Defence Science Journal, Vol 47, No 4, October 1997, pp. 435-444

Submunition Dispensing Mechanisms

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ABSTRACT

The effectiveness of a weapon system is enhanced manifold when it is incorporated with submunitions instead of being a unitary one. A large unitary warhead produces effects that are too concentrated and localised for many target types, resulting in a very high probability of either causing no damage or an over-kill. The submunition warhead incorporating a single-stage ejection process has the drawbacks of lesser area coverage and non-uniform distribution of submunitions. To overcome the above drawbacks, dispensing mechanisms with multistage ejection of submunitions are being employed worldwide by the warhead designers. Extensive work has been carried out by the authors to achieve wide area coverage by using multistage ejection instead of single-stage ejection.

1. INTRODUCTION

It is quite common in multipurpose weapon systems to pack a number of submunitions and disperse them evenly over the target area to enhance their effectiveness. A suitable dispensing mechanism capable of performing the dispensing activity of the submunitions to achieve a desired dispersion pattern over the target area is, therefore, essential for such multipurpose systems.

The projectiles may be either spinning or nonspinning. In the case of spinning projectiles, the spin of the projectile, which provides the necessary centrifugal force for radial dispersion, is utilised in dispensing the submunitions. The design of the dispensing system is simple, since the submunitions are ejected from the base using an expulsion charge located near the nose end. The disadvantage of a spin-assisted ejection mechanism is an elongated and narrow dispersion pattern of the submunitions.

In the case of a nonspinning projectile, it is essential to cut and remove the casing of the projectile, prior to the ejection of submunitions. Further additional factors like requirement of ejection velocity for the submunitions, and a proper stabilisation system for submunitions need to be incorporated in the system, thereby complicating the design of the dispensing mechanism. The dispersion pattern of the submunition achievable from these submunitions is more or less circular over a wide area.

The effectiveness of a submunition warhead depends on the kill probability of the target given a hit and probability of the submunition hitting the target. The hit probability of the submunition on the target increases with the number of submunitions packed in a warhead[1]. To achieve a high kill probability of the targets over a wider area, the dispensing mechanism incorporating a multistage ejection system for the submunitions is considered essential.

Received 16 June 1997

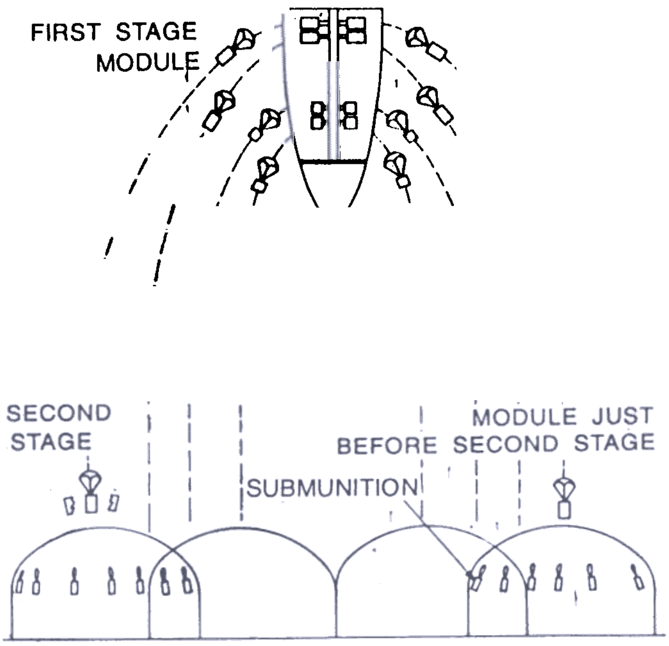

Figure 1. Two-stage ejection event

This paper presents a unified approach to the design of an effective dispensing mechanism for wider area coverage using a two-stage ejection mechanism.

2. ELEMENTS OF DISPENSING MECHANISM

The basic elements of a multipurpose dispensing mechanism are:

- Nose cone opening mechanism, which involves cutting of the warhead casing and its separation
- Submunition ejection mechanism
- Safety arming mechanism and sequencing unit.

In addition to the above, the most desirable feature of a dispensing mechanism is incorporation of modular design concept with multistage ejection events, making it adaptable to various weapon systems. The submunitions packed in the modular form called modules are first ejected out of the parent projectile. Subsequent stage events take place in air at predetermined time and space. A pictorial presentation depicting a two-stage ejection event is shown in Fig. 1. Both the conventional unguided and the terminally-guided submunitions can be effectively dispersed with this type of dispensing mechanism to obtain the desired dispersion pattern.

3 DESIGN PHILOSOPHY

3.1 Nose Cone Opening Mechanism

To achieve the desired dispersion pattern of the submunitions, it is mandatory to separate the outer skin of the parent projectile prior to the ejection of modules/submunitions. Detailed aerodynamic studies of the processes during skin separation and parametric studies on scale-down models in wind tunnel are required to be carried out to design, analyse and evaluate the integrity of various elements/subsystems of the nose cone opening mechanism.

Cutting and removal of skin is generally carried out using gas-operated mechanical systems. This kind of a system has got its inherent disadvantages in terms of its reliability, bulkiness, etc. The authors have successfully developed and incorporated a flexible linear shaped charge (FLSC) based system for cutting and safe-separation of the outer skin of the parent projectile[2].

The FLSC loading is, however, optimised by carrying out actual trials with the aim of reducing the effect of shock levels on various other subsystems of the warhead generated on detonation of the high explosive contained inside the FLSC.

After cutting, the skin needs to be ejected out by the application of external moment about a fulcrum, as the dynamic pressure outside the skin is multifolds larger than the pressure inside the skin. Due to difference in pressure, the cut sections have a tendency to collapse inwards, towards the axis of the projectile and collide with the other subsystems. For application of the external force, a pyro-operated jack system has been successfully introduced to perform separation of the cut petals. To ensure the separation of the petals at a fixed angle to the axis of the projectile about a fixed fulcrum, a specially designed hinge joint has been

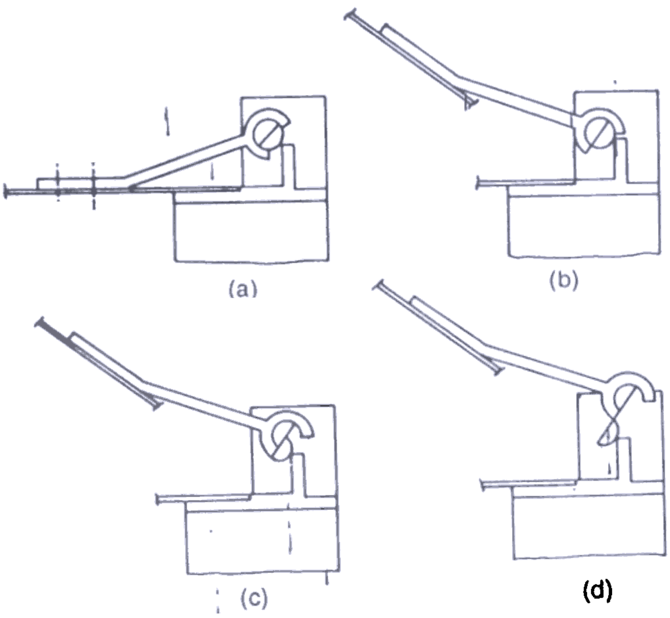

Figure 2. Cutting and opening of nose cone

introduced at the rear end of the nose cone. The sequence of cutting and separation of the nose cone is pictorially depicted in Fig. 2.

3.2 Ejection Mechanism

The support structure, the backbone of the ejection mechanism, is designed suitably considering the mass and volume constraints imposed on the projectile. This is the structure around which the whole ejection and launching mechanism is built. This structure must be capable of withstanding the flight loads and loads imposed on them during the ejection of submunitions. The design can be prepared using standard structural design formulae and optimised using the standard finite element packages.

There can be several ways and means by which the ejection of the childstores from the parent projectile is achieved. A study of literature and the systems available worldwide shows that mainly three types of dispensing systems are prevalent:

- Hot gas operated systems (HGOS)
- Cold gas operated systems (CGOS)
- Self-propelled systems.

Apart from these, a system utilising the stored mechanical energy in devices like closed coil springs and delivering it at the desired time to impart kinetic energy to the submunitions can be thought of.

In HGOS, a gas generator cartridge is employed to generate hot gas at a very high pressure. The work done by the high pressure gases is used to eject the submunitions from the projectile directly or the high pressure gas can be utilised to inflate some suitable fabric bags which convert the p-v work done by the gas to the kinetic energy of the submunitions[3]. BL-755 cluster bomb system is a typical example of this.

In CGOS, gas, at a very high pressure is prestored in gas bottles. This gas is then discharged through suitable mechanical gadgets, etc. to impart kinetic energy to the submunitions.

The self-propelled system incorporates a rocket motor at the rear end of the submunition. The rocket motor can be initiated through issue of electrical pulses from a suitable device.

After a detailed study of all these possibilities and conducting a lot of experiments with HGOS, a special modified HGOS has been devised for incorporation in the system. An electrically initiated gas generator cartridge is employed to perform the first stage ejection of the submunitions packed in modules. The modules are assembled inside launcher tubes at the base of which the gas generator unit is housed, as shown in Fig. 3. At the central axis of the modules, a secondary gas generator is housed with a pyro-delay unit at its base. The submunitions are assembled around the secondary gas generator unit. Each individual module is ejected by a separate gas generator initiated at predetermined time and space. The pyro-delay of the module gets initiated at the instant, the hot gases from the electrically initiated gas generator (stage I) come in contact with the

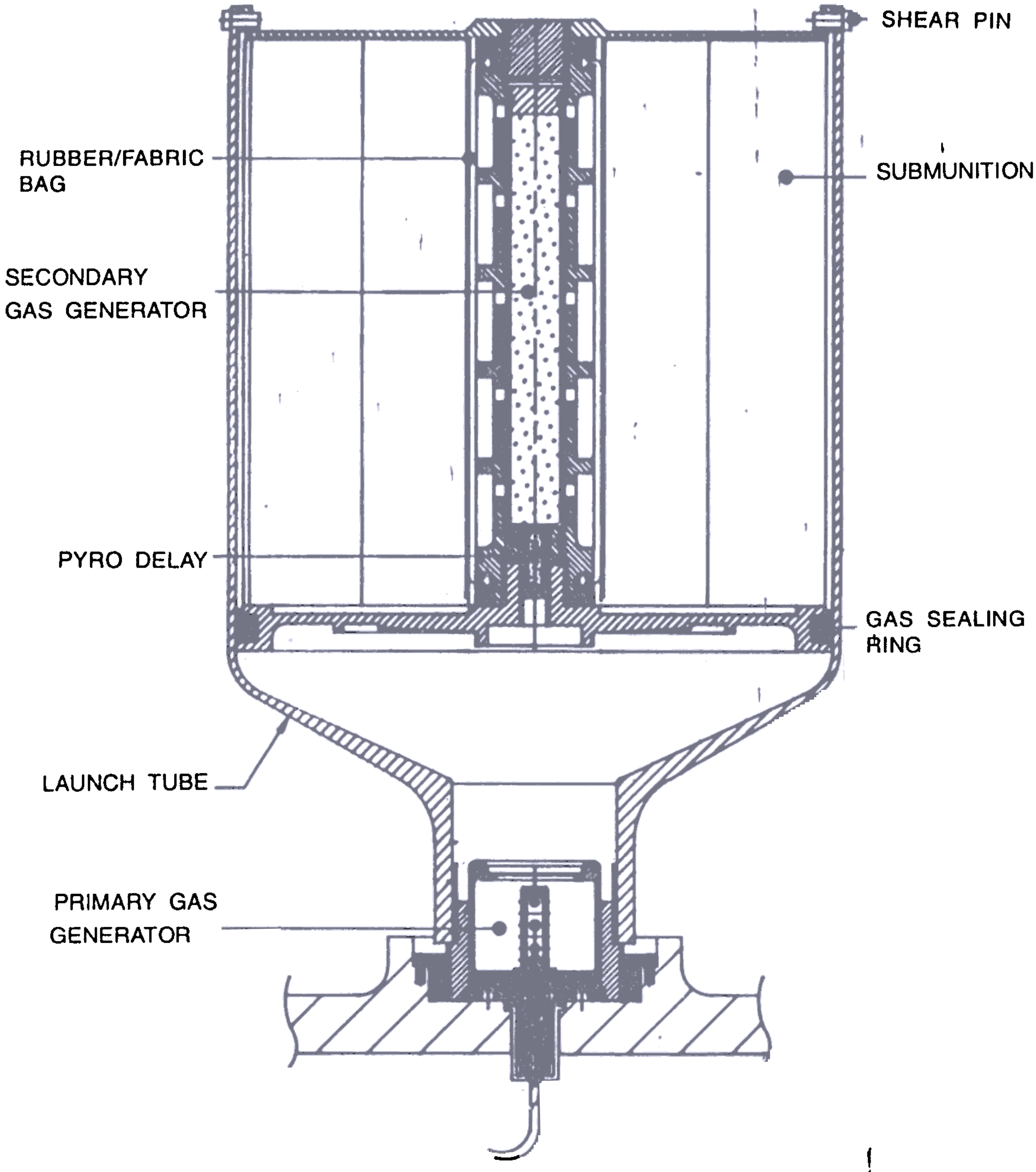

Figure 3. Module assembly

base of the modules. The delay composition initiates the quick reaction propellant of the secondary gas generator. The hot gases thus produced exert pressure on the submunition placed around it. The submunition gets ejected after breaking the outer casing of the module (stage II). This enables one to use different types of gas generators to impart different ejection velocities to the modules and submunitions. Thus, a precise control of the dispersion pattern of the submunitions is possible in the developed system. The mathematical model used in the design of the gas generators is discussed below:

The ejection velocities for the modules to achieve an even ground dispersion to cover a predetermined area is estimated first. Then, to achieve these ejection velocities for the modules, the charge mass required for the gas generator is calculated using the software developed.

3.2.1 Assumptions

- All the propellant surfaces are ignited simultaneously
- The module starts moving just when the shot start pressure is built behind the module, which is sufficient to shear off the shear pins
- The propellant burns under the mean pressure and the pressure on the base of the module imparts momentum to the module
- The pressure index is unity in the rate of burning equation of the propellant.

Formulation and solution of the equations are

The energy equation from the module start to module ejection is

$$FCz = P[(1.0 - Bz) + Ax] + 0.5(\gamma - 1)Wv^2$$

where

F	Specific energy of the propellant
C	Mass of the propellant
z	Fraction of the charge mass burnt $= (1 - f)(1 + \theta f)$
f	Fraction of web remaining
θ	Form factor
P	Pressure
B	$C(b - 1/\rho)/k$
b	Co-volume of propellant gas
ρ	Density of propellant
k	Initial volume behind the module
A	Cross sectional area of the module
x	Module travel length.
γ	Ratio of all specific heat of propellant gas
W	$1.05\,w + Cz/3$
w	Mass of the module
v	Velocity of the module

The equation of motion of the module is

$$\frac{dv}{dt} = \frac{AP_s}{W}$$

The rate of burning equation is

$$-D\,df/dt = P$$

where

D = Linear rate of burning constant

P_s and P are related by the equation

$$P_s = P/(1 + Pz/3w)$$

The solution from module start to module ejection is obtained by Euler's method of numerical integration. Time is taken as the independent variable. The propellant is completely burnt when the value of z approaches unity.

3.3 Safety Arming & Sequencing Unit

Various events like cutting the skin of the warhead with the help of FLSC, separation of the cut skin petals by pyro-jacks, and ejection of the submunition/modules at predetermined time intervals, besides providing safety during handling, transportation, and flight are carried out by the electronic Safety Arming and Sequencing Unit. Initially, all these electrical connections are kept shorted at the sequencing end up to a predetermined point in time and space to provide absolute safety to the system. All these safety shortings are then removed one by one in the desired fashion during the terminal phase of flight.

3.4 Stabilisation System

The size, shape and repeatability of the dispersion pattern besides the performance of the submunition depend on the stability of the childstores. The desirable features of a stabilisation system are shortlisted as

- It should be light in mass
- It should occupy less volume
- It should be simple and effective
- It should produce small aerodynamic drag, so that the velocity of the ejected stores is least affected (for wider area coverage)

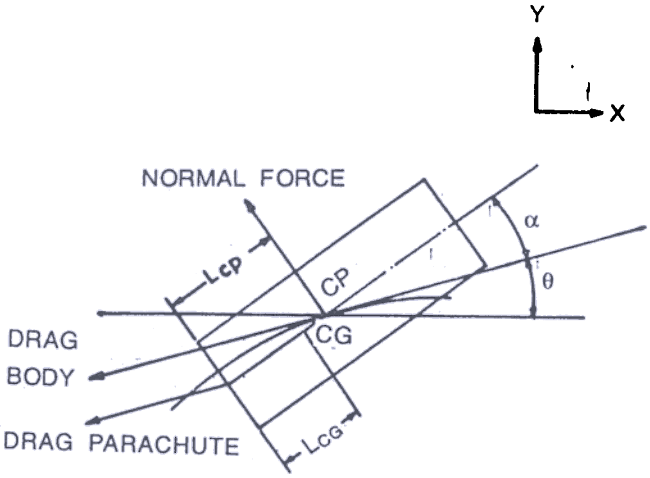

Figure 4. Force system acting on module with parachute

- It should be ensured that the conditions of desired angle of impact for the submunitions are met.

After carrying out in-depth studies in respect of a variety of stablisation systems, the use of cross-tape parachute for submunition modules and ribbon for small sized submunitions have been found most appropriate.

Modules of cylindrical shape with a low L/D ratio having the CG located a little ahead of the CP are expected to experience excessive tumbling immediately after their ejection.

This initial tumbling of the module during release is highly undesirable and the cross-tape parachute has been designed to provide sufficient restoring moment to neutralise the tumbling tendency of the modules. Restrictive optimisation of the tape size to ensure the required dispersion has also been carried out as follows:

The force system acting on the module with the parachute on is represented in Fig. 4. It could be appreciated that, at this instant both flight load and tape drag generate restoring moment about CG to arrest the initial tumbling. Equations of motion representing the flight dynamics of the module during its flight are

$$\frac{dx}{dt} = V\cos\theta \tag{1}$$

$$\frac{dy}{dt} = V\sin\theta \tag{2}$$

$$\frac{dv}{dt} = -\frac{\frac{\rho v^2}{2}\left(S_{ref}Cd_{body} + S_{par}Cd_{par}\right) + g\sin\theta}{m} \tag{3}$$

$$\frac{d^2x}{dt^2} = \frac{-0.5\,\rho v^2 (S_{ref}Cd_{body}L_{cpcg} + S_{par}Cd_{par}L_{cg})}{I_y} \tag{4}$$

$$\frac{d\theta}{dt} = \frac{-g\cos\theta}{v} \tag{5}$$

where

L_{cpcg}	x_1x
L_{cg}	x_2x
V	Velocity of the shell
θ	Angle of the shell,
ρ	Density of air
Cd_{body}	Coefficient of drag of the body
Cd_{par}	Coefficient of drag of the parachute
M	Mass of the shell
S_{body}	Area of the shell.

In writing Eqns (3) and (4), the effect of the normal force has not been modelled, as the submunition module is having a flat face with a low L/D ratio (< 1.5) configuration. Eqns (1)-(5) representing the trajectory equations are solved simultaneously using fourth order Runge-Kutta numerical method.

The total drag at any velocity v is given by the expression:

$$F = 0.5\,\rho v^2 CdA$$

And the terminal velocity of the store can be calculated from the equation as

$$W = 0.5\,\rho CdA V_t^2$$

where

F	Drag force on the parachute
ρ	Density of air

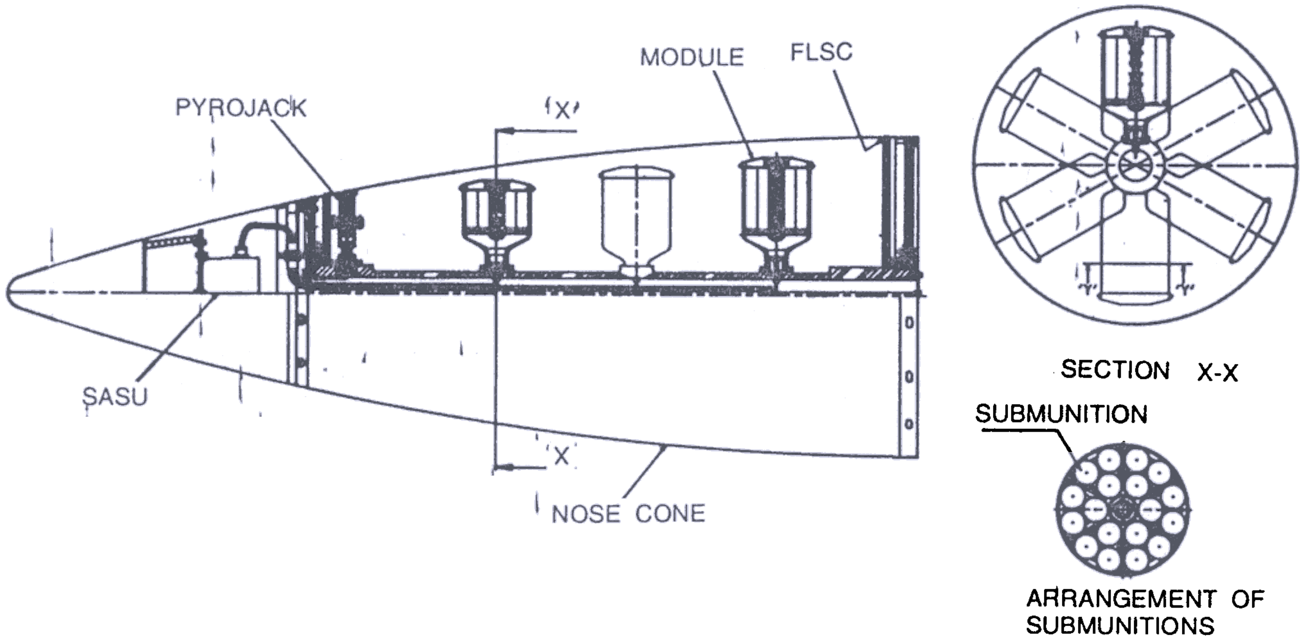

Figure 5. Typical warhead system

C_d Drag coefficient of the parachute

W Total weight of the store

Terminal velocity of store in air of density ρ

Similarly, a stabilisation system for smaller calibre submunitions ensures stability of the submunitions in the case of multistage ejection events.

A typical system thus configured incorporating all the desirable features of an ideal dispensing mechanism is depicted in Fig. 5.

4. THEORETICAL EVALUATION OF DISPERSION PATTERN

A software has been developed in FORTRAN-77 on ND-570 main frame computer and Tectronics Graphics work station. The equations of motion are solved using 4th order Runge-Kutta method in order to compute the trajectories of individual submunitions. The library routines of interactive graphics language (IGL) 10 have been used for the graphical visualisation on visual display unit and Calcomp routines are used to plot the dispersion pattern.

A two-stage ejection event has been considered. At a predetermined height in its terminal phase, over the target area, modules containing requisite number of submunitions are ejected. Each module thus ejected from the projectile after a specified time delay explodes again and the submunitions are thrown in radial directions with a certain initial velocity. Subsequently, the submunitions get distributed over the target area and each submunition detonates on hitting the target, causing the required destruction.

4 Assumptions

- The only aerodynamic force acting on modules and submunitions is the drag force which is acting opposite to the direction of the velocity vector
- Wind conditions are not taken care of
- It is assumed that the projectile does not have spin.

4.2 Reference frame

A right handed reference frame is considered with Y-axis as the vertical axis, X and Z axes being horizontal. The first module is assumed to be ejected at a height of Y metres above the origin. So, the coordinates of the point of ejection for first layer of modules are (0,Y,0).

4.3 Methodology

The software is in three parts. The first part computes the trajectories of the submunitions taking into consideration the resultant velocity and angle of elevation for each submunition. The second part of the software computes the points of hit on the ground for each submunition taking into account the range and azimuth angle. The third part is a graphics part, which is used to visualise the dispersion pattern on the VDU.

The following four equations of motion are used to compute the trajectory of modules and submunitions. The dynamic modelling is done on the basis of free body diagram, as shown in Fig. 4.

$$\frac{dx}{dt} = V\cos\theta \tag{6}$$

$$\frac{dy}{dt} = V\sin\theta \tag{7}$$

$$\frac{dv}{dt} = -\frac{\frac{\rho v^2}{2}\left(S_{ref}Cd_{body} + S_{par}Cd_{par}\right) + g\sin\theta}{m} \tag{8}$$

$$\frac{d\theta}{dt} = \frac{-g\cos\theta}{v} \tag{9}$$

The trajectory is computed for each module till the ejection time of submunitions. The last point of the trajectory for the module is taken as the starting point of submunitions ejected from the module. Afterwards, the trajectory of each submunition is computed till the submunition touches the ground.

4.4 Velocity Modelling

The velocity components in X,Y,Z directions for any module with ejection velocity V_{mod} and orientation ψ are given by

$$V_x = V_{proj}\sin\phi + (V_{mod}\cos\psi)\cos\phi$$

$$V_y = V_{proj}\cos\phi - (V_{mod}\cos\psi)\sin\phi$$

$$V_z = V_{mod}\sin\psi$$

where

V_{proj} = Velocity of the projectile at the time of ejection of the module.

ϕ = Orientation of the projectile with reference to vertical axis.

So, the resultant velocity vector having the magnitude $(V_x + V_y + V_z)$ lies in the vertical plane inclined at tan (V_z/V_x) to XY plane and makes an angle tan (V_y/V_{xz}) with the horizontal.

where, $V_{xz} = (V_x + V_z)$

The equation of motion of the module centre of mass subject to gravity and aerodynamic drag is integrated to give its point of hit on the ground. The coordinates of the hit points (in X,Z plane) are stored in a data file and are used to plot on VDU.

4.5 Inputs to Program

- Height of the projectile at the time of module ejection
- Time delay for any module to eject submunition
- Module parachute area
- Remaining velocity of the projectile at the time of module ejection
- Ejection velocity of each module
- Ejection velocity of each submunition
- Orientation of module No. 1 in each layer of modules
- Angle between any two consecutive modules in a layer
- Number of modules in each layer
- Arrival angle of the missile.

The above set of inputs are fed to the program for each layer of modules and the input data is fed through a data file[4]

4.6 Outputs of Program

- Total time of flight of each submunition

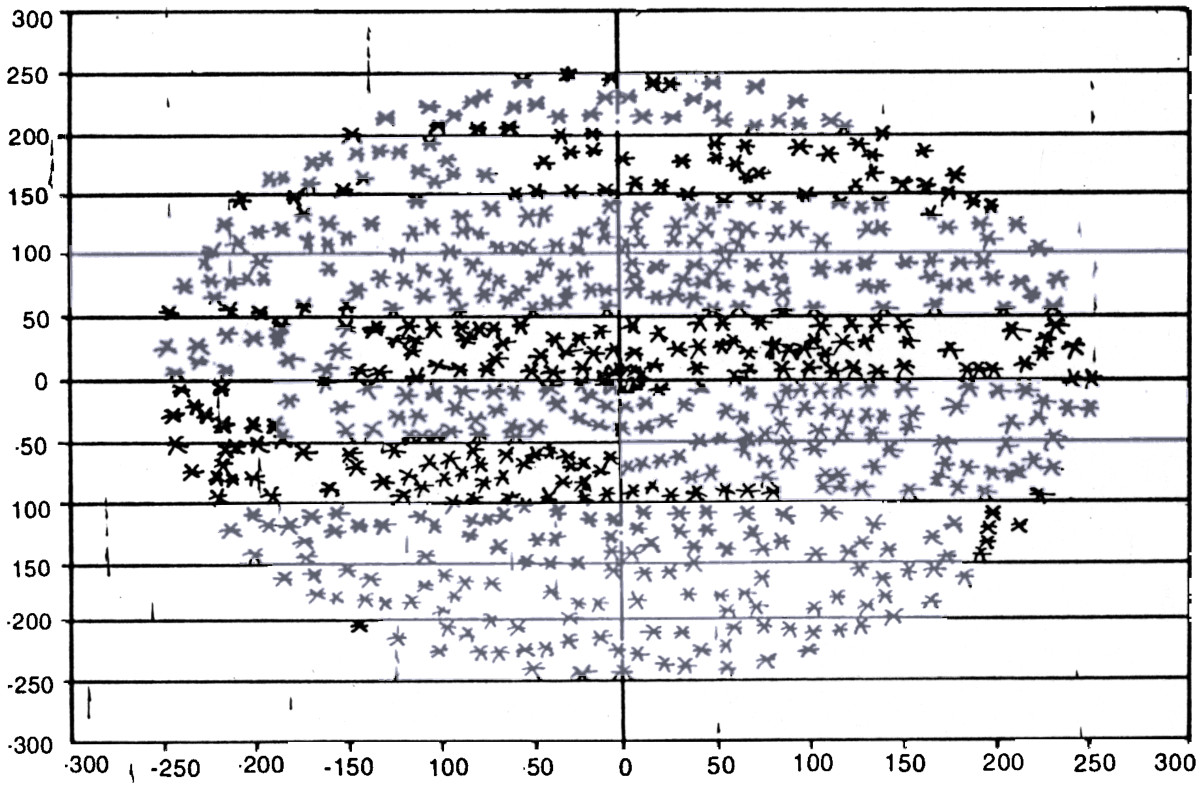

Figure 6. Dispersion pattern of submunitions

Remaining velocity of each submunition just before reaching the ground

Angle made by the submunition on the ground

Range of each submunition

X coordinate of the point of hit

Z coordinate of the point of hit.

5. RESULTS

A typical dispersion pattern for a submunition warhead incorporating about 1000 submunitions dispensed using a two-stage ejection process computed through the model described above is shown in Fig. 6.

ACKNOWLEDGEMENTS

The authors are grateful to Dr S.K. Salwan, Director, Armament Research & Development Establishment (ARDE), Pune, for the guidance and encouragement given in the preparation of this paper. Thanks are also due to Shri J.S. Gharia, Sci F, and his team of High Energy Materials Research Laboratory (HEMRL), Pune; Shri Suresh Chandra, Sci F, ARDE and his team and Shri S. Paneerselvam, Sci F, Defence Research & Development Laboratory (DRDL), Hyderabad, whose contribution have been of immense help in preparation of this paper.

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