, but the process is basically one of equating the striking kinetic Energy of the projectile to the work done by the projectile in perforating the armour. The perforating ability is adequately described by the Milne-do-Marre's formulae. [from Project Study on 'LIGHT TANK FOR 2010 AD' BY TANK TECH COURSE -20]

$$\frac{MV^2 \cos^2\theta}{D^3} = \log C \left(\frac{T}{D}\right)^{1.43}$$

where m = weight of the penetrator in lbs.
v = striking velocity in ft/sec.
θ = angle of strike.
D = diameter of the penetrator in inches.
C = a consant depending on type of shot, angle of strike and strength of armour.
T thickness of armour just penetrated.

The penetration T can thus be increased by increasing velocity, mass, reducing Q and the diameter. [16]

12. Kinetic Energy ammunition being used in present day gun has been APDS sub calibre type. To obtain high muzzle velocity on the hand and on the other to keep the decay of velocity along trajectory to the minimum, use of high density material of the Projectile is resorted to, thereby increasing mass per unit cross section. This is also achieved by increasing the length to diameter (L/D) ratio of the projectile. There is no scope for increasing the density

of the material of the projectile, since highest limits in this regard have been reached by the use of Sintered Tungston Carbides (density upto 18.5 gms/cm as compared to steel 7.85 gms/cm). Dense materials like depleted uranium which has the added advantage of its exothermic effect on impact cannot be used due to political implications. The net result is that to have maximum terminal effects in case of KE projectiles, the penetrator has to be made longer to have maximum sectional loading at the target.

13. In the case of spin stabilized round, the practical attainable limit of L/D is around 5 using high rifling angles. the stability factor is given by the expression.
[Project study on 'LIGHT TANK FOR 2010 AD' BY TANK TECH COURSE-20]

$$\frac{A^2 N^2}{4 B}$$

where A is the moment of inertia about the longitudual axis.
N is the rate of spin
B is the moment of inertia about the transverse axis.

as L/D increases A reduces while B increases and so there is a practical limit to L/D from point of view of stability in spin stabilized round. To increase penetration we have to go in for fin stabilization where there is no limit to the L/D ratio. It is for this reason that smooth bore guns are being used in Russian Tanks, German Leopard II and the American XM-1, A-brams Tank. Only the British are still keen on the Rifled Gun. [16]

Smooth Bore Vs Rifled Guns

14. A great controversy has been let loose because of the development of the smooth bore gun by the Germans and its subsequent adoption by the Americans. The increase in penetration could be achieved by increasing the L/D ratio beyond what could be achieved by spin stabilised. The other advantage is that the HEAT round can be fired without spin being imparted thus greatly increasing its terminal effects.

15. In addition to this smooth bore guns offer the following advantages:-

(a) Lighter barrel for the same strength due to lack of rifled portion metal, so that the centre of gravity is further back.

(b) Longer life or less wear per round fired. This is due to reduced friction.

(c) Easy to manufacture and hence cheaper.

(d) Higher muzzle velocity is possible.

(e) It can be fired using hotter charge i.e higher peak pressures can be used.

(f) Easier to clean and maintain.

16. The disadvantages of the smooth bore gun are:

(a) Dispersion is more.

(b) APFSDS and HEAT round only have been developed.

(c) The manufacture of fin stabilised ammunition requires use of special alloys and precision manufacture problems.

Choice of Gun

17. Up gunning of present BMP-1 or BMP-2 would involve installation of any of the following guns already under trials.

(a) 90 mm gun of the AMX 10 PAC (BMP-1).

(b) 100 mm fully automatic rifled Gun (BMP-3).

(c) 105 mm SOFMA gun (BMP-2).

18. During user trials of the AMX 10 PAC 90 light tank held in June'82 VRDE under took a feasibility study for mounting a TS 90 turret of the AMX 10 PAC 90 on a BMP-1 chassis. The study proved that adoption was feasible and General staff concurred. A turret was imported from M/s SOFMA, France and fitted on a modified BMP-1 Chassis. The existing turret ring diameter of 1300mm in the BMP-1 was increased to 1700mm to fit the two man turret. Subjected to trials, this model performed extremely well. The weight of the BMP increased by over 1.5 Tonnes as compared to the 13 Tonnes of the BMP-1. The BMP retained its amphibious characteristics. [16]

19. Further upgrading is feasible by installing a 105mm gun as against the 90mm of the AMX 10 PAC to meet the requirement. It was decided that mounting of a SOFMA 105 mm TGG turret on the BMP-2 would meet the requirements. I would concentrate on upgunning using this Gun.

20. Effective upgunning of BMP has been carried out by Russia in what has been presented to the world as the BMP-3 It incorporates a 100mm fully automatic rifled gun, this gun is of low medium pressure type capable of firing both the APDS and HE/HEAT rounds.

Modifications on BMP-2 for Up Gunning By 105 mm GUN

21. The weight of the BMP-2 turret is 2.7 tons with a ring opening diameter of 1540 mm. The 105mm gun turrets require an opening dia of 1800mm and these weigh around 5 tons. This would require shifting of existing turret centre line to the rear in order to accommodate the bigger turret as well as to facilitate removal of engine without removing the turret. The thickness of BMP-2 hull top plate being only 5mm, it will not be able to withstand the stresses developed during firing of 105mm APFSDS round, which will generate a trunnion pull of around 15 tons. Therefore following major design changes will be required for mounting the 105mm gun/turret system:

(a) Replacement of existing hull top plate with at least a 20mm thick plate. Also reinforcement of existing hull roof supporting brackets would be required.

(b) Reinforcing of existing stiffness provided in the hull to withstand higher load and firing stress.

(c) Mounting of an interface ring by bolting on 15mm roof plate on turret race ring.

(d) Relocation and modification of the main fuel tank for fitting the turret floor and basket tray.

(e) Fitment of ammunition racks for 105mm ammunition for accomodating at least 32 rounds.
(16 rounds on either side of fuel tank)

(f) Removal of existing hatch and seat behind the driver and using this opening for placing the batteries into new location.

(g) Replacement of old fenders by extra large new fenders.

(h) Removal of troop seats, firing port on left and right hand side walls and existing fuel tank.

(j) Relocation of bty compartment to the front at the stick seat behind the driver.

(k) Relocation of air intake mechanism of the engine.

(l) Relocation of the second bilge pump.

Recoil Force Analvsis

22. The maximum recoil force at the instant of firing is transmitted from the gun tube through the recoil system to the trunnion bearings. Through the bearings the load passes through the turret, turret race, the hull, suspension and to the ground. The force is calculated by equating the kinetic energy of the gun recoiling masses to the work done in stopping the recoiling portions during the recoiling length. [4]

23. An empirical relationship for the mean recoil force F mean is as under :-

Force is the rate of change of forward momentum.

(a) Let mean trunnion pull = F
(b) Mass of profectile = m
(c) Mass of propellant = m'
(d) Mass of recoiling parts = M
(e) Velocity of recoiling parts = V
(f) muzzle velocity of shot = u
(g) length of recoil = L

Forward momentium = (m+m')u
Rearward momentium = MV

For stability :

$$MV = (m + m')v$$

$$V = \frac{(m + m')v}{M}$$

Kinetic energy of recoiling parts = $\frac{1}{2} MV^2$

$$KE = \frac{1}{2} M \left[\frac{(m+m')v}{M}\right]^2$$

$$K.E = \frac{(m + m')^2 v^2}{2M}$$ Emergy absorbed by recoiling parts.

work done = Force X distance

$$\frac{(m + m')^2 v^2}{2M} = F \times L$$

$$F = \frac{(m + m')^2 v^2}{2ML}$$

Max Trunnion pull = 1.25 X Mean Trunnion pull

F max = F X 1.25

For the 105mm TGG gun the values are

V = 1450 m/s
m = 5.62 kg
m' = 5.10 kg
M = 1080 kg
L = 615 mm or 0.615m

$$F = \frac{(m + m')^2 \, v^2}{2ML}$$

$$F = \frac{(5.62 + 5.10)^2 \, (1450)^2}{2 \times 1080 \times 0.615}$$

F = 181884.93 N or 180 KN

F max = 1.25 X F

F max = 1.25 X 180

F max = 225 KN

24. Once the recoil forces are calculated or known the stability, firing loads and vibration of the hull at the instant of firing all depend directly on the magnitude of the maximum recoil force. The recoil force value should be kept as low as possible.

25. The specifications of BMP-2 with new turret and gun would be as follows:-

Combat mass	-	16.5 tons
NGP	-	0.8 kg/cm^2
Turret	-	105 mm TGG turret ex. GIAT, France
	-	light Al alloy armour
	-	Ballilstic protection of 12.7mm AP beyond 700m.
Gun	-	105mm SA LRF gun with mrzzle brake
	-	Max recoil : 615mm
	-	Max dev : -6 to +20

Amn fired	-	APFSDS
	-	HEAT
FGS	-	Computerised semi automatic LOTAC M-401 System

Parameters measured automatically :

(a) Tgt distance through LRF
(b) Horizontal & Vertical of Tgt
(c) Slant of turret

Parameters fed manually :

(a) Altitude
(b) wind
(c) Powder temp
(d) Type of amn

Gunner sight	-	M504 sight with moving reticle
Cdr sight	-	Panoramic sight
NVD	-	One LLTV with a monitor for cdr and gnr each

Design Criteria-Turret

26. It is interesting to analyse some of the problems generated by the turret as the interface between a vehicle and its armament while each armament type poses its specific design problems, some problems are applicable to all ICV/AIFV turret Systems, these are :

(a) One man turret not suitable for 90mm and higher calibre guns which necessitate a two-man crew.

(b) Two man turret the commander has a total field of view and can override the gunner for all combat functions. This entails higher costs and greater dimensions.

(c) External mounted missile systems - crew must leave the protection of the armour envelop and be exposed to enemy fire in order to reload the launchers.

(d) Externally mounted higher calibre guns would require complex and expensive auto loader. Weapon malfunction forces the gunner to leave the turret to fix it.

(e) Size of turret ring must remain within given limits. For AIFVs in the 7-12t range, turret manufactures have settled for 1.4m diameter while above 12t ring diameters of 1.6m or more can be adopted.

(f) The ergonomy and case of access are important factors - loaders comfort being routinely sacrificed to ordnance loading. The geometry of feed/efection tray is also a critical factor.

(g) A point of equilibrium between the mass of the turret and that of the powerpack must be found, not only to evenly distribute the loads on the transmission and suspension, but also to maintain a centre of gravity that will not affect its ability to float.

(h) The bore axis must coincide with the turret's rotation axis in order to avoid parasitic torque (creep) which would affect the systems reliability and life.

(j) The vehicle should maintain troop carrying capacity. Thus it is usually impossible to freely use the available internal volumes to accomodate ancillaries.

(k) Combat performance offered by the weapon system.

(l) Compromise between the turret basket, the amount of ammunition storage and the troop carrying capacity of the hull.

(m) The problem of mass, not so much by the mass of the weapon and ancillary equipment but rather by the weight of the ballistic protection for the crew.

(n) Turrets where recoil forces generate considerable stresses, that the turret and the vehicle must absorb or it would lead to firing inaccuracies and recoil forces could topple the vehicle in side slope.

(o) Applique armour plates being used on turrets to increase protection adds to weight penalty and problems with the turret servos not designed with a large power reverse margin. Light alloys for both the main armour and the add on plates offer some solution.

(p) The demand for a powerful fume extractor to expel the poisonous gases means installing a fan with a capacity of 8Ø-1ØØ litres/second which adds to further demands on the turret.

(q) NBC protection provided by keeping a slight over pressure inside the fighting compartment entails particular care in the design and manufacture of the different components of the turret mounting ring.

(r) Turret traversing and elevating of the main armament was being done by hydraulic servos. Electro mechanical servos have become much more attractive in performance, dimensions and even cost adding further strains in the turret design.

(s) To engage ground to air fast moving targets, high speeds and accelerations in both traverse/elevation are needed. Current electric servos work on 24V DC, allow traverse speed in the region of 60/s and elevation accelerations of between 3.5 to 4 mil/s. The trend is towards higher tension electric motors or a higher power output.

(t) Positioning of the sight is a complex issue which influences the arrangement of the aiming controls which must then be harmonised with the episcopes.

(u) Adoption of LRF and thermal imagers or stabilisation devices for the main armament are becoming a commonly incorporated feature to have the state of art fire control system. This further taxes the turret.

(v) The requirement of ballistic computer for accurate data, provided by different captors and sensors adds to the turrets strain.

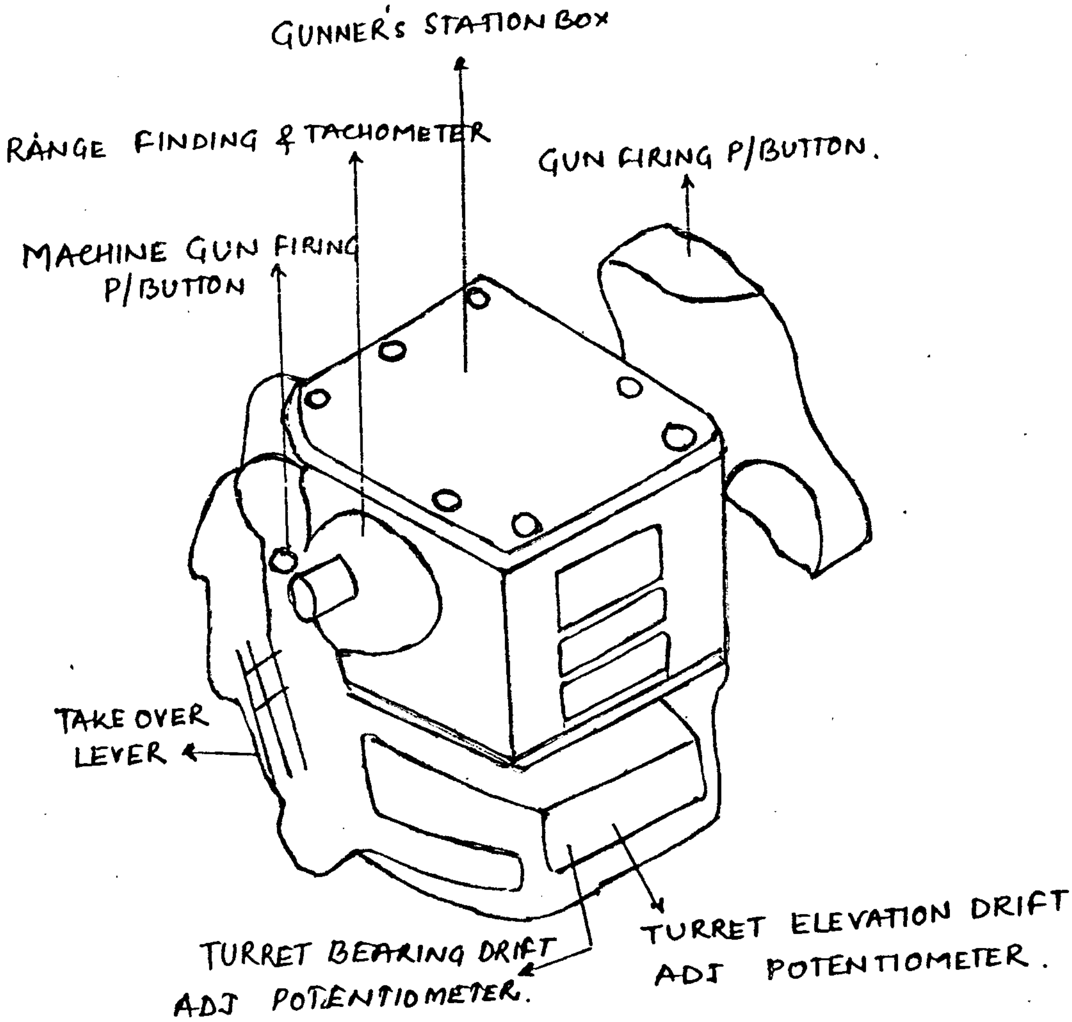
(w) Two axis stabilisation systems are adopted for ICVs to compensate for vehicle movements in roll and pitch.

(x) Turrets equipped with a 90mm or higher calibre gun needs above all, to have stabilised sights with the barrel slave to them in elevation, while missile turrets and dual purpose cannon turrets need complete stabilisation, provided either by a two axis gyro associated to the main armament and backed by rate gyros mounted in both the hull and turret or by a gyro stabilised sight with slaved armament. [18]

SOFMA 105 mm TGG turret

27. Having seen the Characteristics and the problems that can be encountered while designing a turret, let us go through the characteristics of the turret intended to replace the BMP-2 turret.

28. Manufactured by SOFMA industries, a concern of GIAT, of France, this turret is made of light aluminum alloy and weighs 4400kg. It has a ballistic protection against 12.7mm AP rounds all over. It mounts a 105mm low recoil force gun and has a 7.62mm Machine gun co-axially fitted as its secondary armament. It has a three man crew, namely cdr,



(FIG 1) GUNNER'S CONTROL HANDLE

gunner and loader. Four smoke grenades are located to the rear of the turret two on each side. Out of the 42 main gun rounds 10 rounds are stored in the turret. The balance are kept in the ammunition compartment.

29. The various units are :

(a) Gunner's station.

(i) Fire control handle (Fig 1)

(aa) Gunner's station box.
(ab) Gun firing push button.
(ac) Machine gun firing push button.
(ad) Range finding and tachometric measurement potentiometer.
(ae) Take over lever.
(af) Turret elevation drift measuring adjustment potentiometer.
(ag) Turret bearing drift measuring adjustment potentio meter.

30. <u>Gunner's Control</u> :

(i) Gunner's control panel.
(ii) Gunner's sight M 504.
(iii) LLTV monitor.
(iv) BTCM low voltage firing apparatus box for emergency firing.

(b) Tank commander's station.

(i) Control handle. (Fig 2)

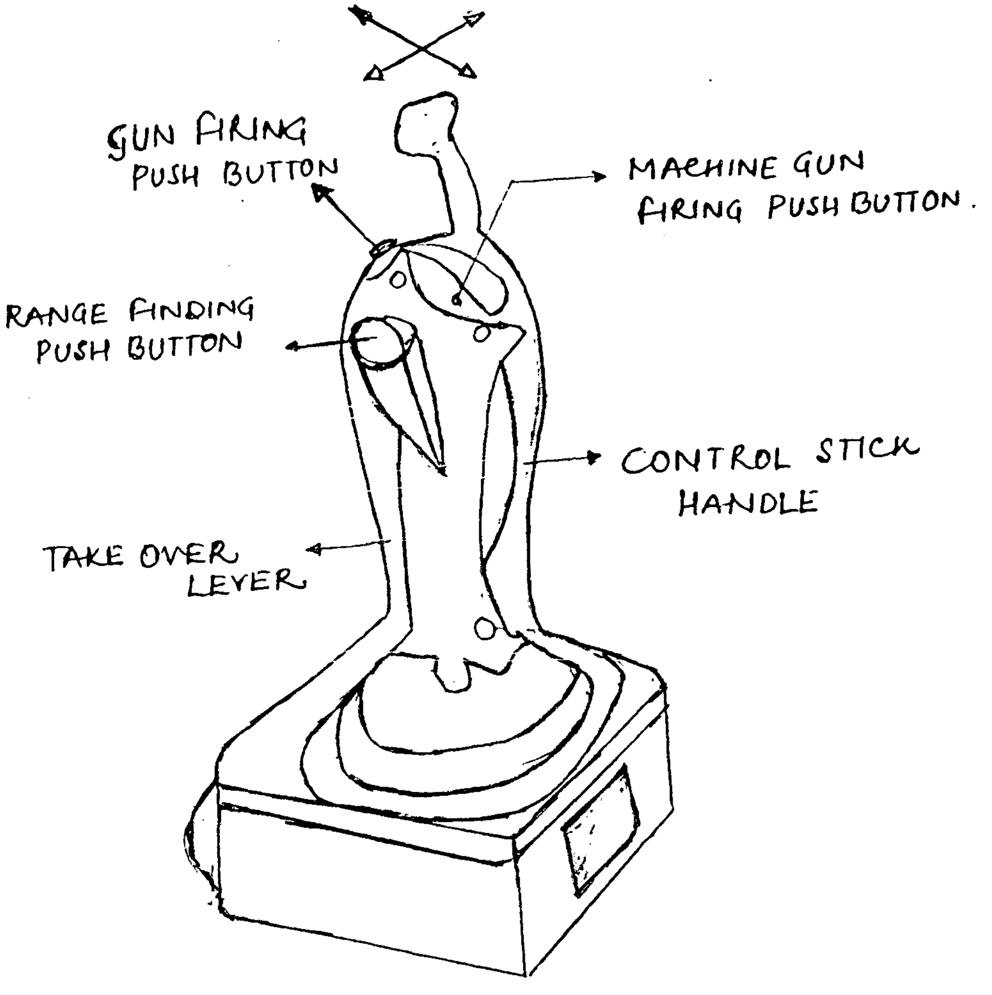
(aa) Gun firing push button.
(ab) MG firing push button.
(ac) control stick handle.
(ad) Take over lever.
(ae) Range finding push button.

(ii) Control panel.
(iii) Manual display of certain FCS parameters.
(iv) LLTV monitor.
(v) Sight M 389.

(c) Hydraulic unit.

(i) Tank or reservoir - capacity 25 litres.
(ii) Electro pump set - a self regulating pump.
(iii) Hand pump - emergency use.
(iv) Servo motor - intake and brake valves and motor.
(v) Actuator assembly.

COMMANDER'S CONTROL HANDLE (FIG 2)



(d) Electrical equipment.

(i) Ballistic processor - This is the heart of the FCS control. It works out all calculations and accordingly sends out correction to the sights. The GCE is connected through this system to the sight.

(ii) Function box No 1 - contains various circuit breakers.

(iii) Logic box - provides turret logic functions.

(iv) Hydraulic system electronic unit - controls elevation and azimuth servo valves either by :

(aa) Joy sticks

(ab) Cdr's sight

(ac) Tachometer.

(v) Range processor - Computer all data affecting firing.

(vi) Tachometer unit - Measures gun's angular displacement in elevation and turret's in azimuth.

(e) Loader's station.

(i) Control panel - it operates certain turret functions and provides relevant displays.(Fig 3)

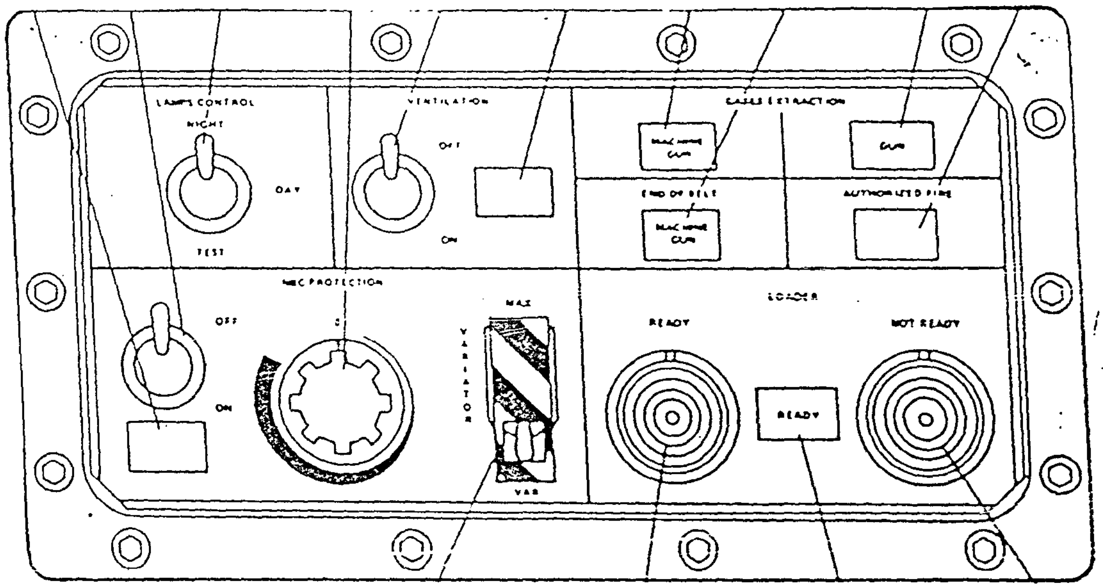
(aa) Loader ready/Not ready light.
(ab) Loader ready/Not ready push button.
(ac) End of belt (MG) light.
(ad) Ventilation on/off switch and light.
(ae) Gas extraction lights.
(af) NBC indicator/Protection light and switch.

(f) Suction and extraction for gases due to firing.

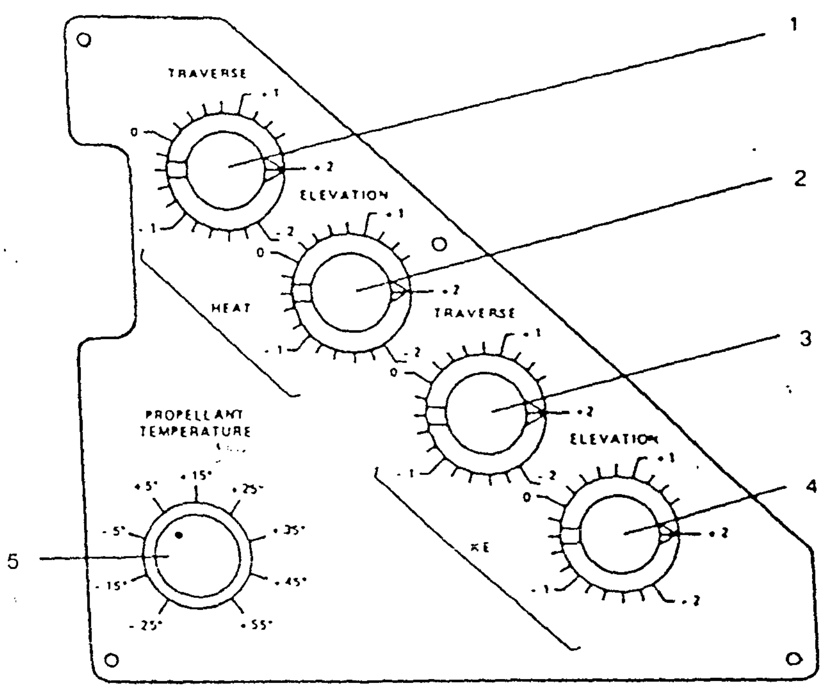
(g) Turret ventilation system - located in turret rear which is connected to the air supply system/NBC system on the BMP chassis.

(h) Propellant temperature control unit - for HEAT and KE rounds traverse and elevation setting switches to feed in reading or shooting in readings. There is also a propellant temperature setting switch.(Fig 4)

LOADER'S CONTROL PANEL (FIG 3)



PROPELLANT & TEMP CONTROL UNIT (FIG 4)



1 - TRAVERSE setting switch for HEAT round

2 - ELEVATION setting switch for HEAT round

3 - AZIMUTH setting switch for KE round

4 - ELEVATION setting switch for KE round

5 - PROPELLANT TEMPERATURE setting switch

31. **Optics**

(a) **Gunner's sight**:- The gunner has a M 504 telescopic sight with moving reticules. It caters for APFSDS and HEAT ammunition firing. There is a laser range finder incorporated in this sight. This sight is used for

(i) Observations during or before firing.
(ii) Fire in the FCS mode.
(iii) Fire outside FCS mode.
(iv) Fire in emergency mode.

(b) **Commander's sight**:- The commander has a panoramic sight designated M 389. It comprises of (Fig 5)

(i) The upper revolving section consisting of

(aa) the sight firing ring.
(ab) revolving gasketed collector.
(ac) azimuth locking mechanism.
(ad) Prism rotation mechanism.

(ii) The sight electronics consisting of

(aa) electronics processing boards.
(ab) sight counter rotation mechanism.
(ac) Emergency battery.

32. **Operating Modes**:- Known as the LOTAC type fire control system. This system has three modes :-

(a) Observation mode - done by commander.(Fig 6)

(i) Telescope is on " free lock".

(ii) No take over - whichever direction the joystick is rotated, the sight will rotate in that direction.

(b) Target designation mode.

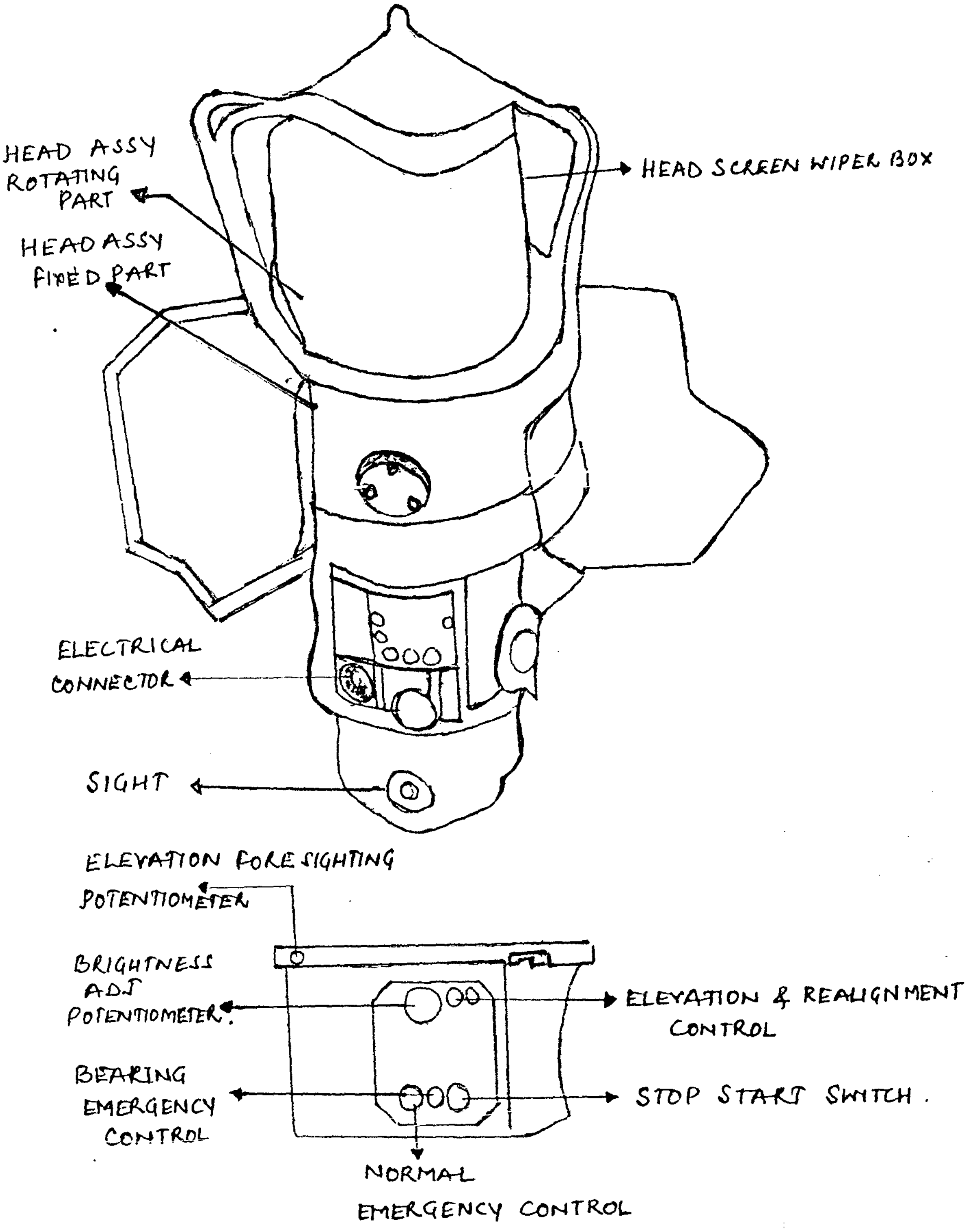
(i) Commander acquires target.

(ii) Puts telescope on "friction lock" with take over.

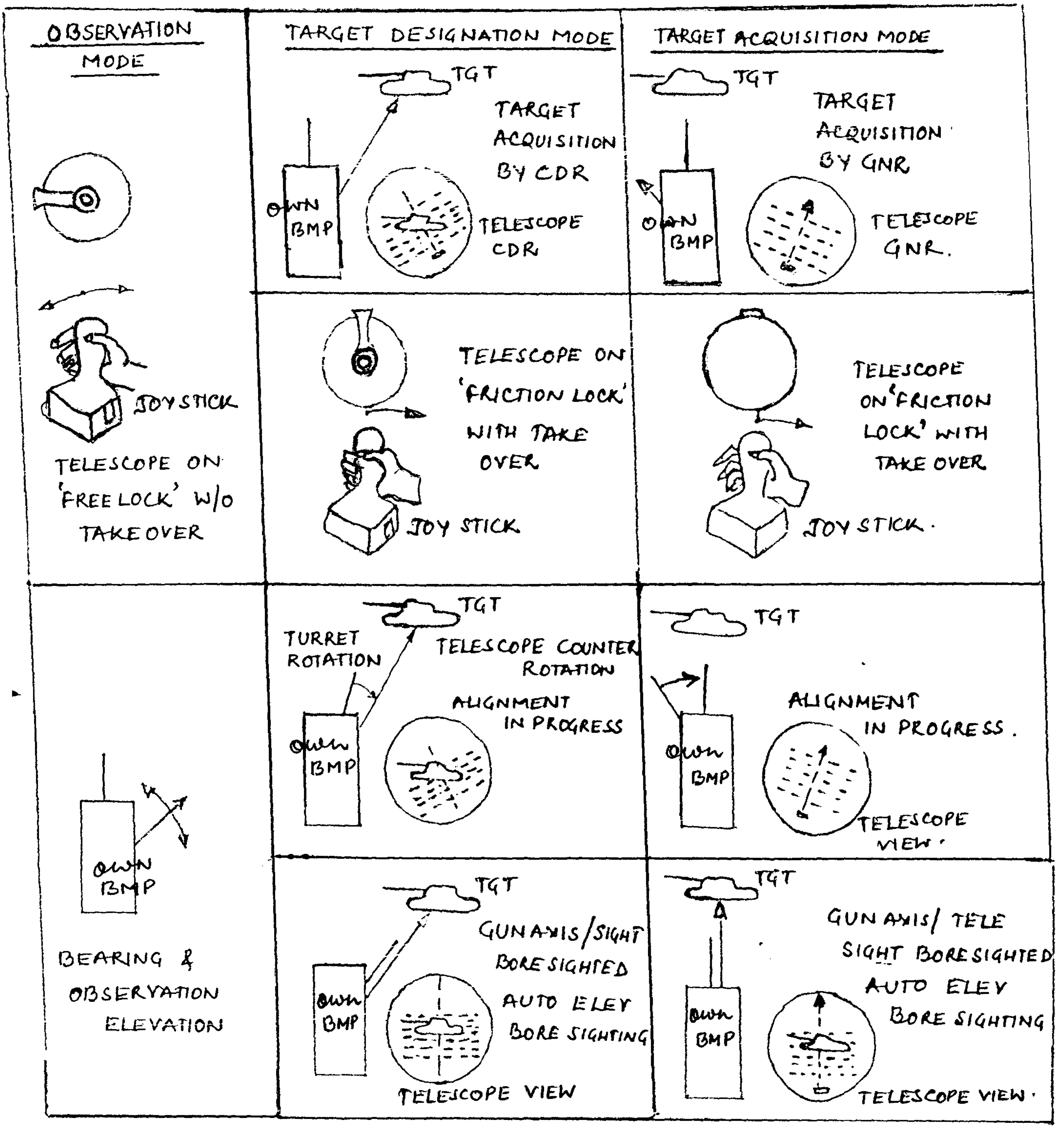
(iii) Turret rotates, telescope counter rotates and aligns.

(iv) Gun axis and telescopic sight bore sighted.

(v) Automatic elevation boresighting takes place. when the sight lines up in azimuth, the three horizontal dots on the micrometer come on. When the gun repeats, the sight elevation angle,automatically, the three vertical points come on. The gun can now be fired using the fire control system or without fire control system.



COMMANDER'S PANORAMIC SIGHT (FIG 5)



COMMANDER'S TELESCOPE OPERATING MODE (FIG 6)

(c) Target acquisition mode.

(i) Target acquisition done by gunner.
(ii) He informs commander by interphone.
(iii) Puts telescope on 'friction - lock' without take over.
(iv) Commander operates his sight in azimuth and brings the arrow in his sight to a vertical position.
(v) Once sight lines up in azimuth, the three horizontal lines come on.
(vi) Elevation alignment of the sight automatically repeats gun elevation angle.
(vii) The vertical points on the micrometer come on. Gun can now be fired using the fire, control system or without the fire control system. [1]

Micrometer

33. To avoid disorientation of the commander due to the rotating panoramic sight, there is present in the sighting graticule pattern, the use of micrometer arrow symbology. This arrow symbolizes the gun position in relation to the commander's sight. Also when gun axis and sight are boresighted, the elevation and azimuth bore sighting points light up. (Fig 7)

LOW LIGHT TV UNIT

34. This unit (Fig 8) is designed for nightime firing against stationary or mobile targets at a range of about 100 - 1000m. The firing reticule of the analysis box is boresighted with respect to the centerline of the gun. It is a fully passive unit and hence fully undetectable & unjammable. The unit can also be used in daylight, even in full sunlight. It can therefore replace the sights M 389/M 504 if needed. This unit, therefore enables:

(a) boresighting procedure at anytime.
(b) uninterrupted combat operation at nightfall and at sunrise - first and last light.
(c) can be operated by a single operator.

The primary parts of this system are :-

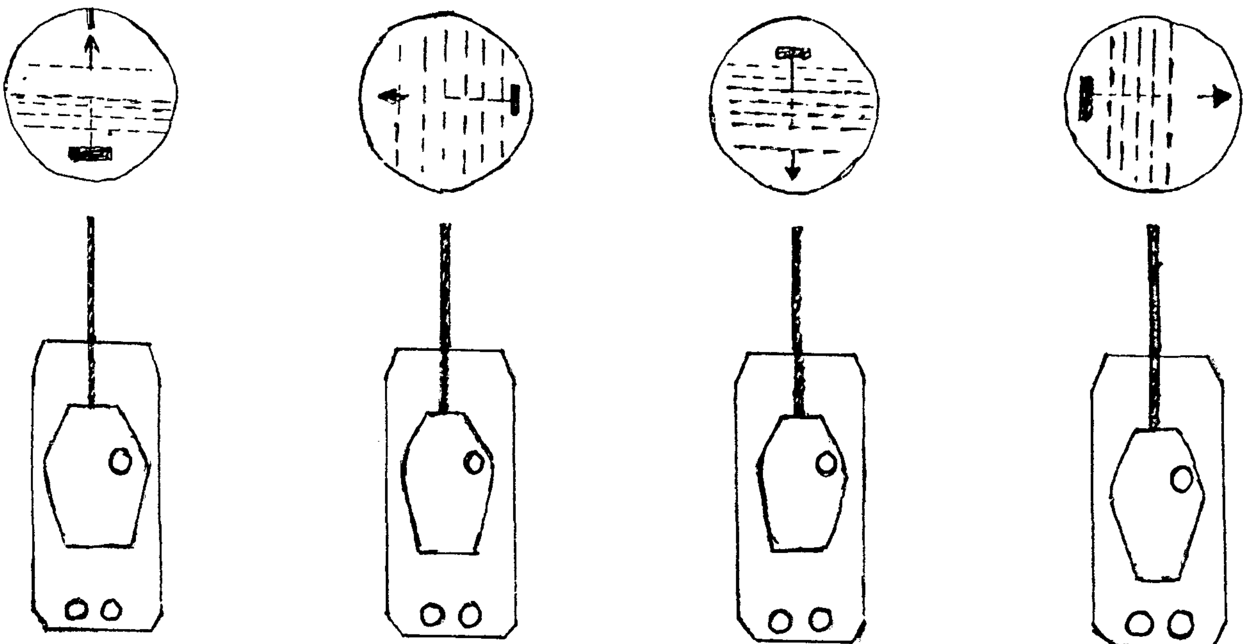
(a) The analysis box (camera) :

(i) Installed inside the turret and attached to the mantlet, left of the gun with four bolts.
(ii) connected to the control box.

(b) Control box :

(i) installed in tank commanders station.
(ii) connects the analysis box, TV monitors, the fire control system and the power supply.

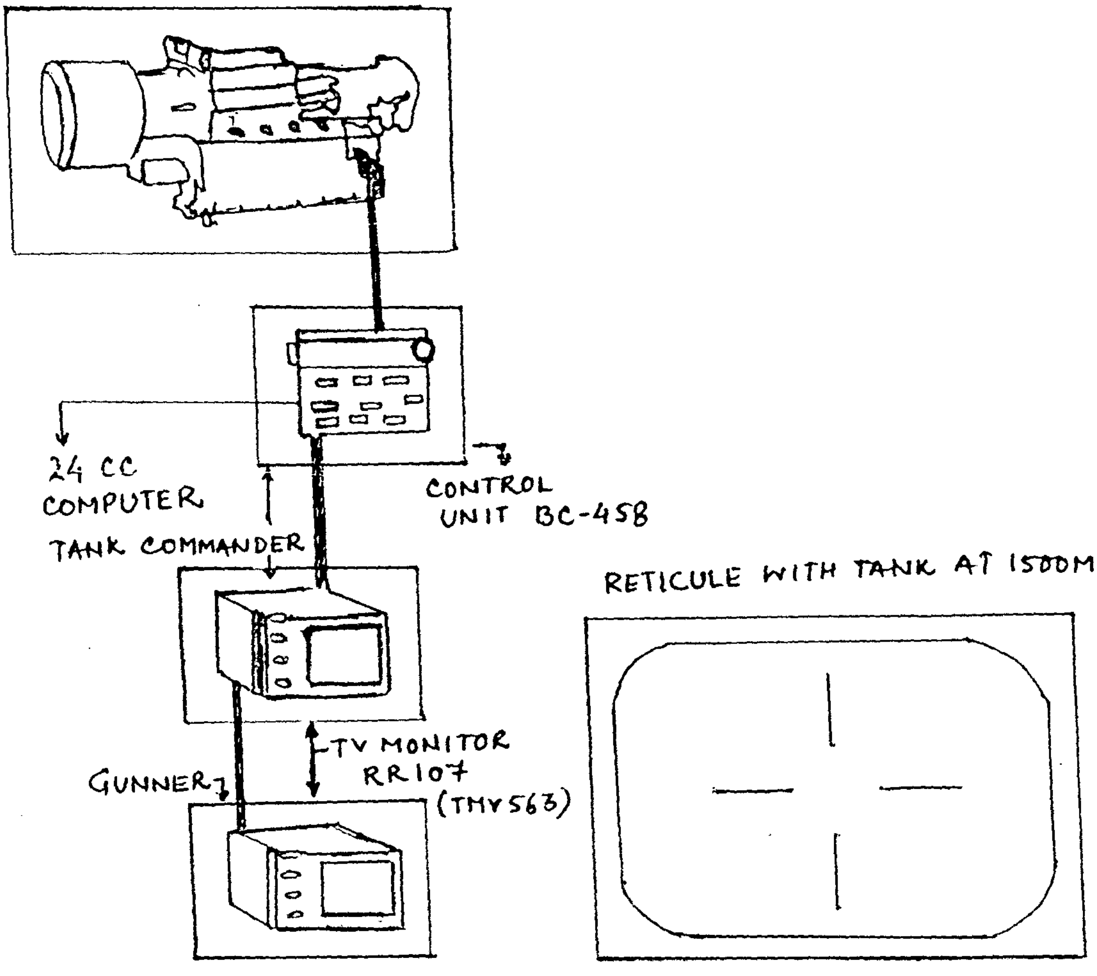
(ARROW SYMBOLIZES GUN POSITION RELATIVE TO COMMANDER'S TELESCOPE)



TELESCOPE AT 12 O'CLOCK | AT 3 O'CLOCK | AT 6 O'CLOCK | AT 9 O'CLOCK

COMMANDER'S TELESCOPE MICROMETERS (FIG 7)

LLTV UNIT (FIG 8)



(c) TV monitors :

(i) Two in number, one for commander & another for gunner.
(ii) 11 cm screen.
(iii) Displays sight picture and enables sighting & aiming during engagements.

35. **Range**:- The range of this system depends on three factors.

(a) Illumination - moon or dark night, cloudy or clear.

(b) Atmospheric Transparence : mist or no mist, rain. Due to long range of the system, even slight mist or rain affects its performance tremendously.

(c) Contrast between target and background. With average contrast and good transparency the range is :-

(i) 1000m to 1500m in dark conditions (no moon, starry sky and 10 - 3 lux illumination).

(ii) 1500 to 2000m in a clear night with moon and when operating in daylight.

(iii) During cool and moist nights, with temperatures between 5 and 10 degree centigrade, mist and fog are almost Omnipresent. The slightest mist shall cause the range of the system to drop quickly and in the event of thick fog, it shall become very small. Also with no moon or heavy cloud cover, range is very small.

36. **Detection**:- The unit can detect at ranges in excess of 2000m.

(a) Interior turret lights.
(b) Glow of a cigarette.
(c) IR driving lights.
(d) Moon reflections on periscopes, window panes or body paint.

37. **Firing**

(a) Aiming mark is a simple electrically generated reticle in the shape of a cross.

(b) Position of the reticle is controlled by firing computer.

(c) Positional accuracy is 0.25m.

(d) Once a target is sighted, the reticle is aligned to it by use of gun controls and the round is fired.

(e) When a round is fired, the camera blanks for 1/2 second which presents blinding of the crew by the muzzle flash and helps in observation of the fall of shot.

38. **Drawbacks**

(a) The effective range varies according to environmental conditions.

(b) Slightest amount of mud or water on optics reduces range.

(c) System cannot see through fog.

(d) Dazzling takes place when a source of light is viewed head-on(even moon).

FIRE CONTROL SYSTEM :-

39. The FCS incorporated is a " LOTAC" type computerised semi - automatic fire control system.

Components and operation :

(a) LRF - rg from 320m to 10000m

(b) Commanders control panel which has manual inputs for :

(i) Altitude
(ii) Wind
(iii) Temperature - air and charge both
(iv) Type of ammunition

(c) Gunner's telescope & Commanders telescope.

(d) LLTV unit.

(e) Gun control handles.

(f) Sensors.

(i) Slant sensor

(ii) Elevation sensor

(iii) Bearing sensor

(g) Tachometer box

(h) Deviation computing box(ballistic computer).

(i) Electronics - hydraulics box

(j) Elevation and bearing servo valves

(k) Logic box.

THE TGG 105mm GUN

40. The main armament (Fig 9) of the BMP would be 105mm rifled gun which is 51 calibres long. It has been suitably modified to reduce trunnion pull from 48 tonnes to 15 tonnes to enable its mounting on the BMP. This modification includes incorporation of:

- (a) 2 X symmetrical recoil brakes (Fig 10)
- (b) Oleopneumatic recuperator
- (c) a single baffle muzzle brake

The length of recoil is thus increased from 300mm to 615mm. The gun has a semi - automatic breech block as is the case with the L7A1. [16]

41. **Main Characteristics** :

Total length	:	6.63m
Barrel length	:	5.347m
Recoiling mass	:	1060kg
Total weight	:	1610kg
Barrel weight	:	680kg
No of grooves	:	28
Groove angle	:	9° 54'
Centre of gravity	:	31m ahead of trunnious
Normal recoil	:	0.600m
Maximum recoil	:	0.615m

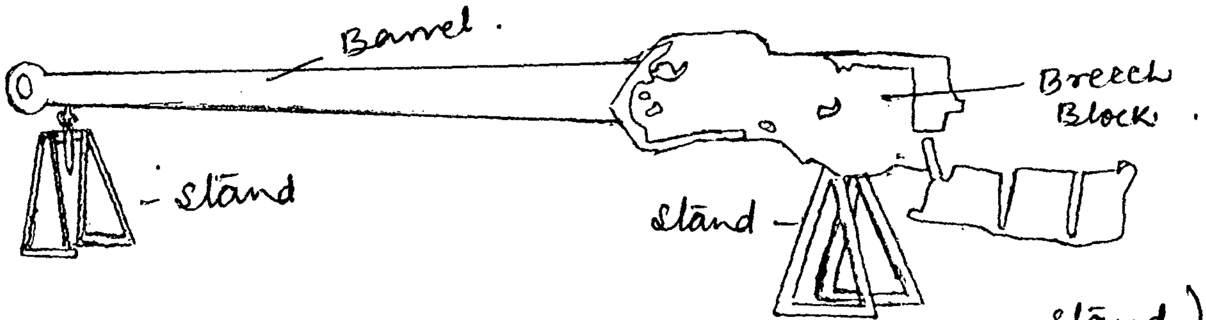
Sub assemblies

- NATO standard barrel
- Semi automatic breech with a 20° left slanted breech block
- 2 x Symmetrical recoil brakes
- Oleopneumatic recuperator
- light alloy one piece cradle
- direct anti - rotation device between barrel and cradle
- 2 x thermal jackets
- Bore baffle muzzle brake
- Electrical firing gear
- fume blower/extractor inside cradle

Performance

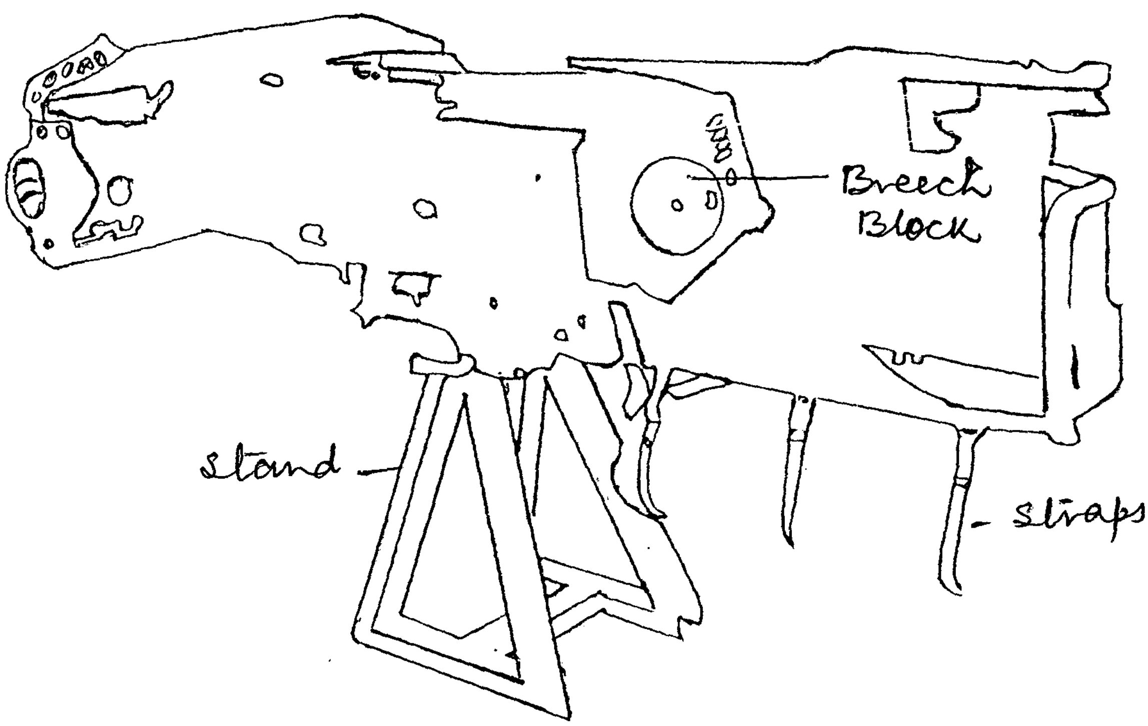
Maximum impulse	:	21,300 NS
Max impulse with muzzle brake	:	17,700 NS
Muzzle brake efficiency	:	30 to 40%
Max recoil force	:	210 KN
Firing limits azimuth	:	360
Firing limits elevation	:	-6 to 20

105 MM GUN (FIG 9)

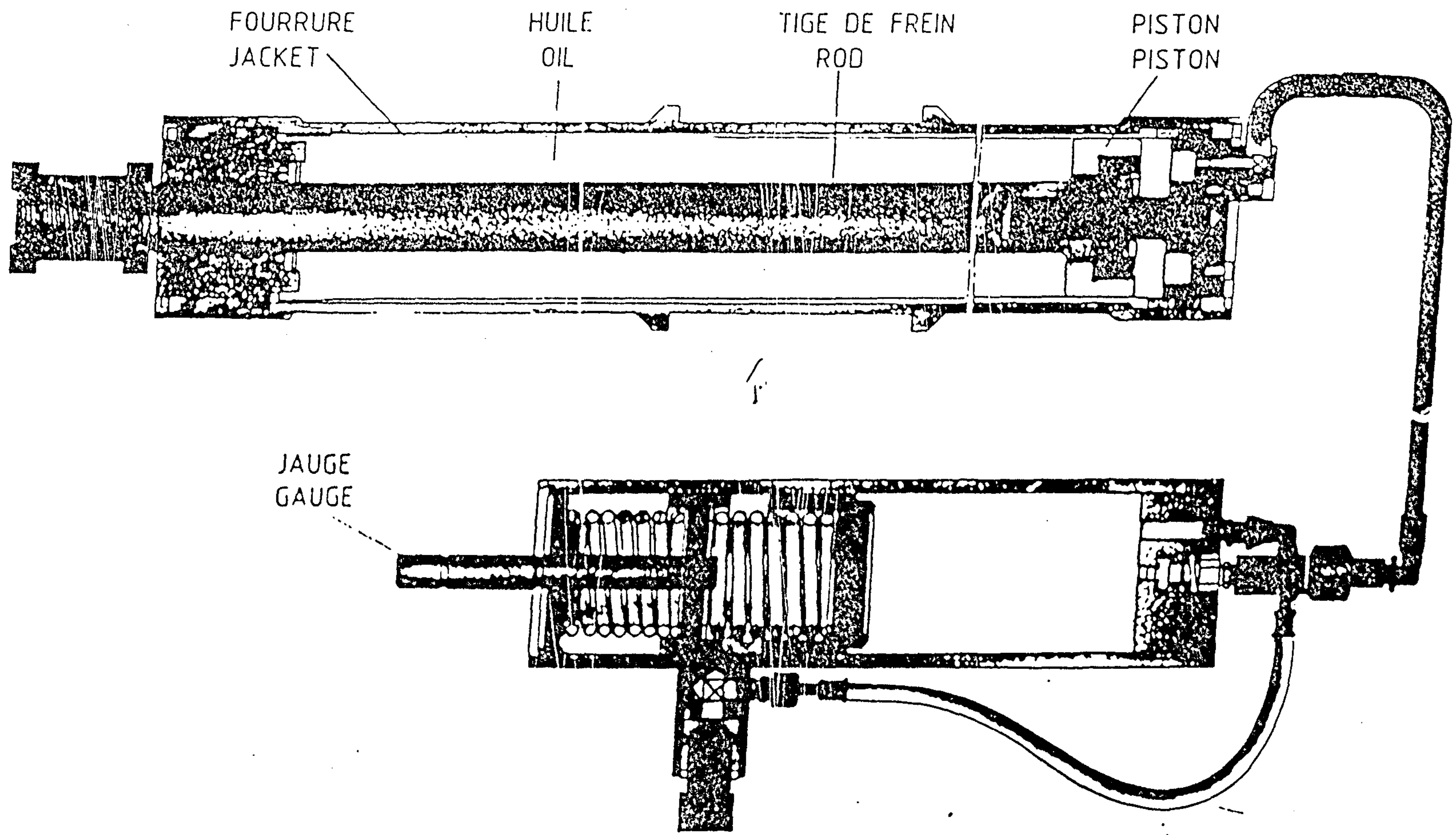


(view of the 105mm Gun mounted on stand)

[View of the Semi Automatic Breech Block of the TGG 105 mm Gun]



FIRING BRAKE AND RESPLENISHER (FIG 10)



As is therefore seen above, the main armament is as powerful as any of the existing medium battle tanks. Two types of ammunition can be fired from this gun APFSDS and HEAT rounds, we shall have to be contest with firing APFSDS rounds till such time the required HEAT rounds roll out from the production lines of our ordnance factories.

MATHEMATICAL ANALYSIS FOR STABILITY

1. Introduction. The mathematical analysis for the new configuration of upgunned BMP II system is based on a two degree of freedom model for pitch and bounce.

2. Symbols The list of symbols used in the analysis are:

(a) Mass

(i) M_B - Mass of ICV BMP II.

(ii) M - Mass of ICV upgunned BMP II.

(iii) m_{tb} - Mass of ICV BMP II turret

(iv) m_{tT} - Mass of the new turret system.

(v) m_p - Mass of the projectile.

(vi) m_c - Mass of the charge.

(vii) M_r - Mass of the complete round.

(viii) m_s - sprung mass of the upgunned BMP.

(ix) m_r - Mass of the recoiling parts.

(b) Length.

(i) h_{cg} - height of cg above ground level

(ii) h_t - height of trunnion above ground level.

(iii) d_t - distance of trunnion from turret centre in the horz plane

(iv) l_r - length of recoil.

(v) P_i - dist of ith bogie wheel from cg along horz plane.

(vi) d_i - vertical deflection of the ith bogie wheel.

(vii) x - vertical deflection of the cg.

(viii) S - distance travelled by the veh before toppling.

(ix) S_r - distance travelled by recoiling parts to achieve vel V_r.

(x) B - Width of BMP II over tracks.

(c) Angles.

(i) β - Side slope angle.

(ii) γ - gun depression angle.

(iii) θ - angular deflection of cg of vehicle.

(d) Forces.

(i) F - Trunnion pull (with muzzle brake)

(ii) F_{max} - Max trunnion pull.

(e) Constants

(i) K - spring constant of each torsion bar.

(ii) c - damping coeff of each damper.

(iii) g - acceleration due to gravity.

(iv) FOS - Factor of safety.

(v) η - efficiency.

(f) Velocity.

(i) V - Muzzle velocity

(ii) V_r - recoil velocity.

(iii) V_c - velocity of veh in curved path.

(iv) V_v - final veh velocity after toppling.

(g) Accelerations

(i) a_v - Min acceleration reqd to topple the veh.

(ii) a_r - Acceleration reqd to increase the velocity of recoiling parts to V_r

(h) Time

(i) t - time elapsed since firing of the gun.

(ii) t_f - time for which F is acting

(iii) t_{ar} - time reqd to accelerate recoiling parts to vel V_r

(iv) tv - Max time reqd to topple the vehicle.

(j) Energy.

(i) E - recoil energy.

(ii) E_m - net recoil energy with muzzle brake.

(k) Couples.

(i) C_o - overturning couple.

(ii) C_s - Stabilising couple.

(iii) I_c - impulsive couple.

(l) Miscellaneous

(i) I - Moment of inertia of veh about traverse axis.

3. Schematic representation of BMP II configuration showing the veh in a two degree of freedom model for pitch and bounce is shown in fig 11.

4. Assumptions

(a) For simplicity sake, this analysis is based on a two degree of freedom model for pitch and bounce.

(b) The vehicle is assumed to be static and there is no input from the grnd.

(c) The height of cg does not vary with the change in turret configuration.

(d) The location of cg does not vary with the change in turret configuration.

P_1 – Horizontal distance between CG of the BMP and the 1[st] Bogie wheel Centre
P_2 – " " " BMP " " 2[nd] Bogie wheel "
P_3 – " " CG " BMP " " 3[rd] " " "
$P_4/P_5/P_6$ – Horz distances between CG of the BMP & the 4[th], 5[th] & 6[th] Bogie wheel centres. resp.

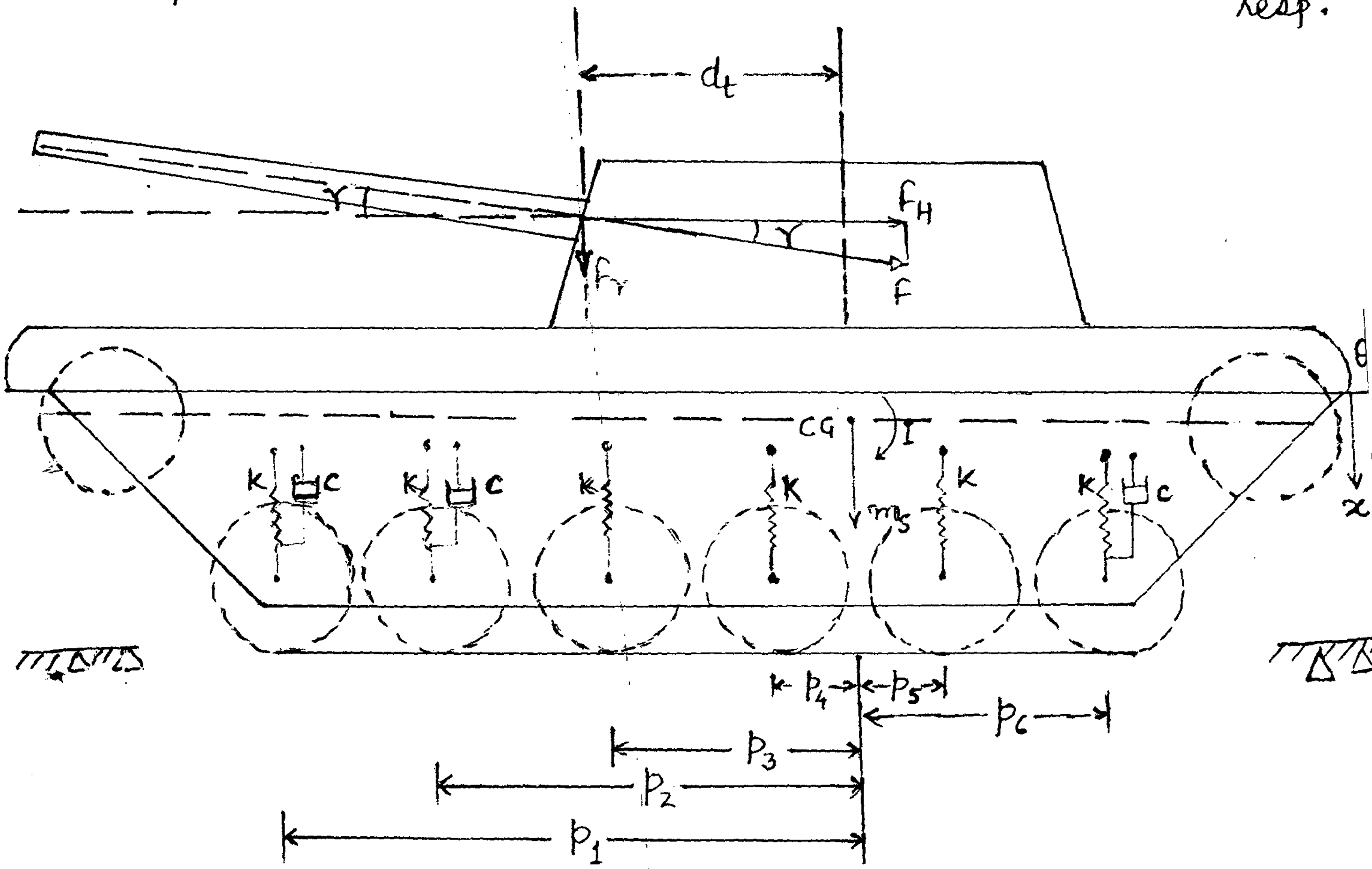


FIG 11

SCHEMATIC LAYOUT OF BMP II UPGUNNED

SHOWING LOC OF SPRINGS AND DAMPERS

(NOT TO SCALE)

DYNAMIC RESPONSE OF THIS SYSTEM ON FIRING OF THE WPN.

5. Mathematical Analysis.

(a) Bounce Mode. The second order differential equation for the model, when the gun is fired is given by:

$$m_s \ddot{x} = -2K[6x + \theta(P_5 + P_6 - P_1 - P_2 - P_3 - P_4)] - 2c[3\dot{x} + \dot{\theta}(P_6 - P_1 - P_2)] + f \sin\beta.$$

$$m_s \ddot{x} = -6c\dot{x} - 2c\{(P_6 - P_1 - P_2)\dot{\theta}\} - 12Kx - 2K(P_5 + P_6 - P_1 - P_2 - P_3 - P_4)\theta + f \sin\beta.$$

The values of various constants are as follows:

$c = 7141$ N s/m

$K = 68303$ N/m

$P_1 = 2.132$ m

$P_2 = 1.472$ m

$P_3 = 0.812$ m

$P_4 = 0.152$ m

$P_5 = 0.588$ m

$P_6 = 1.328$ m.

Let $-\dfrac{6c}{m_s} = b_1.$

$$-\frac{2c(P_6 - P_1 - P_2)}{m_s} = b_2$$

$$\frac{-12K}{m_s} = b_3$$

$$\frac{-2K\,(P_5 + P_6 - P_1 - P_2 - P_3 - P_4)}{m_s} = b_4$$

$$\frac{f \sin\beta}{m_s} = b_5$$

$$\therefore \quad \ddot{x} = b_1 \dot{x} + b_2 \dot{\theta} + b_3 x + b_4 \theta + b_5 \qquad \ldots\ldots (1)$$

(b) Pitch Mode

$$I\ddot{\theta} = 2K[(x - P_1\theta)P_1 + (x - P_2\theta)P_2 + (x - P_3\theta)P_3 + (x - P_4\theta)P_4$$
$$-(x - P_5\theta)P_5 - (x - P_6\theta)P_6] + 2c[(\dot{x} + P_1\dot{\theta})P_1 + (\dot{x} - P_2\dot{\theta})P_2$$
$$-(\dot{x} - P_6\dot{\theta})P_6)] + f\cos\beta(h_t - h_{cg}) - f\sin\beta(d_t)$$

$$= 2K[x(P_1 + P_2 + P_3 + P_4 - P_5 - P_6)] - \theta\,(P_1^2 + P_2^2 + P_3^2 + P_4^2 + P_5^2 + P_6^2)]$$
$$+2c[\dot{x}(P_1 + P_2 - P_6) - \dot{\theta}(P_1^2 + P_2^2 - P_6^2)] + f[(h_t - h_{cg})\cos\beta$$
$$-d_t \sin\beta]$$

$$= x[2K(P_1 + P_2 + P_3 + P_4 - P_5 - P_6)] - 2c(P_1 + P_2 - P_6)\dot{x} - 2K(P_1^2$$
$$+ P_2^2 + P_3^2 + P_4^2 + P_5^2 + P_6^2)] + 2c(P_1^2 + P_2^2 - P_6^2)\dot{\theta} - F[(h_t - h_{cg})$$
$$\cos\beta - d_t \sin\beta]$$

$$\theta = d_1 x + d_2 \theta + d_3 x + d_4 \theta + d_5 \qquad \ldots\ldots (2)$$

where $d_1 = \dfrac{2c(P_1 + P_2 - P_6)}{I}$

$$d_2 = \frac{2K(P_1 + P_2 + P_3 + P_4 - P_5 - P_6)}{I}$$

$$d_3 = -\frac{2c(P_1^2 + P_2^2 - P_6^2)}{I}$$

$$d_4 = -\frac{2k(P_1^2 + P_2^2 + P_3^2 + P_4^2 + P_5^2 - P_6^2)}{I}$$

$$d_5 = \frac{f}{I}\left[(h_t - h_{eq})\cos\beta - d_t \sin\beta\right]$$

(c) We are now left with two equations

$$\ddot{x} = b_1\dot{x} + b_2\dot{\theta} + b_3 x + b_4\theta + b_5$$

$$\ddot{\theta} = d_1\dot{x} + d_2\dot{\theta} + d_3 x + d_4\theta + d_5 \quad \text{------ (3)}$$

Lets make substitutions to solve these equation

i.e, Let $\dot{x} = z \Rightarrow \ddot{x} = \dot{z}$

and $\dot{\theta} = y \Rightarrow \ddot{\theta} = \dot{y}$

Substituting these in (3), we get

$$\dot{z} = b_1 z + b_2 y + b_3 x + b_4\theta + b_5$$

$$\dot{y} = d_1 z + d_2 y + d_3 x + d_4\theta + d_5$$

$$\dot{x} = z$$

$$\dot{\theta} = y \quad \text{---------- (4)}$$

Integrating these equation wrt 't' in the limit '0' & 't', we get

$$z = b_1 zt + b_2 yt + b_3 xt + b_4\theta t + b_5 t \quad \text{------ 5(a)}$$

$$y = d_1 zt + d_2 yt + d_3 xt + d_4\theta t + d_5 t \quad \text{------ 5(b)}$$

$$x = zt \quad \text{---- 5(c)}$$

$$\theta = yt \quad \text{----- 5(d)}$$

Substituting the values of 'x' and 'θ' from equation 5(c) and 5(d), we get

$$\begin{cases} z = b_1 zt + b_2 yt + b_3 t(zt) + b_4 t(yt) + b_5 t \\ y = d_1 zt + d_2 yt + d_3 t(zt) + d_4 t(yt) + d_5 t. \end{cases}$$

$$\Rightarrow \begin{cases} y = (d_2 t + d_4 t^2) y + (d_1 t + d_3 t^2) z + d_5 t \\ z = (b_2 t + b_4 t^2) y + (b_1 t + b_3 t^2) z + b_5 t \end{cases}$$

$$\Rightarrow \begin{cases} y(1 - d_2 t - d_4 t^2) = z(d_1 t + d_3 t^2) + d_5 t \\ z(1 - b_2 t - b_3 t^2) = y(b_2 t + b_4 t^2) + b_5 t \end{cases}$$

$$\Rightarrow \begin{cases} y(1 - d_2 t - d_4 t^2) - z(d_1 t + d_3 t^2) + d_5 t = 0 \\ y(b_2 t + b_4 t^2) - z(1 - b_1 t - b_3 t^2) + b_5 t = 0 \end{cases}$$

Solving using Kramer's method, we get

$$\frac{y}{-b_5 t(d_1 t + d_3 t^2) - d_5 t(1 - b_1 t - b_3 t^2)}$$

$$= \frac{z}{-d_5 t(b_2 t + b_4 t^2) - b_5 t(1 - d_2 t - d_4 t^2)}$$

$$= \frac{1}{-(1 - d_2 t + d_4 t^2)(1 - b_1 t - b_3 t^2) + (d_1 t - d_3 t^2)(b_2 t - b_4 t^2)}$$

$$\therefore \; y = \frac{b_5 t(d_1 t + d_3 t^2) + d_5 t(1 - b_1 t - b_3 t^2)}{(1 - d_2 t + d_4 t^2)(1 - b_1 t - b_3 t^2) - (d_1 t + d_3 t^2)(b_2 t - b_4 t^2)}$$

$$\& \; z = \frac{d_5 t(b_2 t + b_4 t^2) + b_5 t(1 - d_2 t - d_4 t^2)}{(1 - d_2 t + d_4 t^2)(1 - b_1 t - b_3 t^2) - (d_1 t + d_3 t^2)(b_2 t - b_4 t^2)}$$

Substituting these values of 'y' and 'z' into equations 5(c) and 5(d) resp, we get

$$\theta = t\left[\frac{b_5 t(d_1 t + d_3 t^2) + d_5 t(1 - b_1 t - b_3 t^2)}{(1 - d_2 t + d_4 t^2)(1 - b_1 t - b_3 t^2) - (d_1 t + d_3 t^2)(b_2 t - b_4 t^2)}\right] \quad - 6(a)$$

$$x = t\left[\frac{d_5 t(b_1 t + b_4 t^2) + b_5 t(1 - b_2 t - b_4 t^2)}{(1 - d_2 t + d_4 t^2)(1 - b_1 t - b_3 t^2) - (d_1 t + d_3 t^2)(b_2 t - b_4 t^2)}\right] \quad \ldots 6(b)$$

6. Equation 6(a) and 6(b) can be plotted on 'x' vs 't' scale and 'θ' vs 't' scale respectively.

7. This would give the dynamic response of the upgunned BMP. The shorter the time taken to stabilise, the higher is the rate of fire of the weapon.

8. The displacement achieved - linear as well as angular should be minimum so that the crew do not suffer excessive jerking, thereby leading to fatigue at a faster rate.

STABILITY ANALYSIS.

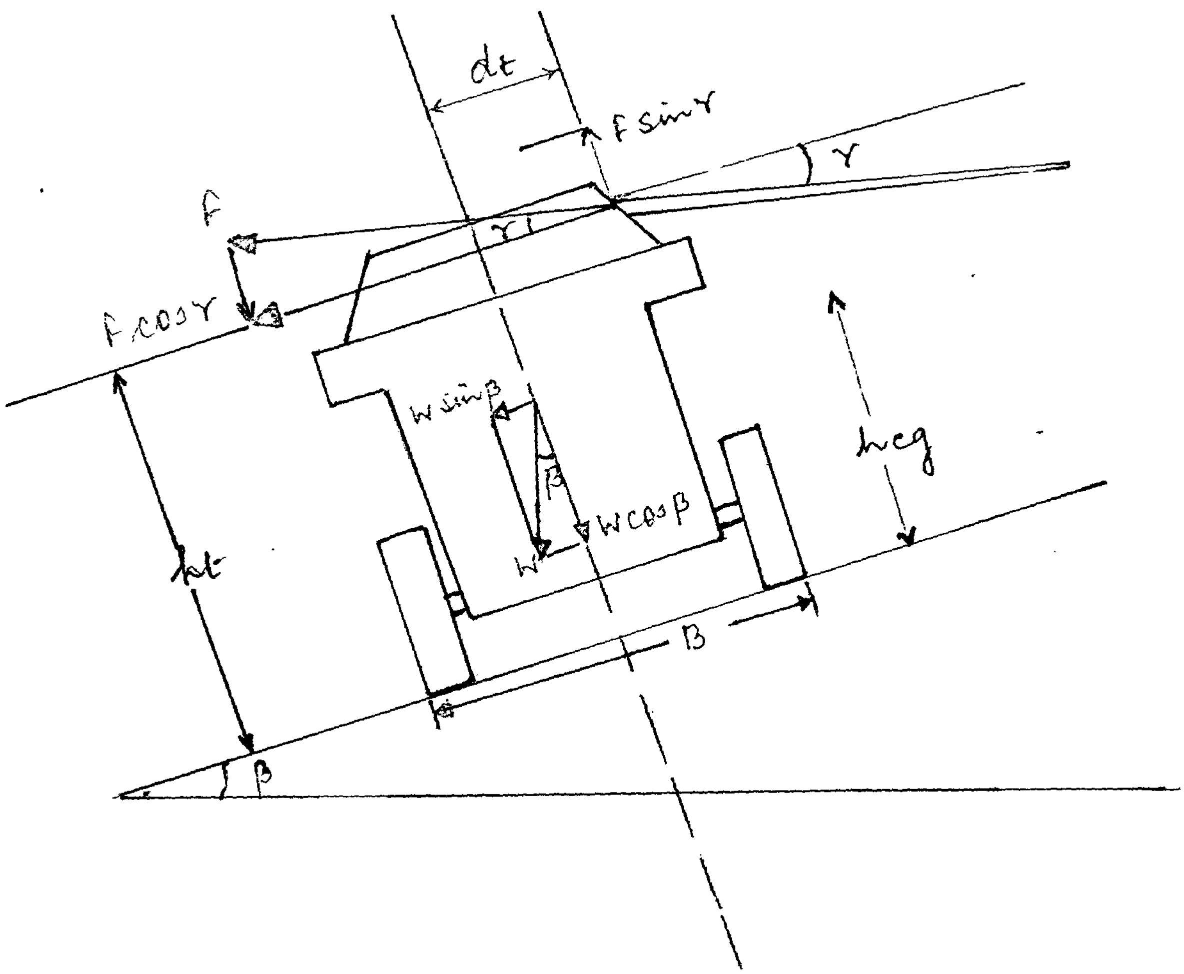
9. The Stability characterstics of the upgunned BMP when the gun is fired. Ref fig 12.

10. Calculation of Trunnion pull : Equating the momentum of the projectile with the momentum of the recoiling mass of the gun, we get

$$(m_p + m_c)V = m_r . V_r$$

$$V_r = \frac{m_p + m_c}{m_r} . V$$

$$\therefore V_r = \frac{M_r}{m_r} . V \qquad (7)$$



(FIG 12)

PICTORIAL REPRESENTATION OF FORCES

ACTING ON BMP II UPGUNNED DURING FIRING

ON A SLIDE SLOPE

(NOT TO SCALE)

Now E = Kinetic energy at trunnion due to recoil

$$V_r = \frac{1}{2} m_r v_r^2 \quad \text{.... (8)}$$

$$E_{max} = \text{Max KE}$$

$$= \text{FOS} \; \frac{1}{2} m_r V_r^2 \quad \text{.... (9)}$$

$$f_{max} = \text{max trunnion pull.}$$

$$= \frac{E_{max}}{L_r}$$

$$= \frac{1}{2} \text{FOS} \frac{m_r V_r^2}{l_r}$$

$$= \frac{1}{2} \frac{\text{FOS}}{l_r} \cdot m_r \frac{m_r^2}{m_r^2} \cdot v^2 \text{ (multiply and divide by } m_r^2)$$

$$\therefore f_{max} = \frac{1}{2} \frac{\text{FOS}}{l_r} \cdot m_r \frac{M_r^2}{m_r^2} \cdot v^2 \quad \text{... (10)}$$

If η = efficiency of muzzle brake

$$F = (1-\eta) \cdot f_{max}$$

$$= \frac{1-\eta}{2} \frac{\text{FOS}}{l_r} m_r \frac{M_r^2}{m_r} \cdot v^2 \quad \text{... (11)}$$

11. Calculation of Acceleration of Recoiling Mass

(a) Time t_F for which the trunnion pull 'F' shall act is given by $t_F = 2\, t_{ar}$

where t_{ar} = time reqd to accelerate the recoiling

Parts from an initial velocity $U_r (=0)$ to final velocity V_r

(Assumption : Max velocity U_r is assumed to occur at the middle of recoil length)

$$\therefore t_{ar} = \frac{U_r - V_r}{a_r} \quad \text{---- (12)}$$

$$\text{Also} \quad a_r = \frac{U_r^2 - V_r^2}{2 \cdot S_r} \quad \text{---- (13)}$$

(b) The impulsive couple 'Ic' required to topple the veh is given by

$$I_C = F_{min} (B/2) \cos\beta \, t_u \quad \text{--- (14)}$$

where F_{min} = min force at cg reqd to topple the veh

$$\text{Now} \quad F_{min} = M \cdot a_v \quad \text{---- (15)}$$

$$\text{Now} \quad S = U_v t_v + \tfrac{1}{2} a_v t_v^2$$

Since $U_v = 0$

$$\Rightarrow S = \tfrac{1}{2} a_v t_v^2$$

$$\Rightarrow t_v = \left(\frac{2S}{a_v}\right)^{1/2} \quad \text{---- (16)}$$

Let 'R' be the distance of cg of the vehicle from the topping edge of the vehicle track,

$$R = \sqrt{h_{cg}^2 + (B/2)^2} \quad \text{---- (17)}$$

$$\text{we have} \quad S = \left[R(90-\beta) \cdot \frac{\pi}{180}\right] \quad \text{--- (18)}$$

where β = Side slope angle.

Resolving the trunnion pull with its two components, we get

(i) <u>Horizontal Component</u>

$$F_H = F.\cos\gamma$$

(ii) <u>Vertical Component</u>.

$$F_V = F.\sin\gamma$$

γ = gun depression (worst case)

$$\therefore C_F = h_t + F_V\left(d_t + B/2\right)$$

C_F = Moment of couple generated due to F about the toppling edge.

$$I_{CF} = C_F \cdot t_F \quad \text{- - - - (19)}$$

12. Now, when the veh is moving in a circular path, the centrifugal forces also try to topple the veh, when the gun is fired towards the centre of the circular path. F_c = centrifugal force created due to motion in a circular path.

$$F_c = \frac{M \cdot V_c^2}{R_c}$$

V_c - velocity of veh in curved path.

R_c - Radius of curved path.

F_c is max (worst case) when the radius is min and corresponding veh velocity is max.

$R_{c_{min}} = B/2 = 1.275$ m.

corresponding vehicle velocity (1st gear only possible with neutral turn)

$= 7.36$ Kmph $= 2.1$ m/s.

$$\therefore F_c = \frac{V_c^2}{R_c} \cdot M = \frac{(2.1)^2}{1.275} \cdot M = 3.459 \cdot M \text{ Newton}$$

(Assumption: It is assumed that the same $\frac{V_c^2}{R_c}$ ratio is applicable at different veh speeds)

$\therefore C_{F_c}$ = couple generated by F_c

$$= \frac{F_c \cdot h_{cg}}{\cos\beta} \quad \text{------(20)}$$

$I_c F_c$ = Impulsive couple generated.

$$C_{Fc} = C_{Fc} \cdot t_F \quad \text{-----(21)}$$

$\therefore I_{Ct}$ = Total impulsive couple $= I_{CF} + I_{CFC}$ ---(22)

(overturning couple)

$$t_{ar} = \frac{V_r - U_r}{V_r^2 - U_r^2} \cdot 2S_r$$

$$= \frac{2S_r}{U_r + U_r^2}$$

$$= \frac{l_r}{V_r} \qquad \because U_r = 0 \ \& \ l_r = 2S_r$$

Substituting the expression for U_r from equation (7)

we get, $t_{ar} = \frac{l_r}{M_r \cdot U^2} m_r$

$$t_F = 2 t_{ar}$$

$$= \frac{2\, l_r\, m_r}{M_r\, V}$$

Now $I_c = M\, a_r \cdot B/2 \cos\beta \cdot t_v$ .... (23)

from equation 14 and 15 - stabilising couple

$a_v = 9.81\ m/sec^2$.

where $t_v = \left(\frac{2S}{a_v}\right)^{1/2}$

$$S = R\left[(90-\beta)\cdot\frac{\pi}{180}\right]$$

$$R = \left[h_{cg}^{\,2} + \left(B/3\right)^2\right]^{1/2}$$

13. Acceleration of gunner's Head due to firing

Let O_c = Oscillating couple at cg $= I_m \cdot \alpha$

where $I_m = M\, k_r^2$ = moment of inertia.

and k_r = radius of gyration about transverse axis

$\therefore O_c = M\, k_r^2 \cdot \alpha = C_{FC}$

$$\therefore \alpha = \frac{C_{FC}}{M\, K_r^2}$$

Let a_g = acceleration at gunner's head.

$\therefore a_g = \alpha \cdot d_g$

where d_g = linear distance between gunner's head and turret.

AMPHIBIOUS ANALYSIS.

Let h_{ha} be the actual height of the hull.

and h_{hc} be the calculated height of the hull.

Therefore depth of submergence d_s is given by

$$d_s = \frac{M}{\rho \cdot l_{sp} \cdot w_{sp}}$$

where

l_{sp} = length of submerged portion of the upgunned BMP.

w_{sp} = Width of the submerged portion of the upgunned BMP.

ρ = density of fresh water.

$$h_{hc} = d_s + g_c$$

where g_c = ground clearance.

Now if this value of h_{hc} is greater than the actual hull height, h_{ha}, of the BMP II the upgunned BMP will not float on the surface of water. [20]

RECOMMENDATIONS

42. With the above analysis and the conclusions drawn, we can safely conclude that the GIAT 105 mm GTT Turret System is quite suited for our retrofitment on BMP II. However, with the increase in the combat weight of the vehicle, a few other vital parameters are adversely affected, remedial measures for which are discussed in the succeeding paragraphs.

Power to Weight Ratio

43. Since the vehicle weight has increased to 16.64 tons, the power to weight ratio has reduced from 21 hp/ton to 17.8 hp/ton. This shall severely affect the mobility of the BMP. Therefore to overcome this problem, one of the following can be a solution:

(a) A new engine for the vehicle
(b) Up-Powering of the existing engine.

44. Buying a new engine ex trade is not recommended due to following reasons:

(a) It will be a very costly proposition as the volume of BMPs that will be converted is going to be small and hence the cost of a new engine will be large.

(b) A new engine will mean that a new inventory of spare parts is also required, further adding to the problems of the logistics.

(c) Lot of time is required for another retrofitment.

45. The existing engine of the BMP II is a naturally aspirated engine and its power output can be increased by turbocharging it. Indian manufactures have started developing turbochargers and one can be suitably produced to match the operational requirements of this engine and this exercise is likely to be quite cheap and time saving one.

Suspension

46. With the increase in weight and higher firing stresses being generated in the vehicle, there is a requirement to absorb these shocks more effectively and at the same time a better and comfortable ride is required to be given to the crew. With this aim in mind the suspension is required to be redesigned in which the following is recommended.

(a) Increase the stiffness of the torsion bar springs.

(b) If considered necessary, additional dampers can be added to the bogie station which are not having one.

Mobility Across A Water Obstacle

47. Since the speed of the BMP II ICV in water is only 7 Kmph, it is markedly slow especially in the new role it is going to be used, more so in the face of the enemy. To improve this capability, it is recommended that two hydrojets be retrofitted on the vehicle to its swimming speed. The pump can take its drive from the engine and the expulsion of water can take place through the rear trap doors,after a suitable modification has been carried out, as the rear doors are also to be used for the purpose of replenishing the main ammunition.

Armour Protection

48. The BMP II Provides armour protection upto 20 mm AP shot. This can be increased by substituting the armour with the indigenous Kanchan armour, which can provide not only a better armour protection, but also a weight saving.

49. A few more additions suggested are :

(i) Fitment of stabiliser system at present no such facility exists.

(ii) Two revolver type magazines holding six rounds each could be accomodated in the turret bustle for use in the autoloading mode.

(iii) Fitment of a Meteorological sensor (MET) as is in the case of MBT Arjun can be done as this system would help the isolated and vulnerable BMP crew with much real time battlefield info/data.

(iv) Lastly, the LLTV can be replaced by a thermal Imager which is undoubtedly the best among all Night firing systems in the modern world. It should be noted here that the LLTV is operational only in particular weather and light conditions, the lower limit being cloudy moonlight.

Drawbacks : BMP 1/2

50. By the standards of the early 1970s the BMP - 1 boasted relatively high fire power and excellent cross-country mobility. During exercises in the Soviet union and in particular during military operations in middle east conflicts, a number of short comings and deficiencies of the BMP - 1 became increasingly apparent :

(a) limited arcs of fire (a maximum depression of 4, and a 55 blind arc caused by the positioning of the IR searchlight in front of the commander's hatch).

(b) Inability to fire on move using either the main gun or stagger missile,and poor performance of the electric turret drives(laying acceleration/speed).

(c) Poor hit probability of the 73 mm main gun (maximum useful range 800m) due to the dispersion of its HEAT round (velocity between 400 - 700 m/s), leading to a low effective rate of fire.

(d) The difficulty of controlling the manually guided sagger missile, which was also hard to reload. This Could not be done without comprising the NBC Protection and required that the Gun be elevated to 3.5 degree causing the target to disappear from the gunner's view.

(e) The Commander's limited field of view affected his ability to command the vehicle.

(f) No air - defense capability with turret weapons.

(g) Insufficient ballistic protection and high vulnerability.

51. The development of an improved BMP - 1 version was therefore started in the early 1970s. The serious shortcomings of the BMP - 1 had been comprehensively addressed through the introduction of BMP - 2 :

(a) A two man turret for the commander and gunner, giving a significant enhancement to both command capability and firing response.

(b) A 30 mm 2A42 cannon as main armament to provide an effective air defense capability.

(c) Two - axis stabilization for the cannon allowing fire on the more.

(d) The second - generation semi-automatic 9M113 spandrel anti tank missile, with a maximum range of 4000 m in place of the obsolete first-generation sagger.

(e) A more appropriate weapons mix : a 30mm cannon for light armoured targets (penetration 55mm rolled homogenous armour at 500m) and air defence (maximum elevation +75), plus an anti-tank missile with HEAT warhead against more heavily armoured targets.

52. The introduction of the BMP-2 solved many shortcomings but a few remained unresolved. These were :

(a) Problem related to the vehicle's bow-heaviness .

(b) Inadequate damping of its chassis despite the installation of the second shock absorber at the BMP-2s second wheel station.

(c) Modifications were needed to the weapon mounts.

53. This resulted in testing of several modifications and the BMP-3, made its debut in 1990. Both the requirements of this dissertation have been suitably met in the BMP-3, i.e, upgunning of BMP gun to 100mm and launching of a missile through the gun tube. Let us see the details of this veh.

Armament :

54. The main armament of the BMP-3 consists of a 100mm 2A70 combined gun/missile launcher and a 30mm 2A72 cannon. The 100mm gun fires both laser-guided missiles (a variant of the 100mm 9M117 Bastion missile also fired from the T-55 AM2B) and conventional HE rounds. The missile is intended to be used against armoured targets at ranges of up to 4000m. Given the calibre constraint, the penetration of its HEAT warhead is probably limited to 500mm RHA. The use of laser beam rider guidance (the emitter for which is installed on the mantlet) and a stabilised sight makes it possible to fire the missile on the move under favourable conditions.

55. The 30mm 2A72 machine cannon has both single-shot and burst-fire modes, the latter with high or low rates of fire. The dual belt feed mechanism can handle three types of ammunition : AP-T, HE-T and HE-I, a HEAT round is also under development. The HE-T and HEI rounds are normally mixed and fed through the same channel. The muzzle velocity of the rounds varies between 960-970m/s, empty cases are ejected through an opening in the mantlet. In the vehicle documentation, the AP-T round is credited with an armour-piercing capacity of some 25mm/60 degree at 1,500m (that is, 50mm at zero obliquity). [17]

56. The turret also has a 7.62mm co-axial machine gun (type PKT, rate of fire - 250 rounds/min). All the turret weapons are stabilized as in the case of BMP-2 and they have an elevation of -5 degree to + 60 degree. Their high-elevation capability is appropriate not only to air defence but also to self-defense, particularly in mountainous terrain-a lesson from afghanistan. A fire-control system is fitted, both the commander and the gunner being able to operate the weapons. The tight space within the turret dictates the use of an automatic loader, which handles both the conventional ammunition and the 25 kg missiles for the 100mm gun. BMP - 3 also features two partially swiveling machine guns in the right and left corners of the hull bow .[17]

(a) Aluminium alloy hull and powered by a 10 cylinder, 500 HP UTD 29 diesel engine.

(b) power is transmitted to the sprockets by means of a new hydrostatic cross-drive transmission.

(c) BMP- 3 shows fundamental conceptual similarities with BMD-1. It weight is 18.7 Tonnes.

(d) High level of fire power "break through ICV" making it a logical accompaniment to the T-80 tanks.

(e) High mobility not with standing a 28 percent weight increase. Improved power to weight ratio than BMP-2.

(f) Engine placed at the rear of the veh would have a beneficial effect on the centre of gravity assuming weight of frontal armour is nearly the same as that of the Engine.

(g) All weapons can be reloaded under armour BMP-1/2 externally mounted missile and its launcher were quite vulnerable.

(h) The driver is seated at the centre in front, just ahead of the turret.

(j) The front two road wheels are close because of the additional weight of ammunition at the front.

(k) BMP - 3 is priced at Rs 2.8 crores.

Armament

57. NOW let us see the main Gun of BMP - 3 and its special features as listed :

(a) 100 mm fully automatic rifled gun.
(b) barrel length is less than 50 calibres.
(c) It is a low medium pressure type.
(d) It has no muzzle brake or fume extractor.
(e) Elevation/depression from -5 degree to +60 degree.
(f) Auto loader, which can help fire 10 Rounds/min.
(g) Reduced barrel thickness.
(h) Fire both APDS and HE rounds.
(j) Muzzle velocity 250 m/sec.
(k) Range 4000m of 100mm Shells.
(l) Hatch at rear of turret for used cases.
(m) Capacity 40 rounds, 22 rounds in auto loader and balance 18 are in hull.
(n) Tube launched anti tank missile.

58. The Characteristics of the 30mm cannon are :

(a) The BMP - 3 cannon is recoil operated unlike the BMP - 2 which is gas operated.
(b) Rate of fire - 350 to 390 rounds/min.
(c) Range - 2000m.
(d) Muzzle velocity - 960 m/sec.
(e) It has dual belt - feed mechanism.
(f) It can handle AP - T, HE -T and HEI.
(g) Total : 500 rounds.
(h) It is mounted on a parallel axis and is coupled with the 100mm gun.

59. The turret of BMP-3 is a marvel of an engineering feat. It houses not only the two crew of commander and gunner but also other sights and controls. The special characteristics of the turret are listed.

(a) Up Armouring of the turret has been carried out to cope with higher calibre.

(b) It has a semi circular ring in the front which acts as bolt on spaced armour.

(c) It has add on armour of thickness 40mm in the frontal arc collar.

(d) The semi circular ring provides improved protection against KE and shaped charges.

(e) It houses the breeches of 100mm gun and the 30mm cannon along with the recoil.

(f) controls and sights for the commander and the gunner are housed in the turret.

(g) Feeding system for the 30mm cannon is also inside the turret.

(h) It has the recovery device for spent 30mm cases.

(j) It has the loading arm and tray for 100mm gun.

(k) Autoloader and its mechanism are also incorporated in the turret.

(l) The turret also houses a ballistic computer for environmental information and a computerised fire control system. [17]

Missile

60. The BMP-3 main gun is capable of firing a missile through the gun tube. The BMP-1 had MALUTKA/FALANGA missile mounted above the barrel. It was a SPANDREL/FAGOT missile above the 30mm cannon. It has been replaced by a second generation missile. The characteristics of the BMP-3 missile are listed.

(a) Tube launched missile.

(b) 9M 117 stabber missile.

(c) The missile can be launched through the main gun on move.

(d) Stabilization of both the armament/sight.

(e) Range - 5500m.

(f) Bastion system (AT - 10).

(g) Guidance is semi automatic command line of sight (SAGLOS) with ATGM being laser beam riding.

(h) Eight 100mm ATGMs in the hull each weighing 23 Kg.

(j) The missile is loaded manually and its length is twice the HEF round.

(k) At the maximum range, the missile takes 12 seconds for engagement at a speed of 375m/s.

(l) Penetration of the missile is 650mm RHA.

Sight

61. The sights which are fitted in the BMP-3 have the following features :

(a) Day/Night Sight with integrated Laser ATGM.

(b) Stabilised Sight for the gunner.

(c) Independent Sight with override facility available with the commander.

(d) Gunner's magnification by day - 8 times and by night 5.5 times.

(e) Commander's magnification by day - 5 times and by night 3 times.

The incorporation of the armament of BMP-3 directly into the BMP-1/2 would pose many problems. Infact, incorporation is not possible due to the following reason :-

(a) The turret of BMP-3 is totaly different from BMP-1/2 and has the necessary characterstics to mount the 100mm gun.

(b) BMP-3 has the eng at the rear and the front portion is used for ammunition storage.

(c) Different sight/controls for commander/gunner.

(d) Computerised fire control system in the BMP-3.

(e) Auto loader of BMP-3 is different from BMP-2.

(f) BMP-3 is a complete change of design and follows the BMD-1 pattern.

(g) Load balancing on road wheels in the case of BMP-3 is different from BMP-1/2. [17]

Gun launched missile

Need for gun Launched Missile

62. **Advantages**

(a) It can engage enemy tgts at longer ranges.

(b) It reduces the vulnerability of own armr

(c) Anti Heptr capability.

(d) It increases the "K" kill capability.

(e) Reduction in expenditure of APFSDS/HEAT amn.

(f) It increases the single shot kil probability.

63. **Disadvantages**

(a) It involves a complex and costly design.

(b) It needs a separate sighting system and requires integration with gun stabilisation.

(c) Cost of amn higher

(d) Redesign of auto loader.

(e) storage and replenishment difficult.

(f) Separate trg required for the crew.

64. Choice of launching system : The launching of the missile could be gun launched/rail launched. The second launching system requires a third weapon system on the BMP and it also needs separate stabilisation with Fire control system and sighting system.

65. Trajectory of the missile :

(a) Indirect fire - these are generally fire and forget types which locks on to target before launch like NAG or SALH (semi automatic lases homing) and have an indirect trajectory. Such weapons and missiles are used against strategic and tactical targets at a distance greater than 5 Km range. The disadvantages of such a system are :

(i) target designation by laser beam.

(ii) longer time of flight (BMP cannot fire the next round till missile hits the target.

(iii) Costly guidance and control.

(iv) Complex trajectory.

(v) Susceptible to jamming.

(b) Direct fire - These have a direct flight trajectory and have a limited range of 2 to 3 Km like the malutka and Faggot missiles. The missile fired from the BMP is compatible with the fire control system and optical sights. The advantages of such a system are :

(i) Simple or no navigation required.
(ii) Simple guidance and control.
(iii) Light weight.
(iv) Constant effect of atmospheric conditions.
(v) It cannot be jammed.

66. **Reqmts for missile for effect of target** - A tgt for a missile would be a tank, bunker or attack Heptr and the reqmts are :

(a) Penetration - 800mm RHA - frontal armr.
250mm RHA - Top armr.

(b) Hit probability - 90%

(c) Range

(i) Tanks - Greater than 3 to 4 kms.
(ii) Heptr - Greater than 4 to 5 kms.

67. Intervisibility Data - tgt observation depends upon sighting system capability on tank/BMP.i.e,

(a) Magnification of sight
(b) contrast of tgt.
(c) Projected cross sectional area of tgt.
(d) Environmental conditions.
(e) Cross sectional area of the object lens on the sights.
(f) Type of sight - active or passive.
(g) luminance of tgt.
(h) Camoflauge of tgt.
(j) speed of tgt.

68. Visual observation - Tank tgt depends on visual observation (Vo). Vo is defined by size of tgt, contrast between reflected light and background.

$$C = \frac{(Bt - Bb)}{Bb}$$

C - contrast
Bt - luminance of tgt.
Bb - luminance of back ground.

The spectrum of light warelengths of interest is from 0.4 to 0.7 microns.

69. Sighting system - The BMP sight range is restricted to 3 kms during day and 800 m for night mission. Thermal Imagers is the solution :

(a) Completely replace the sight with thermal imagers having LRF or.

(b) Add on thermal images sight for missile and retain other sight for BMP amn firing. A separate thermal imager sight can be developed with guidance, LASER IR/Radio and can reduce minimum modification of sight stabilisation. There is also the flexibility of removing the thermal imager sight in peace.

70. **Guidance and Control** : It is the brain of the missile . It increases the SSKP and computer movement of missile to left/right or up/down. The missile system uses closed loop feedback guidance.

```
                 /-----------\              /----------\
Tgt data------¦ Guidance-¦---STEERING--¦-Missile ¦-----
         ¦      ¦ Computer ¦    ORDERS    \----------/    ¦
         ¦      \-----------/                              ¦
         ¦                                                 ¦
         ¦                                                 ¦
         ¦        /-------------------\                    ¦
         ¦        ¦ Sensor observing  ¦      Missile      ¦
         \------¦ position           ¦-----------------/
                  \-------------------/      Position
```

The instrumentation measures behaviour of missile and this data is compared with tgt data in guidance computer and steering orders given. Instrumentation may be in missile/ground/mobile launch platform/Intermediate platform. SAM missile - GOT/GOLIS.

GOT - guide on to tgt (Sensor observes the motion of tgt during the complete flight of missile).

GOLIS - guide on to location in space (static tgts map ref fed to computer guidance.

71. Trajectory - Straight line or LOS trjectory needed for gun launched missile and is difficult to achieve hit because both the tgt and the BMP may move. LOS missile are the following types :

(a) CLOS

SACLOS

(b) ACLOS

(c) MCLOS

72. CLOS - The tgt tracker and missile tracker located at launcher point. Zero Axis of tracker and missile are kept parallel and missile launched. The flame or beacon shinning backwards is used to detect displacement from LOS. A computer located at base calculates the acceleration (lateral) from missile and a signal is sent for correction over a command link (CL) by wire, fibre, laser etc.

(a) MACLOS - Joy stick with eye - missile - tgt(CL-WIRE).

(b) SACLOS - Eye assisted with optical system - goniometer aligned with bore sight of the tgt tracker or slave to it. (Auto tracker detects the errors of the missile and passes it to the computer.)

(c) ACLOS - It does not need the operator. It has a separate tracker for the missile/tgt. Signal processing required for the tracker to recognise the tgt signal and missile signal separately.

73. LOSBR - laser transmitter is used in place of missile tracker. Laser beam is laid parallel to LOS. The rearward looking Laser receiver in missile can locate the position of tgt with ref to laser beam. The beam riding the missile navigates to the LOS with gyro help carried in the missile. These are also called special form of navigational guidance. These systems are more difficult to jam than CLOS. Guidance Computer is Present in the missile.

74. The ATGW for gun launched missile should have LOSBER rather than MCLOS or SACLOS that need wire or IR or Radio link for command. The wire spool will increase the wt of the missile hence limiting the range. The IR or Radio link will have the disadvantage of atmospheric attenuation of signal and are prone to jamming. The laser beam has the advantages of less attenuation and coded laser beam can be used to avoid jamming. Therefore, the LOSBR will be more appropriate for Present day gun launched missiles.

75. <u>Control</u> : This involves the various sensors and instruments to drive the control surfaces. Therefore, there is a need for signal processor which continuously senses the position of missile wrt LOS (laser beam), generates the error signal and feeds to autopilot located in the missile. The auto-pilot sends the driving signal to control surfaces. Therefore, for LOSBR system, we need a computer which receives the position signal from signal processor. An auto-pilot which generates error signal for pitch, roll and yaw acceleration of the missile and sends signal to control surfaces.

Mode of Attack

76. In case of armour targets, the modes of attack can be:-

(a) TOA (Top of Armour)

(b) Frontal Attack

The typical fragmentation, blast or continuous rod would be used against tgts such as aircraft. Against modern armour fitted with ERA, Tandem shaped charge warhead is used. In TOA type the amount of explosive carried and the type of electronics required for the Top attack will become much more complex and may have bulkier guidance & control which may seldom be fired up to its maximum range and comparing complexity of TOA with frontal attack, it is better to adopt frontal attack mode of attack. In case the attack heptr has to be included as the target for the missile, the warhead may have to be fragmentation or continuous rod type. Therefore, the following could be adopted :-

(a) Against Armour target _______Frontal Attack with Tandem Shaped charge warhead.

(b) Against Helicopter/Short range aerial targets ____ Fragmentation with Laser activated proximity fuse.

77. **Proposed Parameters of the missile**

(a) Gun launched missile with direct LOS attack calibre 105 mm

(b) Targets

(i) Primary target _ Tank

(ii) Secondary target - Attack helicopter

(c) Capabilities

(i) Tank target

(aa) Frontal Attack

(bb) Penetration of 800 mm RHA

(cc) Tandem shaped charge warhead

(ii) **Helicopter target**

(aa) Fragmentation warhead

(bb) Frontal Attack

(cc) Laser activated proximity fuse

(d) Range : Maximum Range __5 km.

Minimum Range __ 1000m.

(e) **Sights** : Thermal Imaging for both day and night as add on sight with existing stabilised gunner's sight.

(f) Cruising Speed : 800m/s such that maximum exposure time 10 to 20 secs.

(g) Guidance & control : Line of sight laser beam riding LOSBR.

AIRFRAME

78. For short range SSM, a single stage solid or liquid propellant rocket motor is generally used. However, in this particular case, the propellant is packed in a separate container. When propellant burns in the chamber, the missile is subjected to very high temperature and "g" effect. Therefore, a careful attention has to be provided to limit the maximum "g" effect that the guidance & control electronics can with-stand and high temp of the order of 3500 K & Pressure - 550 Mpa. Therefore, an isolation spacer plug between missile and propellant charge may be required.

79. For short range SSM, only moderate maneuverability is required. The airframe of GW is the structure required to maintain the essential elements of the weapons system in the correct relative positions for the weapon to fulfill its mission. The external shape should be such that :-

(a) Air drag is kept low.

(b) Provides for control of missile on a particular path.

(c) Provide for aerodynamic force required to change the path for target interception.

(d) Should be as light as possible.

(e) Strong enough to carry external and internal loads without bending and distortion.

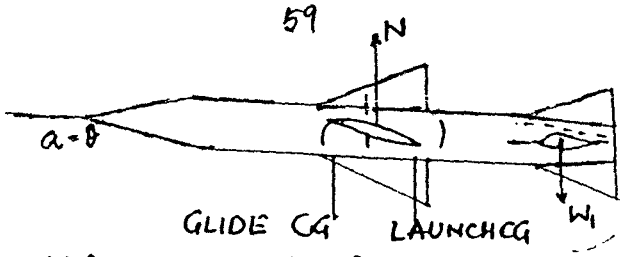
80. The various loads to which short range SSM is subjected to are :-

(a) Forward thrust from within the gun.

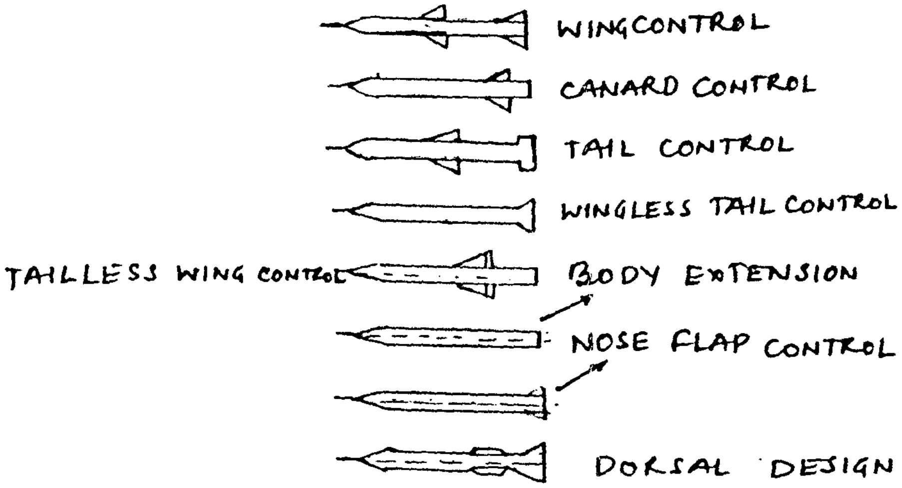
(b) Loads due to missile acceleration.

(c) Lift from the wings and control surfaces.

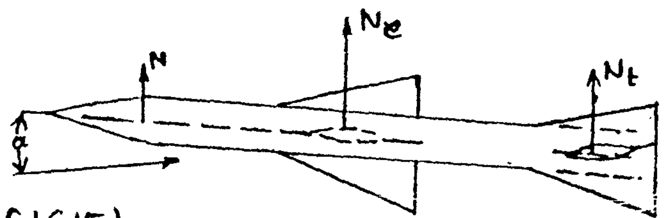
(d) Transported load e.g.warhead, guidance & control module, auto pilot and sustainer module, if provided.



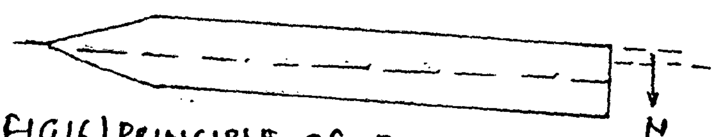
AERODYNAMICS OF WING CONTROL (FIG13)



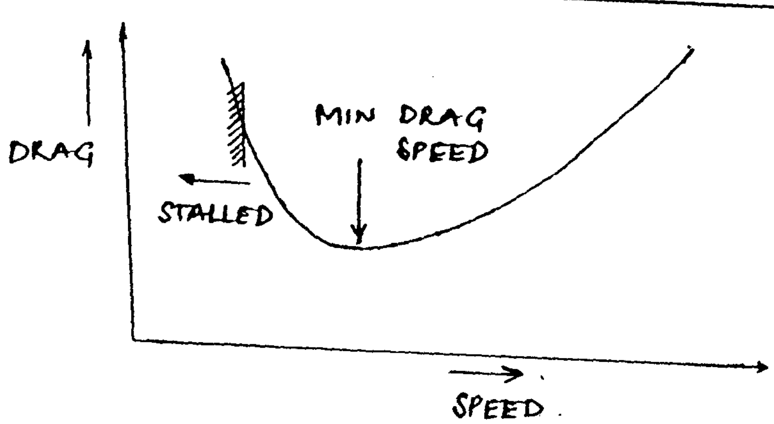
TYPES OF DESIGN AND CONTROL (FIG 14)



(FIG15) TYPICAL COMPONENT LOADING - TAIL CONTROL



(FIG16) PRINCIPLE OF BODY EXTENSION



(FIG17) MISSILE DRAG AT SUBSONIC SPEEDS.

(e) Local pressure forces due to its motion through the air.

81. In plan view, the missile will consist of a body, normally circular in cross-section containing guidance package, warhead, fuse and safely & mechanism, control servos and power pack. It also usually has wings to provide aerodynamic lift and a set of control surfaces. The nose and tail are shaped to reduce the drag. The missile should be symmetrical about horizontal axis. For lateral maneuverability, another set of wings is usually provided at right angles to the horizontal pair. Therefore, GW usually has a cruciform layout and is broadly identical in both plan and elevation.

TYPES OF AERODYNAMIC CONFIGURATION

82. **Wing control** : A wing control consists of a relatively large wing located close to the CG of the missile and a set of tail or stabilising surfaces at the rear end of the missile. This type of control is used mostly in AAM (Anti Air msl) because of its extremely fast response characteristics. The main features of this type of control are as under (Fig 13) :-

(a) Higher Instantaneous lift for maneuvering flight.

(b) Control effectiveness from wings is low due to location near CG.

(c) Greater down wash at the tails helps in developing increased angle of attack due to turning moment.

(d) Critical design area :-

(i) Relatively large loss in tail effectiveness due to down wash to static stability contribution.

(ii) Non-linearity in aerodynamics resulting from down wash & angle of attack.

(iii) Severe adverse rolling moment induced on tail surfaces from combined effect of angle of attack and wing deflection.

83. **Canard control** : It consists of a set of small control surfaces called canards located well forward on the body and a set of large surfaces attached to the middle or aft section of the missile. These do not generate a significant amount of down wash to affect the longitudinal stability characteristics adversely. The salient feature are (Fig 14) :-

(a) Longitudinal stability is not affected much.

(b) Lift is derived from angle of attack since lift of the canards is almost nullified by the down load on the wings caused by down wash.

(c) Inherent simplicity of packaging due to the small size of control system and its location in the nose.

(d) Changes in CG locations due to the design changes may be easily accommodated by simple relocation of the wings.

(e) Total drag & wt of missile reduced due to lower lifting surface area.

(f) Less servo power requirement.

(g) Disadvantages :-

(i) Difficult roll stabilisation hence wing tip control may be required.

(ii) Relatively high control surface rates required to obtain desired rate of response since the angle of attack must be generated before any lift is developed.

(iii) Higher servo power requirement since high surface rate required but overall servo power requirement low.

(iv) Used for small missile e.g. SSM short range.

84. **Tail control** : In this type of control, the control surfaces are at the tail hence tail deflection is opposite in direction to the angle of attack. The salient features are (Fig 15) :-

(a) Slow in response characteristics.

(b) Low tail loads & high moments since total angle of attack at the tail reduces. Hence low body bending.

(c) No downwash due to wing deflection.

(d) Aerodynamic characteristics are more linear than that of wing control design.

(e) Disadvantages of design.

(i) Limited space at the tail end for control mechanism of solid rocket motor used.

(ii) Deficiency of tail surfaces to provide the desired lateral control.

85. **Tailless control** : A tailless type of configuration involves only one set of control surfaces (wings) with control flaps located at the trailing edge. The salient features are :-

(a) Reduced no of surfaces hence reduced drag.

(b) Reduced manufacturing costs.

(c) Extremely critical location of wings like :-

(i) Locating wings too far aft would provide such excessive stability as to require very large control surface size deflection to get desired load factor.

(ii) On the other hand, locating wings too far forward near the CG would cause a reduction in control effectiveness as well as aerodynamic damping which is generally desirable/required in most missile systems.

86. **Body Extension** : Another method of providing Control is the Profitable use of the base pressure or, rather, the pressure differential between the base and the free stream. A segment extending rear of the tail into the region of differential pressure as shown in the fig 16 experiences a lift force for control. The salient features are :-

(a) Extermely low servo power requirements since no hinge moments.

(b) Simple and compact in design.

(c) Disadvantages.

(i) Low maneuverability.

(ii) Inoperatibility at subsonic speeds due to very negligible base pressure.

(iii) Reversal in control between power-on and power-off conditions due to jet effects.

87. **Nose flap control** : This type of control is composed of segments of a nose section or flap extended from each of the four quadrants. When not in use, they are retracted to form nose contour. These are suitable for air launched missiles because of compact design. This type has low maneuverability and hence may be considered only in limited applications.

88. **Dorsal Design** : In certain applications where overall span of missile is severely limited, the use of dorsal may be necessary. Dorsal, when used in missile design, may be considered as an "aerodynamic fix" required to make up for the loss in aerodynamic efficiency due to reduction in tail aspect ratio and/or area. Since this fix is rather inefficient hence used for limited and specialised cases.

89. After having discussed the various control surfaces for aerodynamic configurations, it is worthwhile to select the canard controls due to the following reasons :-

(a) SSM in our case is a short range missile primarily intended for static or slow moving tank.

(b) The maneuverability requirements are low.

(c) Simplicity and smaller in design.

(d) Longitudinal stability is not effected adversely.

(e) Low drag and wt of missile.

(f) Low servo power requirements.

(g) Roll stabilisation not required in short range SSM.

CONTROL SURFACE ARRANGEMENT

90 Though there are various types of arrangements used such as monowing, Triform and cruciform. Monowing arrangement are generally used on air crafts and cruise missile. The Triform arrangement has its wings equal spaced 120 degrees apart achieved in terms of pressure, drag and height saving. The most commonly used arrangement on missile is cruciform. The advantages are :-

(a) Fast response in producing lift in any direction.

(b) Identical pitch and yaw characteristics.

(c) Simple control system.

91. One of the most important aspect is the orientation of tail surfaces with respect to the wings or control surfaces. Two orientations are used i.e. in - line & cross tail configuration. Although an in-line tail configuration provides low stability at low angles of attack, this feature can be easily compensated for by simple changes in the control system gains.

AERODYNAMIC CHARACTERISTICS OF AIR FRAME

92. The external shape of the missile is largely dictated by the aerodynamic characteristics of the airframe. The properties of missile like range, speed of flight and radius of turn are determined, in part, by aerodynamics of the missile. Both range and flight speed are determined, for a given propulsion package, by resistance to forward motion of missile called drag. The rate

and radius of turn i.e. maneuverability of the missile is determined, at a given speed, by lateral force available. This force is at right angles to the direction of motion, regardless of its direction wrt vertical, called lift. Apart from this, the pressure waves are also generated while the missile tears apart the air and travels. These shockwaves increase the drag on the missile. This type of drag is low for subsonic missiles i.e. Mach Number less than unity. However, for supersonic missiles, the nose drag is significant. Therefore, the nose design and design of fins/wings need careful consideration.

DRAG

93. There are three types of drag associated with a missile moving through air. These are skin friction, pressure drag and drag associated with the production of lift.(Fig 17)

94. **Friction Drag** : It is due to viscosity of air. It depends upon the type of flow i.e. laminar or Turbulent and Reynolds Number.

Skin friction Coeff, Cfl = 1.328/sqrt(R_l) -(1)-

due to laminar flow

Skin friction coeff for turbulent flaw is given by

$$\sqrt{C_{ft}} \log_{10} C_{ft} R_e = 0.242.$$

-(2)-

Equation (1) is applicable for $R < 10^6$

Equation (2) is applicable for Turbulent $R > 10^6$

For missiles the flow is turbulent. Hence skin friction coefficient is calculated from equation (2). However, the flow for this front portion of missile and turns to completely turbulent at the tail. The transition point is generally 30% as far back of its length. Therefore, once transition is known, the skin drag coefficient can be found from the relation.

$$* \quad C_f = C_{fl} \times S_x / S_l + C_{ft} \times (S_l - S_x) / S_l \qquad -(3)-$$

where :-

Cn & Cn----- Skin drag coeffs in laminar and Turbulent folw respectively.

Re for Cn ------ Based on length x

Re for Cn ------ Based on length l.

Sx ------------- Wetted area over length x

Sl ------------- Total wetted area

For supersonic flow, the effect of compressibility of flow also comes in. The effect of compressibility of flow for laminar & turbulent are as given below :-

Laminar flow : $C_f/C_{fo} = \left(1/(1+0.85M^2/5)\right)^{0.1295}$ -(4)-

Turbulent flow : $C_f/C_{fo} = 1/(1+0.8M^2)$ -(5)-

The equation (4) is given by karmar & Prandtl for subsonic flows. However for turbulent compressible flow, the theory used for design purposes is the Frankl Voishell theory. The expression for effect of compressibility for turbulent supersonic flow on skin friction can be computed from :-

* $C_f/C_{fo} = 1/\left(1-(\gamma-1)/2 \times M^2\right)^{0.467}$ -(7)-

γ - Density of air

where Cn is the skin friction coefficient in turbulent incompressible flow

Hence the friction Drag coefficient is obtained by

* $C_D = C_f \times S_{wetted}/S_{reference}$ -(8)-

10% allowance can be given for preliminary calculation for surface roughness and small protuberances. [6]

95. <u>Pressure Drag</u> : Pressure drag for subsonic flow can be neglected in preliminary design. However, in supersonic region, the pressure drag constitutes a great percentage of the total missile drag. The base pressure of the missile can be computed form the formula :-

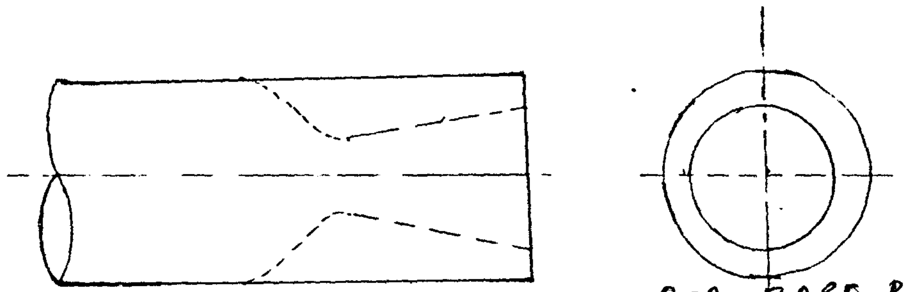
* $C_{Db} = C_{rb} \times S_b/S$ -(9)-

C_{Db} --------Base pressure drag coefficient.

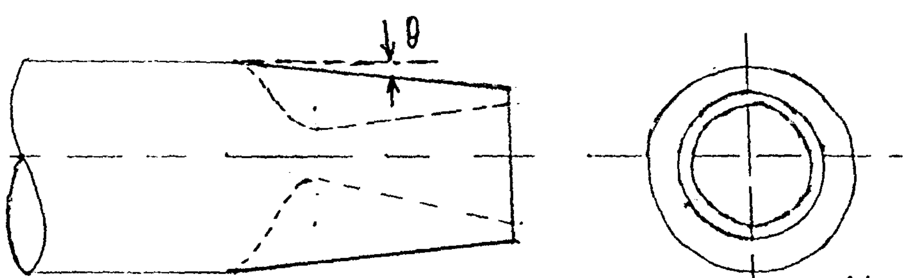
Sb ---------Base area.

S ----------Body cross-sectional area.

C_{rb}---------Base Pressure coefficient.



CROSS SECTIONAL AREA FOR BASE PRESSURE.



θ → Difference between Actual and Effective Area.

EFFECTIVE BASE AREA (FIG 18)

For power-on condition, only effective base area is used as shown in figure 18. The drag of the body at the supersonic is primarily dependent on the nose shape and amount of boat-tailing. The body pressure drag consists of three parts, Nose wave drag, boat tail wave drag and base pressure drag. For tangent ogive nose, the wave-drag coefficient is given by :-

$$* \; C_{DW} = P\left[1 - 2\left\{196\left(\frac{l}{d}\right)^2 - 16\right\} / \left\{28(M+8)(l/d)^2\right\}\right] \qquad -(10)-$$

Where

l = length

d = diameter

M = Mach No.

Mach No	**Cpw(from equation10)**	**Cdn(from corrected results)**
1.3	0.115	0.124
1.5	0.101	0.106
2.0	0.095	0.095
2.5	0.094	0.093

Wave drag coefficient for air foil : It varies with thickness squared. For an untapered rectangular wing with a double wedge airfoil section, the wave drag coefficient is given by :-

Drag coefficient, $$C_D = \left(4 * \frac{d^2}{b}\right) \times \left\{\left(1 - \frac{1}{2b} \times A\right)\right\} \qquad -(11)-$$

Where :- C_D = Drag Co-eff.

d --------- wedge semivertex angle (radians).

b = sqrt(M - 1) ---- Prandtl Glauert factor.

A = b/c ------- Aspect Ratio.

96. **Induced drag** : The basic lifting mechanism of a wing is to push down - wards the air that it influences. It follows that behind a lifting wing, there is a mass of air that is flowing downwards at an angle to the line of sight. The vertical component of this upward velocity known as upwash in the region outside the wing tips. Induced drag for supersonic speeds is given by :(Fig 19)

$$* \; C_{DN} = C_{Di} = K \times C_N^2 = C_N^2 / C_{N\alpha} \qquad -(12)-$$

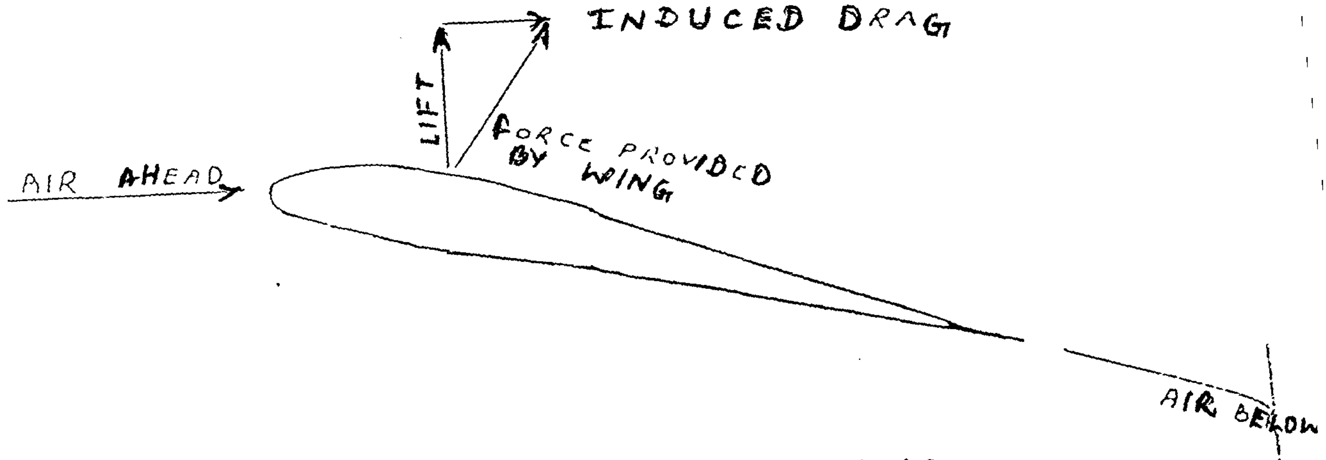
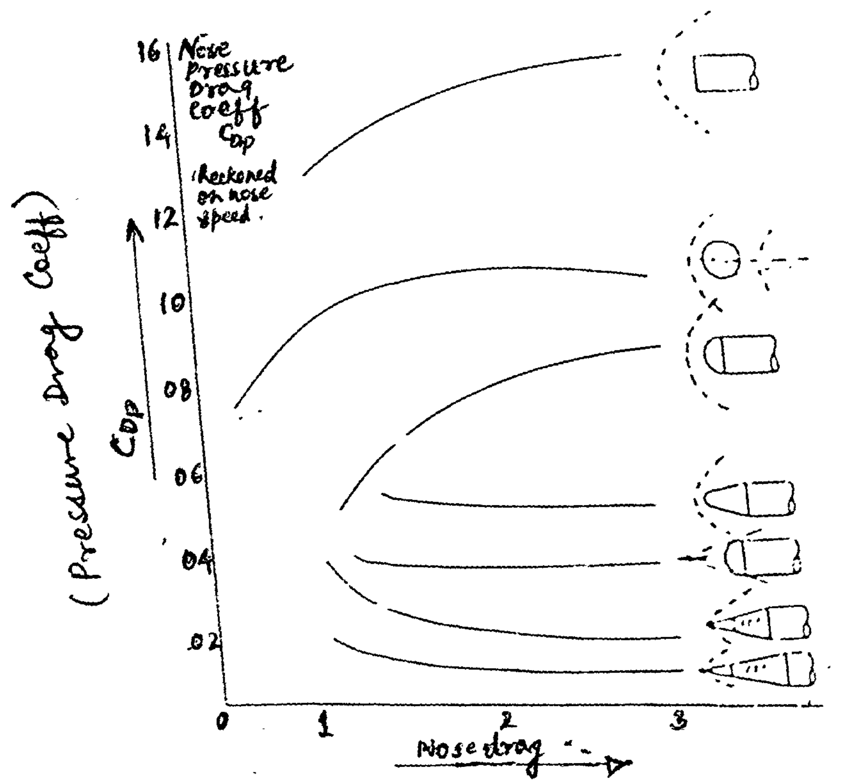


FIG-19 FORCES ON WING
AIR FOIL



Nose drag at supersonic speeds

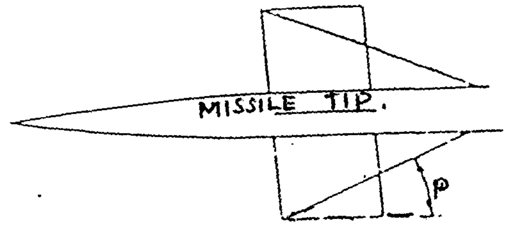


FIG. 20 TIP effects at supersonic speeds.

C_{Dn} ------- Drag due to normal force.

C_{Di} ------- Induced drag coefficient.

K -------- Drag rise factor.

C_N -------- Normal force coefficient.

$C_{Na} = dC_N/da$ ----- Normal force - curve slope.

a --------- Angle of attack.

97. <u>Cummulative effect of Drag</u> : The cumulative effect of drag varies with square of speed. At speeds beyond mach 1.3, the frictional forces are so intense that aerodynamic heating of the missile surface can occur. However, in our case, the aerodynamic heating will not be significant since missile flight time is small. The presence of shockwaves also becomes significant at higher speeds. The drag coefficient for mach No 2 onwards is about Ø.3 to Ø.4. The maximum drag is due to the projected frontal area of the nose and wing tip design. The figure 20 shows the effect of nose design and tip effects of the wings.

AERODYNAMIC CHARACTERISTICS OF AIRFRAME COMPONENTS

98. The body of missile may be divided into three major sections, the forebody or nose or ogive, the mid-section and tail section. The forebody has many shapes, most common of them are conical, ogival or hemispherical. For supersonic missiles the shapes used are ogival in shape due to the following advantages over conical shapes :-

(a) More volume for a given bore and length (l/d ratio).

(b) Structural superiority due to blunt nose.

(c) Slightly lower drag.

99. The various ogival shapes used are tangent ogives, power series, parabolic series and Haack series. The most commonly used ogive for supersonic missiles is called compound ogive; n/m CRH(Calibre Times Radius Head) as shown in the figure 21 . Here mD decides the length of nose and nD decides the slenderness to reduce nose drag. The Semi-empirical equations to determine nose drag and centre of pressure are given below.

$$*C_{DF} = P\left[1 - 2\left\{196\left(l/d\right)^2 - 16\right\} / \left\{28 \times (M+18)\left(l/d\right)^2\right\}\right] \qquad -(13)-$$

$$*\frac{C_P}{L} = \frac{1}{2}\left[50(M+18) + 7M^2P(5M-18)\right] / \left[40(M+18) + 7M^2P(4M-3)\right] \qquad -(14)-$$

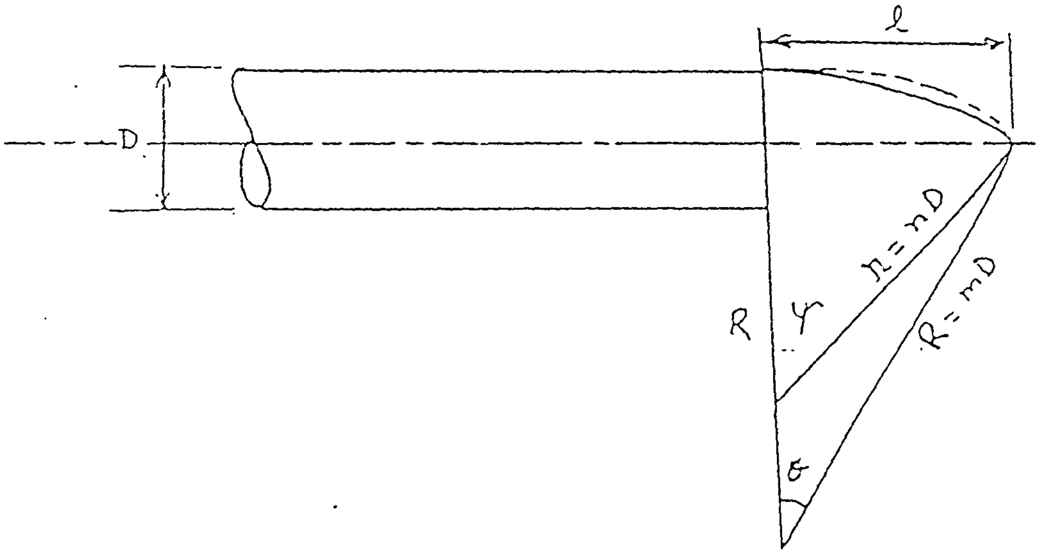


FIG 21 PROFILE OF COMPOUND (N/M CRH) OGIVE

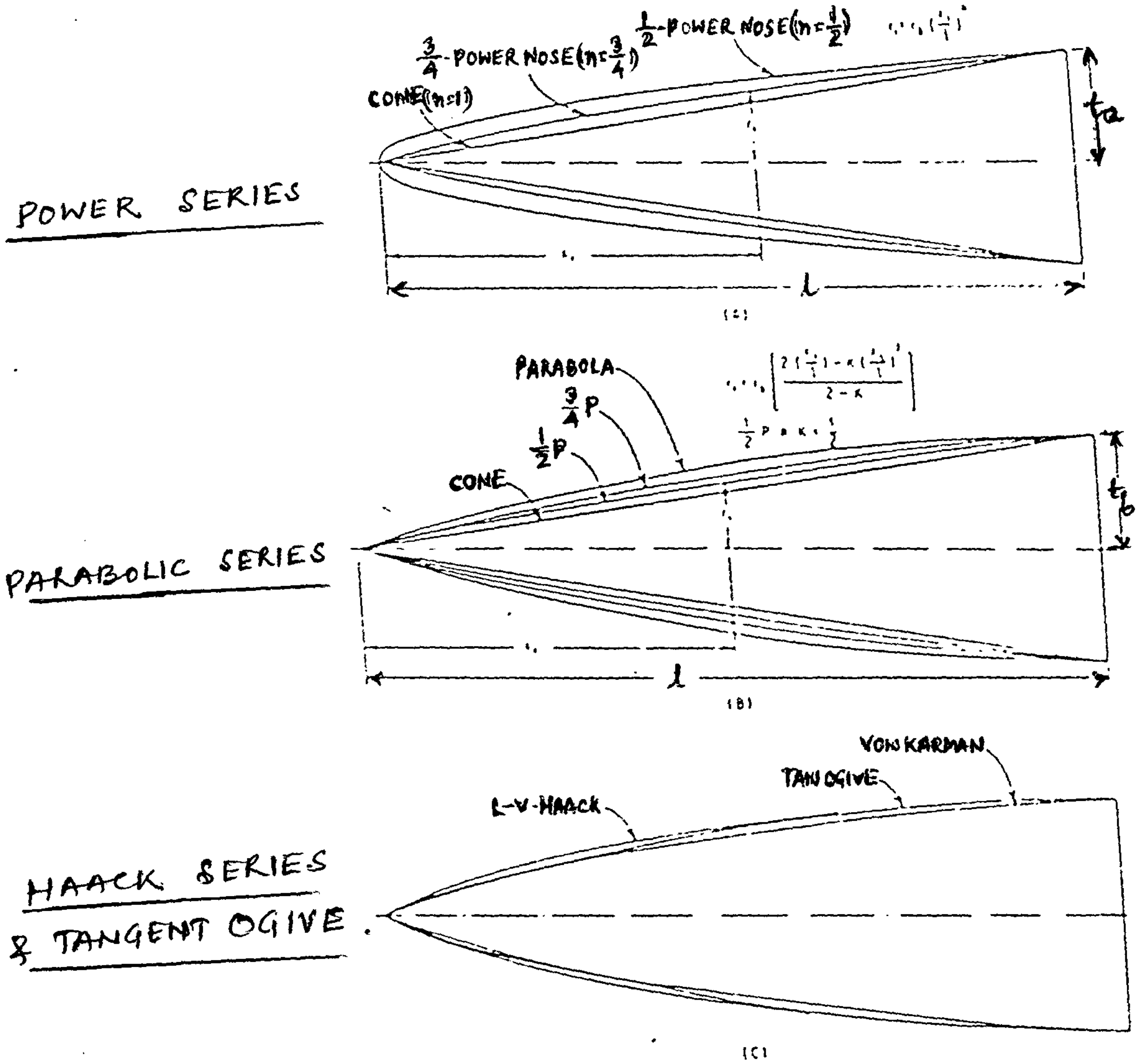


FIG. 22 (A) Profiles of fineness ratio, 3 noses—power Series (B) Profiles of fineness ratio, 3 noses—parabolic series. (C) Profiles of fineness ratio, 3 noses—Haack series and tangent ogive.

Semivertex angle of ogive, So at the tip of the nose is given by:

$$So = 2\,A\,\tan(1/2l/d) \qquad -(14)-$$

Figure 2.2 gives the nose shapes of power, parabolic, Haack series and tangent ogive giving profiles of fineness ratio. [15]

100. **Mid-section** : In most missile configurations, the mid section is cylindrical in shape. This shape is advantageous from the drag point of view, case of manufacturing and load carrying capability. In our case, since the missile is to be launched from conventional gun, the most suitable design is cylindrical as all other shapes will end up reducing the effective volume of missile since maximum length of missile is limited. The zero-lift drag is caused by viscous forces (Skin friction) only. At low angles of attack, the normal force developed on the mid-section is due to carry over from nose-section. However, some force is developed at larger angles of attack due to cross flow of air. In SSM, the angle of attack is going to be small for both tank as well as heptrs. However, the effect of viscous cross flow at angles of attack can be calculated from the following equation :-

$$* C_N = 2a + C_{Da=90deg} \times A_P \times a^2/S \qquad -(15)-$$

Where;

Ap-------- Planform area.

S--------- Reference area.

C_N ------- Normal force coefficient.

$C_{Da = 90deg}$ ------ Drag ciefficient at a = 90deg.

a -------- Angle of attack.

101. **Tail Section** : The tapered portion of the aft body is called boat tail. The purpose of the boat tail is to reduce the drag on the body that has a squared off base. By boattailing, the rear portion of the body, the base area is reduced and thus a decrease in base drag is realised. However, the boat tailing has the following disadvantages which should be weighed before incorporating it :-

(a) Lift on the boat tail is destabilising which must be overcome by some increase in tail area.

(b) CP travel is increased with angle of attack.

1Ø2 . **Aspect Ratio** : In most practical cases, 3 D airfoils are employed. In this, the concept of mach cone is employed. According to this concept the effect of disturbance is felt only within the interior of circular cone whose vertex is located at the point of disturbance and whose axis extends downstream parallel to the free stream flow direction. The geometry of the cone is determined by the requirement that the components of the free stream velocity normal to the surface of the cone be equal to the speed of sound in the undisturbed stream. Hence semivertex angle of the cone is a function of free stream mach number only.

$$m = A \sin(c/v) = A \sin(1/M) \qquad -(16)-$$

C ----- Speed of sound.

V ----- Free stream velocity.

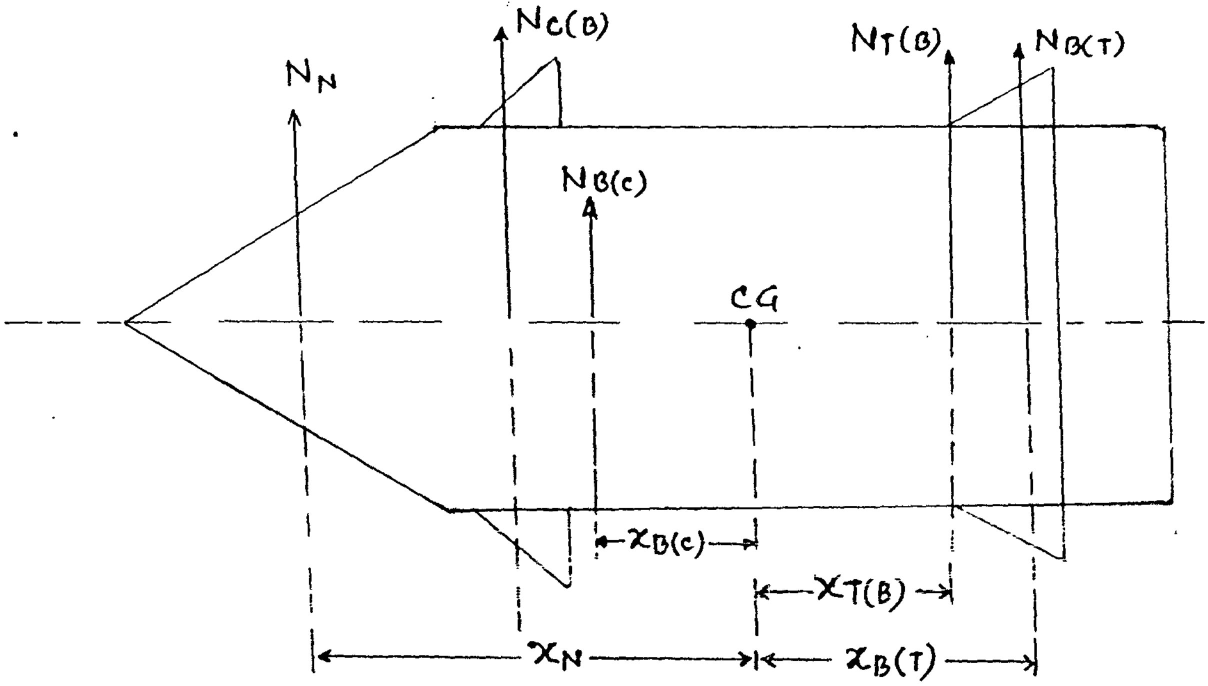
m ----- Semivertex angle.

For rectangular wings there will be a loss of pressure at the tips. The tip losses are similar to those realised in subsonic flow phenomenon except that in supersonic case these tip losses are restricted to shaded area as shown in the fig23 . The tips are sometimes raked to reduce the tip losses or aspect ratio. These tip losses may be completely eliminated by cutting the tips at an oblilque angle equal to or some what greater than mach angle. Therefore, the most commonly used wings are rectangular with raked tips.

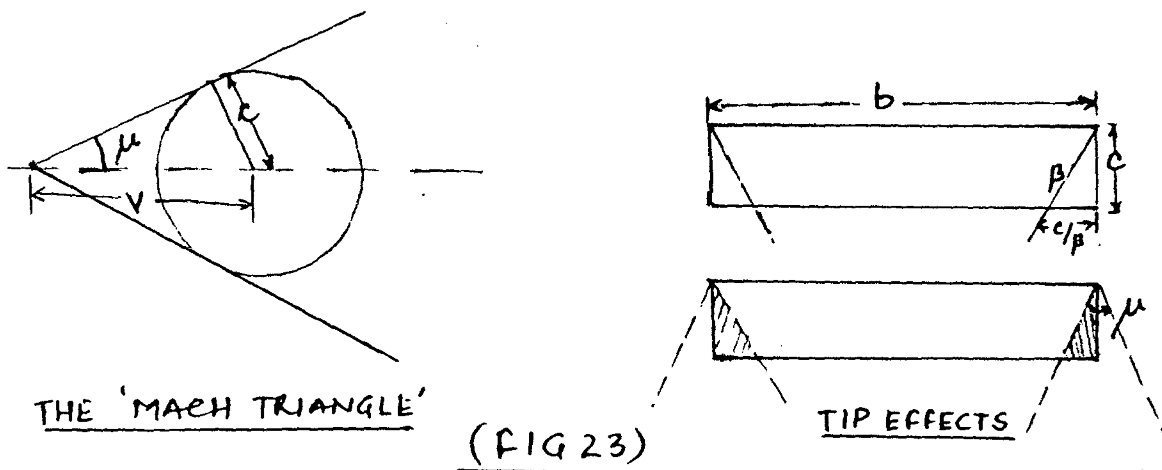
1Ø3. However, in our case, the missile is gun fired. The most suitable design of lifting surfaces i.e. canards should be retractable delta or triangular with leading edges tapered to fall within mach cone. As far as fins are concerned, these need be wrap around rectangular with raked tip or clipped delta. Both fins and canards are required to come out of the cylindrical portion only when missile is out of the gun muzzle. Therefore, the design or canards & fins should be such that the leading edge angle should be equal to or less than mach cone angle to reduce the supersonic shock waves. Shock waves have detrimental effect on the body surface and total drag of the missile.

STATIC & DYNAMIC STABILITY

1Ø4. One of the most important jobs of the frame configuration designer is to see that sufficient natural static and dynamic stability and damping is provided to the air frame. However, stability and maneuverability are conflicting requirements. Therefore, a compromise has to be reached between stability and maneuverability.



FORWARD CONTROL MODEL (FIG 24)



(FIG 23)

Static longitudinal stability for forward control

105. Consider a forward control model as given in the figure 24. with control surfaces forward of CG. Aerodynamic forces and moments are as under :-

$$* \; N_{CM} = N_N + N_{C(B)} + N_{B(C)} + N_{T(B)} + N_{B(T)} \qquad -(17)-$$

$$* \; M_{CM} = N_N X_N + N_{C(B)} X_{C(B)} + N_{B(C)} X_{B(C)} + N_{T(B)} X_{T(B)} + N_{B(T)} X_{B(T)} \qquad -(18)-$$

Where;

M_{CM} & M_{CM} ---- Normal force & moment of complete model.

N_N ------- Normal force on nose section.

$N_{C(B)}$ ---- Normal force on canards in presence of body.

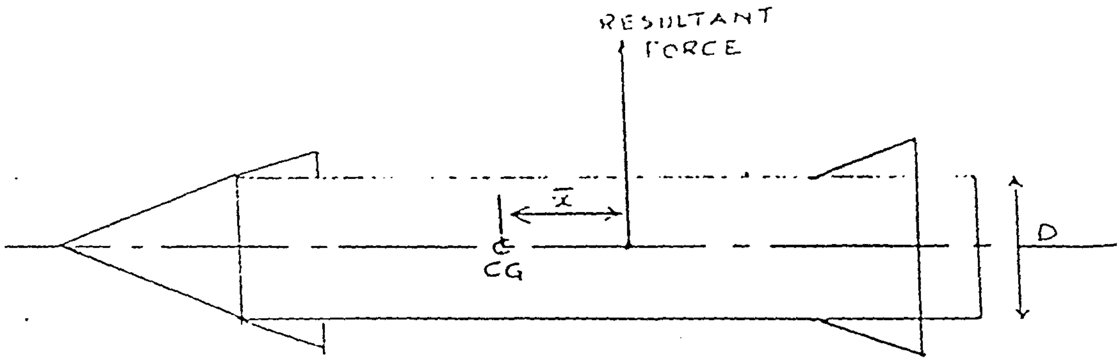
$N_{B(C)}$ ---- Normal force on body due to canards.

$N_{T(B)}$ ---- Normal force on tail in presence of body.

$N_{B(T)}$ ---- -do- body due to tail

* X_N, $X_{C(B)}$, $X_{T(B)}$, $X_{B(T)}$, $X_{B(C)}$ -- Moments arms from CP to missile CG.

The CP location of nose, canard and tail may be determined by relations given in their respective sections. The effect of moment due to CP on canard and canard on body is neglible. However, the locations of CP due to canard and tail are functions of mach number, aspect ratio and taper ratio. The experimental results of similar missile can be used. The configuration and size of the tail fins can be so adjusted to bring the static margin to desired loaction. Static Marigin (SM) - The SM of the missle is the distance of CG from centre of pressue. If CG & CP are at the same position, the missile is neutrally stable. However, with large l/d of the missile, the CG and CP are not at the same position. If CP is forward of CG, the missile will experience lift due to gust of air and forward motion of the missile. Therefore, there is a neutral point at which the moments of all forces on the missile are zero.. If SM is zero i.e CP & CG coincide, the missile is neutrally stable. When SM is negative i.e CP is ahead of CG, the missile is unstable. From the figure 25 the static margin can be calcuated. [8]



STATIC MARGIN FIG- 25

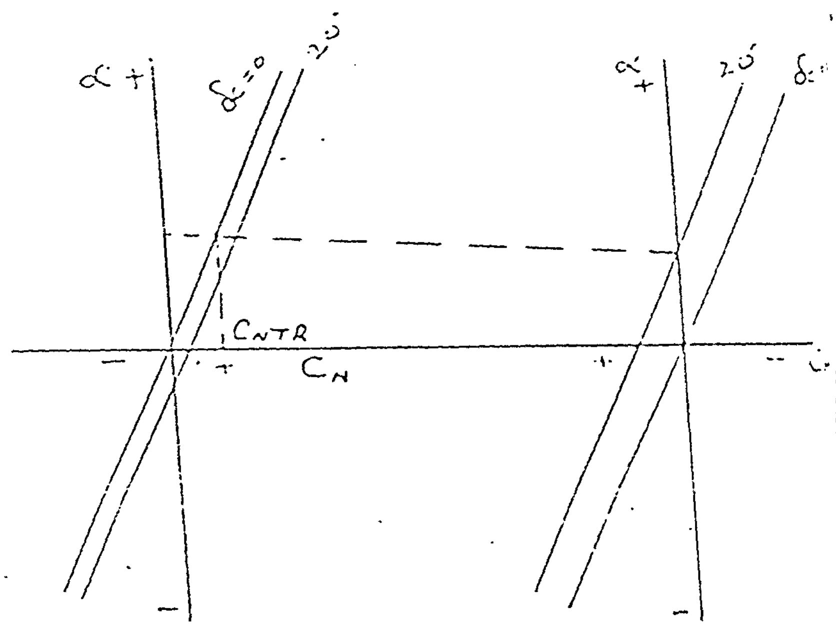


FIG. 26 TYPICAL COMPLETE NORMAL FORCE AND PITCHING MOMENT CURVES - FORWARD (CANARD) CONTROL

$$* \quad X/D = C_{Ma} / C_{Na} = C_M C_N \qquad -19-$$

Static margin is defined in terms of missile body diameter. Hence;

X/D ----- Static Margin

Cma & CNa ------ Missile derivatives.

CMCn--------- Normal force component.

CMa & CNa can be calculated by simplifying and manipulating equation (17) & (18).

107. **Load factor capability** - (Canard control). To evaluate the aerodynamic load factor maneuvering capability, the following equation can be used :-

$$* \text{ Load factor, } n = \frac{N}{W} = C_{NTR} \times qs/W \qquad -20-$$

For a typical canard configuration, Load factor per unit deflection

$$* \quad \frac{n}{d} = \left[C_{Nd} - C_{Na} \times C_{md}/C_{ma} \right] qs/W \qquad -21-$$

Where,

n ------- Load factor.

d-------- Control surface deflection

N-------- Normal force.

W--------- Wt of missile.

q--------- Dynamic pressure.

s--------- Reference area.

CNTR----- Trim condition normal force component at zero moment point at that deflection.

* $C_{Nd}, C_{Na}, C_{ma}, C_{md}$ ------ Pitching moment derivatives.

CNTR can be determined from the figure 26 directly.

108. **Relationship between Maneuverability and static stability Margin**

We know

$$* \frac{n}{d} = \left(C_{n\delta} - C_{m\alpha}/C_m C_N\right) \times qs/W$$

$$* C_m C_N = (d\, C_M/d\alpha)/(dC_N/d\alpha) = x/d \qquad -22-$$

Here sign Cmd is positive and CmCN is negative for all practical designs. Therefore, it is apparent that with increasing static stability margin CmCN results in decrease in load factor capability.

Structural Design Considerations.

109. The primary function of the structure is to withstand high temp, pressure, withstand the stresses due to air friction during flight and capable of carrying the mass of enclosed missile components. The missile casing should have the following characterstics :-

(a) With stand high temp and pressure of the explosive at the tgt.

(b) Withstand flight stresses.

(c) Stiff enough to carry the load of the missile components.

(d) Corrosive resistance.

(e) Fabrication limitations.

(f) Cost and availability.

(g) Should be light not to add undue weight to the missile.

110. The material generally used is aluminium alloy. Since the impact velocity of the missile at target is about 400 m/s, the material is likely to encounter high T & P with low impact velocity only for a small duration. Hence very hard and tough material is not required as compared to KE energy shots. Hence, body should be constructed as monocoque or semi-monocoque stiffened with longitudinal stringers and traverse bulk heads. The tail fins and canards need be constructed out of Mg-Al alloy to withstand high aerodynmic stresses. [6]

Guidance And Control

Guidance

111. Guidance is a process that brings missile and target together at the same time in space and in the same instant. It

is kinematic in nature because it is fundamentally concerned with pure motion. -It is governed by simple constraint statements or guidance laws. If guidance laws are perfectly obeyed, the missile will hit the target. However, this is seldom the case for high maneuvering target e.g aircraft's etc. Therefore, in case of high maneuvering targets, proximity fuzes are used which detonate the missile in the vicinity of the target called mis distance.

112. **Beam Rider Guidance** In our case, the missile has SACLOS with beam riding. Therefore, the missile position is controlled, so it always lies on a line between a reference point i.e tracker, and the target. The target is designated by laser beam from the tract at the launching site and the missile computes its deviation from the centre of the beam to the target and gives the required movement signal to the control surfaces to turn. Therefore, the missile is guided by the beam till target.

113. **Coordinate System** : The LOSBR missile follows Cartesian Coordinate system i.e. up-down and right-left movement. Here we take the convention of X-positive to the right and Y positive-up.

114. Line of sight Guidance. This follows the basic guidance law.

$$\theta_m = \theta_t.$$

θm = LOS angle from tracker to missile .

θt = LOS angle from tracker to target.

Now in the figure 27

*ψ_m, ψ_t ->Steering angles measured relative to fixed reference.

*σ_m, σ_t ->Angles made by missile & target with LOS.

*R_m, R_t->Ranges from tracker to missile and target.

* a_n ->Missile normal acceleration.

No analytical solution for the trajectory of a LOS missile exists, even with simplifying assumptions at constant speeds. A point to point numerical technique allows the calculation of LOS trajectories against an arbitrary target motion. (Fig 28)

* $$\dot{\theta}_t = \frac{V_t \sin(\sigma_t)}{R_t} \qquad -(1)-$$

* $$\text{Also } \dot{\theta}_t = \frac{V_m \sin(\sigma_m)}{R_m} \qquad -(2)-$$

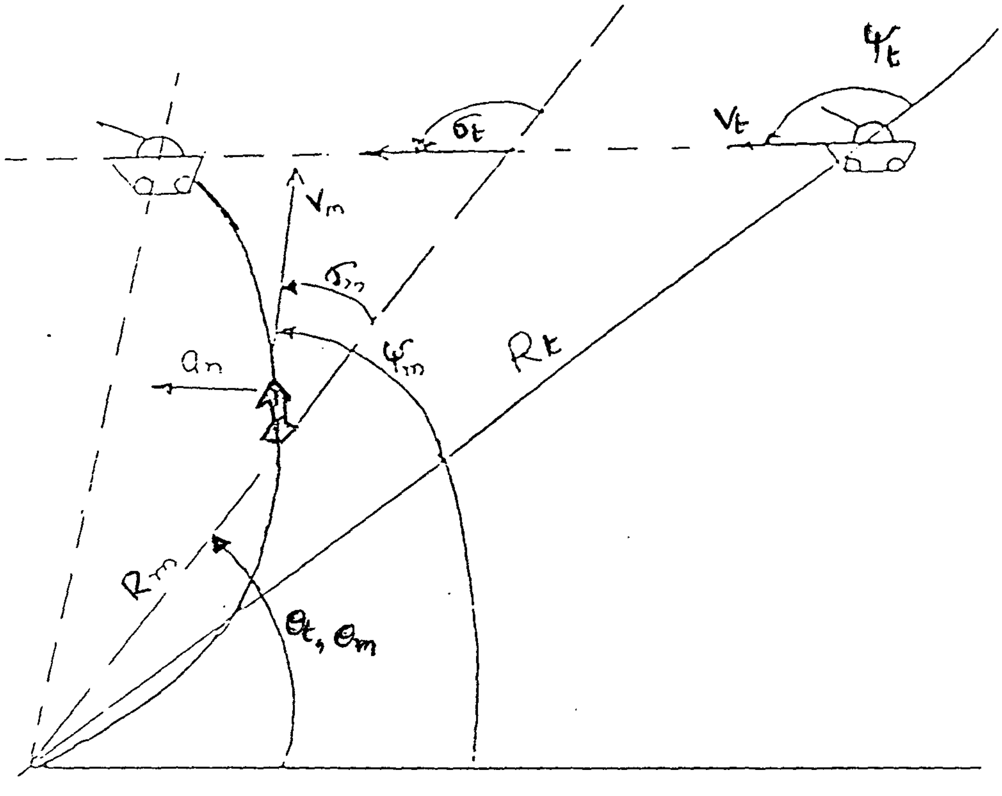


FIG-27 LINE OF SIGHT GUIDANCE GEOMETRY

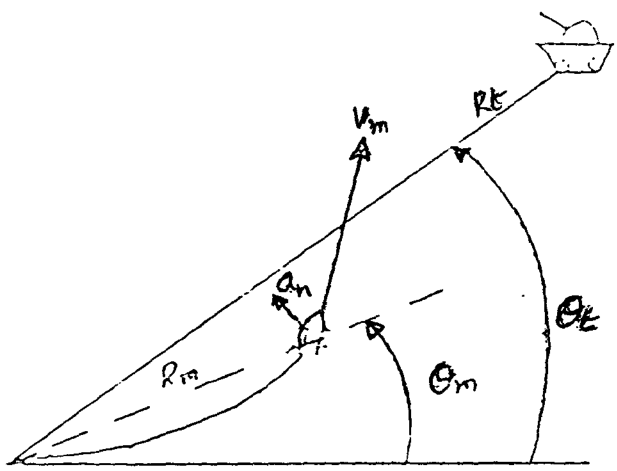


FIG-28 LOS GUIDANCE LAW

for missile to remain on LOS;

$$* \ \dot{\theta}_t = \frac{V_t \sin(\sigma_t)}{R_t} = \dot{\theta}_t = V_m \frac{\sin(\sigma_m)}{R_m}$$

$$* \ V_m R_t \sin(\sigma_m) = V_t R_m \sin(\sigma_t) \qquad -(3)-$$

Performing implicit differentiation on both sides and solving for yields.

$$* \ \dot{\sigma}_m = \frac{(\dot{V}_t R_m + V_t \dot{R}_m)\sin(\sigma_t) - (\dot{V}_m R_t - V_m \dot{R}_t)\sin(\sigma_m) + V_t R_m \dot{\sigma}_t \cos(\sigma_t)}{V_m R_t \cos(\sigma_m)} \qquad -(4)-$$

We also know that Steering rate,

$$* \ \dot{\psi}_m = a_n / V_m$$

$$* \ \theta_m = \theta_t \qquad -(5)-$$

$$* \ \therefore \psi_m = \theta_m + \sigma_m$$

$$* \ \therefore \dot{\psi}_m = \dot{\theta}_m + \dot{\sigma}_m$$

where,

a_n - missile normal acceleration

Vm - missile velocity

$\dot{\psi}_m$ - missile steering rate

$$\text{Also } \dot{R}_m = V_m \cos(\sigma_m)$$

$$\dot{R}_t = V_t \cos(\sigma_t) \qquad -(6)-$$

Then,

$$\theta_t = \tan^{-1}(y_t / x_t)$$

$$R_t = \sqrt{x_t^2 + y_t^2}$$

Now at t = Ø, $X_m = R_m \cos(\theta t)$

$Y_m = R_m \sin(\theta t)$

Then,

$$\sigma_m = \sin^{-1}\left(\frac{V_t R_m \sin(\sigma_t)}{V_m R_t}\right) \qquad -(7)-$$

Hence initial steer angle can be determined. The missile steering and range rates can be determined from equations (5) & (6).

115. **LOS Missile Guidance Implementation**

The method of control is based on estimation of lateral displacement of the missile from target LOS.

* $\therefore x_e = R_m (\theta_t - \theta_m)$

Hence normal acceleration command to the missile will be proportional to this linear error . The effective gain decreases as the missile to beam angle increases because only a portion of the normal acceleration is available along the perpendicular from the missile to the LOS.

The figure 29 illustrates the guidance mechanisation in block diagram form.

e_θ = LOS angle error

e_x = Lateral position error

a_{nc} = commanded normal acceleration

a_n = achieved normal acceleration

$\bar{X}_m$ = lateral position of missile

θ_m = missile LOS angle

Kg = Guidance gain.

Input here is the tracker target LOS angle. The tracker missile LOS angle is fed back and substracted from the input forming an angle error (in radians). The lateral error multiplied by guidance gain gives that acceleration. Here the missile is represented by a first order transfer function $(1/\tau_m s+1)$ that relates achieved acceleration to command acceleration. The lateral momentum is double integration of acceleration. The Xm is divided by Rm to get the lateral angle command. Therefore, here the LOS can be considered as fixed in space with command position represented by a point which moves normal to LOS at an arbitrary range. [10]

116. The control diagram is considered unstable and hence compensation is used. The figure 30 shows the control block diagram with compensation. This lead-lag compensation has better response i.e. positive phase angle and hence better jerk inputs and constant acceleration.

Control

117. Normally, a beam rider system should function in such a manner that the missile can be positioned on the beam all the time. Furthermore, the missile will be off the beam center when launched from the gun. The general guidance and control model can be depicted as shown in block diagram 31. The laser beam of Nd-YAG laser having 1.06 um wavelength. Nd-YAG laser is harmful

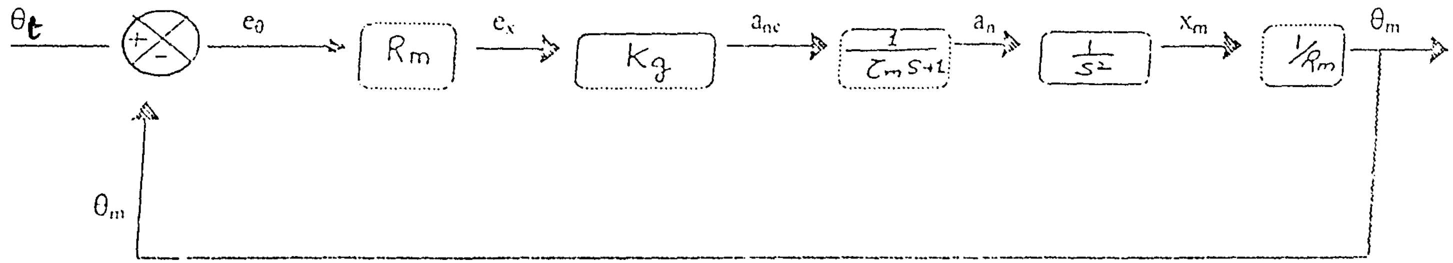


FIG.29 GUIDANCE MECHANIZATION

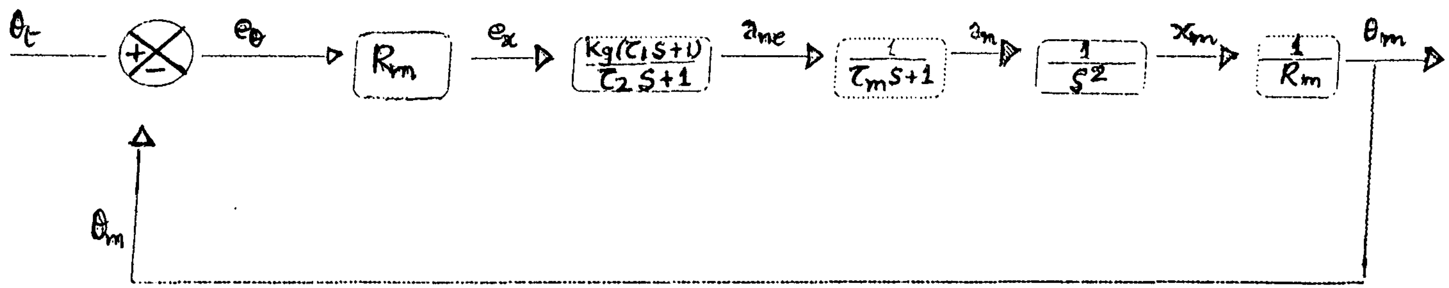


FIG-30 CONTROL BLOCK DIAGRAM WITH COMPENSATION

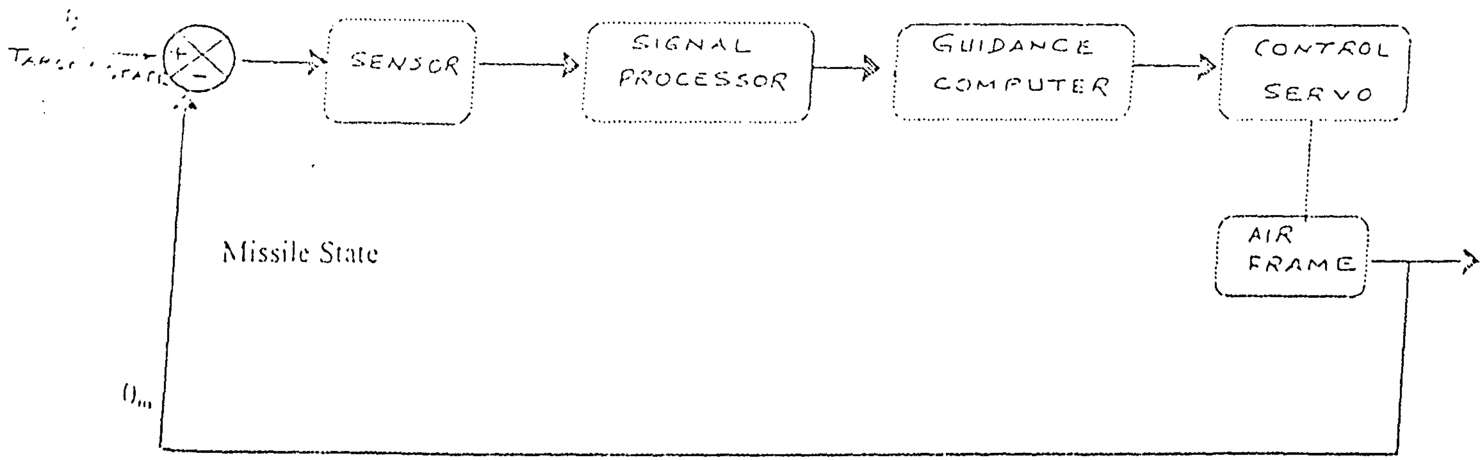


FIG-3.1 GENERAL GUIDANCE & CONTROL MODEL

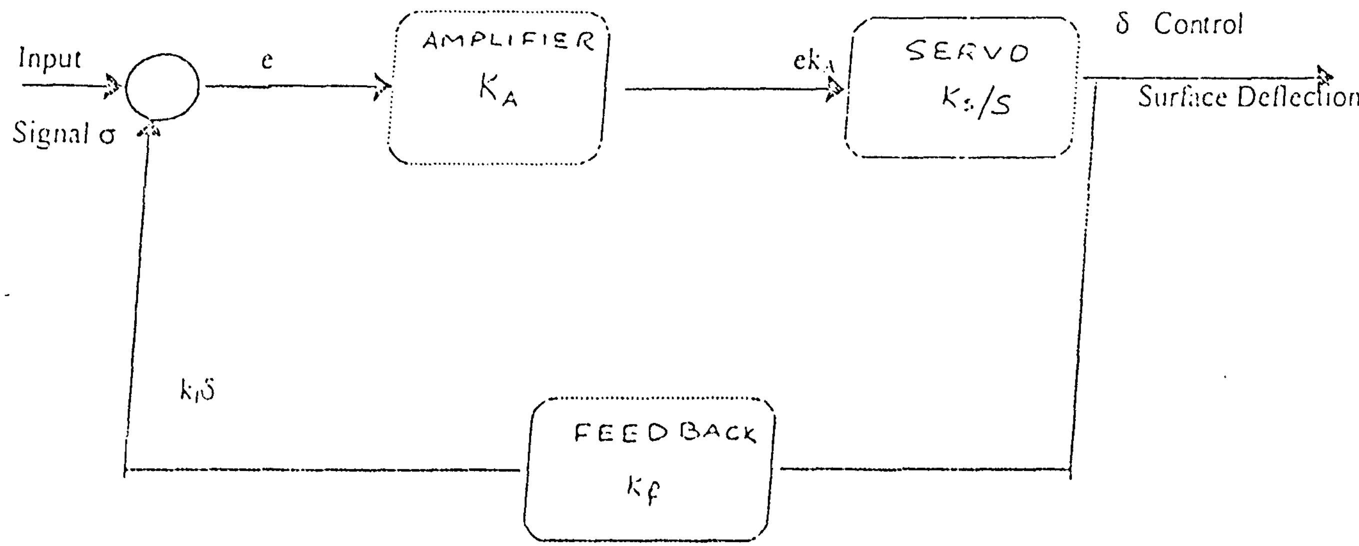


FIG-3.2 SERVOMECHANISM

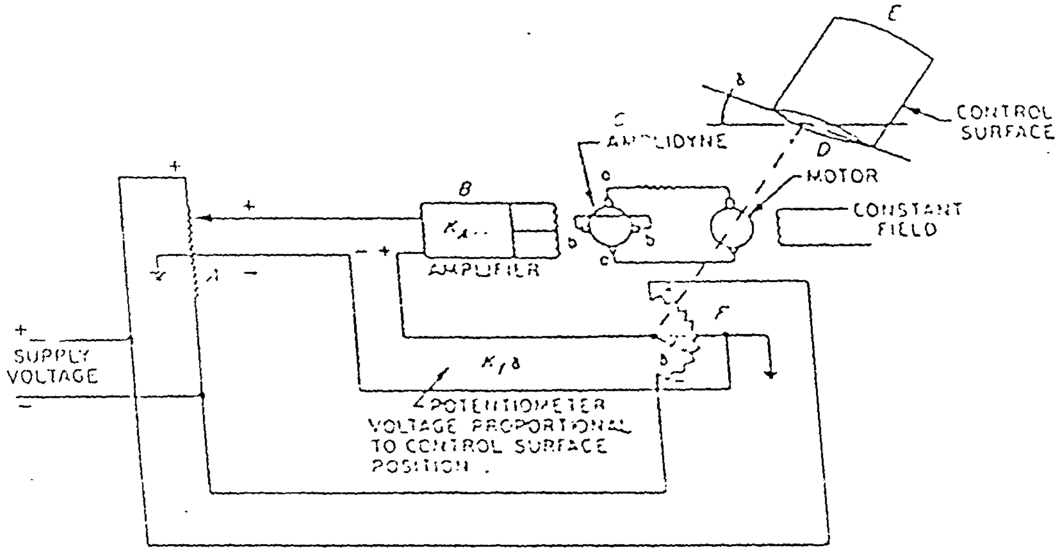


FIG. 33 Electric Motor Position Servo.

to eyes. Hence latest Raman shifted Nd-YAG laser is eye safe and works with wavelength of 1.54um. It is developed by CILAS France using patented intra-cavity Raman resonator developed by Hughes Aircraft Company, France(IDR Oct 95). The gunner at launcher keeps the beam at target till missile reaches the target. The missile uses laser window and hence keeps itself around the beam in a sinusoidal path. The criticality of the system is to align the missile with laser beam after launch from the gun. The beam received at missile and receiver is passed through band pass filter, the signal is processed and computed in terms of voltage. This voltage is given to the control servo which effects the deflection of canards for missile maneuverability. The missile position is continuously sensed at receiver senson stage and error signal is generated with reference to beam axis at the signal processor.

118. **Servo Mechanism** : The simplest form of a servomechanism consists of an input signal, amplifier, servomotor and feedback as shown in block diagram. The block diagram shows first order transfer function. This can be achieved in a number of ways viz, electric motor position servo, two position on-off controller servo (Bang Bang theory)(Fig 32).

$$* \quad \frac{\delta(s)}{\sigma(s)} = \frac{K_A K_S}{s + K_A K_S K_f}$$

119. **Electric Motor Position Servo (PID Controller)** : In this type of servo, the set point is at voltage divider which results in reference voltage. Feedback potentiometer 'F' is positioned by rotation of control surface in either direction about the hinge-line. Potentiometer voltages is proportional to control surface deflection being equal to Kf. The difference between potentiometer voltage and input voltage becomes the impute to servo-amplifier and then used for rotation of motor through amplidyne. The transfer function is (Fig 33):

$$* \quad \frac{\delta(s)}{\sigma(s)} = \frac{K_A K_g K_w}{s + K_A K_g K_w K_f}$$

Kw = motor constant, Kg = No load Amplidyne quadrature field, Kf = feedback gain.

120. **Two Position-on-off Servo Control** : The simplest form of the servo system for laser beam guided can be achieved by fitting a quadrant detector e.g. CA 30845 silicon PIN photodiode having spectral range from 400 to 1100 nano meters. The quadrant detector can be fitted on the focal plane of the receiver optics such that centre of the detector can be aligned at the centre of the missile and x,y coordinates of the detector aligned with two mutually perpendicular vertical canards. The quadrant detector

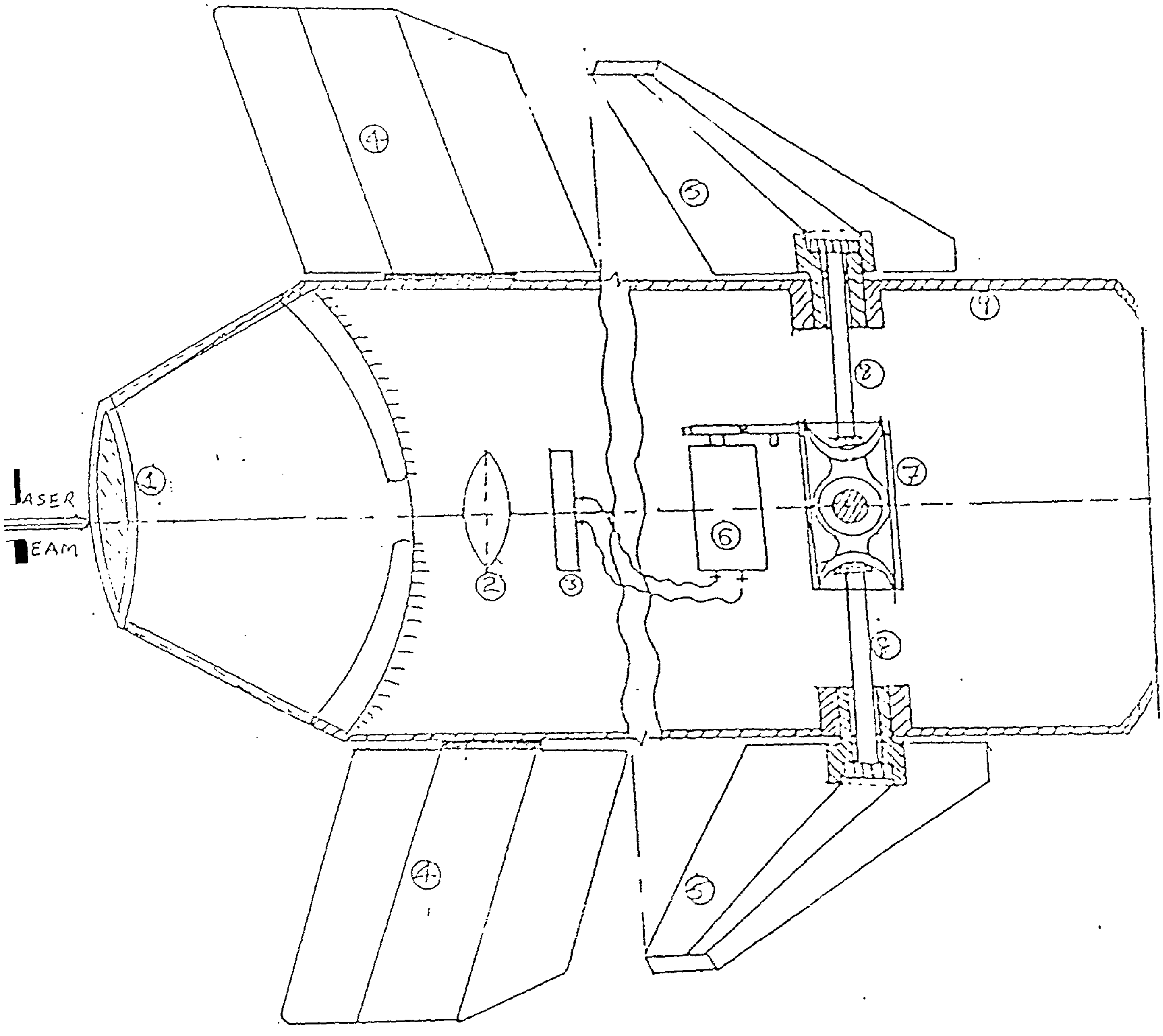


FIG 34 LASER SEEKER

SERVO UNIT

1. LASER COLLECTING RADOME
2. FILTER LENS
3. QUADRANT DETECTOR
4. TAIL FINS
5. CONTROL SURFACES
6. STEPPER MOTOR
7. CENTRAL GEAR UNIT
8. HALF TORSION SHAFT
9. FRAME

and lens can be fixed wrt each other in such a way that any movement in missile will not change the position of one wrt other. The output of four quadrants as received from the detector can be amplified to four outputs as Quad A, Quad B, Quad C, and Quad D. The four Quad outputs can be further used to get three outputs using Td 4452 package e.g. Quad (A + B) + Quad (C + D), Quad (A +B) - Quad (C +D) and Quad (A +D) - Quad (B + C). From above 3 signals, the error signal in both elevation and Azimuth can be generated in the following manner :

$$X = \frac{Quad(A+D)-Quad(B+C)}{Quad(A+B)+Quad(C+D)}$$

$$Y = \frac{Quad(A+B)-Quad(C+D)}{Quad(A+B)+Quad(C+D)}$$

The general layout of the laser seeker head (servo unit) and receiver ckt diagram as suggested is given opposite in figure 34, 35.

121. **Proposed System** : The proposed block diagram for control is given at figure 36. Apart from the system given in block diagram, a continuous signal equal to 1'g' will be required to compensate for force due to gravity in Y-axis as the same will be acting throughout the flight of the missile. [15]

122. **Constraints** : The missile is gun fired hence subjected to very high 'g' effect. The electronics for the guidance and control servo should be such that it can sustain high 'g'effect. Therefore, the maximum 'g' acceleration with which missile can be launched in restricted. The system may be more electro-mechanically based so as to withstand the high 'g' effect. The choice of guidance and control servo may be dictated by these constraints including constraints of space available for receiving optics, receiver unit and control servo. The most common type of control system used in ATGMs is Bang Bang type in which the control surfaces are deflected between on and off positions in either side of the neutral axis. The time of deflection dictates the amount of control on the system. The electronics can withstand 'g' acceleration of the order of 10000g as used in world systems. Copperhead missile used 7200 'g' in early sixties. Russian 152 mm Howitzer missile is likely to use 10000g - 12000g with 250 MPa peak pressure. Hence it is fairly feasible to achieve the 10000 'g' electronics for guidance and control of the missile. [12]

BATTERY

123. Thermal Bty's are the most commonly used bty's in missiles today. Another type of Bty used is Lithium Bty. The Lithium Bty's have an advantage of higher density of three times the Nickel-cadmium bty's.

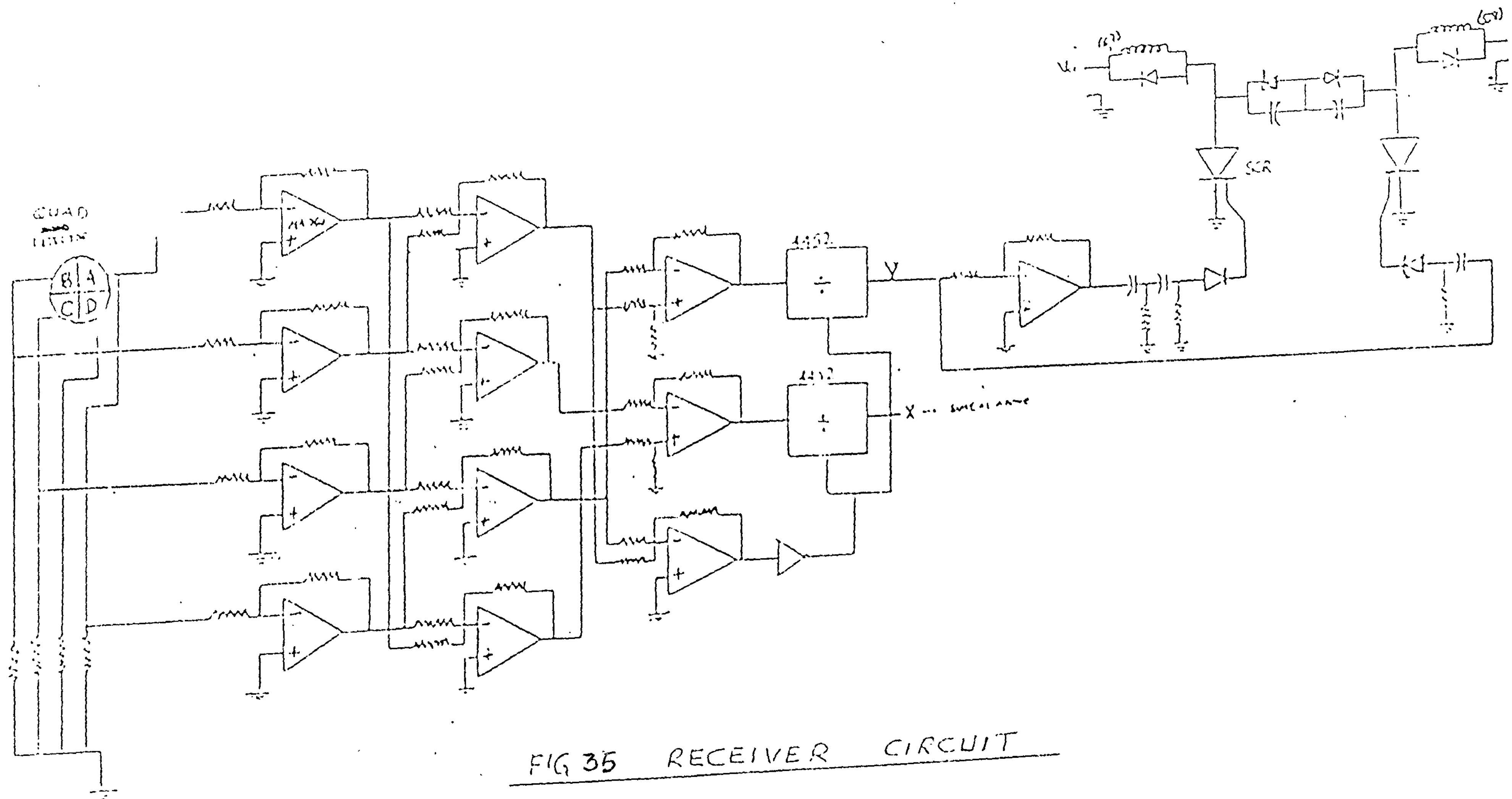


FIG 35 RECEIVER CIRCUIT

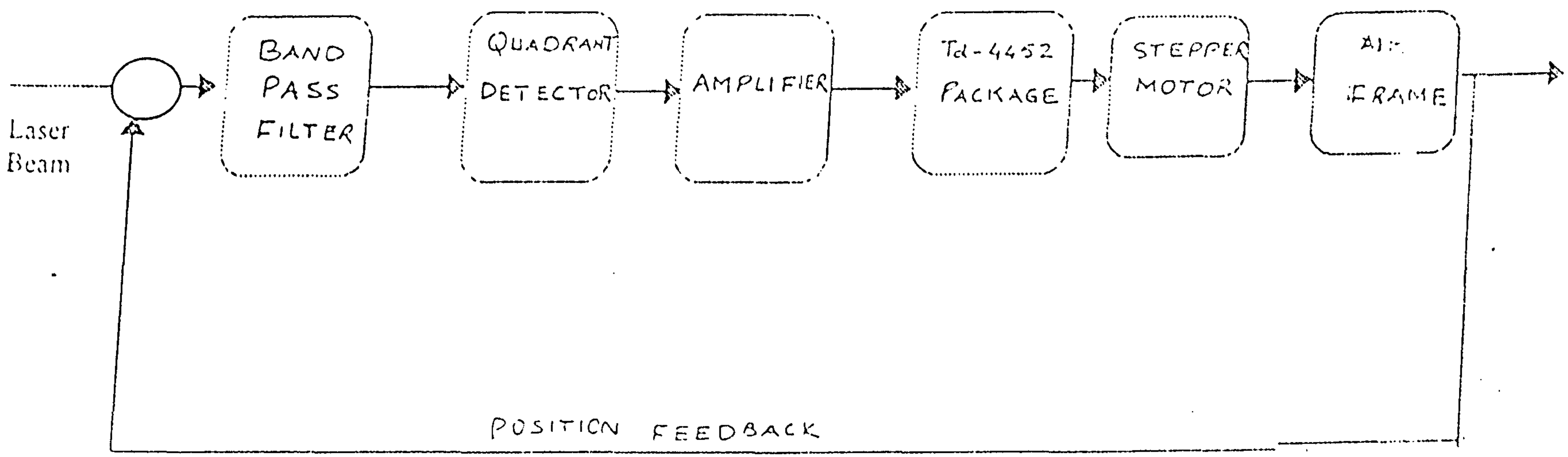


FIG.36 PROPOSED CONTROL SYSTEM BLOCK DIAGRAM

War Head

124. The primary tgt would be tank armr and the secondary tgt attack Heptr. The wt of the warhead would be 4 to 5 kg. A tandem shaped charge with capability for fragmentation in case of Heptr tgt is best suited as a common design for both roles/tgts can achieve an purpose.

125. **Tandem shaped charge** : In the case of a single shaped charge used against armr with ERA, the jet is distorted and hence effectiveness is reduced. Therefore a tandem shaped charge is used. In tandem shaped charge there are two charges : the front charge, defeats ERA and the main charge defeats tank armr. The warhead is a thin case fitted with explosive with a symmetrically placed lined cavity at the front and initiator cum booster at the rear. The impact fuse is at front and copper is used as the cone mtrl with a 40 degree to 60 degree cone angle.

126. **Fuses and safety Arming mechanism** :

(a) Impact fuse : Two types for tandem warhead.

(i) Piezo fuse crystal - gives electric pulse on impact to the initiator and booster explosive train.

(ii) 'g' Sensor fuse - It closes the electrical pulse cct on sensing impact 'g' on the tgt. Both type of fuses are available in India.

(b) Proximity fuse :- Used as anti Heptr with a 10 to 20 miss distance. It could be IR, Radio or laser activated.

127. **Arming and safety mech** : The msl is activated after loading in the gun, therefore the msl bty's should be set on after loading the cartridge case. The spacer plug should have a pin which pierces the tail of the msl to set the bty cct. The fire control computer can be integrated to check the msl serviceability by BITS and flash it on board to the gunner.

128. **Arming** :- The missile would be armed outside the gun muzzle at a safe distance and would defeat tgt at a range of 1000m. The velocity of the missile would be 800m/sec and would get armed in 0.5 to 1 sec. An electro mechanical mechanism based on acceleration (g) can be used. The max'g' of the missile during launch is 10,000g. It falls exponentially and deceleration takes place due to air drag and force due to gravity on missile. The acceleration at gun muzzle is expected to be 1000g (1/10th of max 'g').

Draag $F = \frac{1}{2} C_d \rho A v^2$ — (i) —

(A - Area of the missile)

$F = ma$

$$F = \frac{m.dv}{dt} = \frac{m.dv}{dx} \cdot \frac{dx}{dt}$$

$$F = \frac{mv\ dv}{dx} \qquad \text{......(ii)}$$

Equating equations (i) and (ii)

$$= \frac{mv\ dv}{dx} = 1/2\ Cd\ \rho\ AV^2$$

$$\therefore V = V_0\ e^{\frac{-Cd \rho A x}{2m}}$$

hence velocity after 500m

$$V = 800\ e^{\frac{-0.3 \times 1.293 \times 0.01131 \times 500}{2 \times 17.5}}$$

V = 750m/sec

$$\text{De accleration} = \frac{800 - 750}{5/8} \qquad \because (V = U - at)$$

$$= 80 m/sec^2$$

De acceleration = 8g - acting constantly on the missile.

missile acceleration = 500g after 0.8 sec.

Arming mechanism can be tuned to act between 600g and 400g band. [15]

Data for Anti tank warhead :

1. Cone angle - 54 degree

2. Thickness of liner - 15mm

3. Liner mtrl OFHC (oxygen free high cleanliness) (Cu : ASTM B 152 C 101)

4. **Expl** :

   (a) HMX/TNT : 85 : 15 pressure casted charge.

   (b) Density - 1.84 to 1.86 gm/cc.

5. **Wave shapes** :

(a) Dia - 60 mm

(b) mtrl - silicon foam.

(c) density - 0.7 to 0.8 gm/sec

(d) length of wave shaper - 30mm.

(e) Design based on shock propulsion, mtrl of wave shaper and detonation pressure of explosive.

6. **Fuse** :

(a) Impact.

(i) Piezo electric crystal.

(ii) 'g' sensor.

(b) proximity.

(i) Laser activated.

(ii) IR or radio activated.

129. **Fragmentation liner**

(a) Mtrl - Titanium Alloy.

(b) Thickness - 15mm, 5gm cubical single layer performed fragments.

130. **Front Charge** :

(a) Dia - 60 mm.

(b) length - 80 mm + 30 mm for fuse and safety arming mechanism.

(c) Mass - 0.4 to 0.5 kg.

131. **Main Charge** :

(a) Dia - 94 mm.

(b) Length - (1.5 l/d) : 150 mm.

(c) Mass - 4 kg.

(d) Mass of TA liner - 1 kg.

INTERNAL BALLISTICS OF GUN

132. The beam riding gun launched missile is intended to have no propulsion unit. It is due to the reason that the laser receiver is placed at the tail of the missile. If propulsion unit is placed at the rear, placing of receiver unit will become difficult. Hence the entire propulsion energy will be imparted to missile during launching to take it to the target. Since the warhead is HEAT, the terminal energy at target is not of much consequence as long as the missile reaches the target. In order to compute velocity, range and mass of charge required for the missile launch, missile parameters need to be worked. Apart from this, the biggest limiting parameter for missile launching would be the maximum acceleration which the missile can withstand. The maximum acceleration which the electronics of missile guidance and control can withstand is about 10000 g universally followed in the world. The examples are copperhead Howitzer launched missile of USA, 152 mm Howitzer launched missile of Russia under development. [11]

Missile Parameters

133. **Mass of Missile**

(a) Mass of warhead = 4.5 Kg

(b) Mass of fragmentation TA liner 1 Kg

(c) Mass of guidance and control module = 1/2 Kg

(d) Mass of Power Pack = 1/2 Kg

(e) Length of missile = 8.78 mm.

(f) Maximum dia of missile = 100 mm, limited by gun calibre

(g) Thickness of Al alloy casing = 1/2 kg

(j) Volume of case material = Surface Area X thickness of casing

$$= \left(2 \cdot \frac{\pi}{4} D^2 + \pi D l \right) t$$

$$= \left(2 \cdot \frac{\pi}{4} (0.10)^2 + \pi \times 0.10 \times 0.878 \right) \times 0.015$$

$$= 4.37 \times 10^{-3} m^3.$$

Taking density of Al = 2.66 gm/cc

(k) Mass of casing material = $4.37 \times 10^{-3} \times 2.66 \times 10^{3}$
$= 11.63$ kg

Hence total mass of missile = 4.5 + 1 + 1/2 + 1/2 + 10.5

Mass = 18.5 kg

Pressure

We know that :

M*a = P*A

Where m = mass of projectile

a = Acceleration

P = Pressure at the base of projectile

A = Area of base of projectile
m = 1.05 w + c/3 where c= Mass of charge
m = 19.5 Kg
a = 10000g limited due to electronic parts
$A = \pi/4\ d^2 = \pi/4\ (0.10)^2$ and

$$\therefore P_{max} = \frac{19.5 \times 10{,}000 \times 9.81}{\pi/4\ (0.10)^2} = 240 \text{ MPa.}$$

134. **Velocity**

P max as calculated above = 240 Mpa

The pressure curve and acceleration curve in internal ballistics are similar. Hence mean pressure and mean acceleration will be 2/3 times of maximum values.

Hence,

* P mean = 2/3 P max = 2/3 x 240 = 160 MPa

Similarly mean acceleration = 2/3 x 10000g

= 6666.7 'g'

Length of barrel of Tank = 534cm

$$V^2 - U^2 = 2as$$

Taking U, initial velocity inside gun = 0.

$$* \ V = \sqrt{2 \times 6666.7 \times 9.81 \times 5.34}$$

Velocity = 835 m/sec

The similar missile Reflexs of Russia has velocity of 800 m/s. Hence above value agrees with the data.

Calculation for Mass of Charge

135. Heat ammunition may use NQ/M & NQ/S Propellant. The parameters of ammunition are as given below :

Composition of NQ/M propellant

NC - 'B' = 20.8 + 0.5%

Picrite = 55 + 1%

Carbamite (stabilizer) = 3.6 + 0.2%

K_2SO_4 (flash reducing agent) = 0.3 + 0.1%

N Stands for flashless

Q stands forhigh calorific value

M stands for multitubular (Hepta tubular)

S stands for monotubular slotted.

Gun and shot Parameters

(a) Mass of projectile = 18.5 kg

(b) Dia 'd' of barrel = 103.8 mm

(c) Length of barrel = 5.347m

(d) Effective chamber volume, Ko = 0.01 cubic meters

(e) Shot start Pressure, Ps = 60 Mpa

(f) Co - volume = 0.9754 cubic cm/gm

Gun Propellant Parameters

Type	NQ/M 119	NQ/S 400-100
Web parameter 'D'	0.1368 cm	0.155 cm
Force constant 'F'	1063 J/gm	1063 J/gm
Rate of burning 'B'	0.13 cm/sec-Mpa	0.13 cm/sec-Mpa
Form function'Q'	-0.172	+ 0.2
Density 'p'	1.678 gm/cc	1.678 gm/cc
Pressure index 'n'	1	1
Ratio of sp heats 'r'	1.25	1.25

Internal Ballistic Solution

136. The standard equations of internal ballistics are :

(a) Energy Equation

$$* \; FCZ = P\left\{A(x+1) - CZ\left(b - \frac{1}{\rho}\right)\right\} + \frac{1}{2}(\gamma - 1) W_1 v^2 \qquad -(1)-$$

(b) Rate of Burning Equation

$$* \quad -D\frac{df}{dt} = \beta \cdot p^n \qquad -(2)-$$

(c) Form Function Equation

$$* \quad z = (1-f)(1+\theta f) \qquad -(3)-$$

(d) Equation of Motion of Projectile

$$W_1 \, dv/dt = AP \qquad -(4)-$$

$$dx/dt = v \qquad -(5)-$$

where

f = fraction of web remaining at time 't'

z = fraction of mass burnt at time 't'

p = Pressure in the chamber

n = pressure index

β = Burning rate coefficient

D = web parameter of propellant

F = force constant

C = charge mass

A = cross sectional area of base of projectile

l = equivalent length of the chamber

ρ = density of propellant

b = co-volume of propellant

W1= equivalent mass of projectile

v = velocity of projectile

x = length of shot travel

t = time

W1= 1.05 w + C/3 —(6)—

Where w = mass of projectile

l = (KØ - C/ρ)/A —(7)—

where KØ = volume of chamber

Equation (i) can be modified as under

$$* \quad P = \frac{(Z - EV^2)}{\alpha\left\{\frac{(x+l)}{l} - BZ\right\}} \qquad \text{—(8)—}$$

where

$$* \quad E = \tfrac{1}{2}(\gamma - 1)\, W_1/FC$$

$$\alpha = Al/FC$$

$$B = \left(\frac{C}{Al}\right)\left(b - \frac{1}{\rho}\right)$$

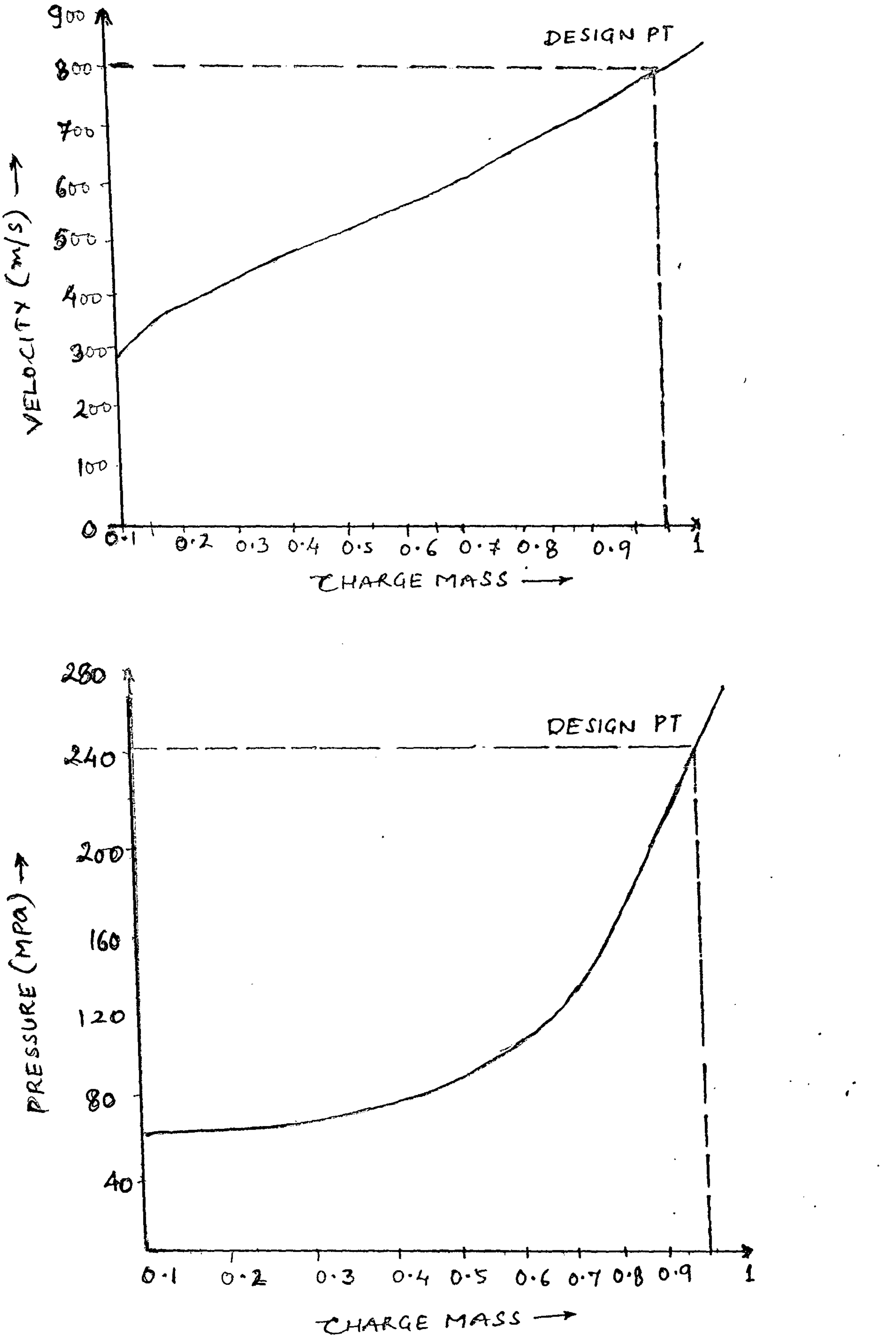
137. These equations can be solved using Euler's method for solving simultaneous equations. [11,15]

138. <u>Critical Analysis</u> : Firstly the same propellant as used in tank ammunition has to be used for the missile propulsion. We can achieve pressure space curve and velocity can be found out. The various combinations can be worked out to give us the most suitable propellant. (REFER FIG 36A & 36B)

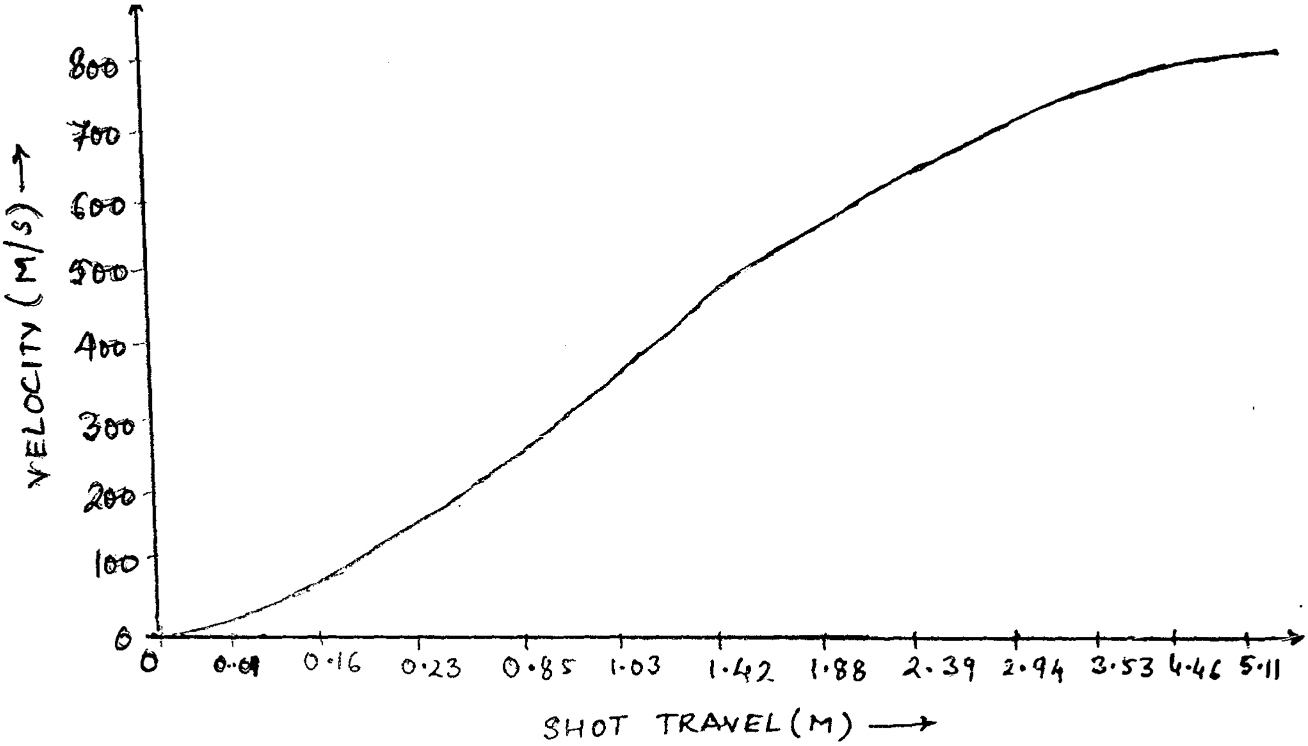
139. After the missile has been fired, the range results can be taken vis-a-vis maximum acceleration of the parts inside barrel. Based on those results, the HEMRL can be assigned the responsibility of developing a new propellant, if need be. Another solution can be found by modifying the launch angle of the gun with NQ/M propellant. The external ballistics of the gun are discussed ahead. The reduction in effective chamber capacity used will facilitate the use of obturation cum temperature isolation pad behind the missile. This pad will isolate the missile from high temperature of the chamber.

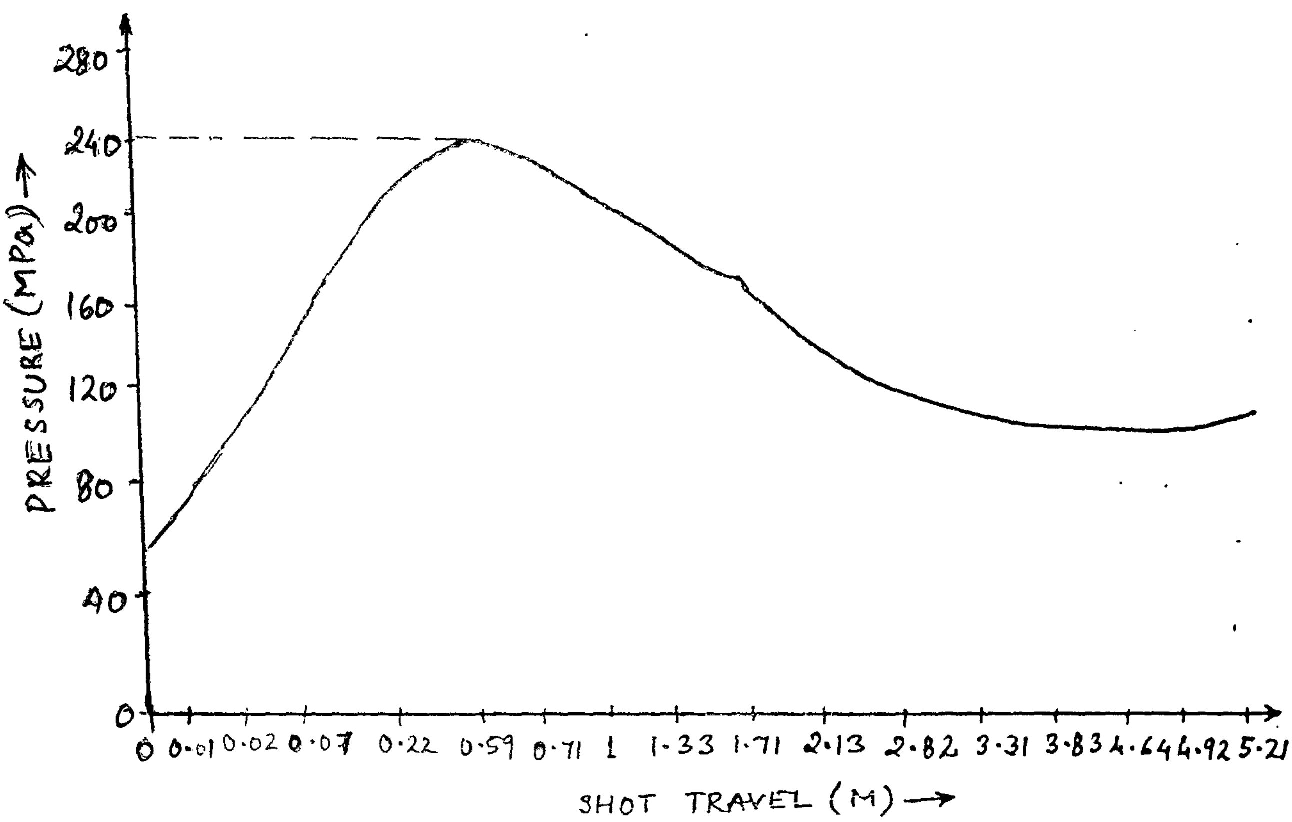
EXTERNAL BALLISTICS

140. Beam rider missile trajectory is sinusoidal about the center of the beam and hence it is very difficult to model it. In order to ensure that the missile reaches the target accurately, it



(FIG36A) VARIATION OF VELOCITY AND PRESSURE WITH CHARGE MASS.





VELOCITY AND PRESSURE SPACE CURVES (FIG 36B) should be given sufficient energy at the launch. The accuracy of the missile will depend upon the capability of its guidance and control system and power pack. The deflection of missile about the center of beam will depend upon the various parameters like time constant, time lag of control system, aerodynamic lag, maneuvering lag etc. However, its capability to reach the intended range depends upon its drag coefficient and launch velocity. This aspect is discussed in succeeding paragraphs.

141. **Drag Coefficient** : Drag coefficient for supersonic missiles is about 0.3 . The figure 17 shows the variation of drag coefficient with Mach Number. If the missile does not have sufficient energy. the control surfaces will deflect and try to bring the missile into center of beam thereby causing increase in drag coefficient since missile does not remain in horizontal position. In worst case when missile becomes purely vertical, its drag coefficient may rise to maximum value i.e.0.8 . Control system becomes redundant and falls down due to force due to gravity. Another aspect which is quite clear from figure that the velocity of missile should not fall below Mach 1.2 since value of Cd in transition from subsonic to supersonic is unpredictable and hence may cause oscillations in missile resulting in lack of dynamic stability. In order to determine whether the missile has sufficient velocity to reach the target, the following two cases can be considered.

Case I - For drag coefficient 0.3

Case II - For drag coefficient 0.8; the worst case.

Case I

The terminal velocity can be computed from equation:

$$V = V_0 e^{-\frac{\rho A C_D \cdot x}{2M}}$$

where

V_0 = initial velocity

ρ = density of air = 1.293 kg/cm^3

A = frontal projected area of missile

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.10)^2 = 0.00785$$

C_D = drag Coefficient.

X = range

V = velocity at any instant

M = mass of missile

for intended range of 5 Km $V = 800 e^{-\frac{1.293 \times 0.3 \times 0.00785 \times 5000}{2 \times 18.5}}$

$V = 530$ m/sec.

Case II

When CD = 0.8

$$V = 800\, e^{-\frac{1.293 \times 0.8 \times 0.00785 \times 5000}{2 \times 22.5}}$$

$$V = 270\, m/sec.$$

142. Form above two cases, it is clear that the missile has velocity of 270 m/sec even when its drag coefficient is 0.8 which is a hypothetical case. The missile drag will normally be around 0.3 and hence terminal velocity will be around 530 m/sec which is greater than 1.2 Mach. Hence missile will remain stable in its flight.

143. **Launch Angle** : The missile minimum range as discussed in terms of reference is 1000 m. Even though it is armed between 0.5 to 1 sec after the missile leaves the muzzle. The launch angle can be worked out as follows :-

$$* \quad R = \frac{V^2}{g} \sin 2\theta, \quad R = \text{Range} = 1000m, \ \theta = \text{launch Angle}.$$
$$V = \text{velocity of launch} = 800\, m/sec.$$

$$\therefore \theta = \frac{1}{2} \sin^{-1}\left(\frac{Rg}{V^2}\right) = \frac{1}{2} \sin^{-1}\left\{\frac{1000 \times 9.81}{(800)^2}\right\} = 0.44^\circ$$

Hence launch angle is 0.44 degree. At 1000 m, the missile will catch on with laser beam. Moreover, the missile will always remain within 30 degree receiver window reducing the probability of missile being lost.

MISSILE DIMENSIONS

144. The length of the missile would be 878 mm approx equal to the present length of Fagot missile. Spacer plug will be required to isolate the missile from high temperature of chamber during launch. The following approximate dimensions a~~re~~ suggested in fig 37 & fig 38)

(a) Warhead

(i) Main charge : 250 mm

(ii) Front charge : 125 mm

(iii) SAM : 80 mm

Total : 455 mm

(b) Receiver cum tail unit : 100 mm

(c) Power pack : 200 mm

(d) **Ogive Length** : The design of ogive suggested is n/m CRH compound ogive. The figure 21 gives the design for supersonic projectiles. From the figure we can see that the length of ogive is decided by the smaller angle i.e, r. For tangent ogives as shown in the figure,

$$R = D/2 + R\cos\theta \qquad -(1)-$$

$$l = R\sin\theta \qquad -(2)-$$

$$l/R = \sqrt{1-\cos^2\theta}$$

$$\cos\theta = \sqrt{1 - l^2/R^2}$$

Substituting in equation (1) above,

$$R = D/2 + R\sqrt{1 - l^2/D}$$

Rearranging above equation, we get

$$1 - D/2R = \sqrt{1 - l^2/R^2}$$

$$\text{or} \quad R = D/4 + l^2/D$$

$$\text{Also} \quad l/d = \sqrt{R/D - 0.25} = \sqrt{C - 0.25}$$

where C = calibre of ogive.

For l/d = 2, the R = 4.25 D

The θ = 28 degree

Hence length of ogive = 240 mm

For laser proximity fuze, there is a requirement of receiving lens of about 2 cm dia. Hence taking apex angle of 28 degree about 20 mm length will be reduced. The front charge can be accommodated in ogival portion.

Hence actual length of ogive = 220 mm

Length of fuzing portion = 220 - 127 = 93 mm

Total length of missile = 455 + 100 + 200 + 93

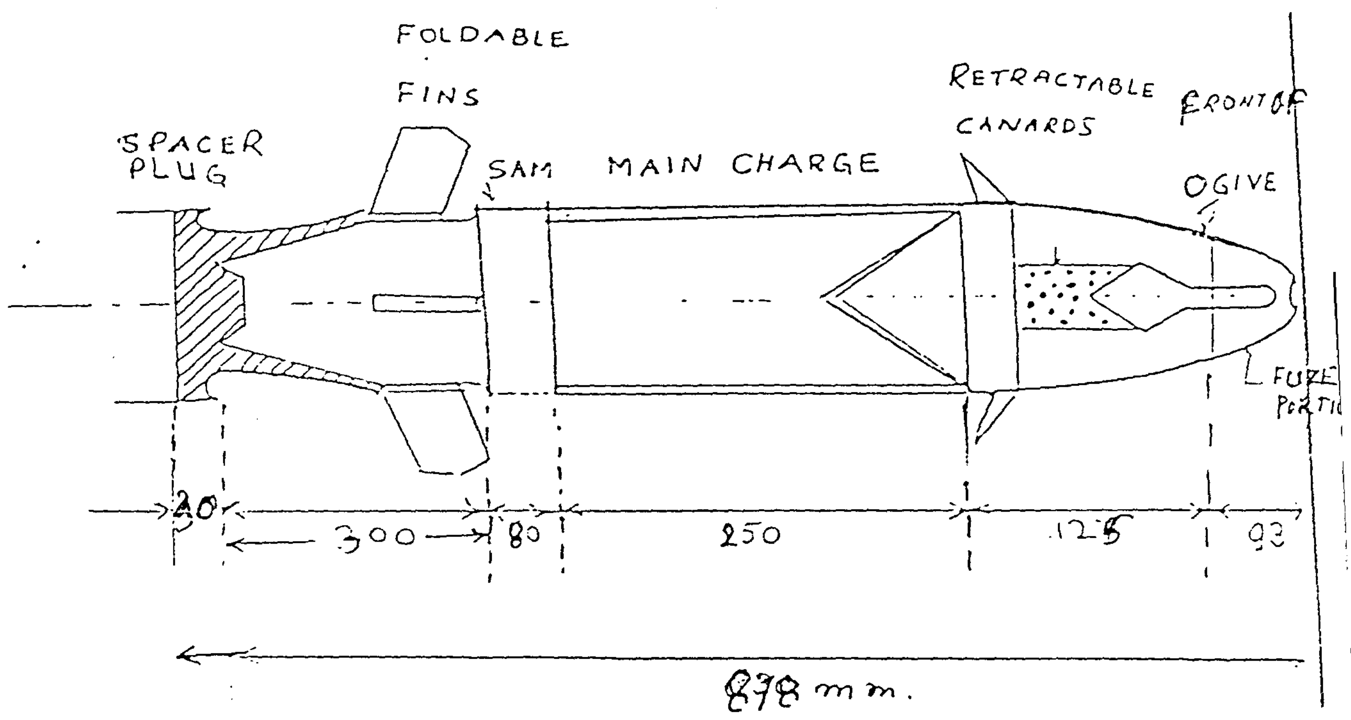


FIG 37 OVERALL DIMENSIONS OF MISSILE

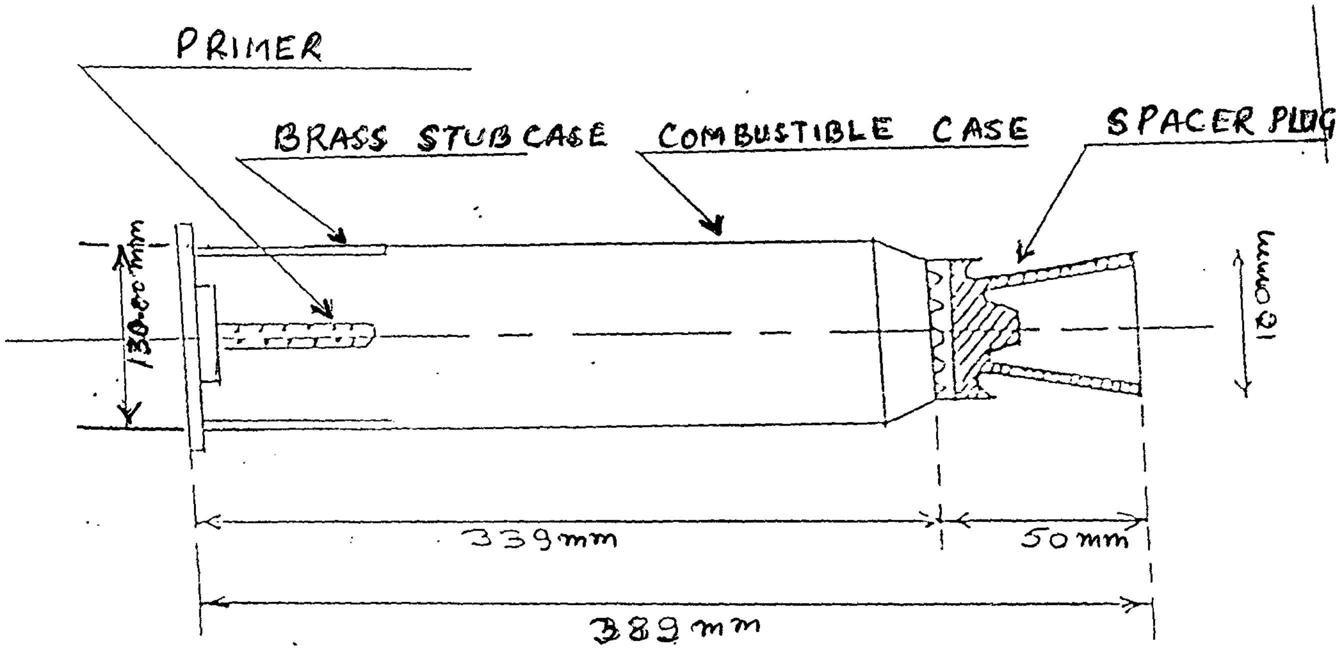


FIG. 38 CARTRIDGE CASE

PRESENT MODE OF OPERATION

145. The switching on procedure presently followed is in BMP as given below :-

(a) Close drivers, Cdrs and all hatches.

(b) Put 'On the Bty' master switch.

(c) Put off NBC protection switch near driver.

(d) Put off the over ride switch on Cdr control panel.

(e) Put auto/aided switch on Cdr control panel in auto position.

(f) Unlock the turret (traverse setting switch operations).

(g) Unlock the Gun (elevation setting switch operates).

(h) Traverse and elevate the gun by manual hard wheels.

(j) Ensure hatch indication lamp is off.

(k) Keep 'Missile SW' on BY-25-2C unit in on/off position as requried.

(l) Put on the No 1, 2, and 3 circuit Breakers on KP-25 unit.
(m) Put auto/aided switch on gunner's control pannel in required position.
(n) Put on the convertor switch and system is ready for operation.

The various assy/sub assy used are :-

(a) Control unit by - It has 8 PCB's and 2 gain potentiometers for elevation and traverse.

(b) Controller handle for gunner and Cdr - It has five LEDs including the Missle LED, traverse and elevation creep potentometer and auto aided switch. It also has the convertor switch and firing button for main Gun.

(c) Convertor motor and frequency stabiliser - located below the Cdr's seat. The output from here is applied to Gyro motors and tgt designation unit.

(d) Traverse and Elevating Rate Gyros - located below the gun towards the gunner and the cdr resp. They have the traverse and elevating integrator cct.

(e) Compensating rate Gyro - located behind the Azimuth indicator and output fed to a summing ampilifier.

(f) Traverse and Elevation drive amplifier - located behind the gunner's seat. They are identical and inter changeable and have 5 PCB's having a pulse width modulator and cct component unit.

(g) Target designation unit - located in front of cdr and mechanically compled to cdr's cupola.

(h) Cordon gear mechanism and electro magnet - located behind the cdr on the right side. It is used for locking the cdr's cupola with turret ring.

(j) Belt motor - used for feeding ammunition in main gun.

(k) Traverse and Elevation drive motors - located on left and right side of gunner.

(l) Traverse and Elevation electro magnets - It locks/unlocks the hand wheel and are located near the motors.

(m) Traverse and elevation limit switch - It mechanically locks/unlocks the gun and are located below the left side of gun.

(n) Belt selector switch - It has two position - O & b.

(o) Power supply filter - It is located above the radio set.

(p) Power distribution box - Located on right side of control unit by - 25-2C. It has seven switches.

(q) Tacho generator - Located on left side of gun trunnion. It gives DC feedback in elevation.

(r) BY-25-2C control unit - Main unit having 13 LED's for various fuses. It also has the Missle ON/OFF switch, Gun ready to fire, type of belt and rate of fire. It also has the ammunition check button, search light and bty switches.

MODIFICATIONS TO THE BMP

146. The modifications required for capability to fire a missile from the BMP gun system from the terms of Reference. The various assys/sub systems which need modification could be as under :

(a) Gun.

(b) Firing Mechanism.

(C) Gun control eqpt.

(d) Sighting system.

GUN

147. The max acceleration which the electronic parts of missile can withstand is approx 10,000g. Therefore, the max pressure developed in the chamber will be much less against that developed during firing of conventional amn. The max pressure developed during firing of APFSDS amn is of the order of 450 MPa where as for missile would be able to withstand this and no modification of this new gun is needed.

148. **Spacer plug** : In order to isolate missile from high temp of chamber, a spacer plug of low temp conducting material eg -Mg Alloy with polymer liner can be used. The plug can be in the form of cup which can be jettisoned aerodynamically. The configuration can be as shown in fig.

149. The spacer plug initially is formed part of cartridge case so as not to limit the length of the missile. Therefore the shape of the cartridge case has to be changed from cylindrical to bottle type. It is due to this reason that the spacer plug, which is initially part of cartridge case, fits behind the missile over boat tail and moves alongwith missile during launching. The design of spacer plug is such that it gets jettisoned due to its aerodynamic shape once the missile is out of muzzle. It is due to this reason that the effective volume of chamber is reduced to 95%. The equivalent full charge (EFC) for wear per missile fired can be computed from the actual wear during trials.

Firing Mechanism

150. The firing in upgunned BMP for main gun would be electrical cum percussion type. The manual firing would be by percussion only. The various modes for triggering the main gun would be :

(a) Manual

(b) Standby.

(c) Coincidence or main.

151. Manual mode is followed when firing set for coincidence and standby modes fail. The coincidence or main firing is done when gun is in stab mode. The standby firing mode is selected for non-stab mode of tank.

152. The existing set would need to be modified to cater for the following in case of missile fire :

(a) Firing should not take place until the missile power pack is activated.

(b) Firing should not take place until the laser designation has been switched on.

(c) Various modes of triggering may be retained for simplicity but serial (a) and (b) would have to be by passed in case of manual firing.

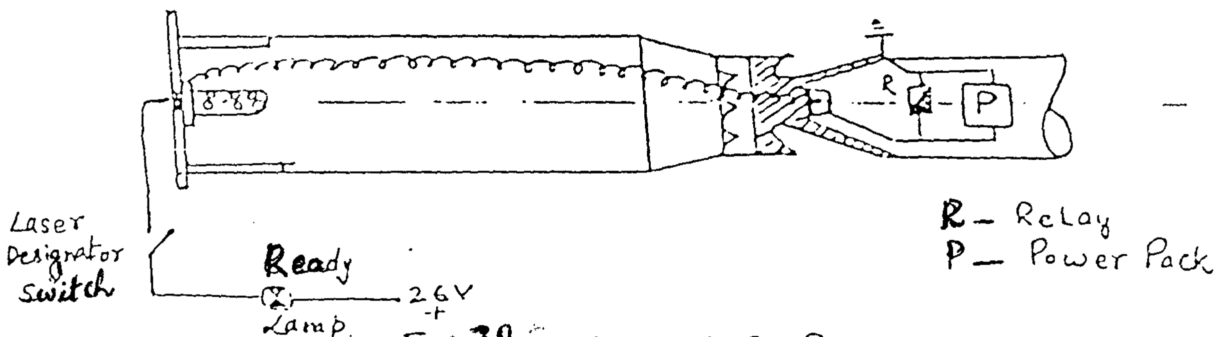


FIG 39. CCT FOR POWER PACK

153. The fig 39 shows the set to ensure that the powerpack is activated. As the laser designator switch is switched on, 24 V/ 26V supply is available at the tip of the spacer plug through a wire as shown. This fires a relay and power pack is switched on by means of circuit completion. The lamp gives the indication that missile is ready for fire. The selection switch (for selecting missile / APDS amn) and laser designator switch would be in series with the set switches. Hence the firing of missile would only take place when selector switch is on missile position and laser designator is in on position.

Sighting System

154. BMP has the following sights with their salient features :

(a) **Gunner's Sight** :

(i) Prismatic periscope binocular.

(ii) BMP - I has combined day and night passive type with a range of 400 m where as BMP - II has combined day and night Active and passive both with active having a range of 350 m and passive having a range of 700m.

(b) **Commander's Sight** :

(i) BMP - I has combined day and night sight active type with a range of 300 to 400m where as BMP - II has combined day and night active and passive type with active having a range of 300 m and passive having a range of 400 m.

(c) **Driver's Sight**

(i) BMP - I has an active type with a 50 m range and BMP II has active cum passive type with a range of 60 m and 100 m respectively.

(ii) Day periscope.

155. From above it is evident that the sight range for commander and gunner is limited to about 400 to 700m. The night vision capability available is active IR sight and has limited range. Therefore, to fully exploit the high SSKP of missile, the sighting system range has to be extended to 3 - 5 Km for gunner and cdr. The sighting system has to be thermal imaging type. The following are the options available for TI sight for retrofitment.

156. **Option I** : Change over to integrated sight unit replacing existing as done in Tank T - 80 and T- 72 S of Russia. The integrated sight has LRF, TI and day vision optical prismatic periscopic binocular. The sight is stabilized in vertical plane. The laser designator is located on front side of turret and interfaced with gun with controls at gunner station. [13]

(a) **Advantages**

(i) Gunner's sight redesigned to fit in the limited space available in the turret.

(ii) Enhanced range.

(iii) Display of missile ready available at cdr station.

(iv) cdr over side control cut off till the gun remains in missile firing mode.

(b) **Disadvantages**

(i) Complete replacement - high cost.

(ii) Dumping of old sights.

(iii) Limited observation for commander both by day and night.

(iv) Interfacing of sights required.

157. **Option II** : Common day / night T I sights have already been developed in the world. The 2nd and 3rd generation TI sight based on CCD (charged coupled devices) gives video out put. The video monitors can be located on the turret. The following are the problems envisaged:

(a) Costly equipment.

(b) Interior of the turret may need to be modified to accomodate the TI system.

(c) Entire fire control system may have to be changed to be compatible with TI system.

(d) Not compatible for retrofitment.

158. **Option III** : Retain the original day sight and replace the existing gunner's night sight by TI sight. The eye piece of the TI can be located near the loc of the original eye piece of present sight.The existing Interfacing of the gun would have to be Interfaced with the upgunned version. The graticule can be modified to cater for Msl firing and incorporated in TI. Msl control panel can be installed and Interfaced with gunner's sight fitted with TI.

(a) **Advantages** :

(i) Less cost since only night sight replaced.

(ii) No modification to the interior of turret.

(iii) Enhanced range.

(b) **Disadvantages** :

(i) Cdr day/night vision - not enhanced.

(ii) Gunner's night sight has to be dumped.

Gun control Equipment

159. With proposed option III for add on TI sight, the existing fire control system can be utilised. However for option I and II, the compatible fire control computer will have to be fitted which may need reprogramming of EPROM of the ballistic computer. Therefore, for exploring the feasibility of firing a missile from gun, option III involves least modifications / replacement is proposed.

160. The wiring diagram of only few of the subsystems need to be modified in order to introduce one additional type of ammunition i.e, missile. One of them would be the control unit selector switch - for missile/Main Gun selection.

CONCLUSION

161. BMP is a technology of 70s and early 80s. It is also likely to stay as the backbone of Mech Infantry Bns till replaced with more modern ICVs. With upgunned barrel and missile firing capability , BMP will become an excellent fighting machine having fightability at par with most modern ICVs of the world. The missile fired from the barrel will be unconventional. Moreover, it will need to be fired initially like a gun projectile with its guidance, control and warhead becoming active only after it leaves the muzzle.

162. In this dissertation work, an attempt has been made to present the conceptual design, its guidance and control, airframe and warhead. The various changes/modifications in the BMP sub systems have been proposed and analysed to facilitate the firing of the missile from 105 mm upgunned barrel.

163. In the absence of terms of reference, the work needed to be commenced from the very tactical and technical requirements of this missile. In the course of this work, many areas, have been encountered where the subject dealt is more conceptual in nature. Information available on missiles is only through journals which is extremely inadequate.

164. In upgunning of BMP - various options in the form of different calibre guns are available. The choice has been narrowed down by upgunning the BMP without major changes to the BMP and easy interfacing with the present version of BMP - I or BMP - 2.

165. BMP-3 effectively meets the requirement of this dissertation both in terms of upgunning and missile firing through the barrel, but it is based on the BMD series of Russian eqpt which would involve complete change of design of Eng, transmission and various compartments and is therefore not suited for the BMP-1/2.

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