Flight Dynamics of a Spinning, Sequential Munition-Dispenser

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A new concept of sequentially dispensing submunition from a spinning dispenser is described. Flight dynamics of a weapon system based on this concept was simulated to investigate its flight characteristics and its ability to create both linear and curved impact patterns over the target. Performance of such a weapon is illustrated by considering both cruise missile and ballistic-type launch trajectories. Effects of varying launch conditions and ejection strategy as well as flight path disturbances on the weapon performance are presented. It is shown that this dispensing concept has the potential of growing into a versatile weapon system.

Nomenclature

h	= launch altitude, ft
h_D	= dispensing altitude, ft
$I_{xx,yy,zz}$	= dispenser moments of inertia about its reference body axes system whose origin is at the center of mass, slug-ft^2
S	= dispenser spin rate, rpm
T_δ	= time interval between release and spin-up, s
V_D	= dispenser launch velocity, ft/s
V_e	= submunition ejection velocity, ft/s
V_s	= submunition velocity, ft/s
x	= longitudinal distance at impact, ft
y	= lateral distance at impact, ft
α_O	= launch angle of attack, deg
α_P	= dispenser angle of attack in the nonspinning reference body axes, deg
β_P	= dispenser side slip angle in the nonspinning reference body axes, deg
γ_D	= dispenser flight path angle, deg
γ_s	= submunition flight path angle, deg
δ_f	= fin deflection, deg
Δq	= disturbance in dispenser pitch velocity, deg/s
Δr	= disturbance in dispenser yaw velocity, deg/s
ΔS	= disturbance in dispenser spin rate, rpm
Δt	= time interval between successive dispensing events, s
$\Delta\alpha_p$	= disturbance in α_p
$\Delta\beta_p$	= disturbance in β_p
$\Delta\theta$	= disturbance in dispenser pitch attitude, deg
$\Delta\phi$	= disturbance in dispenser roll attitude, deg
$\Delta\phi_s$	= disturbance in submunition roll orientation, deg
$\Delta\psi$	= disturbance in dispenser yaw attitude, deg
Φ_s	= submunition roll orientation at ejection, deg
ψ_s	= submunition heading angle, deg

Introduction

TACTICAL munition dispensing from a spinning or nonspinning dispenser is used[1] typically to scatter a number of small bombs or submunitions over tactical targets, such as airfields, SAM sites, fuel dumps, or groups of armored vehicles. In these cases, the probability of target destruction is maximized when both the submunition and its ground impact pattern are tailored to the target. However, existing dispensing techniques allow limited control of the submunition deployment and subsequent ground impact pattern.

In efforts to alleviate these limitations and improve weapon effectiveness, a new concept[2] of spin dispensing has been evolved in which the submunitions or submissiles are dispensed sequentially. This has been found to yield the required projectile angles and spatial separation at ejection to achieve a specified impact pattern over the target. In this concept, the submunition ejection strategy would be software reprogrammable, which results in a wide selection of dispersion patterns with the same hardware.

This paper describes the sequential dispensing concept and its application. Flight characteristics of an example dispenser system based on this concept are described. These characteristics have been obtained from a six-degree-of-freedom flight dynamics simulation of such a weapon system. Typical performance of the dispenser, including impact patterns achieved, is illustrated by considering both cruise missile and ballistic launch-type trajectories.

Sequential Dispensing Concept

Basically, the concept of spin dispensing is coupled here with programmed, temporal separation of submunitions at ejection into the airstream to obtain a controlled dispersion pattern over the target. For instance, if two submunitions are ejected simultaneously so that one moves vertically up while the other moves vertically down, these submunitions would achieve maximum longitudinal separation over the ground plane. Similarly, if they are ejected simultaneously so that both move with opposite horizontal velocity, then they will achieve maximum lateral separation at impact. Ejecting at any other projectile angle would result in the submunitions developing both longitudinal and lateral separation. By programming the subsequent ejections to occur at specific time intervals, the submunitions could be spatially separated in their impact pattern. It should be noted that the effectiveness of this dispensing concept depends significantly on the operational capabilities of its carrier or launch vehicle and the type of submunition to be deployed. For instance, if the carrier vehicle is capable of low-altitude level flight over its target area, then the dispersion patterns could be tailored for specific targets such as a runway. Dispensing from a carrier on a ballistic trajectory could be effectively used to create an arc or segment of an elliptical or circular pattern. Typical impact patterns that may be achieved with this dispensing concept are shown in Fig. 1.

A particular impact pattern required for a specific target may also be created by changing ejection strategy via software. Indeed, the temporal separation of the submunitions at ejection could be combined with spatial separation due to dispenser travel to obtain almost unlimited variation in pat-

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tern geometry. Any limitations in this regard would likely be hardware oriented. This aspect of the dispenser will be considered subsequently.

In order to illustrate the application of this concept, an example weapon system capable of sequentially dispensing submunitions from a spinning dispenser will be considered. For convenience, such a system has been assumed to be similar to the SUU-65/B tactical munition dispenser in its aerodynamic configuration[3] and spinning capability. However, the submunition packaging and ejection mechanics are entirely different in the present case. This example is intended mainly to illustrate the working principle and associated flight characteristics typical of such a weapon system. Consequently the results presented here should be considered as exploratory. In this illustration, a six DOF flight dynamics simulation of this weapon system that was obtained by modifying an existing flight simulation code for a SUU-65/B tactical munition dispenser was used. A brief description of this simulation and its modification to represent the dispenser configuration considered are given below.

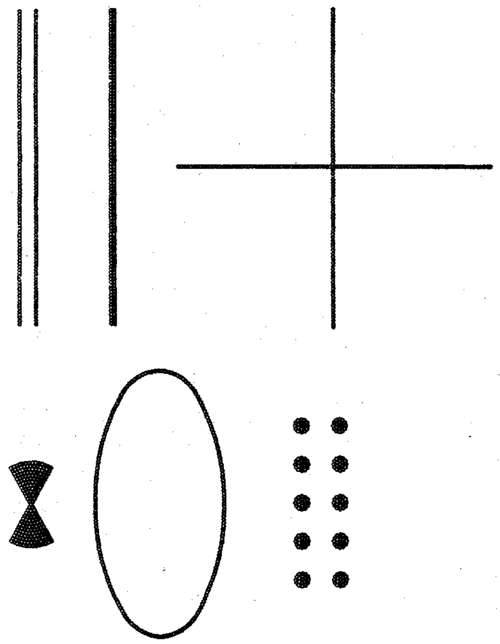

Fig. 1 Impact patterns from sequential dispensing.

Table 1 Physical and operational characteristics of example dispenser

Item		Description/Value
Dispenser		
Gross weight		828 lb
Geometric configuration	Cylindrical:	1.3 ft diam, 7.6 ft long
I_{xx}		5.43 slug-ft^2
$I_{yy} = I_{zz}$		96.71 slug-ft^2
Submunition		
Weight		3.5 lb
Geometric configuration	Cylindrical:	2.5 in. diam, 6 in. long
Number of submunitions		162
Nominal drag area		0.0168 ft^2
Simulated Operational Conditions		
Flight speed		400 to 800 ft/s
Launch altitude		2000 ft
Launch angle		+20 to −90 deg
Spin rate		500 to 1000 rpm
Fin deflection time		0.5 to 3.0 s

Flight Dynamics Simulation

A six DOF flight dynamics simulation of the SUU-65/B tactical munition dispenser was used extensively during the development of aerospin technology of that weapon system. It has the capability to simulate all aspects of that unguided dispenser system from launch through spinup and dispersion of submunitions. Extensive wind tunnel data[4,5] and, subsequently, flight test data[6] have been incorporated into this simulation program to make it a realistic design tool. Consequently this simulation was used as a convenient starting point for representing the sequential spin dispenser (SSD).

Table 1 shows the physical and operational characteristics of the dispenser configuration in the present example. Typically, the SSD flight simulation began with launching from an aircraft at a specified flight condition. Subsequently, spin was initiated by deflecting the fins. Upon reaching the desired rpm, the outer cover over the munition bay was blown off and then the submunitions were dispensed sequentially. Unlike the SUU-65/B, dispensing occurs in the present system over several seconds depending upon the size of the impact pattern to be achieved. Consequently the corresponding changes in the dispenser mass, moments of inertia, and c.g. shift have been incorporated in the simulation as follows.

In the example weapon, the submunitions were assumed to be packed in two concentric layers (Fig. 2). In computing the mass properties, the outer layer (consisting of 108 submunitions) was assumed to be dispensed first followed by the inner layer of 54 submunitions. The corresponding changes in the dispenser inertial characteristics are given in Fig. 3. It was

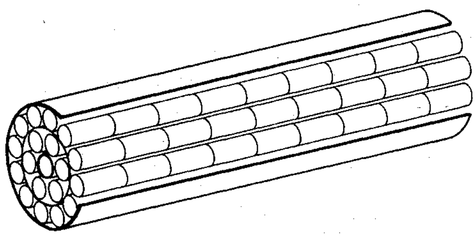

Fig. 2 Submunitions layout for sequential dispensing.

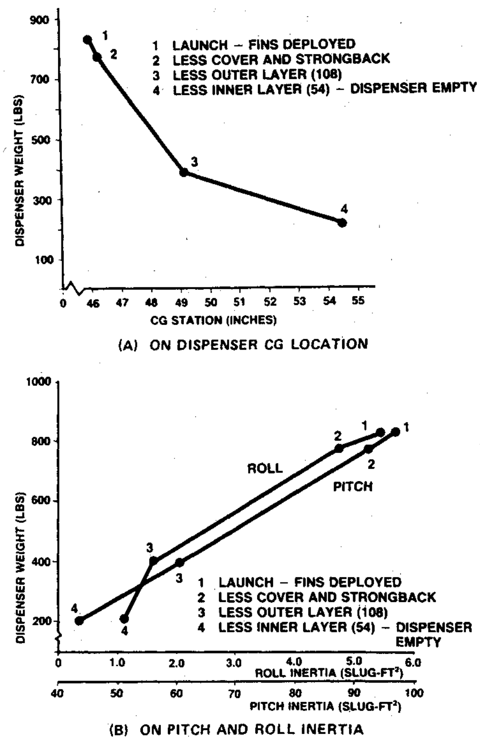

Fig. 3 Sequential dispensing effect.

found that the c.g. shift could be controlled or eliminated by adding a ballast or by using packing material selectively and distributing their weight. In the present simulation, c.g. shift and changes in inertial characteristics due to dispensing were included to determine their effect on the dispenser flight dynamics.

In the current illustration, the dispenser was assumed to have been launched from an aircraft at a nominal altitude of 2000 ft at a speed of 800 ft/s. Spin was initiated typically 0.5 to 3.0 s after launch. The fins were deflected so that a nominal spin rate of 1000 rpm was achieved in 1.2 s. The dispensing events were preprogrammed to occur at specific time intervals at selected roll angles. Several flight parameters were varied to determine their effect on submunition ejection and their subsequent impact patterns. These are discussed below in detail.

Dispenser Performance Characteristics

The flight dynamics of the sequential dispenser from launch through spinup was found to be similar to that of a SUU-65/B dispenser. For instance, where launch was initiated at an angle of attack of 10 deg, the corresponding flight trajectory was simulated and the following observations were made. Immediately after launch, the dispenser experienced a stable oscillation in its angle of attack (Fig. 4) and developed coning motion in both pitch and yaw degrees of freedom (Fig. 5). Subsequently, during spinup the amplitude of these excursions was found to decrease significantly due to the stabilizing effect of spin. As in SUU-65/B, the critical decision here is to specify the timing of fin deflection or spin initiation. Generally, spinup should be done quickly to minimize loss of altitude but not before sufficient aircraft clearance has been achieved. Another factor that influences this decision is the potential for instability if spin is initiated prematurely and thereby creates distortions in the impact pattern of the submunitions. These have been addressed previously in Ref. 3 and are equally applicable to the present dispenser.

It is pertinent, however, to note here that optimum fin deflection time based on certain stability and performance criteria can be established for specific designs. Consequently a minimal time of 0.5 s prior to fin deflection has been chosen here. This time delay was found[3] to provide adequate vehicle stability during spinup. The corresponding spinup time history is shown in Fig. 6 for a fin deflection of 25 deg. The dispensing events were programmed in this case to occur at intervals of 0.1 s after a spin rate of 1000 rpm was reached. These events are shown by symbols in Figs. 4-11. Both coning and oscillatory motions were found to prevail during the dispensing process with no significant change in their character. The spin rate was found to peak during dispensing with a maximum deviation of 70 rpm over its nominal value. It was found that the spin rate tends to asymptotically reach this peak rpm in the absence of dispensing. The range of excursions in dispenser pitch and yaw attitude during dispensing in this case was 6 and 3 deg, respectively. The corresponding excursion in the dispenser complex angle of attack was 2.25 deg. These variations were found to be significantly less in a case where the spinup was initiated 3 s following release. The corresponding flight characteristics are shown in Figs. 7-9. It should be noted that these excursions have significant effect on the ejection conditions of submunitions and eventually on their impact patterns.

Table 2 shows simulated range of disturbances in dispenser parameters and corresponding errors in submunition ejection conditions at a roll angle of 0 deg. Note that the longitudinal offset of the submunition from the pitching or yawing axes does not result in any significant errors. Consequently, pitch and yaw rates that are prevalent during dispensing are not as

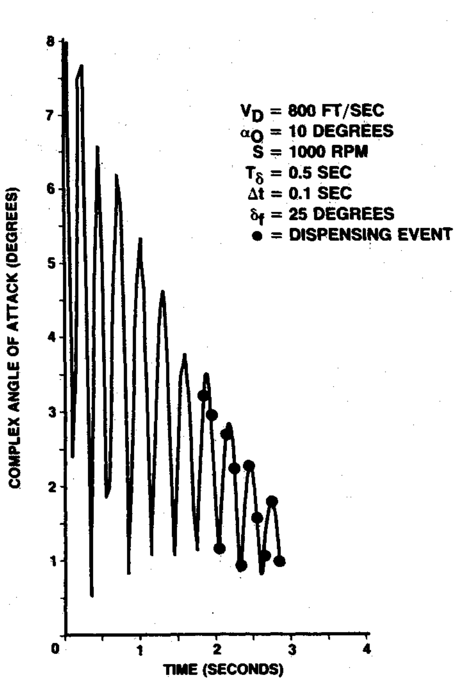

Fig. 4 Angle of attack oscillation of sequential dispenser.

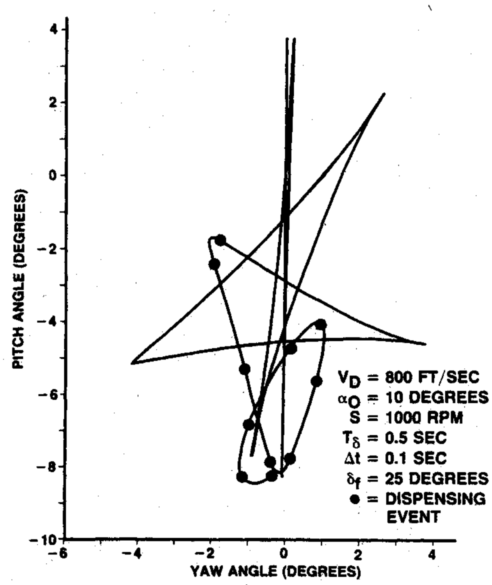

Fig. 5 Pitch-yaw coning motion of sequential dispenser.

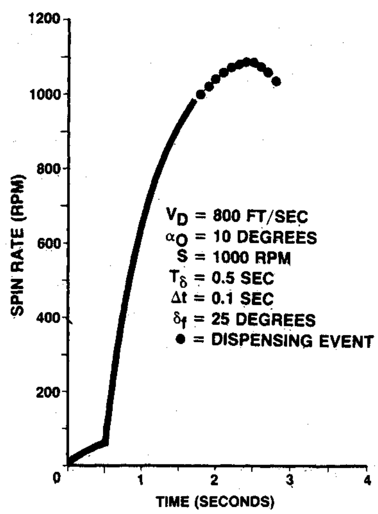

Fig. 6 Spin rate time history of sequential dispenser.

much of concern as the corresponding attitudes. The associated perturbations in submunition flight path angle and heading angle have been found to be small. The corresponding distortion in the munition impact pattern also tends to be small, as will be illustrated here subsequently.

Effects of Flight Parameters

Launching at zero angle of attack has been found to suppress both the oscillatory variation in angle of attack (Fig. 10) as well as pitch-yaw coning (Fig. 11). In this case, the dispenser was found to pitch down steadily while the angle of attack remained zero throughout the dispensing. Increasing the time interval between dispensing events in this case was found to decrease the corresponding flight path angle at each ejection.

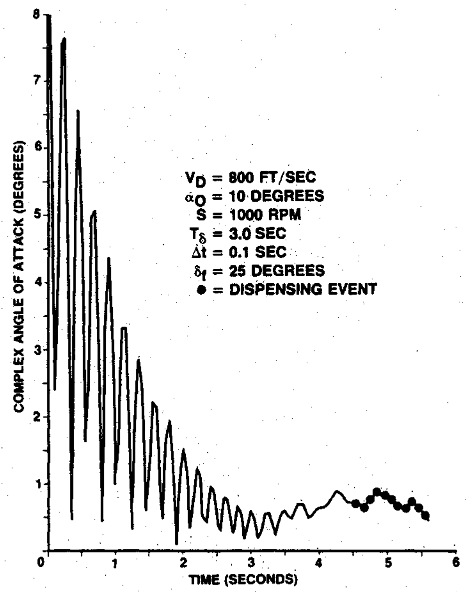

Fig. 7 Effect of time delay on angle of attack oscillation.

Table 2 Dispenser flight dynamics effect on submunition ejection (flight speed = 700 ft/s, spin rate = 1000 rpm)

Ejection condition	V_s, ft/s	γ_s, deg	ψ_s, deg
Nominal ($\phi_s = 0$ deg)	702.1	0	−4.45
$\Delta\phi_s = \pm 5$ deg	–	±0.39	0.02
$\Delta\phi = \pm 5$ deg	–	±0.39	0.02
$\Delta\theta = \pm 1$ deg	–	±1.0	–
$\Delta\psi = \pm 1$ deg	–	–	±1.0
$\Delta\alpha_p = \pm 1$ deg	–	±1.0	–
$\Delta\beta_p = \pm 1$ deg	+0.9	–	±1.0
$\Delta q = \pm 10$ deg/s	–	–	–
	±0.1[a]	+0.04[a]	
$\Delta r = \pm 10$ deg/s	–	–	–
			+0.04[a]
$\Delta S = \pm 100$ rpm	±0.5	–	+0.44

[a]Submunition located at a longitudinal offset of 2.5 ft.

Table 3 Flight speed effect on spin rate deviation

Flight speed, ft/s	Nominal spin rate, rpm	Spinup time, s	Spin rate variation while dispensing, Δrpm
800	1000	1.80	+100
800	500	1.56	+50
400	1000	3.75	+200

Also, smaller variation in spin rate was found during dispensing at lower rpm while the spinup time to reach the lower rpm was essentially the same (Table 3). Consequently, ejecting the submunitions with lower velocities is unlikely to cause distortions in the impact patterns. However, large variations in rpm were found while dispensing at lower flight speeds. Therefore, it may be essential to maintain a minimum speed to create certain impact patterns. A longer time interval between launch and spin initiation has been found to typically decrease the spin rate variation during dispensing, as illustrated earlier. Note that this would be favorable, especially where this weapon system is required to have a standoff capability.

Impact Patterns

For dispensing from cruise missile-type trajectories, simple ejection strategies were used to obtain the corresponding submunition ejection conditions from the flight dynamics simulation. This data was subsequently put into a three DOF trajectory simulation of individual submunitions to determine the corresponding impact pattern over the ground. For the launch conditions of the dispenser illustrated earlier in Figs. 7-9, the corresponding submunition trajectories were simulated. Figure 12 shows the dispersion geometry obtained when the submunitions were ejected vertically at ±90 deg roll angles to create a linear pattern in the longitudinal direction. The maximum lateral deviation in the corresponding impact pattern was only 4 ft. Similarly, Fig. 13 shows the corresponding pattern obtained by ejecting at 0 and 180 deg. The lateral separa-

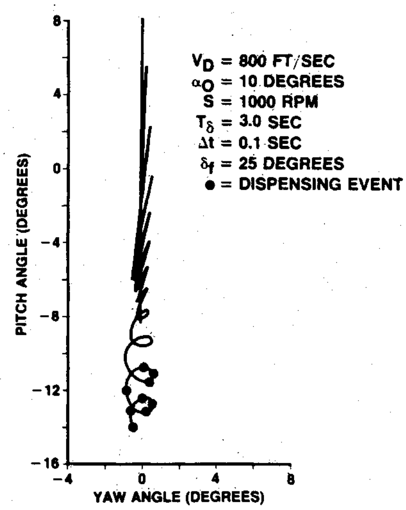

Fig. 8 Effect of time delay on pitch-yaw coning.

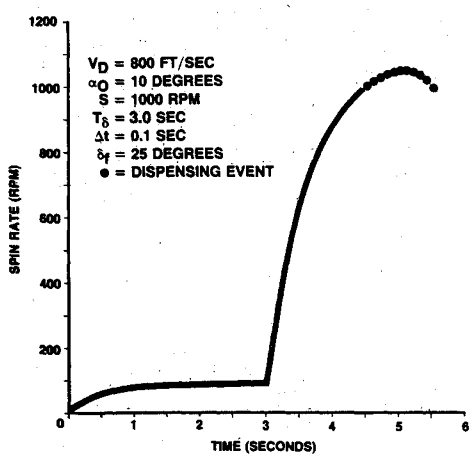

Fig. 9 Effect of time delay on dispenser spin rate.

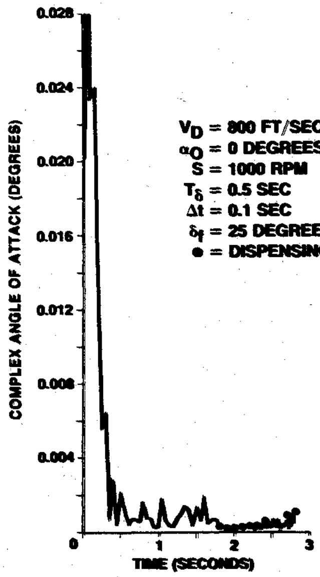

Fig. 10 Launch angle effect on dispenser angle of attack.

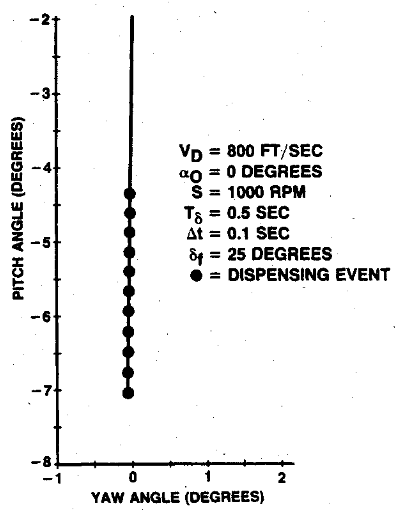

Fig. 11 Launch angle effect on dispenser pitch-yaw coning.

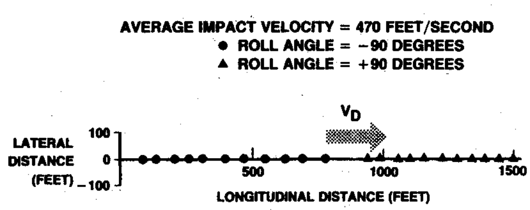

Fig. 12 Simulated impact pattern for longitudinal deployment strategy.

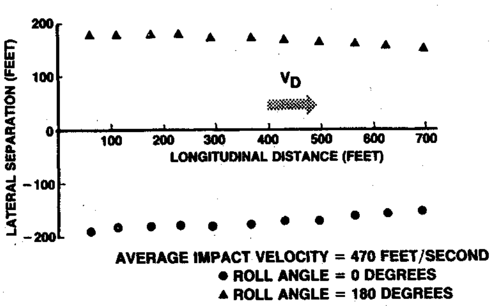

Fig. 13 Simulated impact pattern for lateral deployment strategy.

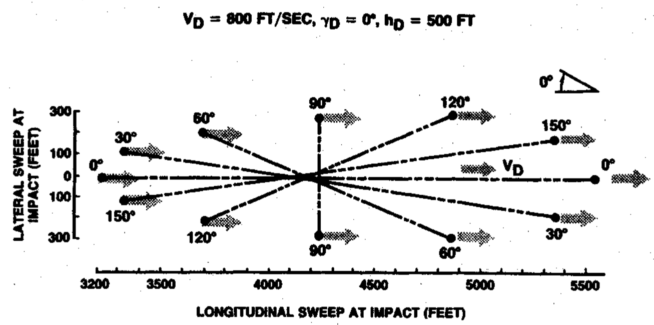

Fig. 14 Generatrix orientation at various submunition release angles.

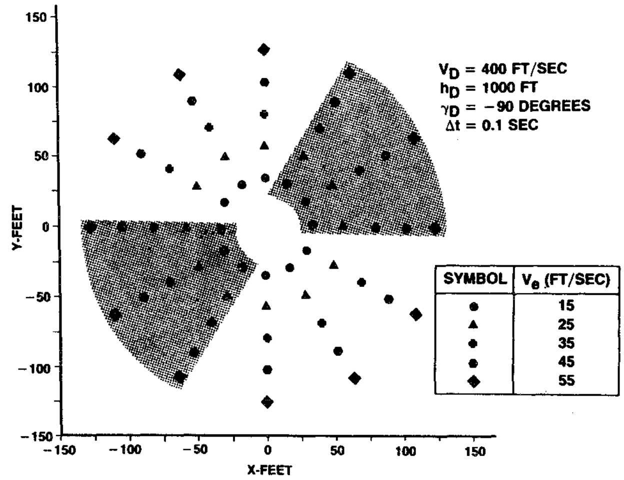

Fig. 15 Typical dispersion pattern from ballistic trajectory.

tion in this case was found to vary up to a maximum of 8% of its desired value over the entire pattern length. The converging tendency observed in this pattern is a consequence of variation in dispenser spin rate and loss of altitude during the dispensing mode. Note that a synergetic pattern could also be created by combining these strategies and ejecting simultaneously. Also, by varying the projectile angle at ejection, one could alter the generatrix and its orientation with respect to the dispenser flight path as illustrated in Fig. 14. When the spin rate is high enough, several of these generatrices could be used to define a particular impact pattern.

A typical dispersion pattern obtained by dispensing from a ballistic trajectory was simulated and is shown in Fig. 15. Each concentric circular pattern corresponds to ejecting all the submunitions in the outer layer at a particular longitudinal station, simultaneously. The radius of this circular pattern was controlled either by varying the spin rate or the ejection velocity of a particular set, or by ejecting at constant spin rate but at various altitudes. By simple omission of some of these ejections, one could create an arc or segment of these circular impact patterns. A similar approach could be used to create elliptical patterns or their derivatives. An important aspect of this dispensing approach is therefore orienting the dispenser relative to the target and designing the corresponding ejection strategy via software. This complex function would certainly require an onboard guidance and control computer and a sensor system with minimal error buildup.

Concluding Remarks

The concept of sequentially dispensing submunitions from a spinning dispenser does provide greater flexibility in selection and control of impact patterns than existing methods. Application of this concept to a particular weapon system should be determined by the type and accuracy of the impact pattern desired and the kind of carrier vehicle used. For instance, impact patterns that require high spin rates of the dispenser may demand a more sophisticated and expensive sensor system. Consequently, appropriate trade studies would be necessary before developing such a weapon system.

Flight characteristics of the sequential dispenser system simulated here tend to resemble those of a spinning missile. The consequences of dispensing sequentially on the weapon flight dynamics do not appear to be significant in this case. This should, however, be confirmed by experimental validation. Indeed, experimental testing of the sequential dispensing concept itself would be the first step in this regard. This is being done through prototype hardware development and by conducting field tests that demonstrate concept feasibility.

Acknowledgment

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