SIMULATION OF WEAPONS RELEASE
FROM CARGO AIRCRAFT

THESIS

Paul M. Wilson, Second Lieutenant, USAF

AFIT/GAE/ENY/06-M33

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty

Department of Aeronautics and Astronautics

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Aeronautical Engineering

Paul M. Wilson, BS

Second Lieutenant, USAF

March 2006

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Paul M. Wilson, BS
Second Lieutenant, USAF

Approved:

Milton E. Franke (Chairman)	date
Paul A. Blue (Member)	date
Donald L. Kunz (Member)	date
Eric J. Stephen (Member)	date

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Abstract

The purpose of this study is to develop a computer simulation capable of providing an accurate flight history of an airdropped munitions dispenser system in order to conduct proof of concept testing. The dispenser system is intended to provide a retrofit combat capability to the USAF C-17 aircraft, delivering massive amounts of precision guided ordinance where needed, when needed, while remaining outside the threat envelope. The dispenser concept was developed and modified through use of the simulation by determining the most favorable parachute system, harness configuration, and munition release sequence which ensure the desired behavior and performance of the twenty-munition dispenser system. The developed dispenser system was subjected to various adverse flight conditions, disturbances, and system malfunctions to determine the dispenser's reaction to such inputs. Overall, the developed dispenser configuration has proven to be a viable weapons release platform for a cargo aircraft.

The simulation is intended to serve as an adaptable tool for the development and testing of any cargo aircraft based weapons dispenser system. The simulation allows the user to conduct low-cost, time efficient, and effective tests of various design concepts. This benefit allows for the research of a wide array of concepts as well as the determination of their operational feasibility and performance envelope. This tool is a benefit to the engineering development process and the goal of timely delivery of a viable weapons platform to the warfighter.

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To My Wife

Acknowledgments

I would like to express my sincere appreciation to my thesis advisor and committee members for their guidance and support throughout the course of this thesis effort. Their insight and experience was vital to the completion of this work. I would, also, like to thank my sponsor, Mr. Eric Werkowitz, from the Air Force Research Laboratory Munitions Directorate, for his support and the opportunity to make an impact.

Also, I would like to express my gratitude to Mr. Brandon Hiller, from Dynetics Inc, and Mr. Mark Kuntavanish, from the Aeronautical Systems Center's C-17 Systems Group. I am indebted to these two professionals who spent their valuable time explaining the processes, procedures, and details such a design concept would require.

Paul M. Wilson

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Acronyms

CARP	Computed Air Release Point
CFD	Computational Fluid Dynamics
CG	Center of Gravity
CP	Center of Pressure
DoF	Degrees of Freedom
DCM	Direction Cosine Matrix
GPS	Global Positioning System
ICBM	Inter-continental Ballistic Missile
INS	Inertial Navigation System
MOAB	Massive Ordinance Air Blast
PGM	Precision Guided Munition
RS	Ring Slot
TMD	Tactical Munitions Dispenser
USAF	United States Air Force
wrt	with respect to

Units of Measure

^{o}	degree
ft	foot
kg	kilogram
kts	knots or nautical miles per hour
lb	pound force
m	meter
N	Newton
rad	radian
s	second

Nomenclature

b	Reference Chord Length of Dispenser (m)
$C_{D_{\alpha^2}}$	Force Derivative of Drag wrt α^2 (1/rad^2)
C_{D_0}	Force Coefficient of Drag at $\alpha = 0$ (-)
C_L, C_D, C_Y	Force Coefficients of Lift, Drag, Sideforce (-)
$C_{L_\alpha}, C_{Y_\beta}$	Force Derivatives of Lift wrt α, Sideforce wrt β (1/rad)
$C_{L_{CP}}, C_{M_{CP}}, C_{N_{CP}}$	Moment Coefficients (-)
$C_{L_{CPp}}, C_{M_{CPq}}, C_{N_{CPr}}$	Moment Derivatives wrt Angular Velocity (s/rad)
C_P	Force Coefficient of Parachute Drag (-)

D	Drag Force (N)
DCM	Direction Cosine Matrix (-)
d_x, d_y, d_z	Distance from Munition CG to Dispenser CP (m)
$\vec{F}$	Resultant Force (N)
F_x, F_y, F_z	Force Components (N)
g	Gravity (m/s^2)
$\vec{H}$	Resultant Angular Momentum (kg-m^2/s)
H_x, H_y, H_z	Angular Momentum Components (kg-m^2/s)
i	Number of Munitions Remaining in Dispenser
I_{xyz}	Inertia Matrix of Dispenser System (kg-m^2)
$\left[I_{xyz}\right]_{dispenser}$	Inertia Matrix of Empty Dispenser (kg-m^2)
$\left[I_{xyz}\right]_{munition}$	Inertia Matrix of Single Munition (kg-m^2)
I_x, I_y, I_z	Mass Moment of Inertia Components of Dispenser System (kg-m^2)
I_{xy}, I_{yz}, I_{xz}	Products of Inertia Components of Dispenser System (kg-m^2)
L	Lift Force (N)
L_{CP}, M_{CP}, N_{CP}	Moment Components (N-m)
$\vec{M}$	Resultant Moment (N-m)
M_x, M_y, M_z	Aerodynamic Moments (N-m)
m	Mass of Dispenser System (kg)
$m_{dispenser}$	Mass of Empty Dispenser (kg)
$m_{munition}$	Mass of Single Munition (kg)
p, q, r	Body Angular Velocity Components (rad/s)
P	Parachute Drag Force (N)
$\bar{q}$	Dynamic Pressure (N/m^2)
q_0, q_1, q_2, q_3	The Four Quaternion Parameters (-)
S	Reference Area of Dispenser (m^2)
$S_{parachute}$	Reference Area of Parachute (m^2)
t	Time (s)
u, v, w	Body Velocity Components (m/s)
u_0, v_0, w_0	Munition Initial Velocity at Ejection (m/s)
u_{exit}	Munition Velocity in x-direction at Dispenser Exit (m/s)
$u_{release}$	Munition Velocity in x-direction at Release (m/s)
$\vec{V}$	Resultant Velocity (m/s)
V_b	Magnitude of Body Velocity (m/s)
W	Weight (N)
x, y, z	Position Coordinates (m) or Axis

X_{-}, Y_{-}, Z_{-}	Forces Acting on Dispenser (N)
Y	Side Force (N)
α	Angle of Attack (rad)
β	Angle of Sideslip (rad)
Δx	Munition CG Travel Distance from Release to Ejection (m)
φ	Earth Latitude Coordinate (^{o})
ϕ, θ, ψ	Roll, Pitch, Yaw Euler Angles (rad)
$\dot{\phi}, \dot{\theta}, \dot{\psi}$	Euler Rates (rad/s)
ρ	Air Density (kg/m^3)
$\theta_{release}$	Dispenser and Munition Pitch Release Angle (rad)
$\vec{\omega}$	Resultant Body Angular Velocity (rad/s)
<u>Subscripts</u>	
A, B, P	Aerodynamic, Body, Parachute Forces
b	Body-fixed Axes Reference System
CG	Center of Gravity
CP	Center of Pressure
e	Earth-surface Fixed Axes, or Inertial, Reference System
$joint$	Parachute-Harness Joint
n	Specific Munition

SIMULATION OF WEAPONS RELEASE FROM CARGO AIRCRAFT

I. Introduction

Background

As the nature of warfare in the twenty-first century continues to change, more military resources and personnel are tasked to conduct additional missions, some which are outside of their normal range of operations. The benefit of having resources with this multi-role capability is to reduce the number of resources exposed to threats in the field, reduce the required number of deployed forces, and potentially reduce the costs involved with the operation itself. From a top-level acquisitions point of view, the more capable a resource is, the more likely it will be funded and will have better staying power for the long-term. To battlefield commanders, the multi-role capability offers more flexibility in developing their operations plans and executing their mission. The development of multi-role resources brings more to the fight and is a benefit for all involved.

With the development of new technologies, sometimes there is a *push* from the engineering community to create a new mission tasking capability before the *pull*, or need, is present from the operational world. The technology can also be at a stage where the capability and need are both present, but the platform required to deliver it is not available, cost-effective, or directly suited to the mission. In this situation, the available platforms in the inventory must be retrofitted or modified in order to try to take advantage of this technology.

In the operational component of the United States Air Force (USAF), roles are typically well defined and resources are used where they work best, for what they were designed. Cargo aircraft handle their areas of cargo and fuel delivery while fighter and bomber aircraft deliver ordinance to the battlespace. Cargo aircraft are slow, poorly maneuverable, and susceptible to damage in a close threat environment while fighter and bomber aircraft do not have the size and ability to deliver large amounts of cargo. However, US operations in the past two decades have required little air-to-air combat and US air superiority was obtained early in these engagements. The primary focus of air combat operations has been in the strategic bombing of important enemy resources. In this same time period, new weapons technology for strategic bombing has improved greatly in the precision of guided munitions and the various sizes of stand-off weapons. An example of this culture change is shown in the acquisition of the F-22A Raptor; it was initially designed as strictly an air superiority fighter, but as the congressionally approved purchase numbers decreased, it had to take on an additional role as a ground attack aircraft to avoid program cancellation. The focus is now on the precision engagement and destruction of enemy targets to achieve an efficient and effective victory with minimal collateral damage, using only what is necessary to complete the mission.

In order to commit less resources to the fight, aircraft need to be tasked with new missions because the option to bring a new platform online is costly, time consuming, and may not be warranted. If a cargo aircraft were capable of delivering ordinance without entering the threat environment, in which it is highly vulnerable, it would fit this multi-role need and allow battlefield commanders the flexibility to employ various options in order to meet time and situation specific needs. This could allow fighter and bomber aircraft to be tasked elsewhere or in addition to the cargo aircraft and increase the available total mass of the applied airpower force. With the use of precision stand-off munitions, a cargo aircraft could stay outside of the threat envelope of anti-aircraft weapons and deliver massive amounts of ordinance to the desired target. This would be comparable to long-range land or sea-based missiles except that by using the aircraft to deliver the munitions closer to the target, more munitions can be delivered with less room for error and a better element of surprise to defeat enemy counter-threat systems. While some bombers are capable of delivering massive amounts of ordinance within the threat envelope, the addition of cargo aircraft to the stand-off precision strike mission could reduce the threat on bomber aircraft, create more airpower assets and options for battlefield commanders, and limit the amount of resources required to conduct operations. The necessary technological step forward is to develop a means by which a cargo aircraft can be easily modified in order to conduct the precision strike mission without sacrificing its vital cargo mission capabilities.

Problem Statement

The USAF acquisitions process typically begins with the development of a concept through multiple methods of analysis and testing to ensure a quality system is produced in an efficient manner. To produce a method by which multiple munitions could be deployed, it would be advantageous to develop a design concept that can be analyzed in computer simulations or small-scale experiments in order to minimize the time and cost spent on a potentially ineffective system. These simulated tests can then be used as the foundation for an educated decision on whether to pursue further large-scale tests and possible acquisition into the USAF operational inventory. This study will utilize computer simulation to investigate the potential viability of a cargo pallet airdrop extraction system for use as the method of deploying multiple precision guided munitions (PGM) simultaneously. These simulations can be used as a tool in the engineering development process to further the understanding of the concept and the subsequent work necessary to bring the system into operation.

Research Objectives and Focus

The primary objective of this study is to develop a computer simulation capable of providing an accurate portrayal of an airdropped munitions dispenser system. This simulation will allow the user to vary the input parameters for flight conditions, dispenser configurations, types of munitions, and munition release sequences. This feature can then be used to conduct a complete range of tests and analysis with a broad range of variables in order to determine optimal operating conditions, range of system stability and capability, and employment options and limitations. The resulting ultimate objective of this particular study is to determine the viability of this concept version of a munitions dispenser as a capable cargo aircraft weapons deployment system through use of the computer simulation. The dispenser concept's viability will be determined through graphical analysis of the dispenser's ability to maintain a dynamically stable flight condition while quickly releasing its complement of munitions within defined operational constraints. The focus of the study, as a proof of concept, is on the airdropped dispenser itself as a capable platform for satisfactory deployment of guided munitions.

Methodology

In order to conduct this study via simulation, a design concept of the munitions dispenser system is developed which will deploy current USAF inventory guided munitions. The computer simulation is built from the developed six degree-of-freedom (DoF) equations of motion for the dispenser system which take into account flight conditions as well as the mass, inertia, and aerodynamic properties of the dispenser and its munitions. This simulation, programmed in the MATLAB Simulink software environment, uses a numerical solution that depicts the motion and performance of the munitions dispenser and the deployed munitions throughout their flight history. With the output of the flight history data, MATLAB post-processing programs are written and used to analyze the system's behavior and effectiveness while determining any possible areas for concern.

Limitations and Assumptions

This study will focus only on one design concept of the dispenser in order to investigate the viability of that particular system as a method of munitions deployment from cargo aircraft; however, the developed computer simulation model and analysis tools are capable of user friendly modifications for various alternate designs of this concept. The focus of the research is the development of the dynamic simulation; therefore, the dispenser and munitions characteristics are obtained through calculated approximations of the mass and inertia properties and simplified computational fluid dynamics (CFD) models. This simulation is intended to serve as an approximation of the actual behavior of the system to a reasonable degree of fidelity based on educated assumptions. The primary assumption of this study is to limit the dynamic equations of the parachute-dispenser system to a six DoF, single rigid body system. This will depict only the motion of the dispenser as a result of the forces acting upon it, neglecting the mass and inertia properties of the parachute extraction system. In addition, the dispenser system is treated as a discretely changing mass and inertia system as each munition is released, in which the equations of motion are recalculated with each new set of initial conditions and characteristic properties. By making certain assumptions, the complexity of the system can be reduced and a satisfactory solution can be obtained for use in a range of test and analysis tools.

Implications

This study has the potential to spark the further development of cargo aircraft weapons systems, whether it is this specific design or another, in simulation and small-scale testing as well as into full-scale flight testing and USAF acquisition. It also will provide the necessary analysis to make educated conclusions on the viability of this design concept as a weapons system as well as show a path for future testing, modifications, employment options, and operational capabilities. Further studies will need to be conducted in order to fully develop the concept and delve further into the range of operations, specific internal systems, system integrity, production, and system infrastructure issues. The information from this study will help to provide a foundation for the viability of this concept as a method to deliver munitions via cargo aircraft, thereby paving the way for future multi-role cargo aircraft capable of contributing more to the fight and increasing the flexibility and capabilities of the airpower component of warfare.

II. Literature Review

Available Munitions Systems and Technology

In order to move forward in the development and simulation analysis of the airdropped munitions dispenser system, it is advantageous to be aware of the other weapons systems and useful technologies that are available to the cargo aircraft based weapons field. Two operational examples of a single munition deployment, by parachute extraction, from a cargo aircraft are the BLU-82 Commando Vault, or Daisy Cutter (see Figures 1 and 2), and the GBU-43/B Massive Ordinance Air Blast Bomb (MOAB) (see Figures 3 and 4). Both systems are mounted on a cargo pallet and utilize a drogue parachute for extraction from a USAF C-130 aircraft; however, the BLU-82 then uses a recovery parachute to separate from the pallet and guide its descent while the

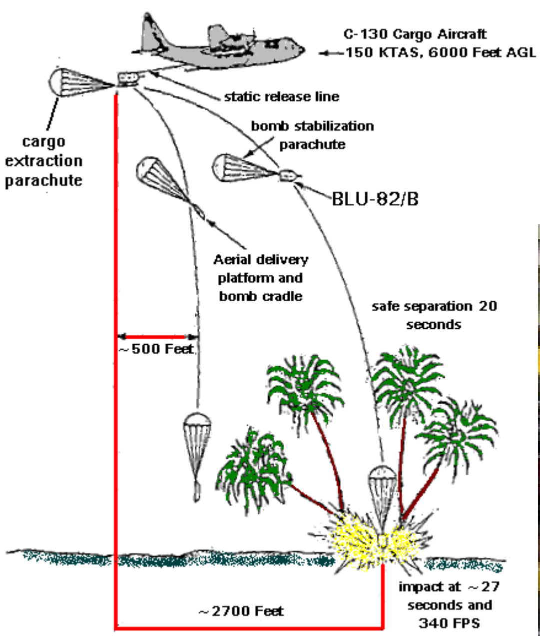


Figure 1. BLU-82 Deployment Sequence [13]

Figure 2. BLU-82 and Harness/Pallet [13]

GBU-43/B is released by gravity from the pallet and makes its descent under the guidance and navigational control of Inertial Navigation System (INS) and Global Positioning System (GPS) with controllable tail fins. Both systems have been deployed in combat operations with success, the BLU-82 in the Vietnam Conflict and Operation Desert Storm and the GBU-43/B in Operation Iraqi Freedom [13].

Figure 3. GBU-43/B Deployment [13]

Figure 4. GBU-43/B and Pallet [13]

A few experimental systems have been developed to deploy various self-propelled munitions from cargo aircraft via parachute extraction, but have not been added to the operational inventory. The first attempt, in 1974, was to deploy a Minuteman I Intercontinental Ballistic Missile (ICBM) from a USAF C-5 aircraft; the ICBM was successfully launched, but proved too costly for operational sustainment in the inventory [14]. A later attempt to launch a cruise missile in 1997 from a USAF C-130 aircraft, designated the AltAir program, proved to be a feasible option as a target vehicle for use in missile defense testing (see Figure 5) [28]. Both systems used methods of parachute extraction from the aircraft similar to the BLU-82 and GBU-43/B.

Figure 5. AltAir Vehicle Deployment [28]

Another system that is analogous to the desired airdropped munitions dispenser system is the parachute stabilized munition with deployed submunitions. An operational example is the CBU-97 Sensor Fuzed Weapon with BLU-108/B submunition (see Figure 6). This munition is a Tactical Munitions Dispenser (TMD) which can be released, like a conventional bomb, from a USAF fighter, bomber, or attack aircraft. It then deploys multiple parachute stabilized submunitions which at a designated altitude will spin and dispense their independently targeting projectiles [11]. The objective of this study is to take the CBU-97 concept to a larger scale for the release of large munitions via airdropped dispenser from a cargo aircraft.

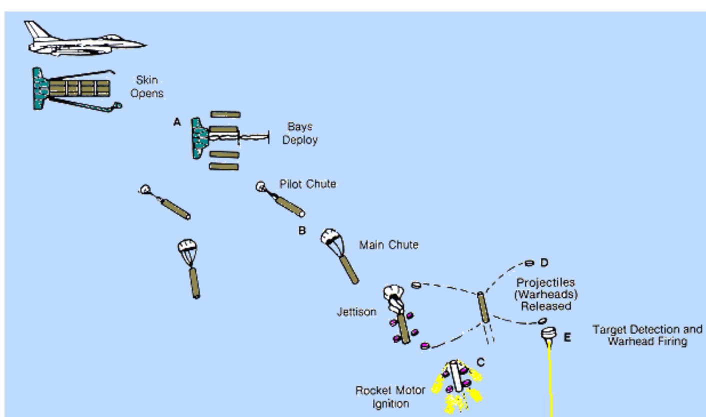


Figure 6. CBU-97 Deployment Sequence [11]

Possible Solutions and Final Design Concept

The premise and thrust for this study is based on the developed concepts for an airdropped munitions dispenser system described by Franke and Ari. They explored the use of a cargo aircraft based weapons system that delivered multiple PGM's, of various types, via a pallet based weapons container with several layers, or munitions trays. The approach of the study was focused on a systems engineering approach in order to meet the requirements and constraints of USAF inventory aircraft and munitions, aircraft interface and safety issues, and possible working design options. Their work provides a conceptual basis with which to conduct this study, with the benefit of their supporting research on systems engineering issues, which ensure feasibility and compatibility with the current USAF inventory. This study is based on a similar version of their weapons container, or dispenser, concept, but the primary difference will be the use of gravity as the munitions dispensing mechanism as opposed to springs or individual munition parachutes [2; 12].

Available Analysis Tools and Their Approach

A wide range of research has been conducted in the areas of parachute dynamics, fluid dynamics in store separations, airdropped payload simulation, and munitions technologies. This study seeks to combine those areas and previous efforts in to the simulation of an airdropped munitions dispenser system. Similar work with TMD concepts has been conducted through use of numerical and experimental studies [10] as well as computational studies to a high degree of fidelity with nine to fifteen DoF dynamic systems [9; 23]. Although this study will be limited to a six DoF system, these studies are important in the analogous relationship to this study and for a full understanding of the areas that will be assumed negligible, such as parachute mass and inertia properties and the elasticity of parachute rigging [23].

Numerous methods of analysis exist to conduct a study of this nature; the primary two are CFD analysis and numerical computation of the dynamic equations of motion via computer simulation, both for their calculation speed and high fidelity capability. CFD analysis has been conducted into the simulation of store separation from cargo aircraft [24; 25], parachute-payload extractions for various cargo aircraft airdrop configurations [27], and parachute dynamics [35]. These studies are all important in the understanding of the complicated flow fields that result from store separation, the effects of aircraft vortices, and the varying development and effects of parachutes. All these studies result in high fidelity data with a thorough understanding of the interacting flow fields and how they affect the motion of the object. Due to the complex multi-body dynamics of the dispenser system, this study will use an approach which applies approximations to the complex flow fields, using a computer simulation based on the dynamic nonlinear differential equations of motion and curve-fit aerodynamic data. This approach has been used extensively for parachute-payload systems in various designs, with varying degrees of freedom, various developments of the equations of motion, and use of Newton-Euler, the most commonly used formulation [16], or Lagrangian dynamics equations [23]. Some approaches seek high-fidelity (i.e., for the purposes of this study, any degree of freedom greater than six DoF) results with nine DoF systems, where two rigid bodies describe the parachute and payload, and twelve DoF systems, where the two rigid bodes also have elastic properties whereas six DoF systems represent a single rigid body system for the parachute and payload [29]. Varying degrees of freedom can be obtained within these ranges by simply making assumptions as to the range of motion or elasticity of the system [19; 20; 21; 33]. Much recent work has been conducted in the areas of steerable parafoil dynamics that provide precision guided airdrop capabilities [17; 20; 33]. Work has also been conducted into the theory of parachute apparent mass and inertia characteristics, which attempt to provide greater dynamic insight into the effects of parachute motion on the system that result from parachute aerodynamics. This addition helps to increase the fidelity of the system, accounting for parachute effects based on the air mass contained within the parachute and the resulting dynamics on the total system [4; 5; 6; 31; 34]. The development of all these studies is important in the understanding of what assumptions can be made and what limitations they present as well as to provide additional options for use in modifying the dispenser system to increase the fidelity of the simulation.

III. Methodology

Simulated Design

The airdropped munitions dispenser system discussed here will be the baseline design concept, based on the initial suggestions of Franke and Ari, for the simulation and analysis conducted in this study [2; 12]. Although the simulation is capable of varying input parameters to simulate various configurations and designs, the focus of this study is to conduct proof of concept testing and evaluation of this specific design in order to determine system viability and prompt further research and development. The baseline model is a cargo pallet based dispenser, containing twenty munitions, harnessed to one or two large extraction, or drogue, parachutes that will extract the dispenser from the aircraft and then stabilize the dispenser's flight as each munition is released.

The dispenser is in a four-by-five configuration, meaning four trays, stacked vertically on a cargo pallet, containing five munitions each (see Figure 7). The munitions are intended to be lightweight PGM's enabling battlefield commanders to employ a weapons system that can deliver a large number of munitions, striking numerous targets, with great accuracy from a single dispenser. The addition of a self-propelled capability to these munitions could also increase the range and options available with the dispenser system while also limiting the delivering aircraft's exposure to the threat environment. The size of this dispenser configuration along with the resulting weight of the payload is designed for release from a USAF C-17 aircraft (see Figure 8), with the configuration maximized to the allowable size limits of the aircraft's cargo door [15]. The payload is then harnessed via four lines from each corner of the exiting side of the payload to the parachute rigging, with either one or two parachutes.

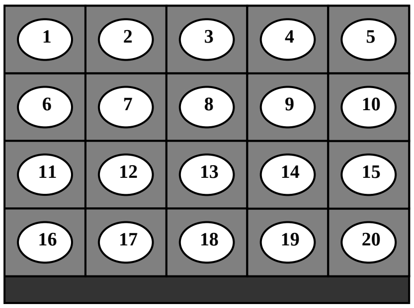


Figure 7. Dispenser-Munition Configuration and Numbering [12]

Figure 8. USAF C-17 Aircraft in Airdrop [13]

In the airdrop scenario, the C-17's cargo door would be opened in flight and the parachute system would be permitted to deploy and fully develop. Then, the aircraft's locks on the payload would be released allowing the dispenser to smoothly move across the rollers of the cargo deck and be extracted from the aircraft with a fully-developed parachute system. Once the dispenser system is safely clear of the aircraft, the munitions are released quickly in order to take advantage of a shallow ejection angle from the dispenser that can only be achieved early in the dispenser's flight. The shallow ejection angle allows the munitions to obtain steady and level flight with less stress and g-loading on the munition from a high-g pull-up. Any wings, fins, or other flight control surfaces can more effectively obtain the munition's desired flight path than if the munitions are released in the dispenser's terminal stage with the munitions directed vertically downward in a ballistic flight path.

The munition release system used in this design is composed of hooks contained in the dispenser that hold a ring attached to the tail section of each munition. The hooks are controlled by an onboard system designed to release each munition in a preprogrammed sequence that ensures the maintained stability of the dispenser and minimizes the separation time between ejections in a manner that releases all munitions as quickly as possible while creating a safe distance between each munition. Based on the programmed time release sequence, each hook sequentially releases its hold on the munition, allowing each munition to slide out of the dispenser along a low-friction rail system solely due to the effects of gravity. Once the munitions are clear of the dispenser and each other, they may execute their targeting, guidance, and propulsion operations while the aircraft completes its mission and the dispenser ends its flight as an expendable delivery platform.

Approach and Assumptions

The simulation developed for this study utilizes a computational numerical solver to drive the developed dynamics model in the MATLAB Simulink software environment. Simulink is a graphical math modeling tool which allows users to add a visual level of understanding to their programming and logic. In addition, this software has the benefit of being a widely used engineering programming language with many included aerodynamic models and tools as well as numerous examples of aerodynamic simulation programs. The computational solution relies on the calculation of the developed nonlinear differential equations of motion for the model based on various input parameters and initial conditions. A recalculation of the equations of motion occurs each time step, the size of which can be modified as necessary in order to change the precision and smoothness of the simulation calculations, for the new flight conditions and system characteristics. For this simulation, MATLAB's explicit Runge-Kutta solver, with Dormand-Prince pair, is used which solves differential equations to a good level of accuracy, recalculating for each time step based on the data provided only from the previous time step [18]. The computational dynamics solution is simplified from the CFD approach through the use of aerodynamic coefficients and other assumptions which attempt to apply trends to the complex aerodynamic behavior of the system. The focus of this method is on the rigid body dynamics based on the applied forces and moments on the system as well as its characteristic properties. While the CFD approach can provide more detailed insight into air flow characteristics, it is not an optimal and efficient solution for the complicated dynamics problems of multiple rigid bodies. In addition, this computational dynamics solution lends itself to a greater range of adaptability and efficient modifications for multiple configurations and tests while also providing much quicker test results.

A CFD approach is used in order to obtain the necessary aerodynamic characteristics of the dispenser and its munitions for use in the dynamic simulation. For this study, the dispenser is modeled as a simple rectangular container on a typical cargo pallet for its aerodynamic, mass, and inertia properties. Through proper dimensioning of the aerodynamic bodies, the basic aerodynamic characteristics of the system are obtained through trend-line comparison of the CFD flow field analysis and are used to develop the aerodynamic coefficients input into the simulation. The simplified CFD model developed for this study limits the aerodynamic characteristics of the dispenser to the flight forces due to the relative wind vector and the damping moments due to the body angular rates [30]. The resulting CFD-based characteristics are used in the simulation tests as constant input parameters, but may be modified and improved for future study of variable dispenser aerodynamics.

The objective of this study is to develop a proof of concept simulation with an adequate level of fidelity to gain enough insight into the system's viability and guide any future courses of action. This simulation makes certain reasonable assumptions in order to limit the complexity of the system without compromising the integrity of the results. These assumptions are all clearly outlined and are based on an educated understanding of the pertinent system dynamics. The dispenser design concept developed for this simulation is modeled as a six DoF single rigid body system, free to translate along all three axes and rotate about each of the three axes. The dispenser is characteristically defined by its mass and inertia properties, along with those of the contained munitions, as well as its aerodynamic force and moment characteristics. The initial conditions will be based on provided typical flight conditions for the dispenser at release, with the simulation starting as the dispenser loses contact with the aircraft.

The mass and inertia properties of the parachute system, as a second rigid body, will not be taken into account due to its small relative mass compared to the dispenser. Instead, the parachute system will be modeled as a simple drag vector, attached to the dispenser at the parachute-harness joint location, with a constant drag coefficient. The parachute drag vector's magnitude and direction is dependent on the resultant wind vector, always remaining parallel to it. This results in a pseudo two DoF parachute drag vector, where the parachute is restricted from translation by the parachute-harness joint.

The parachute is free to rotate about its pitch and yaw axes, while the longitudinal roll axis is of little significance in the system's modeling and dynamics (see Figure 9).

Another important limitation to simplify the model is that the munitions are released in discrete increments within the simulation. Thus, a munition is released from the dispenser's hook and then, on the simulation's next time step, the mass and inertia properties immediately reduce to the new level and the munition is ejected from the dispenser. The discrete increments method takes the place of the complicated time differential calculations of the mass and inertia properties as well as the dynamics of the interaction between the dispenser rail system and the munition, from hook release to ejection. While the changing center of gravity (CG) location will be continuously recalculated as the munitions are released, the center of pressure (CP) will remain constant. The CP is the conflux of the aerodynamic forces and moments on the

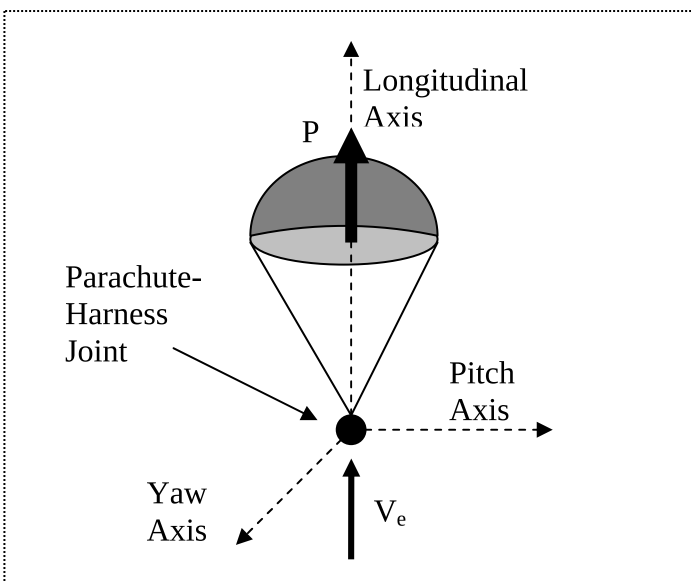


Figure 9. Parachute Axes System

dispenser, about which the characteristic coefficients are defined. It is collocated with the CG of the empty dispenser, in order to limit any changes to the determined aerodynamic characteristics of the dispenser. Also, in order to simplify the nonlinear dynamic equations, all components are assumed frictionless and rigid. Hence, the friction effects of the dispenser release from the aircraft and the munitions release from the dispenser are ignored. The aircraft cargo deck rollers and munition release rails are both low-friction elements, so the effects on the obtained solutions are minimal and affect only the initial velocities of the dispenser and munitions [15]. Also, the elastic or flexible properties of dispenser materials, parachute rigging, and the parachute-dispenser harness are neglected. These materials are considered rigid for this study and should only pose a small variation is system solutions, with the maximum elasticity being approximately 10% for the parachute rigging.

In regard to the simulation of the ejected munitions, each munition's flight history is computed individually based on the initial conditions at the time of release. Since the focus of the study is on the dispenser itself, the munitions' flight history will be limited to three DoF trajectories, the translational motion, rather than computing six DoF solutions for each munition. The munitions are modeled as cylinders while within the dispenser for simulation of the mass and inertia properties of a typical PGM; however, while in flight after release from the dispenser, they are modeled as spheres with a simple aerodynamic drag coefficient, since the orientation of the munitions are neglected. Each munition's flight path will be based on their initial conditions, a simple drag coefficient, and a basic unguided, unpropelled munition drop, simulating either a malfunctioning or dumb munition. This approach will not affect the dynamics of the dispenser, but does not represent the total motion and flight history characteristics of the munitions. The dispenser dynamics are the focus of this study and the munitions simulation is used only as a tool for analysis of the dispenser’s performance, not the complete behavior and performance of a propelled PGM. In future studies, dispenser system models should be further developed to include the full dynamics of the designed munitions to analyze munition-specific dispenser performance and investigate potential release or store separation issues. This simulation may be used as the foundation or template for future research in order to continue the understanding of complete system behavior, performance, and capability.

Equations of Motion

In order to develop the numerical model for this simulation, the appropriate equations of motion that describe the flight history of the dispenser and the munitions, given the discussed assumptions and limitations, must be thoroughly developed. The generic dynamics solution begins with the derivation of the Newton-Euler rigid body equations of motion, from Newton’s second law, which determine the summation of all forces and moments acting on the body [16; 22:97-101]:

$$\sum \vec{F} = \frac{d}{dt}(m\vec{V})\bigg|_e \Rightarrow \vec{F} = m\left(\frac{d\overrightarrow{V_b}}{dt} + \vec{\omega}\times\overrightarrow{V_b}\right) + \cancel{\frac{dm}{dt}\overrightarrow{V_b}} = m\frac{d\overrightarrow{V_b}}{dt} + m(\vec{\omega}\times\overrightarrow{V_b}) \tag{1}$$

$$\sum \overrightarrow{M} = \frac{d}{dt}\overrightarrow{H}\bigg|_e \Rightarrow \overrightarrow{M} = \frac{d\overrightarrow{H_b}}{dt} + \vec{\omega}\times\overrightarrow{H}$$

$$= I_{xyz}\frac{d\vec{\omega}}{dt} + \vec{\omega}\times\left(I_{xyz}\vec{\omega}\right) + \cancel{\frac{dI_{xyz}}{dt}\vec{\omega}} = I_{xyz}\frac{d\vec{\omega}}{dt} + \vec{\omega}\times\left(I_{xyz}\vec{\omega}\right) \tag{2}$$

where

$\vec{F}$ = *resultant force* (N)
t = *time* (s)
m = *mass of dispenser system* (kg)
$\vec{V}$ = *resultant velocity* (m/s)
$\vec{\omega}$ = *resultant body angular velocity* (rad/s)
$\vec{M}$ = *resultant moment* (N – m)
$\vec{H}$ = *resultant angular momentum* (kg – m^2/s)
I_{xyz} = *inertia matrix of dispenser system* (kg – m^2)

and the subscripts *e* and *b* denote the use of the Earth-surface fixed axes, or inertial, reference system and the body-fixed axes reference system, respectively. Note that the equations of motion for the simulation will be solved in the body-fixed reference system. As indicated before, the time derivatives of mass and inertia are neglected; thus, the simulation will model the released munitions as discrete decreases in total system mass and inertia. The resultant vector equations (1) and (2) are then broken into their x-y-z scalar component matrix forms [16; 22:101]:

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \end{Bmatrix} = m\begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{Bmatrix} + m\left(\begin{Bmatrix} p \\ q \\ r \end{Bmatrix} \times \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}\right) = m\begin{Bmatrix} \dot{u} + qw - rv \\ \dot{v} + ru - pw \\ \dot{w} + pv - qu \end{Bmatrix} \tag{3}$$

$$\begin{Bmatrix} L_{CP} \\ M_{CP} \\ N_{CP} \end{Bmatrix} = \begin{Bmatrix} \dot{H}_x \\ \dot{H}_y \\ \dot{H}_z \end{Bmatrix} + \begin{Bmatrix} p \\ q \\ r \end{Bmatrix} \times \begin{Bmatrix} H_x \\ H_y \\ H_z \end{Bmatrix} = \begin{Bmatrix} \dot{H}_x + qH_z - rH_y \\ \dot{H}_y + rH_x - pH_z \\ \dot{H}_z + pH_y - qH_x \end{Bmatrix} \tag{4}$$

where

F_x, F_y, F_z = *force components of* $\vec{F}$ (N)
u, v, w = *velocity components of* $\vec{V_b}$ (m/s)
p, q, r = *body angular velocity components of* $\vec{\omega}$ (rad/s)

$$L_{CP}, M_{CP}, N_{CP} = \textit{moment components of } \overrightarrow{M}\ (\text{N - m})$$
$$H_x, H_y, H_z = \textit{angular momentum components of } \overrightarrow{H}\ (\text{kg - m}^2/\text{s})$$

and the subscript *CP* indicates the center of pressure of the dispenser system which is the coordinates origin for the body-fixed axes of the dispenser system, the location of which will remain constant collocated with the CG of the empty dispenser. The moment and other orientation, or rotational, equations will be based on the motion around the CP in order to constrain the equations of motion to a stationary point, relative to the body, and avoid variation in the obtained aerodynamic coefficients. To further develop equation (4), the components of angular momentum are defined as [16; 22:100]

$$\begin{Bmatrix} H_x \\ H_y \\ H_z \end{Bmatrix} = I_{xyz}\overrightarrow{\omega} = \begin{bmatrix} I_x & -I_{xy} & -I_{xz} \\ -I_{xy} & I_y & -I_{yz} \\ -I_{xz} & -I_{yz} & -I_z \end{bmatrix} \begin{Bmatrix} p \\ q \\ r \end{Bmatrix} = \begin{Bmatrix} pI_x - qI_{xy} - rI_{xz} \\ -pI_{xy} + qI_y - rI_{yz} \\ -pI_{xz} - qI_{yz} + rI_z \end{Bmatrix} \tag{5}$$

where

$$I_x, I_y, I_z = \textit{mass moments of inertia components of dispenser system}\ (\text{kg - m}^2)$$
$$I_{xy}, I_{yz}, I_{xz} = \textit{products of inertia components of dispenser system}\ (\text{kg - m}^2)$$

As the system decays discretely in mass and inertia with each munition release, those parameters input into the simulation's equations of motion change accordingly [16]:

$$m = m_{dispenser} + m_{munition} i, \quad i = 20, 19, \ldots, 0 \tag{6}$$

$$\left[I_{xyz}\right] = \left[I_{xyz}\right]_{dispenser} + i\left[I_{xyz}\right]_{munition}$$
$$+ m_{munition} \sum_{n=0}^{i} \begin{bmatrix} d_y^2 + d_z^2 & -d_x d_y & -d_x d_z \\ -d_y d_x & d_z^2 + d_x^2 & -d_y d_z \\ -d_z d_x & -d_z d_y & d_x^2 + d_y^2 \end{bmatrix}_n, \quad i = 20, 19, \ldots, 0 \tag{7}$$

where

$$\left[I_{xyz} \right]_{dispenser} = inertia\ matrix\ of\ empty\ dispenser\ (\mathrm{kg\text{-}m^2})$$
$$\left[I_{xyz} \right]_{munition} = inertia\ matrix\ of\ single\ munition\ (\mathrm{kg\text{-}m^2})$$
$$m_{dispenser} = mass\ of\ empty\ dispenser\ (\mathrm{kg})$$
$$m_{munition} = mass\ of\ single\ munition\ (\mathrm{kg})$$
$$d_x, d_y, d_z = distance\ from\ munition\ CG\ to\ dispenser\ CP\ (\mathrm{m})$$
$$i = number\ of\ munitions\ remaining\ in\ dispenser$$

and the subscript *n* denotes the specific munition and its properties to be used in the calculation.

Now that the rigid body equations of motion for the model have been developed, equations need to be added to the set in order to determine the orientation and position of the dispenser system. In the field of aeronautics, in order to define the rotation of the body relative to its initial state, or the inertial reference system, it is common to use the Euler angle convention. Euler angles depict the orientation of the air vehicle in terms of its yaw, pitch, and roll angles, in that sequential rotation order. However, a singularity exists in the calculations to obtain and convert the Euler angles, a three parameter system, when the pitch angle is +/- 90^o. Since the dispenser system will always attain a -90^o pitch angle in its terminal phase, due to the set-up of the body-fixed axes, a four parameter system which avoids any singularities is used. The four parameter system used here, quaternions, defines any body's orientation in space by defining a unit vector about which the body is rotated a certain angle. "Because only three parameters define any possible rotation, the quaternions need a constraint so that there are only three independent variables," which is [3]

$$1 = q_0^2 + q_1^2 + q_2^2 + q_3^2 \tag{8}$$

where $q_0, q_1, q_2,$ and q_3 are *the four dimensionless quaternion parameters*, which have no directly evident physical meaning. Now that the method of depicting the dispenser system's orientation is determined, the set of differential equations to calculate the four parameters as part of the equations of motion from the body angular velocities is developed [3; 18]:

$$\begin{Bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{Bmatrix} = \frac{1}{2} \begin{bmatrix} q_3 & -q_2 & q_1 \\ q_2 & q_3 & -q_0 \\ -q_1 & q_0 & q_3 \\ -q_0 & -q_1 & -q_2 \end{bmatrix} \begin{Bmatrix} p \\ q \\ r \end{Bmatrix} \tag{9}$$

Since the four parameters are calculated through numerical integration and the solution of the differential equations of motion, the quaternion initial conditions, which are needed for this solution and are typically provided as Euler angles, must be converted to quaternions [3]:

$$\begin{Bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{Bmatrix} = \begin{Bmatrix} \cos\frac{\phi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} + \sin\frac{\phi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2} \\ \sin\frac{\phi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} - \cos\frac{\phi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2} \\ \sin\frac{\phi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2} + \cos\frac{\phi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2} \\ \cos\frac{\phi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2} - \sin\frac{\phi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2} \end{Bmatrix} \tag{10}$$

where $\phi, \theta,$ and ψ are *the roll, pitch, and yaw Euler angles* (rad), respectively. To use the quaternions as a means of orienting the dispenser system graphically, a rotation matrix, which is calculated from the quaternions, is necessary [3]:

$$DCM = \begin{bmatrix} (q_0^2+q_1^2-q_2^2-q_3^2) & 2(q_1q_2+q_0q_3) & 2(q_1q_3-q_0q_2) \\ 2(q_1q_2-q_0q_3) & (q_0^2-q_1^2+q_2^2-q_3^2) & 2(q_2q_3+q_0q_1) \\ 2(q_1q_3+q_0q_2) & 2(q_2q_3-q_0q_1) & (q_0^2-q_1^2-q_2^2+q_3^2) \end{bmatrix}$$

$$= \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ (\sin\phi\sin\theta\cos\psi-\cos\phi\sin\psi) & (\sin\phi\sin\theta\sin\psi+\cos\phi\cos\psi) & \sin\phi\cos\theta \\ (\cos\phi\sin\theta\cos\psi+\sin\phi\sin\psi) & (\cos\phi\sin\theta\sin\psi-\sin\phi\cos\psi) & \cos\phi\cos\theta \end{bmatrix} \quad (11)$$

where DCM is *the dimensionless direction cosine matrix* and converts a vector from Earth fixed to body-fixed axes. The inverse of the DCM can be multiplied by any x-y-z coordinate vector, in the body-fixed axes, to produce a new rotated x-y-z coordinate vector, represented in the inertial reference system. This simulation uses that ability to convert a collection of coordinate vectors, which visually define the dispenser, into the rotated dispenser at each point in its time history. The second half of equation (11) shows the DCM calculation from Euler angles. By comparing each corresponding matrix element in the two halves of equation (11), a relationship to determine the Euler angles from quaternions can be achieved, which is beneficial due to the readily identifiable physical meaning of Euler angles [3]:

$$\begin{Bmatrix} \phi \\ \theta \\ \psi \end{Bmatrix} = \begin{Bmatrix} \tan^{-1}\left(\dfrac{2(q_2q_3+q_0q_1)}{(q_0^2-q_1^2-q_2^2+q_3^2)}\right) \\ \sin^{-1}\left(-2(q_1q_3-q_0q_2)\right) \\ \tan^{-1}\left(\dfrac{2(q_1q_2+q_0q_3)}{(q_0^2+q_1^2-q_2^2-q_3^2)}\right) \end{Bmatrix} \quad (12)$$

From the computation of the Euler angles from the quaternions, another important set of physical values can be calculated through numerical differentiation, the Euler rates, $\dot{\phi}, \dot{\theta}, \text{and} \dot{\psi}$ (rad/s). In order to determine the translational position of the dispenser system, the linear velocity, in the inertial reference system, can be calculated from the velocity in the body-fixed axes, similar to the calculation of the quaternions time derivatives from the body angular velocities [22:102]:

$$\begin{Bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{z}_e \end{Bmatrix} = DCM^{-1} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = DCM^{T} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \tag{13}$$

where $x_e, y_e,$ and z_e are *the three-dimensional position coordinates for the dispenser system in the inertial reference system* (m) which are calculated through numeric integration from equation (13). The DCM inverse, which is by nature equal to its transpose as with any such rotation matrix, is used to convert from the body-fixed system to the inertial, similar to its application for the graphic display used for this simulation [16]. An important assumption to note here is that the rotation of the Earth is not taken into account for the position calculation of system components. This study is primarily concerned with the relative position of components and not with the precise ground impact coordinates required of a targeting system.

The equations of motion solver in the simulation uses the twelve generic nonlinear differential equations contained in equations (3), (4), (9), and (13), inputting the system dynamics and outputting the system's translational and rotational motion. However, to solve for the specific situation of the munitions dispenser system, the dispenser dynamics must be outlined and included in the twelve differential equations. The dynamics problem begins with the set-up of a free body diagram (see Figure 10), describing the convention for the forces and moments acting on the dispenser, which is

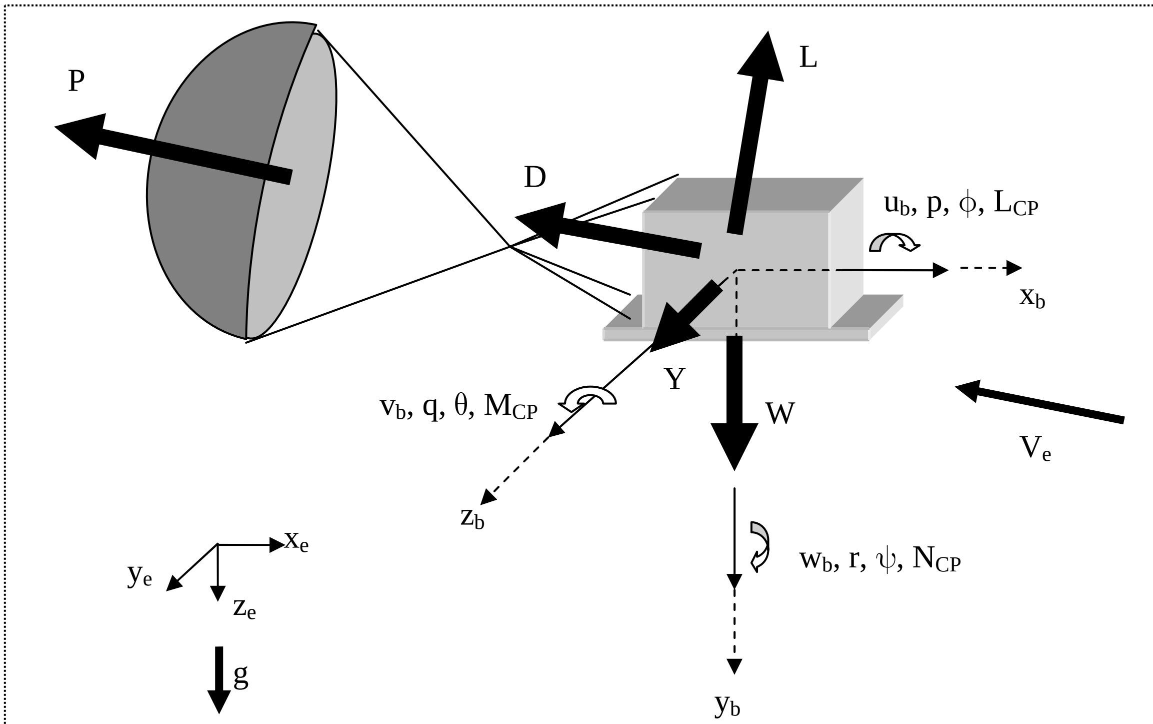


Figure 10. Free-Body Diagram of Dispenser System [22:19-21, 97-98, 103]

used to further develop the equations of motion for this specific system. Expanding on equation (3), the forces acting on the dispenser are a combination of the dispenser and parachute aerodynamics and the body, or gravitational, forces [22:103-105; 32]:

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \end{Bmatrix} = \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{\mathrm{A}} + \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{P} + \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{\mathrm{B}}$$

$$= \begin{Bmatrix} L\sin\alpha - D\cos\alpha \\ Y \\ -L\cos\alpha - D\sin\alpha \end{Bmatrix} + \begin{Bmatrix} -P\cos\beta\cos\alpha \\ -P\sin\beta \\ -P\cos\beta\sin\alpha \end{Bmatrix} + \begin{Bmatrix} -W\sin\theta \\ W\cos\theta\sin\phi \\ W\cos\theta\cos\phi \end{Bmatrix} \quad (14)$$

where

$X_\_, Y_\_, Z_\_ =$ *forces acting on dispenser* (N) $\quad L =$ *lift force on dispenser* (N)

$\alpha =$ *angle of attack* (rad) $\quad D =$ *drag force on dispenser* (N)

$$\beta = angle\ of\ sideslip\ (\text{rad}) \qquad Y = side\ force\ on\ dispenser\ (\text{N})$$
$$W = weight\ of\ dispenser\ system\ (\text{N}) \qquad P = drag\ force\ from\ parachute\ (\text{N})$$

the subscripts *A*, *P*, and *B* indicate the aerodynamic, parachute, and body forces, respectively, and weight is defined as $W = mg$, where g is gravity (m/s^2). The conventions and equations used for the terms in equation (14) are further defined as [7; 22:21; 26; 32]

$$g(z_e, \varphi) = 9.780490[1 + 0.0052884 \sin^2(\varphi) - 0.0000059 \sin^2(2\varphi)] + z_e(3.086 \times 10^{-6}) \tag{15}$$

$$V_b = \sqrt{u^2 + v^2 + w^2} \tag{16}$$

$$\bar{q} = \frac{1}{2}\rho V_b^{\ 2} \tag{17}$$

$$\rho(z_e) = 1.21 e^{(z_e/8000)} \tag{18}$$

$$\begin{Bmatrix} \alpha \\ \beta \end{Bmatrix} = \begin{Bmatrix} \tan^{-1}\left(\dfrac{w}{u}\right) \\ \tan^{-1}\left(\dfrac{v}{V_b}\right) \end{Bmatrix} \tag{19}$$

where

$$\varphi = Earth\ latitude\ coordinate\ (^\circ) \qquad \bar{q} = dynamic\ pressure\ (\text{N/m}^2)$$
$$V_b = magnitude\ of\ body\ velocity\ (\text{m/s}) \qquad \rho = air\ density\ (\text{kg/m}^3)$$

and for the purposes of this study a constant equatorial latitude will be assumed (i.e., $\varphi = 0^\circ$), due to the minimal relative change in position of the dispenser while in flight. Since the simulated dispenser will travel through approximately 9000 m in altitude, equations (15) and (18) are used to describe the changes in gravity and air density, respectively, to provide more realistic data of the dispenser flight conditions. Next, expanding on equation (4), the moments acting on the dispenser about the CP include the effects of the dispenser aerodynamic moments and the moments that result from the weight forces, about the CG-CP moment arm, and parachute forces, about the parachute joint-CP moment arm [22:101, 105; 32]:

$$\begin{Bmatrix} L_{CP} \\ M_{CP} \\ N_{CP} \end{Bmatrix} = \begin{Bmatrix} M_x - (x_{joint} - x_{CP}) X_P + (x_{CG} - x_{CP}) X_B \\ M_y - (y_{joint} - y_{CP}) Y_P + (y_{CG} - y_{CP}) Y_B \\ M_z - (z_{joint} - z_{CP}) Z_P + (z_{CG} - z_{CP}) Z_B \end{Bmatrix}$$

$$= \begin{Bmatrix} M_x - (x_{joint} - x_{CP})(-P\cos\beta\cos\alpha) + (x_{CG} - x_{CP})(-W\sin\theta) \\ M_y - (y_{joint} - y_{CP})(-P\sin\beta) + (y_{CG} - y_{CP})(W\cos\theta\sin\phi) \\ M_z - (z_{joint} - z_{CP})(-P\cos\beta\sin\alpha) + (z_{CG} - z_{CP})(W\cos\theta\cos\phi) \end{Bmatrix} \quad (20)$$

where

$$\begin{aligned} M_x, M_y, M_z &= \textit{aerodynamic moments on dispenser}\ (\mathrm{N\text{-}m}) \\ x_{CG}, y_{CG}, z_{CG} &= \textit{variable location of dispenser CG}\ (\mathrm{m}) \\ x_{CP}, y_{CP}, z_{CP} &= \textit{location of dispenser CP}\ (\mathrm{m}) \\ x_{joint}, y_{joint}, z_{joint} &= \textit{location of parachute-harness joint}\ (\mathrm{m}) \end{aligned}$$

and the variable CG location is defined as [16]:

$$\begin{Bmatrix} x_{cg} \\ y_{cg} \\ z_{cg} \end{Bmatrix} = \frac{m_{munition}}{m} \sum_{n=0}^{i} \begin{Bmatrix} (\cancel{x_0} + \ldots + x_i) \\ (\cancel{y_0} + \ldots + y_i) \\ (\cancel{z_0} + \ldots + z_i) \end{Bmatrix} + \cancel{\begin{Bmatrix} x_{cg} \\ y_{cg} \\ z_{cg} \end{Bmatrix}_{initial}}, \quad x_0 = y_0 = z_0 = 0, i = 20, 19, \ldots, 0 \quad (21)$$

Equations (6), (7), and (21) define the variable mass, inertia, and CG location of the dispenser that change with each munition release. The final pieces of information required to complete the solution of the equations of motion are the calculations for the aerodynamic forces and moments which are characterized by the aerodynamic coefficients obtained through CFD testing. The aerodynamic force properties are characterized as lift, drag, and side force relative to the flight velocity vector of the dispenser and the aerodynamic damping moments are characterized about each of the three body axes, strictly limited to their relation to body angular velocity. In addition, these properties are proportional to the characteristic surface area of the dispenser and parachute as well as the characteristic length of the dispenser (see Table 1) [30]. The

Table 1. Dispenser System Characteristic Force and Moment Coefficients [1; 30]

Dispenser	**Values**	**Parachute**	**Values**	**Munitions**	**Values**
S (m^2)	14.19	SC_D (m^2) - 28' RS	37.81	S (m^2)	0.164
b (m)	5.08	SC_D (m^2) – 2 28' RS	68.19	C_D (-)	0.5
C_{D0} (-)	0.6	SC_D (m^2) - 35' RS	49.15		
$C_{D\alpha^2}$ (1/rad^2)	2.9				
$C_{L\alpha}$ (1/rad)	2.9				
$C_{Y\beta}$ (1/rad)	0.6				
C_{Lcpp} (s/rad)	-1.2				
C_{Mcpq} (s/rad)	-1.4				
C_{Ncpr} (s/rad)	-1.1				

aerodynamic forces and moments of the dispenser and parachute are calculated with the use of the following equations [22:20; 30; 32]:

$$\begin{Bmatrix} L \\ D \\ Y \\ P \\ M_x \\ M_y \\ M_z \end{Bmatrix} = \begin{Bmatrix} \bar{q}SC_L \\ \bar{q}SC_D \\ \bar{q}SC_Y \\ \bar{q}S_{parachute}C_P \\ \bar{q}SbC_{L_{CP}} \\ \bar{q}SbC_{M_{CP}} \\ \bar{q}SbC_{N_{CP}} \end{Bmatrix} \tag{22}$$

$$\begin{Bmatrix} C_L \\ C_D \\ C_Y \\ C_P \\ C_{L_{CP}} \\ C_{M_{CP}} \\ C_{N_{CP}} \end{Bmatrix} = \begin{Bmatrix} C_{L_\alpha}\alpha \\ C_{D_0} + C_{D_{\alpha^2}}\alpha^2 \\ C_{Y_\beta}\beta \\ C_P \\ C_{L_{CP\,p}}\,p \\ C_{M_{CPq}}\,q \\ C_{N_{CPr}}\,r \end{Bmatrix} \tag{23}$$

where

$C_L, C_D, C_Y = \textit{force coefficient of lift, drag, sideforce}$ (-)
$C_{L_\alpha}, C_{Y_\beta} = \textit{force derivative of lift wrt}\ \alpha, \textit{sideforce wrt}\ \beta$ (1/rad)
$C_{D_0} = \textit{force coefficient of drag at}\ \alpha = 0$ (-)
$C_{D_{\alpha^2}} = \textit{force derivative of drag wrt}\ \alpha^2$ (1/rad^2)
$C_{L_{CP}}, C_{M_{CP}}, C_{N_{CP}} = \textit{moment coefficients}$ (-)
$C_{L_{CP\,p}}, C_{M_{CPq}}, C_{N_{CPr}} = \textit{moment derivatives wrt angular velocity}$ (s/rad)
$C_P = \textit{force coefficient of parachute drag}$ (-)
$S_{parachute} = \textit{reference area of parachute}$ (m^2)
$S = \textit{reference area of dispenser}$ (m^2)
$b = \textit{reference chord length of dispenser}$ (m)
*Note: *wrt* indicates *with respect to*

The set of equations (9), (13), (14), and (20), with the initial conditions for the desired flight setting, are used to describe the flight history of the dispenser.

The performance of the dispenser system also depends on the behavior and flight history of the munitions it releases. While the ideal type of munition for this dispenser would be a propelled PGM, this study will simplify the problem and analysis by using an unpropelled, unguided munition, or dumb bomb. Since the focus of this study is specifically on the dispenser concept as a capable delivery platform, the munitions simulation will only be used for a basic depiction of their flight behavior. The only munition flight history data used for analysis will be the flight path of the munitions, neglecting the munition’s orientation. While the orientation and behavior of the munitions are important for a complete analysis of the dispenser system’s effectiveness, detailed munitions characteristics are not developed for this simulation. Complexities such as store separation issues, munition guidance and propulsion, and other factors are not studied here, but would greatly affect the flight behavior of the munitions. Therefore, this study will treat the munition as a spherical object in flight, in order to neglect orientation and all aspects of the equations of motion which refer to rotational motion. Its aerodynamic characteristics are described by a simple drag coefficient, similar to the parachute drag, for a spherical object. This results in the following equations of motion for each munition, carried over from the similarly developed equations (3), (4), (9), and (13); however, all rotational terms in the equations are neglected [16; 22:101]:

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \end{Bmatrix}_n = m \begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{Bmatrix}_n + m \left(\cancel{\begin{Bmatrix} p \\ q \\ r \end{Bmatrix}} \times \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \right)_n = m \begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{Bmatrix}_n \tag{24}$$

$$\begin{Bmatrix} L_{cp} \\ M_{cp} \\ N_{cp} \end{Bmatrix}_n = \cancel{\begin{Bmatrix} \dot{H}_x \\ \dot{H}_y \\ \dot{H}_z \end{Bmatrix}_n + \begin{Bmatrix} p \\ q \\ r \end{Bmatrix}_n \times \begin{Bmatrix} H_x \\ H_y \\ H_z \end{Bmatrix}_n} = \begin{Bmatrix} 0 \\ 0 \\ 0 \end{Bmatrix} \tag{25}$$

$$\begin{Bmatrix} \dot{q}_0 \\ \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{Bmatrix}_n = \frac{1}{2} \begin{bmatrix} q_3 & -q_2 & q_1 \\ q_2 & q_3 & -q_0 \\ -q_1 & q_0 & q_3 \\ -q_0 & -q_1 & -q_2 \end{bmatrix}_n \cancel{\begin{Bmatrix} p \\ q \\ r \end{Bmatrix}_n} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{26}$$

$$\begin{Bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{z}_e \end{Bmatrix}_n = DCM^T{}_n \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_n$$

$$= \begin{bmatrix} \cos\theta\cos\psi & \cancel{(\sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi)} & \cancel{(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)} \\ \cancel{\cos\theta\sin\psi} & (\cancel{\sin\phi\sin\theta\sin\psi} + \cos\phi\cos\psi) & \cancel{(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)} \\ \cancel{-\sin\theta} & \cancel{\sin\phi\cos\theta} & \cos\phi\cos\theta \end{bmatrix}_n \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_n$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_n = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}_n \tag{27}$$

where the subscript *n* indicates to which munition the equation refers. Equation (24) can then be further developed using the forces acting on each munition, similar to equation (14):

$$\begin{Bmatrix} F_x \\ F_y \\ F_z \end{Bmatrix}_n = \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{A_n} + \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_{B_n}$$

$$= \begin{Bmatrix} -D\cos\beta\cos\alpha \\ -D\sin\beta \\ -D\cos\beta\sin\alpha \end{Bmatrix}_n + \begin{Bmatrix} -W\cancel{\sin\theta} \\ W\cos\theta\cancel{\sin\phi} \\ W\cos\theta\cos\phi \end{Bmatrix}_n = \begin{Bmatrix} -D\cos\beta\cos\alpha \\ -D\sin\beta \\ -D\cos\beta\sin\alpha + W \end{Bmatrix}_n \tag{28}$$

where *D* is *the munition drag force* (N). To understand the capability of the dispenser to deliver the munitions effectively, the effect that the dispenser has on each released munition must be understood. The munition initial conditions are described by the flight conditions of the dispenser at the time of each munition release. While the release angle and flight conditions are quickly, and directly, translated from the dispenser to the munitions and the angular velocity of the munition at release is zero, the initial velocity is dependent on several factors, such as dispenser velocity, gravity, friction, and dispenser angular velocity. The calculated initial conditions input into the munition simulation will be established at the point of munition CG ejection from the dispenser, but based on the effecting factors from release to ejection. As stated previously, this study will neglect all friction factors within the system. In addition, based on early simulation trials, the effects of the dispenser angular velocity, which is a complex dynamics problem, can be neglected, since they are an order of magnitude lower than that of gravity, the intended primary ejection mechanism. Thus, the exit velocity relative to the dispenser is solely based on the effects of gravity for this model. Due to the body axes arrangement, the exit velocity is strictly along the x-axis, normal to the dispenser surface; therefore, a simple scalar kinematic velocity equation may be used for any negative pitch angle:

$$u_{exit}\big|_n = u_0\big|_n = \sqrt{\cancel{u^2_{release}} + 2g\sin\left(\left|\theta_{release}\right|\right)\Delta x}\,\Bigg|_n, \quad v_0\big|_n = w_0\big|_n = 0 \tag{29}$$

where

u_{exit} = *munition velocity in x - direction at dispenser exit* (m/s)
$u_{release}$ = *munition velocity in x - direction at release* (m/s)
$\theta_{release}$ = *dispenser and munition pitch release angle* (rad)

$$\Delta x = munition\, CG\, travel\, distance\;\; from\, release\, to\, ejection\, (\text{m})$$
$$u_0, v_0, w_0 = munition\, initial\, velocity\, at\, ejection\, (\text{m/s})$$

Using these equations for the munitions, as well as the preceding dispenser dynamics equations, an adequate dispenser system model for the simulation is ready for use in a variety of tests and other applications.

Simulation Development and Execution

The dispenser system equations of motion form the primary engine for the simulation. In order to solve this set of nonlinear differential equations, a system for solving these equations, based on the initial conditions, in an iterative process for varying flight conditions throughout the dispenser flight history must be developed. The approach to this simulation's construction is to use two separate simulation models, one for the dispenser system and one for all the released munitions (see Figures 11 and 12; see Appendix A and CD-ROM for simulation models and code), which will solve the equations of motion for each system for their entire flight history. The specific layout of the programmed model, and thus the sequential simulation execution, will entail the initialization of the dispenser configuration, characteristics, and initial flight release conditions, the simulation of the dispenser flight history, the simulation of every munition's flight history based on the dispenser data, and a set of post-processing programs which develop video simulations, data plots, and other analysis tools. The simulation developed here, programmed in MATLAB Simulink, uses a numerical solver to calculate the six DoF equations of motion for the dispenser and the munitions for each time step, in this case every 0.1 seconds. Specifically, the differential equations are solved using MATLAB's Runge-Kutta solver, with Dormand-Prince pair, a mathematical

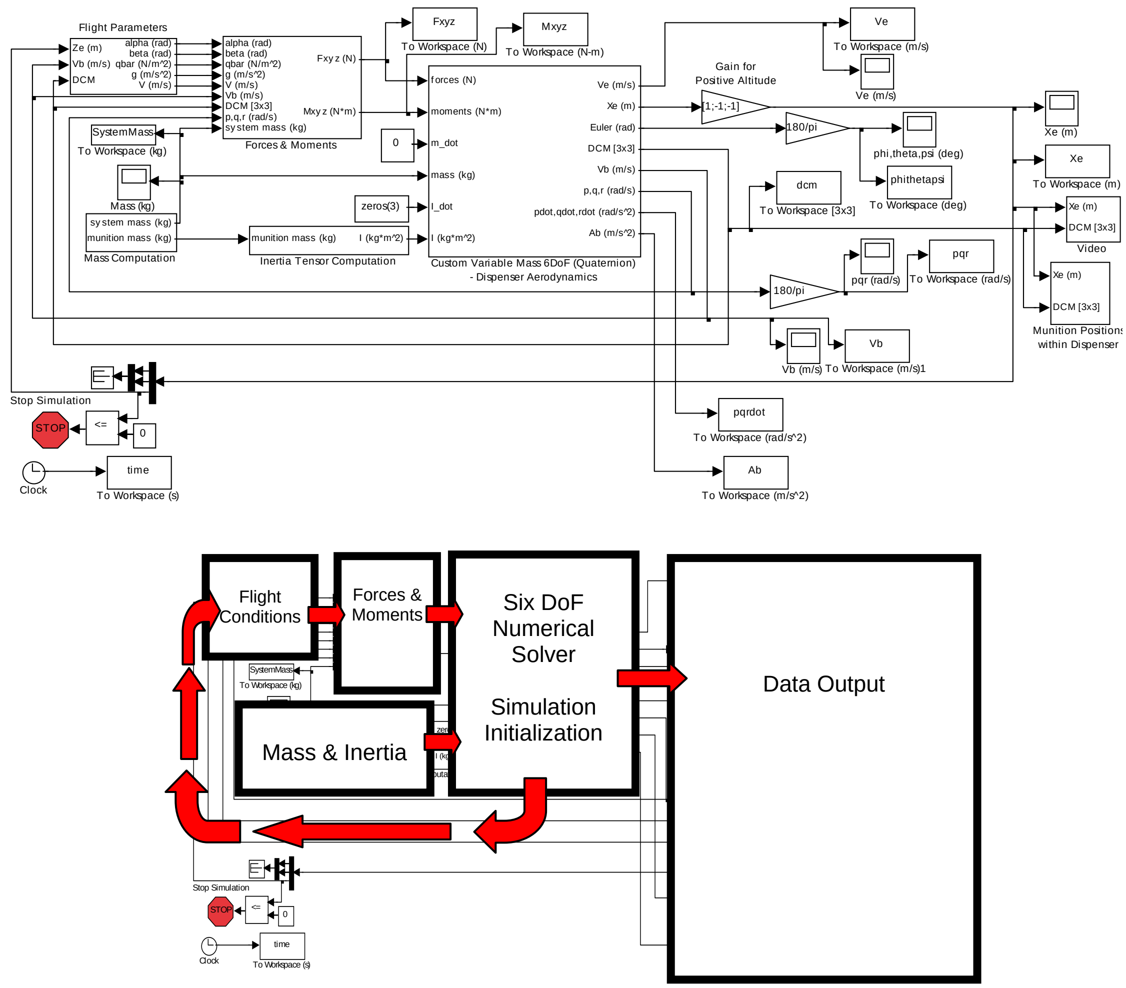


Figure 11. Top-Level Dispenser Simulation Structure (Top) and Flowchart (Bottom)

solver technique for nonlinear differential equations. These differential equations are initialized by the initial flight conditions and in the iterative process, each time step recalculates the differential equations based on the new flight and atmospheric conditions, position and rotation, and the updated dispenser mass and inertia characteristics after each munition release. The munitions simulation uses a similar six DoF solver, in this case only requiring the three DoF translation equations, and calculates the trajectory for all twenty munitions simultaneously based off the initial release conditions from the dispenser simulation. Finally, post-processing programs use the output data from both simulations to develop dispenser and munitions trajectory and orientation plots, the dispenser system video simulation, and additional analysis tests.

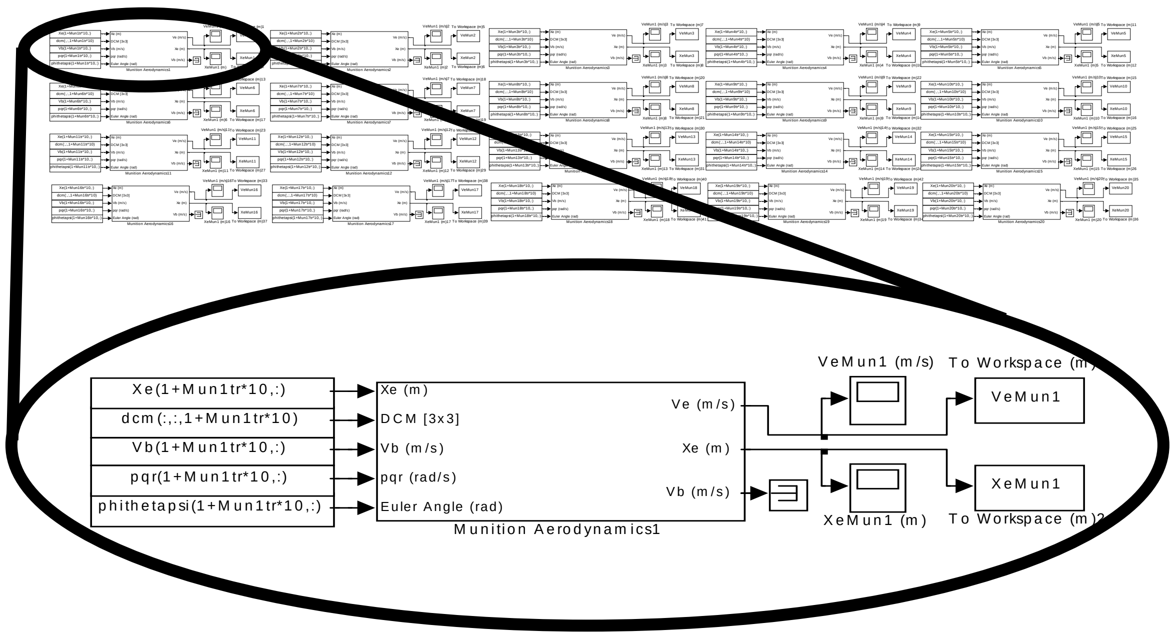


Figure 12. Top-Level Munitions Simulation Structure

Simulation Capabilities

The best feature of this simulation is its ability to be modified for various dispenser configurations and aerodynamics, number and types of munitions, release sequences, and flight conditions. This study will focus on using a few of these features in order to conduct tests that investigate the viability of a specific dispenser configuration. The focus areas for study include tests that characterize the reaction of the dispenser to the effects of input wind and gust profiles, adverse forces or moments at dispenser launch, various aircraft configurations and flight conditions, and the munition release order, including failed release scenarios. In addition, studies are conducted to further develop the dispenser design based on parachute system type, parachute-dispenser joint location for the harness system, and the most favorable munition release sequence. The methods of analysis are primarily based on a graphical understanding of the behavior and flight history of the dispenser and munitions. The primary outputs studied are the dispenser system simulation video and trajectory plots, other plots of relative dispenser motion and orientation, and the minimum separation between dispenser system components in the release sequence and flight. This study will utilize these capabilities in order to determine the validity of this dispenser configuration as a viable weapons system.

IV. Results and Analysis

Simulation Tests

The specified dispenser concept will be tested and analyzed through variation of simulation inputs in order to obtain the output flight history data. The tests conducted here will focus on the ability of the dispenser to safely and effectively release its full complement of munitions. The actual stability characteristics of the dispenser will not be developed in this study; it is the resulting behavior of the dispenser's level of dynamic stability that will be observed through Euler angle oscillation frequencies, rates, and damping characteristics. Graphical analysis of the dispenser flight history will be used to determine the dispenser's mission capability when compared to specified operating constraints. Dynamic stability is defined by the ability of a system to dissipate a disturbance over time in order to reach an equilibrium state [22:41-42]. For this study, the dynamic stability of the system is visualized graphically in the convergence of the dispenser Euler angles to a steady state condition and the Euler rates to a steady state, zero-value. Ideally, the system would initialize at and maintain small amplitude roll and yaw angles while converging to a steady state, zero-value condition in a relatively short time. In addition, the pitch angle would drive towards a terminal -90^{o} state in a well-damped manner while allowing sufficient time for the munitions to be released as desired. The dispenser will also be subjected to various adverse conditions to better understand the effects those conditions have on the dispenser system. These disturbance tests will not be a full parametric study of dispenser stability which seek to define the dispenser's operational envelope, but will be used only to gain a better understanding of system dynamics and their sensitivity to various inputs.

The dispenser system dynamic model and simulation are constrained by the assumptions and limitations imposed by the dynamics approach taken here as well as the operational and regulatory constraints of real-world system components. A USAF C-17 cargo aircraft and the parachute systems used for airdrops of this weight are tested for operations at a maximum altitude of 8991.6 m (29500 ft) and a maximum velocity of 77.17 m/s (150 kts or 253.17 ft/s) for payload release. At these conditions, the dispenser release angle created by the angle of the cargo deck would be approximately 4^o of pitch [8; 15]. These three parameters define the primary initials conditions used for the equations of motion (see Table 2). The assumptions made at the initial state, with respect

Table 2. Dispenser System Parameters and Initial Conditions [8; 15; 16]

	Dispenser	**Munitions**
Position (m - x_e, y_e, z_e)	(0, 0, -8991.6)	-
Velocity (m/s - u_e, v_e, w_e)	(77.17, 0, 0)	-
Euler Angles (^{o} - ϕ, θ, ψ)	(0, 4, 0)	-
Euler Rates (^{o}/s - ϕ, θ, ψ)	(0, 0, 0)	-
Mass (kg)	3175.2	453.6
Dimensions (m - lxwxh, lxr)	3.3528 x 2.794 x 2.54	3.048 x 0.2286
Moments of Inertia (kg-m^2 - I_{xx}, I_{yy}, I_{zz})	(4093.7, 5194.0, 5231.5)	(23.7, 357.1, 357.1)
Products of Inertia (kg-m^2 - I_{xy}, I_{yz}, I_{xz})	(0, 0, 0)	(0, 0, 0)

to the aircraft-dispenser interaction during release, mainly support the use of the above initial conditions. The simulation begins at the instant the dispenser loses contact with the cargo deck. Simplifying assumptions from this are that the cargo deck friction is negligible and that due to the speed with which the dispenser leaves the aircraft, the tip-off angle and moment developed as the dispenser CG passes the edge of the cargo deck is minimal. Additional support for this is the airdrop system used here allows the parachute to fully develop at velocity prior to cargo release [15].

The sequence of testing (see Table 3; see Appendix B CD-ROM for all graphical data test results) will involve the development of the baseline dispenser configuration, including the most favorable parachute system, harness set-up, and release sequence, followed by testing of this dispenser system's reaction to disturbances and malfunctions. The graphical techniques used will focus on the ability of the dispenser system to meet certain constraints, primarily based on the dispenser's position and orientation. These constraints include: at least 15.24 m (50 ft) of maintained separation between the aircraft and dispenser before munition release and between the aircraft and munitions after release; at least -5^o of maintained dispenser pitch for munition release; all munitions must be released prior to a dispenser altitude of 6096 m (20000 ft) and pitch of -70^o; and all munitions must maintain at least 1.83 m (6 ft) of separation at all times during flight. These constraint values are selected solely for use in this study. The minimum pitch angle requirement results from the potential for friction forces to counter munition release by gravity and that munitions, physically, can only be released from the dispenser when it is at a negative pitch angle. The maximum pitch angle constraint prevents the munitions from being released at a near ballistic trajectory. The altitude requirement is set to provide the munitions, if PGM's, ample time to achieve steady and level flight, while the separation distances are selected as possible reasonable values for safety considerations.

Table 3. Dispenser System Simulation Test Matrix - Input Parameters [1; 8; 15]

Test #	Simulation Test	Parachute-Harness Joint Position (m - x_b,y_b,z_b)	Parachute Drag Term (m^2)	Munition Release Delay (s)	Munition Release Interval (s)	Horizontal Wind Velocity (m/s)	Horizontal Wind Angle (°)	Force Disturbance (N - x_b,y_b,z_b)	Pitch Moment Disturbance (N-m)	Disturbance Length (s)	Tip-Off Angle (°)
1	Empty Dispenser - 28' RS, No Harness	(-1.698,0,0)	37.81	0	0	0	0	(0,0,0)	0	0	4
2	Loaded Dispenser - 28' RS, No Harness	(-1.698,0,0)	37.81	112	0	0	0	(0,0,0)	0	0	4
3	Loaded Dispenser - 2 28' RS, No Harness	(-1.698,0,0)	68.19	141	0	0	0	(0,0,0)	0	0	4
4	Loaded Dispenser - 35' RS, No Harness	(-1.698,0,0)	49.15	124	0	0	0	(0,0,0)	0	0	4
5	Loaded Dispenser - 28' RS, Mid-Harness	(-3.396,0,0)	37.81	112	0	0	0	(0,0,0)	0	0	4
6	Loaded Dispenser - 28' RS, Long-Harness	(-6.792,0,0)	37.81	112	0	0	0	(0,0,0)	0	0	4
7	Loaded Dispenser - 28' RS, Offset-Harness	(-3.396,0,-.889)	37.81	112	0	0	0	(0,0,0)	0	0	4
8*	Baseline Dispenser - Favorable Release	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4
9**	Baseline Dispenser - Spiral Release	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4
10***	Baseline Dispenser - Side-to-Side Release	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4
11*	Final Dispenser - Wind at 0	(-6.792,0,0)	37.81	2.5	0.5	8.94	0	(0,0,0)	0	0	4
12*	Final Dispenser - Wind at 45	(-6.792,0,0)	37.81	2.5	0.5	8.94	45	(0,0,0)	0	0	4
13*	Final Dispenser - Wind at 90	(-6.792,0,0)	37.81	2.5	0.5	8.94	90	(0,0,0)	0	0	4
14*	Final Dispenser - Wind at 180	(-6.792,0,0)	37.81	2.5	0.5	-8.94	0	(0,0,0)	0	0	4
15*	Final Dispenser - Tip-Off Angle at 4+5	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	9
16*	Final Dispenser - Tip-Off Angle at 4+25	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	29
17*	Final Dispenser - Tip-Off Angle at 4+45	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	49
18*	Final Dispenser - Force in Y	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,1624.98,0)	0	2	4
19*	Final Dispenser - Force in +Z	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,1624.98)	0	2	4
20*	Final Dispenser - Force in -Z	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,-1624.98)	0	2	4
21*	Final Dispenser - Moment about Y	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	22605.07	2	4
22*	Final Dispenser - Munition 5 Failure	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4
23*	Final Dispenser - Munitions 1,6,11,16 Failure	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4
24*	Final Dispenser - Munitions 1,2,3,4,5 Failure	(-6.792,0,0)	37.81	2.5	0.5	0	0	(0,0,0)	0	0	4

Note: Munition Release Sequences

*	5,16,6,15,20,1,11,10,4,17,7,14,19,2,12,9,3,18,8,13
**	1,2,3,4,5,10,15,20,19,18,17,16,11,6,7,8,9,14,13,12
***	1,6,11,16,2,7,12,17,3,8,13,18,4,9,14,19,5,10,15,20

Simulation Verification and Reliability

The initial tests compare the flight history of an empty and loaded dispenser, with no munition releases, for a better understanding of system dynamics and behavior as well as for verification of the simulation (see Figures 13 and 14). The dispenser system is simplified for this verification study by using one parachute system, a single 28-foot ring slot (RS) parachute. Also, no true harness system is used, in that the parachute is attached directly to the extracted side of the dispenser at the cross-sectional CG location, in the body y and z coordinates. Based on the established initial conditions and dispenser parameters, both dispensers drive towards their terminal equilibrium state and appear dynamically stable. The primary difference is the loaded dispenser's greater magnitude and frequency of its pitch rate and the speed with which it reaches its terminal flight condition, both due to the greater mass and inertia properties of the loaded dispenser.

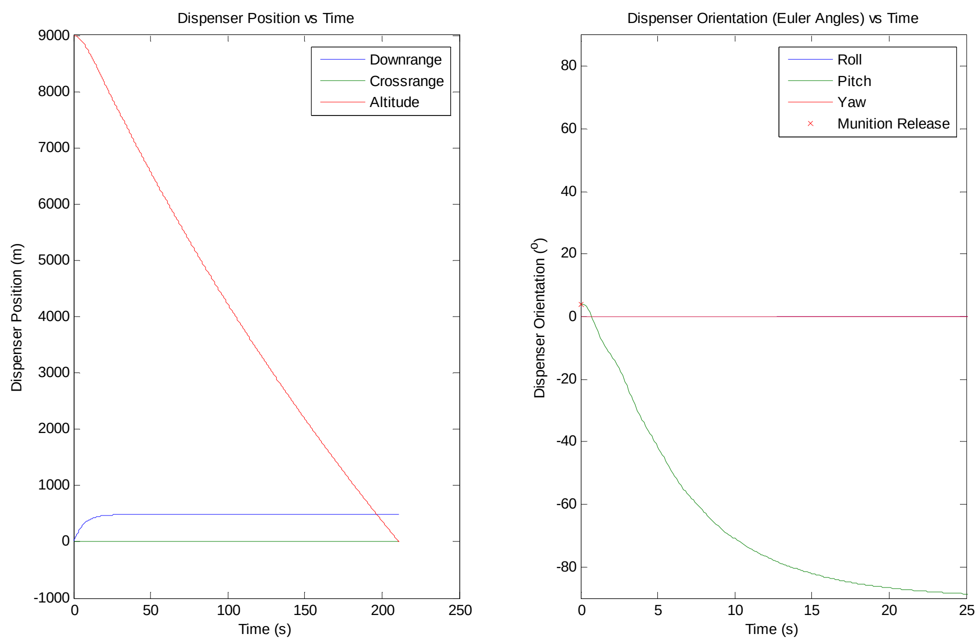


Figure 13. Empty Dispenser Simulated Flight History (Test #1)

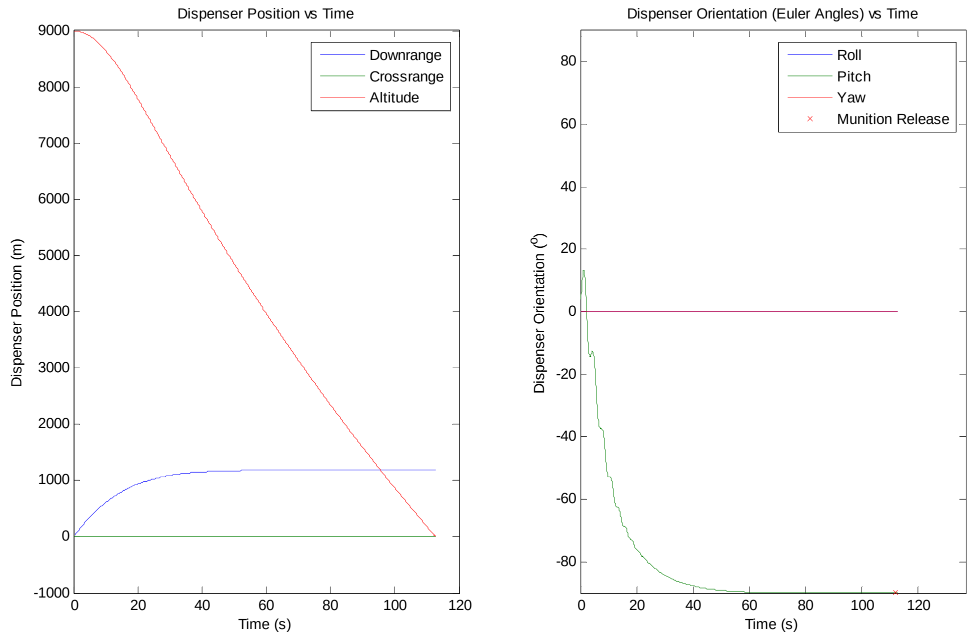


Figure 14. Loaded Dispenser Simulated Flight History (Test #2)

The verification of the system equations of motion is seen in the initial and terminal states of the position and orientation values. The initial conditions set in the simulation match the first data points of the flight history plots. Also, based on the anticipated terminal state of a -90^{o} pitch angle, when compared to all other parachute-payload systems, that terminal flight condition is achieved. In addition, a review of all the output data clearly shows a dynamically stable airdropped dispenser as expected for this basic configuration, similar to any other typical airdropped platform, with no inherent instabilities in the simulation's calculations or obvious contradictions to energy conservations laws.

Another benefit of these early tests is gained in support for the assumption neglecting the dispenser angular velocity effects on munition release velocity. The data obtained from the loaded dispenser model flight history shows that if the maximum dispenser angular velocity were used with the maximum possible munition release radius, the resultant acceleration would be negligible. Using the ejection point for an outer-edge munition as the radius, compared to the minimum acceleration due to gravity at the minimum release pitch angle of -5^o, the calculated result is a comparison of 0.0724 m/s^2 from the angular velocity to 0.8550 m/s^2 from gravity. Based on these tests, as well as other early trial tests, this simulation should be adequately reliable for the purposes of this study. However, flight history data that exhibit unstable flight characteristics or result in dispenser orientations that would contradict the established assumptions should be examined with caution. One contradictory example is if the simulation were to output a scenario in which the dispenser were oriented such that the parachute-harness joint is directed towards the oncoming wind velocity vector, since the parachute drag is always parallel to the wind velocity vector; this would result physically in the dispenser being tangled in its parachute and rigging. For most flight scenarios, this simulation is a valid and excellent tool for use as an indicator of dispenser system viability, given the appropriate initial conditions and assumptions.

Baseline Configuration

The baseline configuration is developed to serve as a model for comparison to other design concepts as well as to be an experimental basis for testing various flight and operational scenarios in this study. This system's design varies from typical cargo airdropped payloads where an extraction parachute, attached to the front of the platform, pulls out the load and then a separate recovery parachute, harnessed to the top of the load, is deployed and slows the load's descent to the ground. This arrangement results in a large moment and initial tip-off angle from the force of the recovery parachute, causing large pitching oscillations for much of the early flight of the payload, not stabilizing until terminal flight [15]. The munitions dispenser system will use a one parachute system, serving as both extraction and recovery, since the dispenser itself is not intended to be reusable or recoverable. Also, the harness will be positioned on the rear of the dispenser in order to limit the payload pitching oscillations, the system rotation, and short time window before terminal flight that occurs in the top-harness arrangement. This system is similar to the BLU-82 and GBU-43/B deployment mechanisms described earlier [13].

The first design step is to choose a standard military parachute system using the same non-harnessed, loaded dispenser configuration used previously. Three parachute systems, a single 28-foot RS, dual 28-foot RS's, and a 35-foot RS, which all meet the airdrop release and weight regulations for this dispenser, are tested to determine their effects on system stability and performance characteristics [1; 8; 15]. The primary performance metrics for the parachute system are the speed with which the dispenser can release its first munition and the length of time available to release its entire complement of munitions, while meeting the defined operational constraints. Based on these tests, the single 28-foot RS parachute system, which provides the smallest drag levels of the three parachute systems, is the best suited as it is able to begin munition releases early in flight and has the longest release window with a shallower decay in pitch angle and no adverse stability effects (see Figure 15). This parachute provides a 14.1 s release window and can start releasing munitions 2.5 s into flight. While the dual 28-foot RS and single 35-foot RS can release their munitions within 2 s of flight, their short release window of 11 s and 13 s, respectively, are undesirable. A longer release window allows for more error to be overcome to accommodate the full time required to release twenty munitions.

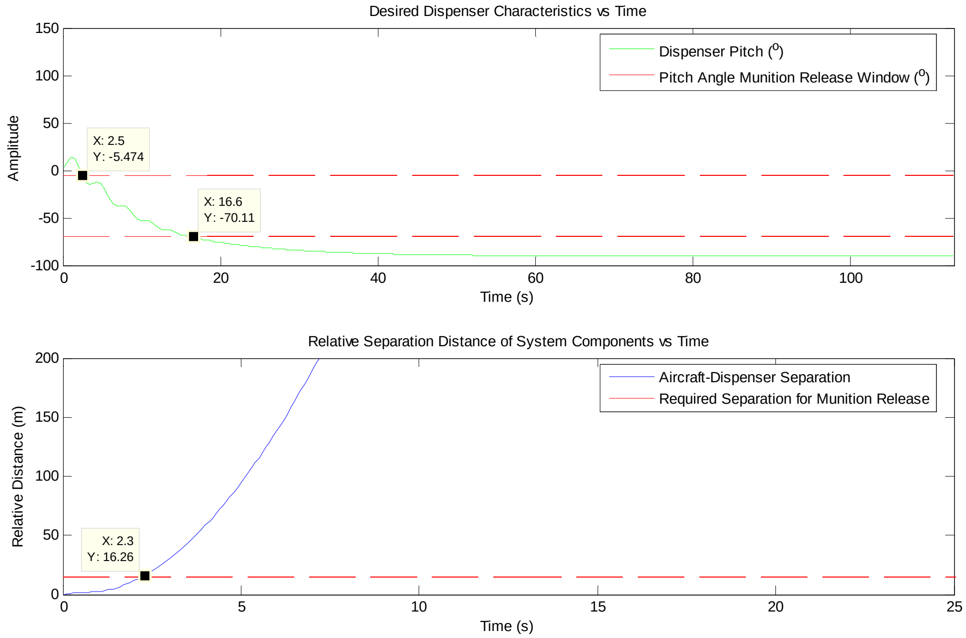


Figure 15. 28' RS Parachute Test for Desired Orientation and Separation (Test #2)

The next step is to use the single 28-foot RS parachute system in conjunction with various harness configurations for the dispenser. This study assumes that the harness is rigid, due to the weight of the dispenser and opposing drag force of the parachute that meet at the harness-parachute joint. The presumption for this dispenser design is that the ideal location of the dispenser-harness points will be the four corners of the extracted side of the dispenser and that the best joint location will be near the CG, projected along the body x-axis. The four joint positions tested for analysis are no-length, mid-length, and long harness types located along the x-axis from the CG and one set-up with the z-axis location of the harness displaced upwards from the CG to potentially create a longer flight within the pitch angle release window. The performance metrics here are similar, with primary analysis geared towards dynamic stability and length of munitions release window. An additional tool available for this study, describes the displacement motion, relative to the CP, of a point on the front center of the dispenser, where the munitions are released, for pseudo-pitch and –yaw motion and a point on the top of the dispenser for pseudo-roll motion. This complements the Euler angle plots with the ability to view the relative motion of the dispenser directly, especially with the relationship to munition release directions. From analysis of the harness tests, the longer harness option provides a slightly shorter release window, 12.1 s, than the no-length and mid-length harness, 14.1 s and 13 s, respectively (see Figures 16 and 17); however, it provides much greater dampening to the pitching oscillations of the dispenser which expands system use in more adverse conditions. Contrary to the typical airdrop top-harness arrangement described earlier, this arrangement achieves the objective of limiting the pitching oscillations and the rotation of the system, in order to release the munitions in the

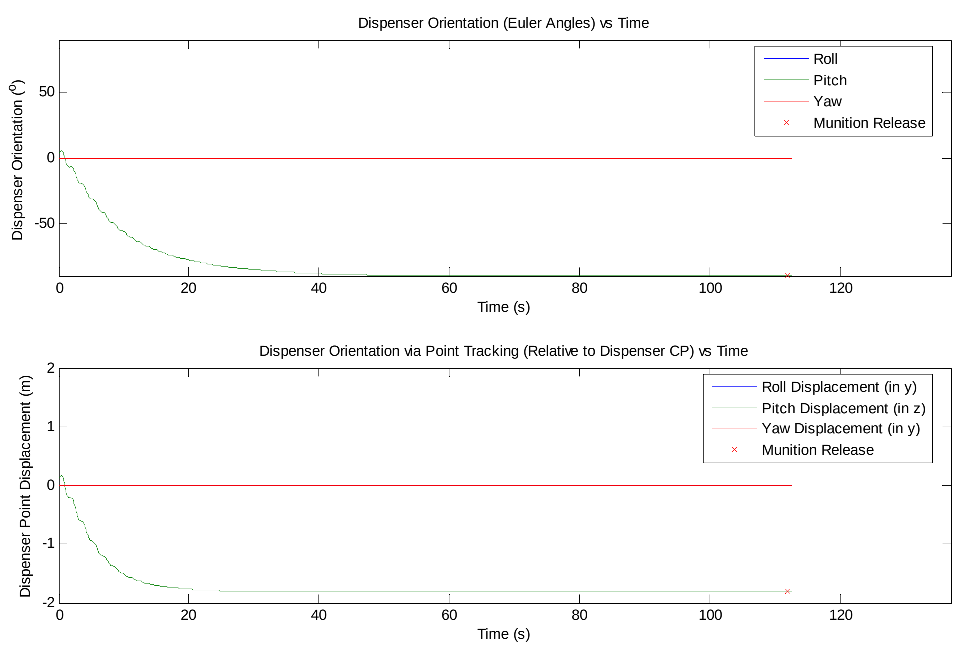


Figure 16. Long Harness Test for Desired Orientation and Behavior (Test #6)

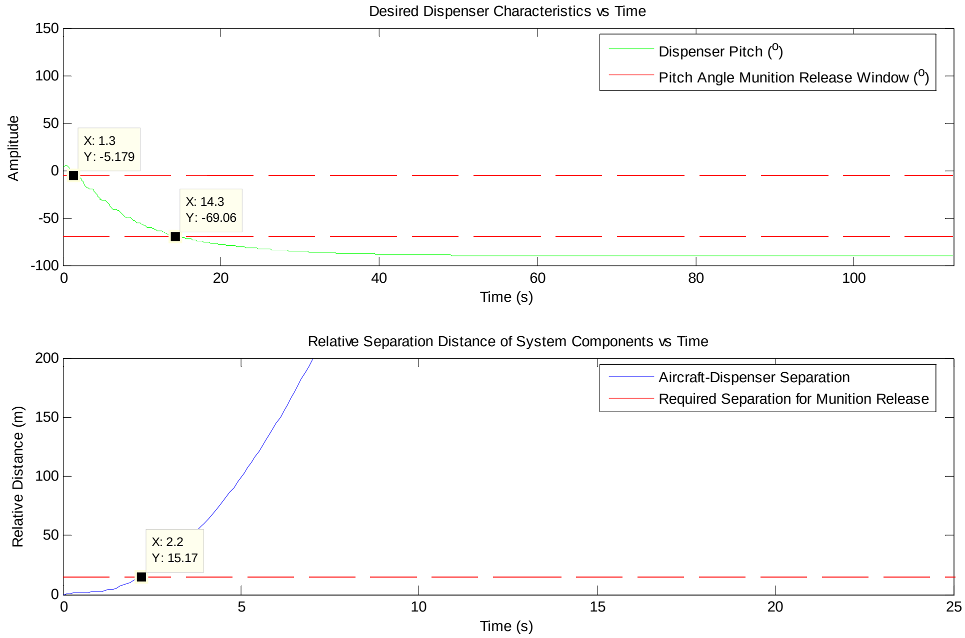


Figure 17. Long Harness Test for Desired Orientation and Separation (Test #6)

required time release window, approximately 9 to 12 s. While the offset harness is designed to create a longer release window, and accomplishes that objective, it exhibits high amplitude and frequency pitch oscillations before it stabilizes. Thus, it requires a longer time for first release, more than 4 s, due to the oscillations, than the basic harnesses located nearer the CG; however, it never pitches below -70^{o}, creating a longer release window if there is no floor altitude for release.

Final Design

The next step in the evolution of this dispenser system is to develop a method and sequence of munition release that meets the operational constraints. The munitions must all be released within the desired pitch angle window and before the minimum altitude, while maintaining the required relative separation. In addition, the sequencing method in which the munitions are released must not adversely affect the motion of the dispenser in such a way that instability or high magnitude and frequency oscillations occur which negatively affect the munitions release. For the purposes of this study, the munition release time interval will remain constant in order to simplify the problem; a variable time sequence could be optimized for any release sequence in order to ensure all munitions are released as quickly as possible and as close in proximity as is allowed. While a simultaneous release of all the munitions would be ideal, to meet the release window constraints and avoid instability concerns, the close proximity of the munitions within the dispenser would cause the sequence to fail the relative separation requirement.

Thus, a method for releasing the munitions, without greatly affecting the CG location and inertia properties which can potentially create undesired instability, is developed. The final design uses a release sequence which releases the munitions on the circumference of the dispenser and works its way to the center, while also alternating between the top, bottom, left, and right sides (see Figure 18). The resulting sequence minimizes movement of the CG location, maintains minimal roll and yaw angles, and allows adequate time for the munitions to be released as desired (see Figure 19). This method also helps to minimize the impact of changes in the inertia matrix and balance, or counteract, forces and moments from opposing sides. A 0.5 s munition release interval is used, to meet the relative separation requirement, and the first munition is released 2.5 s after aircraft release to meet the aircraft-dispenser separation and release window constraints (see Figure 20). The release interval is obtained through repeated testing of the design configuration and release sequence in order to determine the minimum allowable time between munitions and the first release time delay is obtained through analysis of the loaded baseline dispenser (see Figure 17). This release sequence, outlined

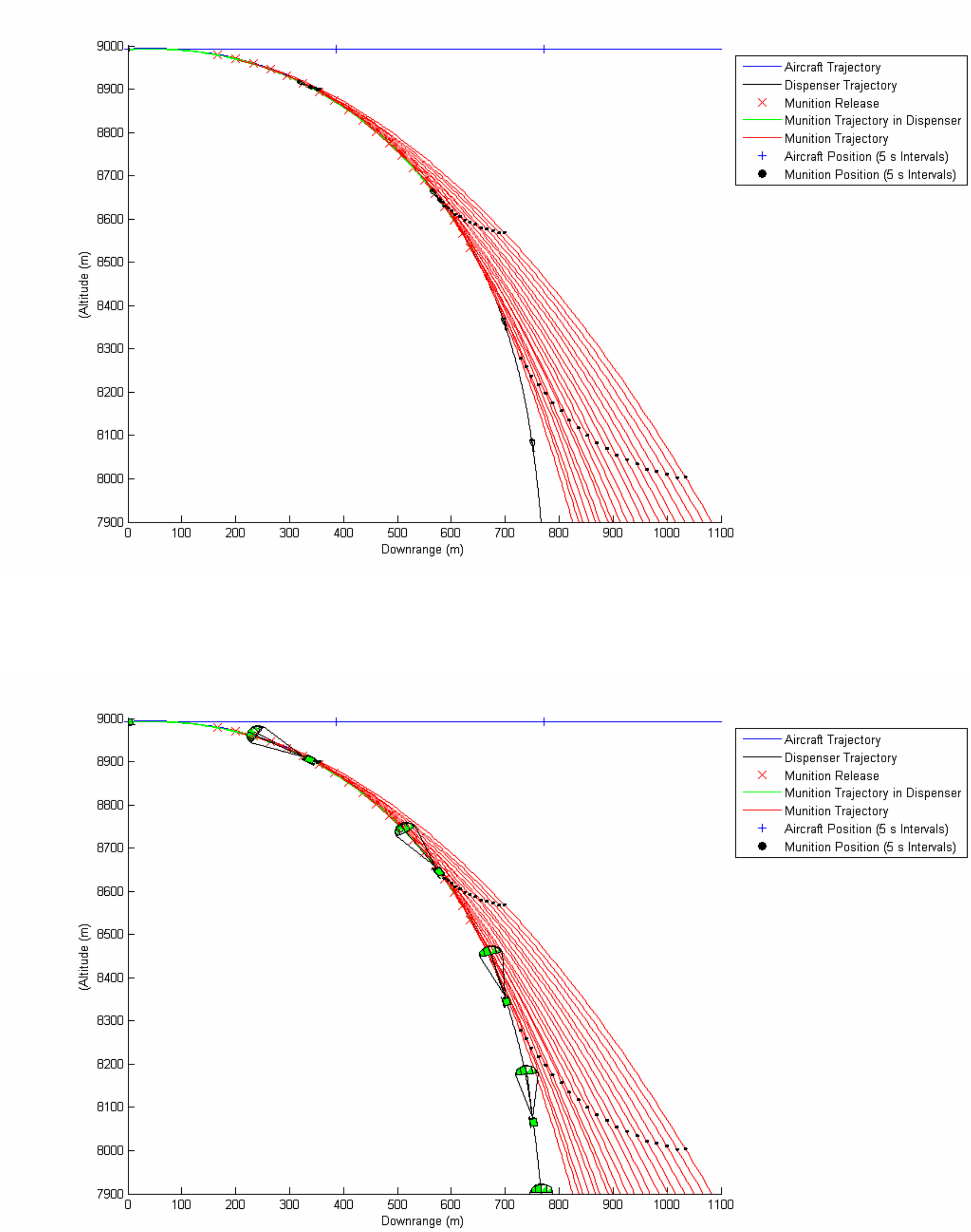


Figure 18. Final Design: Trajectory Plot (Top – To Scale, Bottom – x5) (Test #8)

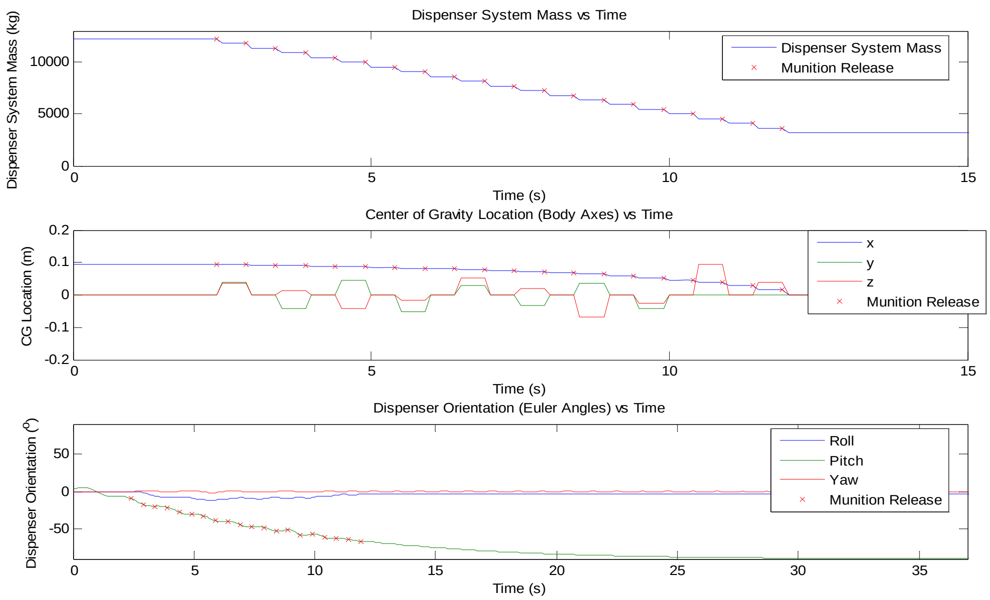


Figure 19. Final Design Release Sequence: Mass, CG, and Orientation (Test #8)

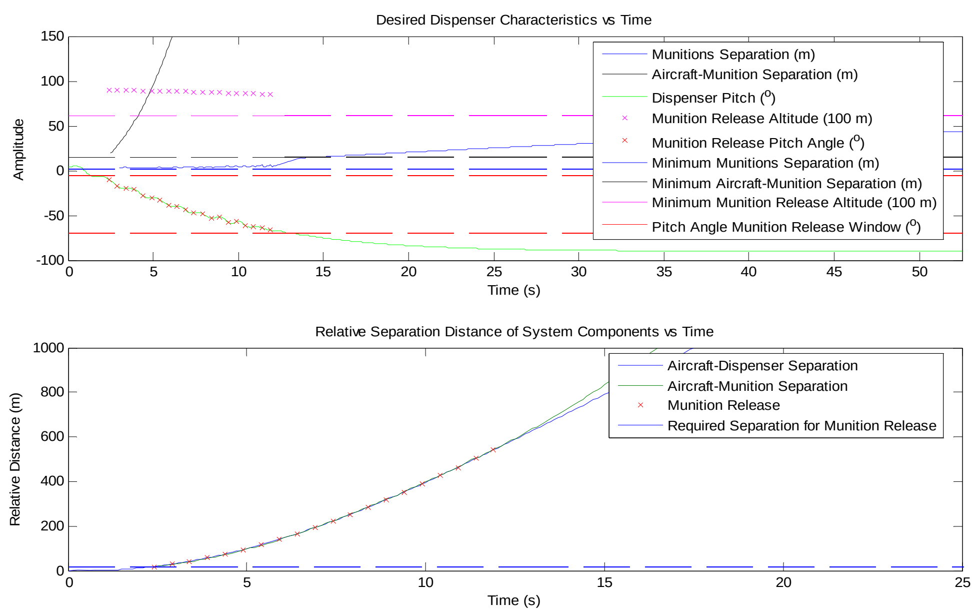


Figure 20. Final Design Release Sequence: Orientation and Separation (Test #8)

in Table 3, results in a dynamically stable dispenser system which delivers its munitions within the defined operational constraints. In contrast to what would happen if a poor release sequence were used, such as an outside-in spiral or a left-to-right release sequence, the final design sequence provides the desired dynamic stability and mission performance. In the case of the spiral technique, a severe roll characteristic is developed as the release pattern continues which would adversely affect munition release and potentially cause parachute-dispenser problems (see Figure 21). With the left-to-right sequence, where each vertical column is released top-to-bottom, left-to-right, a yaw characteristic develops which results in an undesirable flight condition. These poorly developed sequences cause issues with the transitory location of the CG and provide an unbalanced series of forces and moments. An optimized release sequence for any dispenser configuration is vital to its stability and effectiveness.

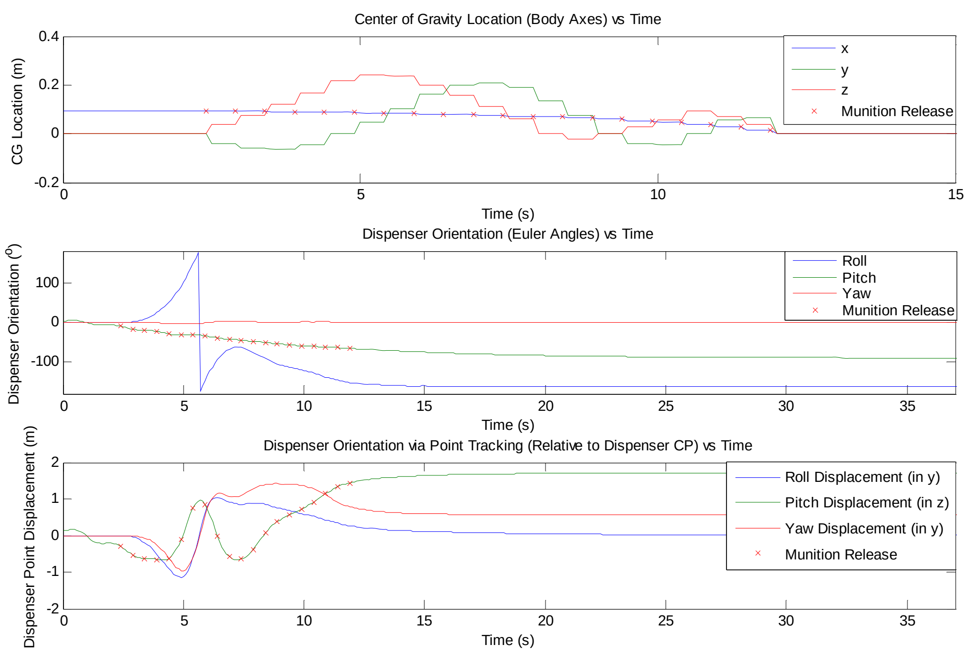


Figure 21. Spiral Munition Release Sequence Behavior (Test #9)

Disturbance Effects and System Malfunctions

The final design configuration of the dispenser and release sequence is subjected to various tests of possible disturbances and system malfunctions. The goal of this testing is not to develop a full parametric study of dispenser stability relative to disturbances, but to obtain a better understanding of system behavior and the effects of disturbances on system performance. This study does not seek to define the operational envelope of the dispenser and the desired range of flight conditions for successful employment, but it should help to provide insight into system behavior and within what conditions safe operations could occur. The primary method of analysis is in the visualization of the change in flight behavior compared to the final design of the dispenser, without the disturbance, and the time required before the munition release could safely begin.

The disturbances are developed to provide realistic scenarios of various adverse conditions that could occur in flight, especially as the dispenser is released from the aircraft. The primary studies involve the application of generically developed tip-off angles, forces, and moments as well as steady force, or wind, conditions. The generic tip-off angles and moments, only about the pitch axis for this study, used in the disturbance testing could be described as the result of an increased aircraft angle of attack, the resultant effects of the dispenser CG as it crosses the edge of the cargo deck, or the effects of various wind or aircraft vortices issues. The tip-off forces are most comparable to wind gusts that occur at release, with the steady wind conditions describing an upwind, downwind, or crosswind condition due to the flight path of the aircraft and the atmospheric air current. The tip-off angles and moments, or the rotational disturbances, can have a profound affect at high magnitudes leading to undesirable dispenser oscillations and requiring additional time for adequate stability to be obtained for munition release. For example, a tip-off release angle of greater than 45° can result in a poor initial deployment, with a potentially compromised parachute and potential failure to meet release constraints (see Figure 22). In this case, the first munition cannot be

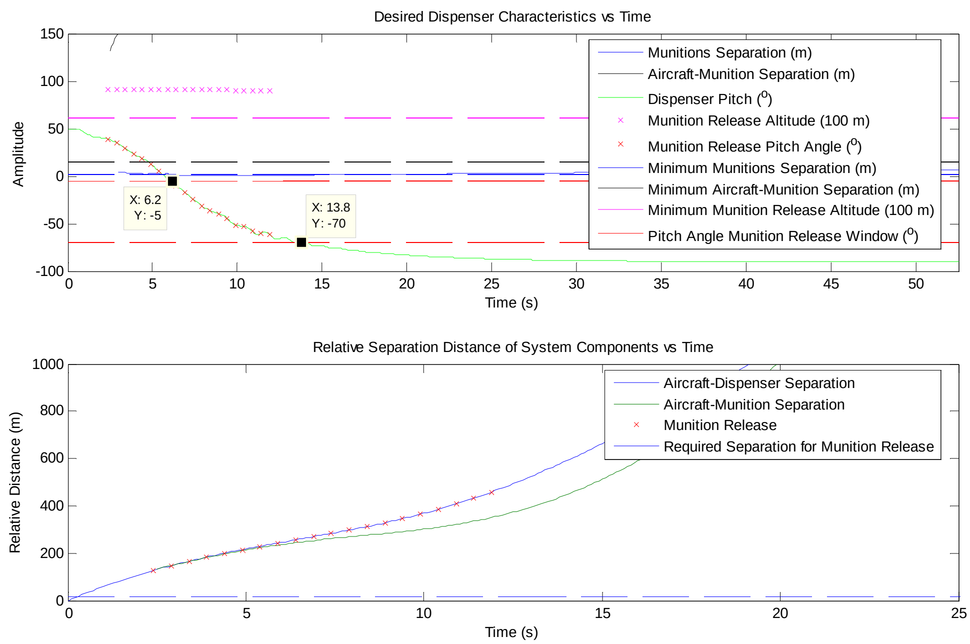


Figure 22. Effects of 45° Tip-Off Pitch Angle on Release Constraints (Test #17)

release for 6.2 s and the release window reduces to 7.6 s, so that only sixteen munitions could be released within the window. The wind gusts and steady winds have minimal effect on the stability of the system, but have a large effect on the resultant range and location of the munitions throughout their flight path (see Figure 23). With the dispenser in an 8.94 m/s (17.38 kts or 29.33 ft/s) wind, it can travel up to 1000 m off course

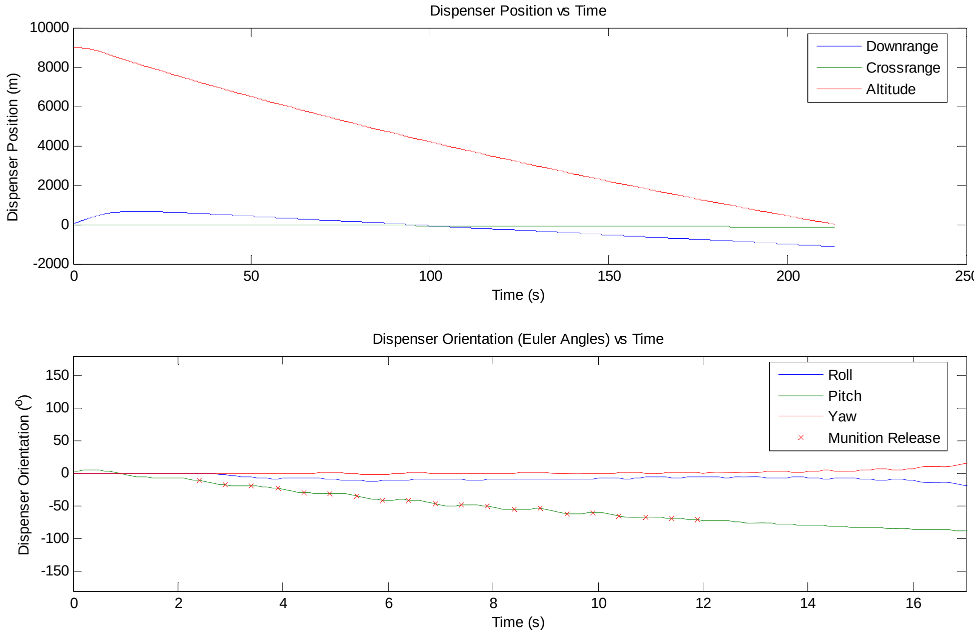


Figure 23. Effects of Steady North East Wind at 8.94 m/s (29.33 ft/s) (Test #12)

compared to calm atmospheric conditions. If the munitions were dumb bombs, the impact point downrange could increase from a range of 400 m, with no wind, to 1300 m, with wind present. These disturbances can be of great important in the planned dispenser deployment location and the targeting of the munitions.

System failure scenarios are important in understanding the reliability of the dispenser system to overcome small or large scale failures. If a failure were to occur in the munition release sequence, ideally, the dispenser would maintain reasonable stability and allow the remaining munitions to be released despite any adverse inertia properties. The most minor possible failure incident would involve the failed release of a single munition. The greatest potential effect would be from the failed release of an outer munition. In this case, the dispenser is negligibly affected in its operation and the remaining munitions are safely ejected. The primary effect is in the terminal orientation of the dispenser with the remaining munition affecting the final CG location. With a larger scale failure, such as an entire tray of munitions or a vertical column of munitions failing to release, the effect can be much greater (see Figure 24). However, due to the

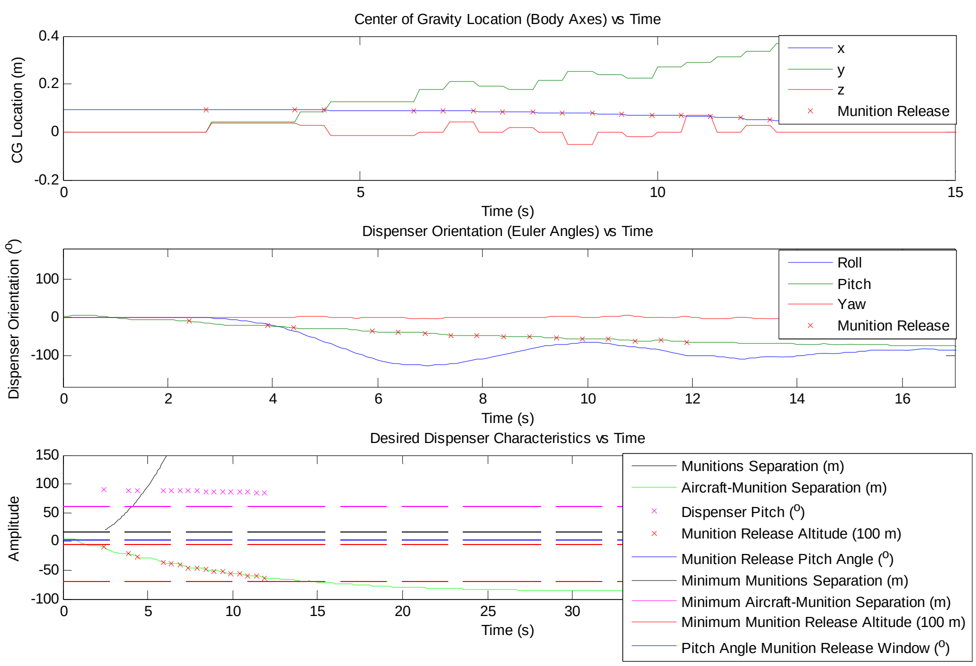


Figure 24. Effects of Failed Column Release on System Behavior (Test #23)

spread-out release sequence, the effect is minimal in the initial stages as the dispenser flight behavior is acceptable for munition release and the primary effect is again in the terminal orientation of the dispenser, which is not of concern. If all munitions were to have a failed release, the dispenser would have the same flight history as the loaded, no-release dispenser test (see Figure 14) and would quickly converge to its steady state condition. This dispenser configuration appears to be dynamically stable enough to handle these malfunctions and accomplish whatever part of its mission it can.

Interpretation of Results

The results of this study provide quality insight into the dynamics and behavior of the airdropped munitions dispenser system. Initial guidance is gained into the development of such a dispenser system and its desired characteristics and properties, such as the effects of parachute and harness systems as well as release sequences on system performance. The primary consideration in the selection of these dispenser attributes is in how they drive the system towards stability and allow the dispenser to deliver its munitions while meeting the defined operational constraints, as shown in the dispenser development and test data plots. In addition, the ability to conduct a wide range of tests is available in order to determine operational envelopes and study the factors that adversely effect system deployment. Since the focus of this system is not with precision airdrop, as with other airdropped platforms, wind effects are of little concern. However, the effects of initial moments and release angle are of great significance to system effectiveness as shown in the disturbance tests. Overall, the simulation provides a foundation with which dispenser configurations may be designed and tested for operational effectiveness, providing guidance for future research and development.

V. Discussion

Relevance of Research

The major accomplishment of this research is the development of a computer-based simulation capable of analyzing the effectiveness and viability of an airdropped munitions dispenser system. This simulation depicts the performance effectiveness of the dispenser to release the munitions as quickly as possible, within the defined release constraints and minimum safety separation distances, while showing the flight history and behavior of the system along with the response to disturbances and malfunctions. It also allows the researcher to use the simulation tool as a means to determine the viability of the dispenser system as a capable munitions release platform. In addition, the simulation has the ability to be modified for various concepts and configurations, such as three-by-four munitions platforms and spring or parachute ejection assisted munitions, and to conduct a wide-range of performance and stability tests. These tests can include stability characteristics and optimization, dispenser performance relative to defined constraints, disturbance tests, and system configuration optimization and development. This study has developed an efficient, flexible, and effective tool for analyzing the dynamics and flight history of the dispenser system and its components so that early development and testing of such a system can be conducted in a low-cost, adaptable environment. It is intended to be a test platform to determine the viable concepts and eliminate the poor ones. This paves the way for future studies, design concept development and testing, and ultimately to the next steps in the development process, such as small-scale wind tunnel testing, CFD analysis, and large-scale operational testing.

From a real-world military perspective, the research of this study provides a basis for further development of a weapons platform that can provide a timely, flexible, precise, and powerful resource. In the ever-changing nature of warfare and with the reduction of military personnel and funding, a multitude of adaptable resources, such as precision weapons delivery capability from a cargo aircraft, are required to wage war at a consistent and effective level.

Conclusion

The numerical model and dispenser system simulation developed here are intended to serve as a basis for testing and analysis of cargo aircraft based weapons systems. The simulation's flexibility allows for adaptable system configurations, or designs, and levels of fidelity for an array of relevant operational tests in stability, performance, optimization, and disturbances. The airdropped munitions dispenser system concept used in this study provides an example of a viable cargo aircraft based weapons platform, capable of performing its mission in the desired manner within the defined operational constraints. This design concept is shown to be a feasible option as a munitions deployment platform and can help to provide guidance in the development of other potential designs. This simulation enables the development of other designs and allows for the required testing of the system for various flight and environmental conditions to ensure the desired performance capability. It may serve as the foundation for future development in cargo aircraft based weapons system concepts.

Improvements and Recommendations for Future Study

Numerous improvements are possible in order to improve the fidelity of the dispenser model and computer simulation, leading into future studies in the development of the dispenser system concept. With the adaptable nature of the simulation, this is an achievable goal with additional detailed studies of system components, such as parachute and harness systems, dispenser and munition dynamics, and aircraft-dispenser interaction. The most overall affecting enhancement to the dispenser simulation would be to improve the overall fidelity of the model by increasing it to a nine-plus DoF system, taking into account the mass, inertia, apparent mass, and rotational properties of the parachute system as well as the elastic properties of the rigging and parachute and the motion of a non-rigid harness system. Also, a more accurate and complete characterization of the dispenser, as munitions are released, and the munition aerodynamics conducted via CFD or wind tunnel testing would be beneficial. This enhancement would be accomplished through the addition of constraint equations and a second set of rigid body equations to the equations of motion engine for the simulation. Additional model improvements to the existing simulation structure include the addition of rotation of the Earth effects, calculation of latitude and longitude coordinates, which would also improve the gravity calculator, and a more detailed air density profile based on position coordinates and sea level atmospheric properties.

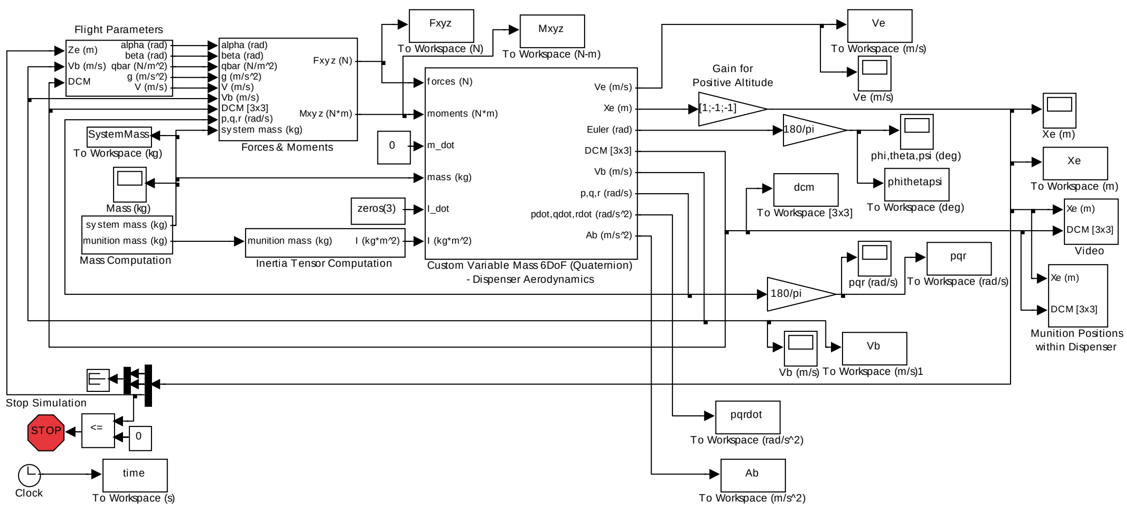
Another important area of improvement is in the relationships between the dispenser and aircraft and the dispenser and munitions. The dispenser-aircraft relationship could be better defined, such as with cargo deck friction, aircraft airflow and shed vortices, and aircraft constraints and regulatory requirements, to establish more accurate dispenser initial flight conditions. The initial condition calculations could be developed within the simulation or as a pre-calculated input to the simulation. The dispenser-munition relationship improvement begins with the removal of the discrete mass changes assumption for munition releases to more accurately depict the continuous dynamics of the dispenser-munition interaction during release. This improvement would include the friction effects of the munition-rail system, the addition of dispenser angular rates in munition release velocity, the decaying time differential of mass and inertia of the dispenser, and the changing CG location and moments caused by the exiting munitions. Also, the munition-dispenser interaction should be studied with respect to the potential issues of faulty munition releases or adverse conditions, relating to store separation and possible munition torquing on the dispenser rails during ejection. These dispenser-munition interaction improvements would require a numerical integration scheme to track the motion of the munitions within the dispenser as part of the dispenser simulation model while the munitions simulation could remain as a separate post-processing simulation; however, the store separation issues would require a CFD or wind tunnel testing approach. The objective of all these improvements is to develop a more accurate and complete model of all system components to determine the ability and performance characteristics of the system.

Numerous potential studies and experiments could be conducted regarding the dispenser concept, either through use of the simulation or as a tangent to it. The munitions behavior could be better studied through the addition of a complete six DoF model of the munitions with all the relevant properties and aerodynamic characteristics of actual munition designed for the dispenser, including propulsion, guidance, navigation, and control systems. Operational dispenser system capabilities can also be studied, such as sequential, multiple dispenser airdrops, computed air release points (CARP) for targeted dumb munitions, and optimization studies for dispenser design and employment concepts. The other primary area of focus is in the parametric study of specific dispenser concepts in order to establish operational parameters, establish the stability characteristics and performance of the system for a wide range of conditions, and determine the necessity of passive or active stabilization systems for the dispenser. This broad array of testing should lead to further research in wind-tunnel, CFD, and full-scale flight test environments to develop the dispenser concept to the level of full operational capability.

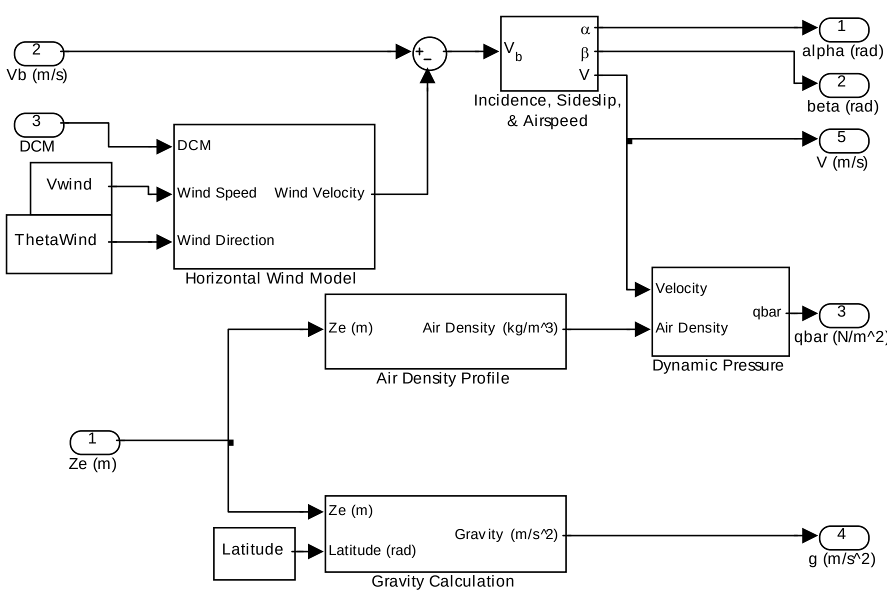
Appendix A: Simulations and Computer Programming Code

Dispenser System Simulation and Subsystems
(Refer to Attached CD-ROM for All Simulink Model Files)

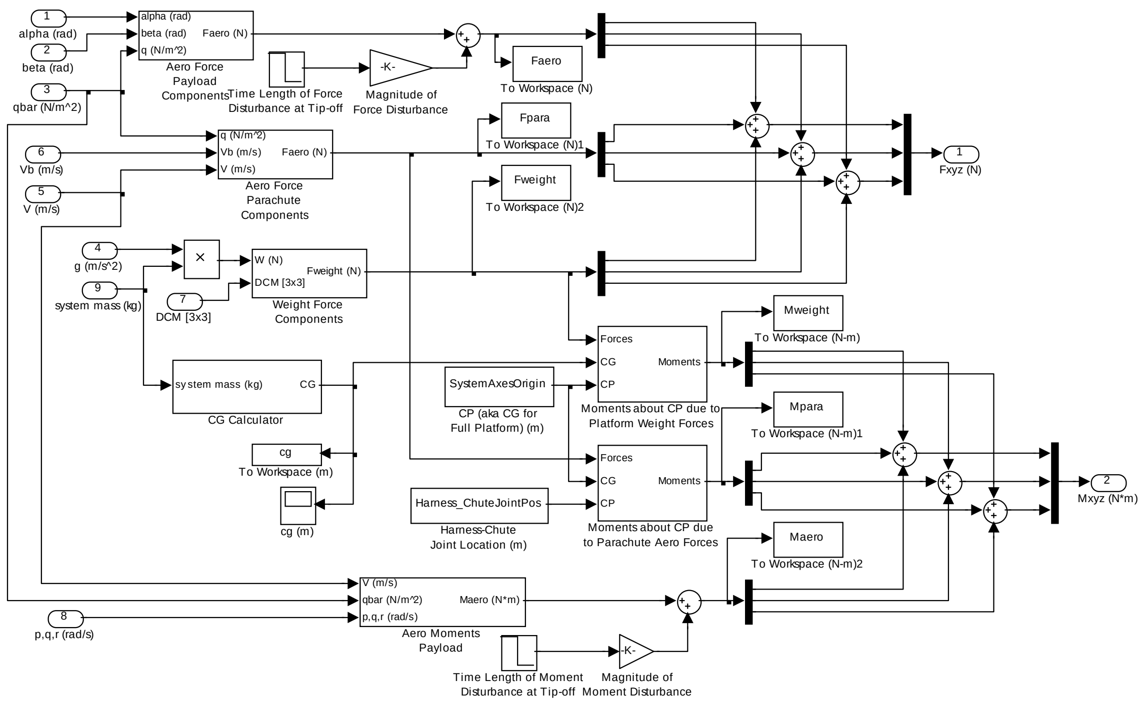
Top-Level Dispenser Simulation



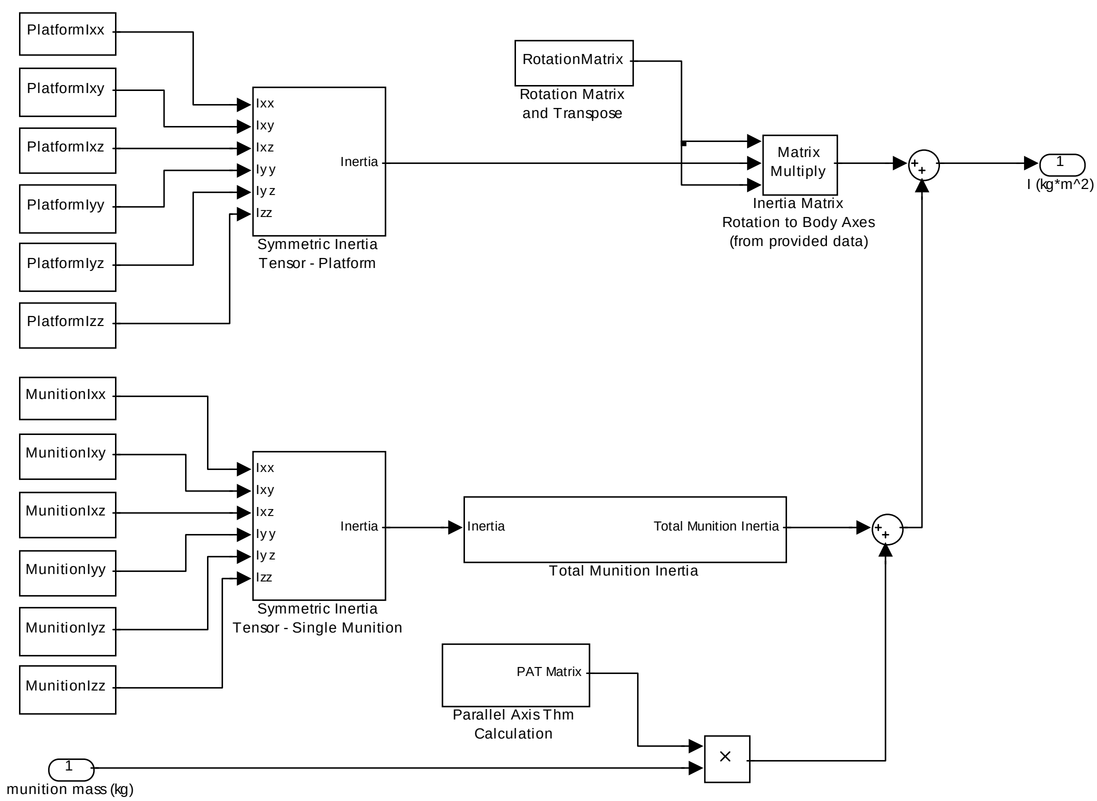
Flight Parameters Subsystem



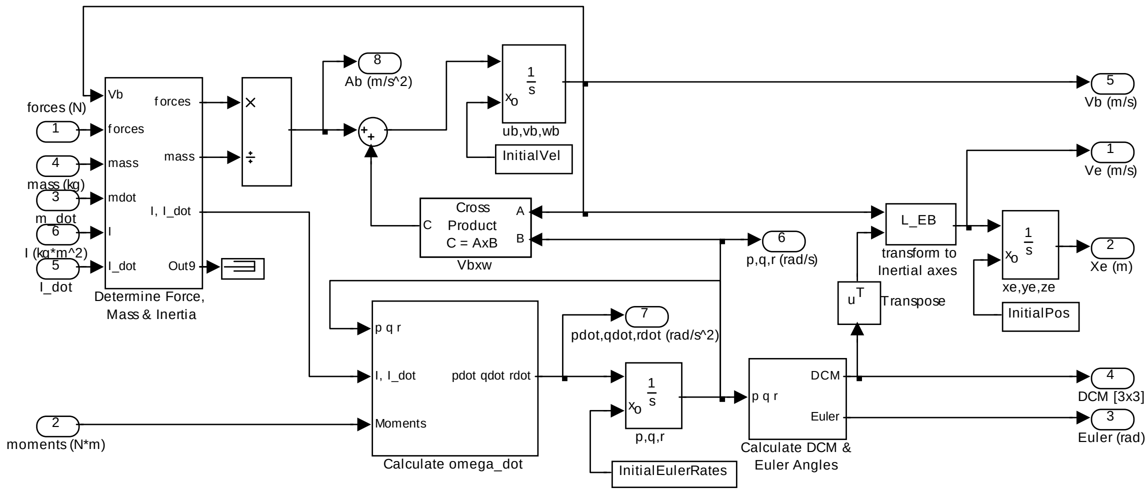
Forces & Moments Subsystem



Inertia Tensor Computation Subsystem

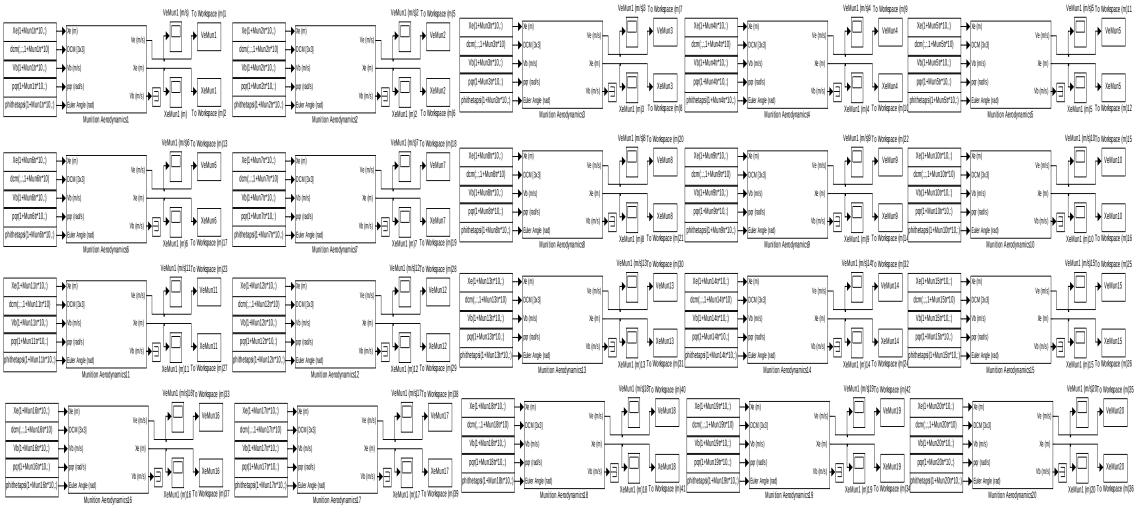


6 DoF – Dispenser Aerodynamics Subsystem [18]

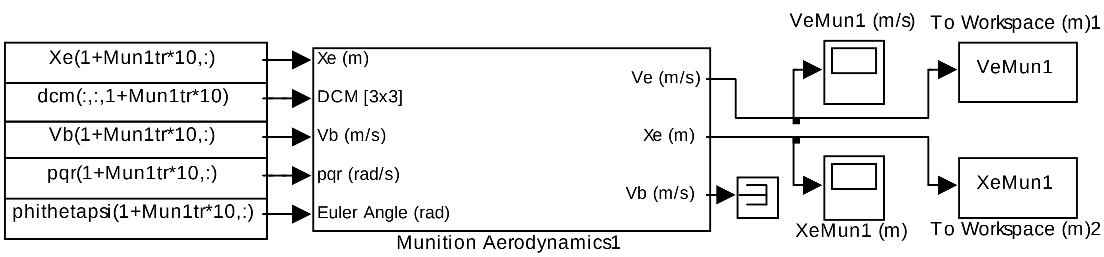


Munitions Simulation and Subsystems

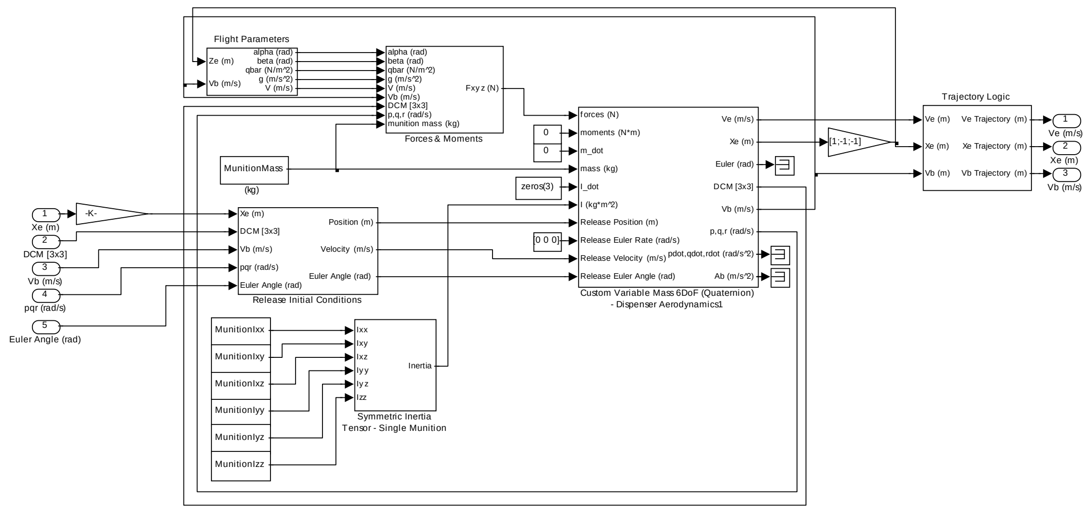
Top-Level Munitions Simulation



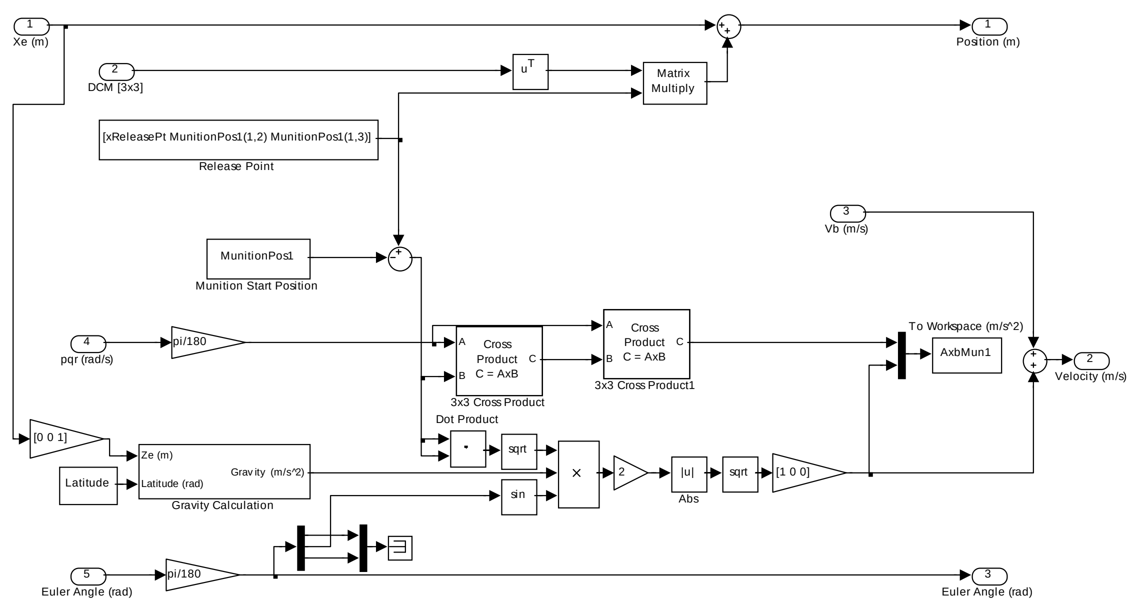
Single Munition Aerodynamics Subsystem (External)



Single Munition Aerodynamics Subsystem (Internal)



Release Initial Conditions Subsystem for Single Munition Aerodynamics



Dispenser System Simulation - Initialization and Post-Processing MATLAB Code (Refer to Attached CD-ROM for All MATLAB Code Files)

Simulation Initialization – Inputs, Parameters, & Test Variables

```
% Paul M. Wilson
% 15 Feb 06
% Munitions Dispenser System Simulation Initialization Code

clc,clear
simtime = 250;  % End time for Dispenser Simulation execution
SimMunTime = 50;    % End time for Munitions Simulation execution
scale = 1;  % Magnification size of dispenser in trajectory plots and video

% Initial Conditions for Equations of Motion
InitialPos = [0 0 -29500*0.3048];   % (m) Initial Position of dispenser at release (Inertial
                                     Reference, Altitude is negative)
InitialVel = [150*0.51444444 0 0];  % (m/s) Initial Velocity of dispenser at release
                                     (Inertial Reference)
% InitialEuler = [0 (4*pi/180) 0];  % (rad) Initial Euler Angles of dispenser at release
InitialEulerRates = [0 0 0];       % (rad/s) Initial Euler Angle Rates of dispenser at release
Latitude = 0;                     % (deg) Initial Latitude at release

% Input Variables for R&D Tests
InitialEuler = [0 (4)*(pi/180) 0];     % (rad) Initial Euler Angles of dispenser at release
Harness_ChuteJointPos = [-132*2 0 0]*.0254;      % (m) Parachute-Harness Joint
                                                  Position relative to dispenser CP
SrefParachute = 1;        % (m^2) Used with Cp for Cp*SrefParachute Value
Cp = 407*(.3048^2);    % (-) Parachute Aerodynamic Drag Coefficient
ReleaseInterval = 0.5;    % (s) Time Interval between munition release
ReleaseDelay = 2.5;       % (s) Time between dispenser release and first munition release
Vwind = 0*5280*.3048/3600;      % (m/s) Steady Wind Disturbance Velocity
ThetaWind = 0*pi/180;     % (rad) Steady Wind Disturbance Angle relative to dispenser
                           +x-axis
ForceDisturbanceLength = 2;           % (s) Time Length of initial force disturbance
ForceDisturbanceMag = [0;0;0*-.5*14*.6*1.21*(40*5280*.3048/3600)^2];    % (N)
                                          Magnitude of initial force disturbance
MomentDisturbanceLength = .5;       % (s) Time Length of initial moment disturbance
MomentDisturbanceMag = [0;0*2000*.4536*9.81*100*.0254;0]; % (N-m) Magnitude of
                                                    initial moment disturbance

% Mass Properties
PlatformMass = 7000*.4536;       % (kg) Dispenser Mass (includes pallet)
PalletMass = 500*.4536;        % (kg) Pallet Mass
MunitionMass = 1000*.4536;          % (kg) Single Munition Mass
TotalMunitions = 20;            % (-) Number of Munitions in dispenser
```

```
% Dispenser Size & Inertia Properties
RotationMatrix = [1,0,0;0,1,0;0,0,1];         % N/A
PlatH = 100*.0254;           % (m) Dispenser Height (z-axis)
PlatW = 110*.0254;           % (m) Dispenser Width (y-axis)
PlatL = 132*.0254;           % (m) Dispenser Length (x-axis)
PalletL = 200*.0254;          % (m) Pallet Length (x-axis)
PlatformIxx = (1/12)*(PlatformMass-PalletMass)*(PlatH^2 + PlatW^2)
          +(1/12)*(PalletMass)*((5*.0254)^2 + PlatW^2)+PalletMass*(PlatH/2 +
          5*.0254)^2;           % (kg-m^2) Dispenser Moment of Inertia about x-axis
PlatformIyy = (1/12)*(PlatformMass-PalletMass)*(PlatH^2 + PlatL^2)
          +(1/12)*(PalletMass)*((5*.0254)^2 + (PlatL+50*.0254)^2)+PalletMass*(PlatH/2
          + 5*.0254)^2;             % (kg-m^2) Dispenser Moment of Inertia about y-axis
PlatformIzz = (1/12)*(PlatformMass-PalletMass)*(PlatW^2 + PlatL^2)
          +(1/12)*(PalletMass)*(PlatW^2 + (PlatL+50*.0254)^2);       % (kg-m^2)
          Dispenser Moment of Inertia about z-axis
PlatformIxy = 0;    % (kg-m^2) Dispenser Product of Inertia about xy-plane
PlatformIxz = 0;    % (kg-m^2) Dispenser Product of Inertia about xz-plane
PlatformIyz = 0;    % (kg-m^2) Dispenser Product of Inertia about yz-plane

% Munition Size & Inertia Properties
MunDiam = 18*.0254;                  % (m) Munition Diameter
MunLength = 120*.0254;             % (m) Munition Length
MunitionIxx = MunitionMass*(MunDiam/2)^2;          % (kg-m^2) Munition Moment of
                                                                  Inertia about x-axis
MunitionIyy = (1/12)*MunitionMass*(3*(MunDiam/2)^2 + MunLength^2);  % (kg-m^2)
                                                     Munition Moment of Inertia about y-axis
MunitionIzz = MunitionIyy;           % (kg-m^2) Munition Moment of Inertia about z-axis
MunitionIxy = 0;                % (kg-m^2) Munition Product of Inertia about xy-plane
MunitionIxz = 0;                % (kg-m^2) Munition Product of Inertia about xz-plane
MunitionIyz = 0;                % (kg-m^2) Munition Product of Inertia about yz-plane

% Munition CG Location for 4x5 Dispenser Configuration
% (m) Location relative to dispenser CP
xp=5*0.0254;
yp1=40*0.0254; yp2=20*0.0254; yp3=0*0.0254;
yp4=-20*0.0254; yp5=-40*0.0254;
zp1=37.5*.0254; zp2=12.5*.0254;
zp3=-12.5*.0254; zp4=-37.5*.0254;
xReleasePt   = PlatL/2;
MunitionPos1 = [xp yp1 zp4];
MunitionPos2 = [xp yp2 zp4];
MunitionPos3 = [xp yp3 zp4];
MunitionPos4 = [xp yp4 zp4];
MunitionPos5 = [xp yp5 zp4];
```

```
MunitionPos6 = [xp yp1 zp3];
MunitionPos7 = [xp yp2 zp3];
MunitionPos8 = [xp yp3 zp3];
MunitionPos9 = [xp yp4 zp3];
MunitionPos10= [xp yp5 zp3];
MunitionPos11= [xp yp1 zp2];
MunitionPos12= [xp yp2 zp2];
MunitionPos13= [xp yp3 zp2];
MunitionPos14= [xp yp4 zp2];
MunitionPos15= [xp yp5 zp2];
MunitionPos16= [xp yp1 zp1];
MunitionPos17= [xp yp2 zp1];
MunitionPos18= [xp yp3 zp1];
MunitionPos19= [xp yp4 zp1];
MunitionPos20= [xp yp5 zp1];

% Dispenser Aerodynamic Characteristics
SystemAxesOrigin = [0 0 0];     % (m) Dispenser CP location, also Empty Dispenser CG
                                  location
SrefPlatform = PlatW*PalletL;        % (m^2) Dispenser Reference Area
LrefPlatform = PalletL;              % (m) Dispenser Reference Length
CD0 = 0.6;          % (-) Dispenser Minimum Drag Coefficient at Zero Angle of Attack
CDalpha2 = 2.9;            % (1/rad^2) Dispenser Drag Coefficient Derivative
CLalpha = 2.9;           % (1/rad) Dispenser Lift Coefficient Derivative
CYbeta = 0.6;             % (1/rad) Dispenser Sideforce Coefficient Derivative
Clp = -1.2;   % (s/rad) Dispenser Rotational Damping Coefficient Derivative about x-axis
Cmq = -1.4; % (s/rad) Dispenser Rotational Damping Coefficient Derivative about y-axis
Cnr = -1.1;   % (s/rad) Dispenser Rotational Damping Coefficient Derivative about z-axis

% Munition Aerodynamic Characteristics
CDMun = 0.5;                   % (-) Munition Drag Coefficient
SrefMun = pi*(MunDiam/2)^2;                   % (m) Munition Reference Length

% Munition Release Times
% (s) Time from dispenser release
MunRelease1  = ReleaseDelay;                    % First Munition Release Time
MunRelease2  = MunRelease1  + ReleaseInterval;
MunRelease3  = MunRelease2  + ReleaseInterval;
MunRelease4  = MunRelease3  + ReleaseInterval;
MunRelease5  = MunRelease4  + ReleaseInterval;
MunRelease6  = MunRelease5  + ReleaseInterval;
MunRelease7  = MunRelease6  + ReleaseInterval;
MunRelease8  = MunRelease7  + ReleaseInterval;
MunRelease9  = MunRelease8  + ReleaseInterval;
MunRelease10 = MunRelease9  + ReleaseInterval;
```

```
MunRelease11 = MunRelease10 + ReleaseInterval;
MunRelease12 = MunRelease11 + ReleaseInterval;
MunRelease13 = MunRelease12 + ReleaseInterval;
MunRelease14 = MunRelease13 + ReleaseInterval;
MunRelease15 = MunRelease14 + ReleaseInterval;
MunRelease16 = MunRelease15 + ReleaseInterval;
MunRelease17 = MunRelease16 + ReleaseInterval;
MunRelease18 = MunRelease17 + ReleaseInterval;
MunRelease19 = MunRelease18 + ReleaseInterval;
MunRelease20 = MunRelease19 + ReleaseInterval;
MunReleaseTimes = [MunRelease1 MunRelease2 … MunRelease20];

% Munition Release Sequence
% (s) Time from dispenser release
Mun1tr  = roundn(MunRelease6,-1);             % Munition #1 Release Time
Mun2tr  = roundn(MunRelease14,-1);
Mun3tr  = roundn(MunRelease17,-1);
Mun4tr  = roundn(MunRelease9,-1);
Mun5tr  = roundn(MunRelease1,-1);
Mun6tr  = roundn(MunRelease3,-1);
Mun7tr  = roundn(MunRelease11,-1);
Mun8tr  = roundn(MunRelease19,-1);
Mun9tr  = roundn(MunRelease16,-1);
Mun10tr = roundn(MunRelease8,-1);
Mun11tr = roundn(MunRelease7,-1);
Mun12tr = roundn(MunRelease15,-1);
Mun13tr = roundn(MunRelease20,-1);
Mun14tr = roundn(MunRelease12,-1);
Mun15tr = roundn(MunRelease4,-1);
Mun16tr = roundn(MunRelease2,-1);
Mun17tr = roundn(MunRelease10,-1);
Mun18tr = roundn(MunRelease18,-1);
Mun19tr = roundn(MunRelease13,-1);
Mun20tr = roundn(MunRelease5,-1);
MunReleaseOrder = [Mun1tr Mun2tr … Mun20tr];

% Open Simulink Models for Dispenser & Munition Simulations
% Execute Dispenser Simulation, Then Execute Munition Simulation
run TheSimMunitions
run TheSim
```

Appendix B: Simulation Test Data, Plots, and Videos

(Refer to Attached CD-ROM for All Output Test Data, Plots, and Final Design Videos)

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Vita

Second Lieutenant Paul M. Wilson graduated from Lutheran High School of San Antonio in San Antonio, Texas. He entered undergraduate studies at the University of Texas at San Antonio where he graduated with a Bachelor of Science degree in Mechanical Engineering in May 2004. He was commissioned through the Detachment 842 AFROTC at the University of Texas at San Antonio where he was recognized as a Distinguished Graduate.

His first assignment was at Wright-Patterson AFB in August 2004 as a student in the Graduate School of Engineering and Management, Air Force Institute of Technology, from which he will receive a Master of Science degree in Aeronautical Engineering in March 2006. Upon graduation, he will be assigned to the Air Force Research Laboratory Munitions Directorate at Eglin AFB.

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6. # of Files/# of Products:	7. Character Set:	8. Disk Capacity:
37/1	ASCII	700MB
	9. Compatibility: PC	**10. Disk Size:** 4 3/4"

11. Title:

Simulation of Weapons Release from Cargo Aircraft:
Thesis, Appendices, Simulation Files, and Test Results

12. Performing Organization:	13. Performing Report #:	14. Contract #:
AFIT/EN 2950 Hobson Way WPAFB OH 45433-7765	AFIT/GAE/ENY/06M-33	N/A
		15. Program Element #: N/A

16. Sponsor/Monitor:	17. Sponsor/Monitor # Acronym:	19. Project #:
AFRL/MNAV Attn: Mr. Eric B. Werkowitz 101 W Eglin Blvd, Suite 143 Eglin AFB FL 32542-6810	AFRL/MNAV	N/A
	18. Sponsor/Monitor #: N/A	**20. Task #:** N/A
		21. Work Unit #: N/A

22. Date:	23. Classification of Product:
17 Mar 06	U
24. Security Classification Authority:	**25. Declassification/Downgrade Schedule:**

26. Distribution/Availability:
A: Approved for public release; distribution unlimited

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27. Abstract: The purpose of this study is to develop a computer simulation capable of providing an accurate flight history of an airdropped munitions dispenser system in order to conduct proof of concept testing. The simulation is intended to serve as an adaptable tool for the development and testing of any cargo aircraft based weapons dispenser system. The simulation allows the user to conduct low-cost, time efficient, and effective tests of various design concepts in determining their operational feasibility and performance envelope. The munitions dispenser system is intended to provide a retrofit combat capability to the USAF C-17 aircraft, delivering massive amounts of precision guided ordinance where needed, when needed, while remaining outside the threat envelope. The dispenser concept was developed and modified through use of the simulation by determining the most favorable parachute system, harness configuration, and munition release sequence which ensure the desired behavior and performance of the twenty-munition dispenser system. The developed dispenser system was subjected to various adverse flight conditions, disturbances, and system malfunctions to determine the dispenser's reaction to such inputs. Overall, the developed dispenser configuration has proven to be a viable weapons release platform for a cargo aircraft.

28. Classification of Abstract: U	**29. Limitation of Abstract:** UL
30. Subject Terms: Air Drop Operations, Air Launched, Cargo Aircraft Bombing, Cargo Parachutes, Degrees of Freedom, Dispensers, Equations of Motion, Free Flight, Munitions, Simulation	**30a. Classification of Subject Terms:** U

31. Required Peripherals:

N/A

32. # of Physical Records:	**33. # of Logical Records:**	**34. # of Tracks:**
35. Record Type:	**36. Color:**	**37. Recording System:**
38. Recording Density:	**39. Parity:**	**40. Playtime:**

41. Playback Speed:	**42. Video:**	**43. Text:**	**44. Still Photos:**	**45. Audio:**

46. Other:

47. Documentation/Supplemental Information:
Includes readme file for execution of MATLAB/Simulink munitions dispenser simulation programs.

48. Point of Contact and Telephone Number:
Dr. Milton E. Franke (AFIT/ENY)
2950 Hobson Way
WPAFB OH 45433-7765
(937)255-3636, ext 4720; e-mail: milton.franke@afit.edu

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1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
23-03-2006	**Master's Thesis**	Sep 2004 – Mar 2006

4. TITLE AND SUBTITLE	
Simulation of Weapons Release from Cargo Aircraft	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	
Wilson, Paul, M., Second Lieutenant, USAF	**5d. PROJECT NUMBER** JON#06-361
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way WPAFB OH 45433-7765	AFIT/GAE/ENY/06-M33

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12. DISTRIBUTION/AVAILABILITY STATEMENT

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

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The munitions dispenser system is intended to provide a retrofit combat capability to the USAF C-17 aircraft, delivering massive amounts of precision guided ordinance where needed, when needed, while remaining outside the threat envelope. The dispenser concept was developed and modified through use of the simulation by determining the most favorable parachute system, harness configuration, and munition release sequence which ensure the desired behavior and performance of the twenty-munition dispenser system. The developed dispenser system was subjected to various adverse flight conditions, disturbances, and system malfunctions to determine the dispenser's reaction to such inputs. Overall, the developed dispenser configuration has proven to be a viable weapons release platform for a cargo aircraft.

15. SUBJECT TERMS

Air Drop Operations, Air Launched, Cargo Aircraft Bombing, Cargo Parachutes, Degrees of Freedom, Dispensers, Equations of Motion, Free Flight, Munitions, Simulation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. Milton E. Franke (AFIT/ENY)
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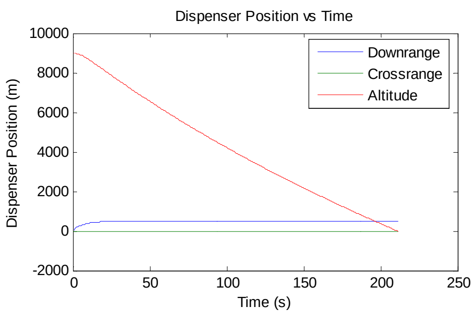
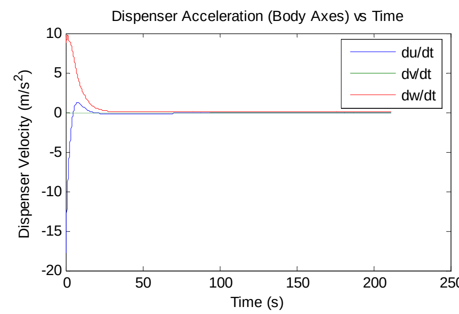
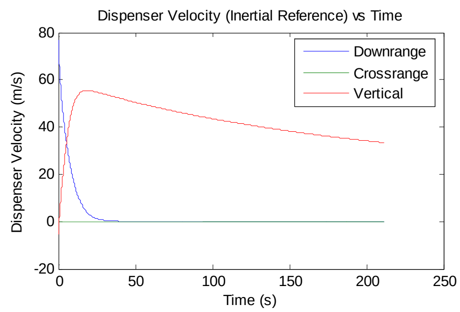
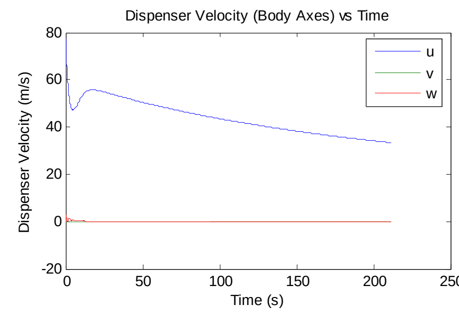
Appendix B: Simulation Test Data and Charts

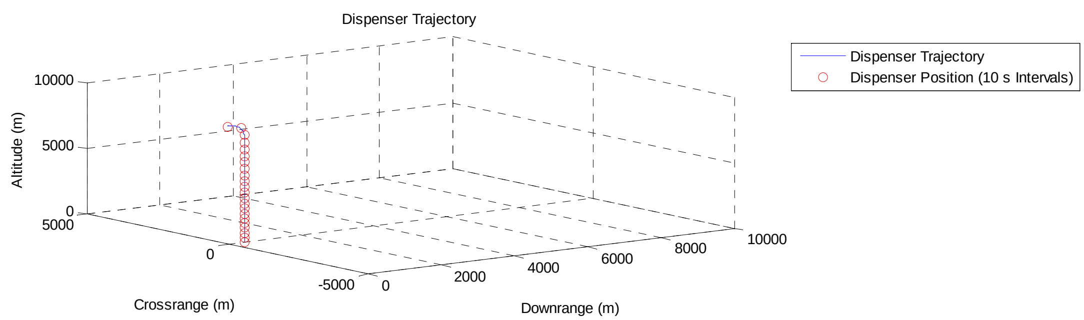
Test #1: Empty Dispenser - 28' RS, No Harness

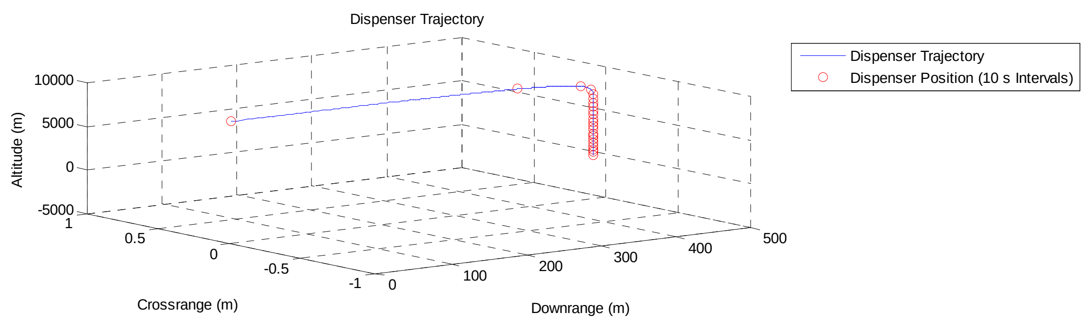


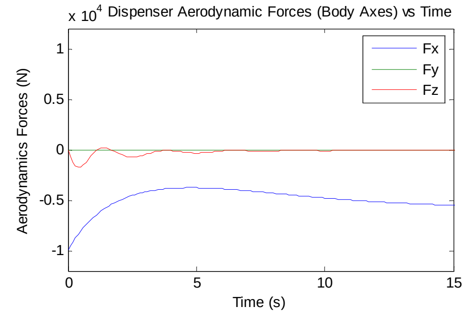


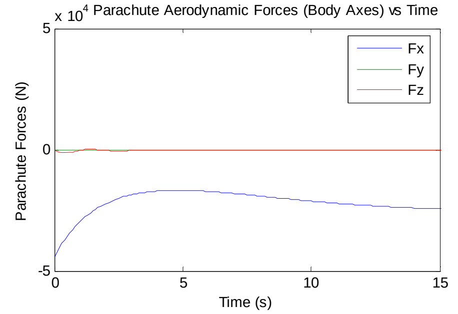









x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz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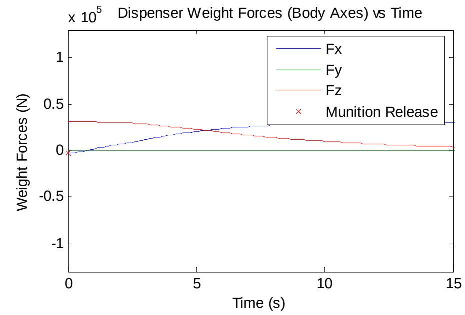
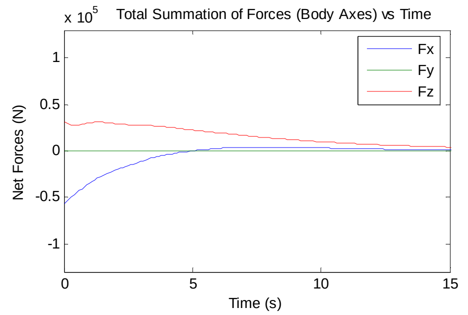
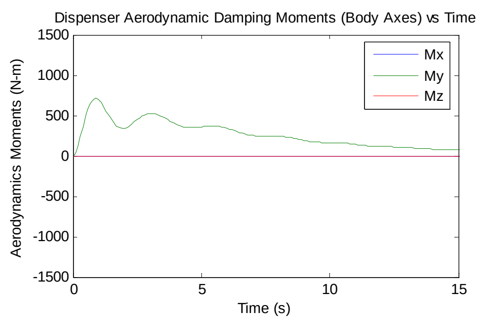
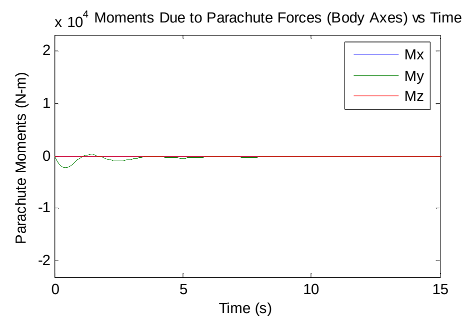
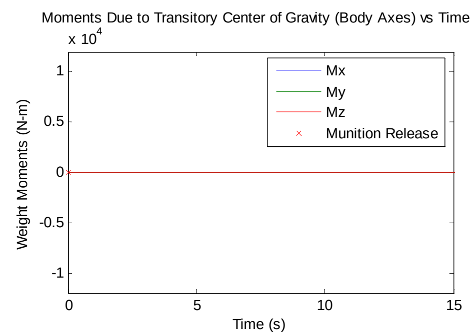
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

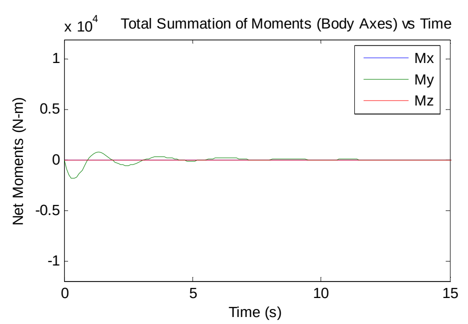

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

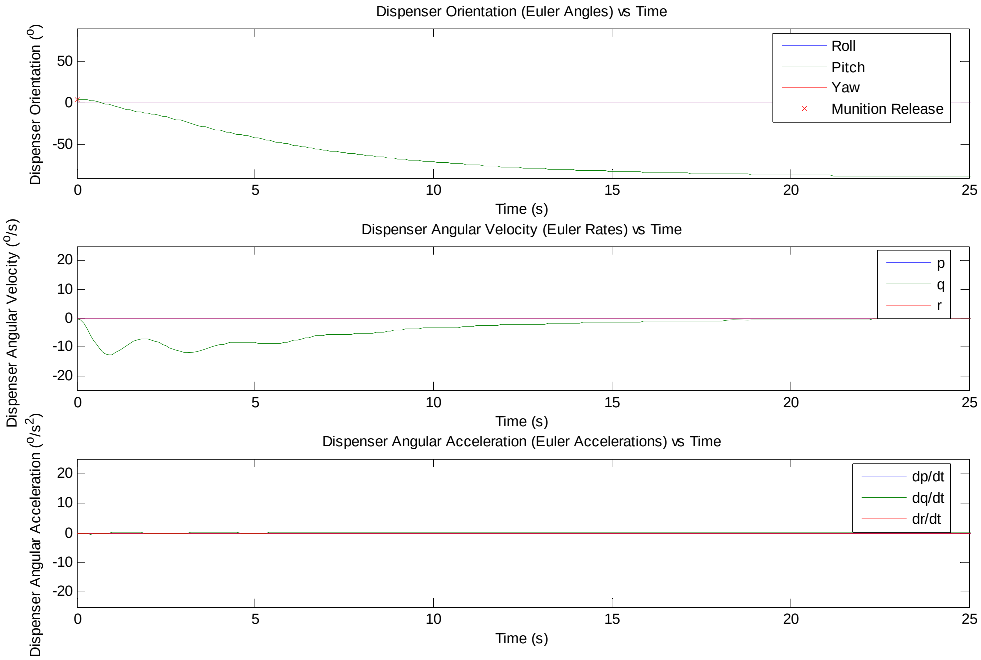

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

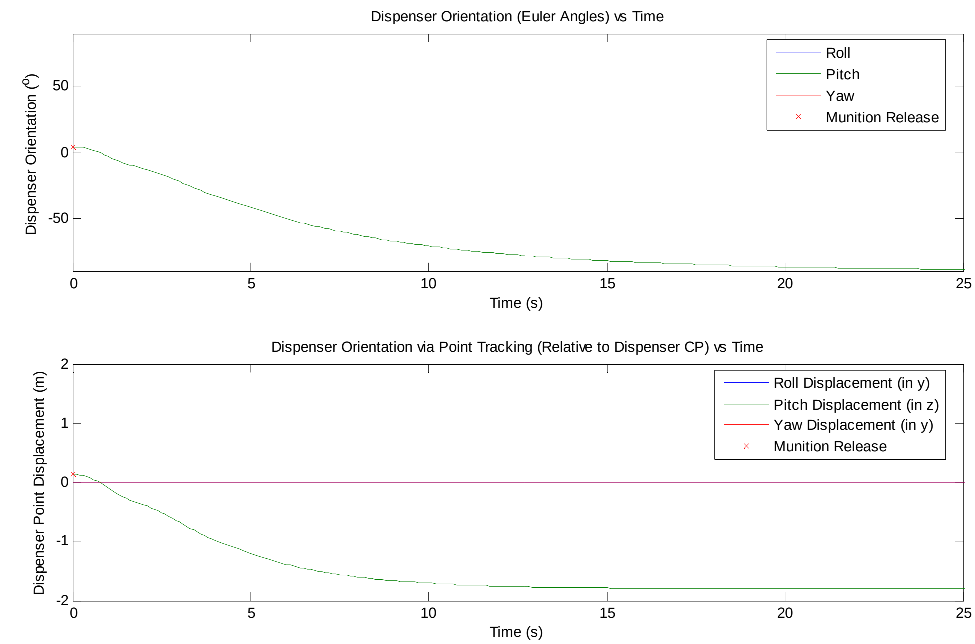

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

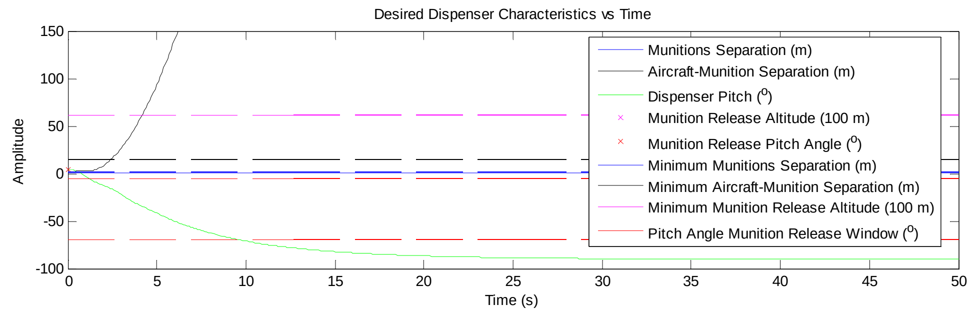

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

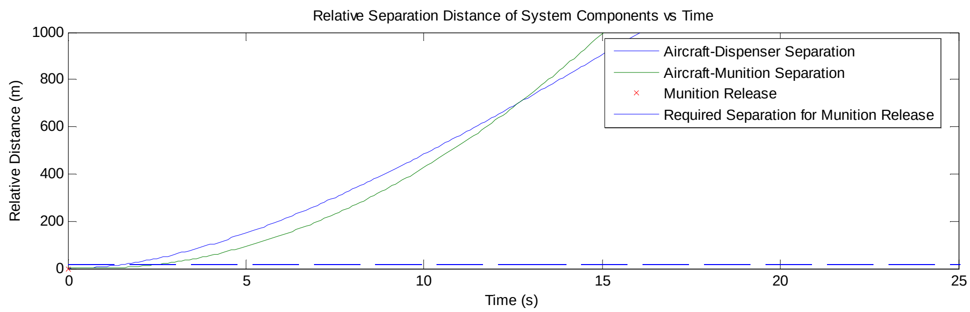

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release


x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

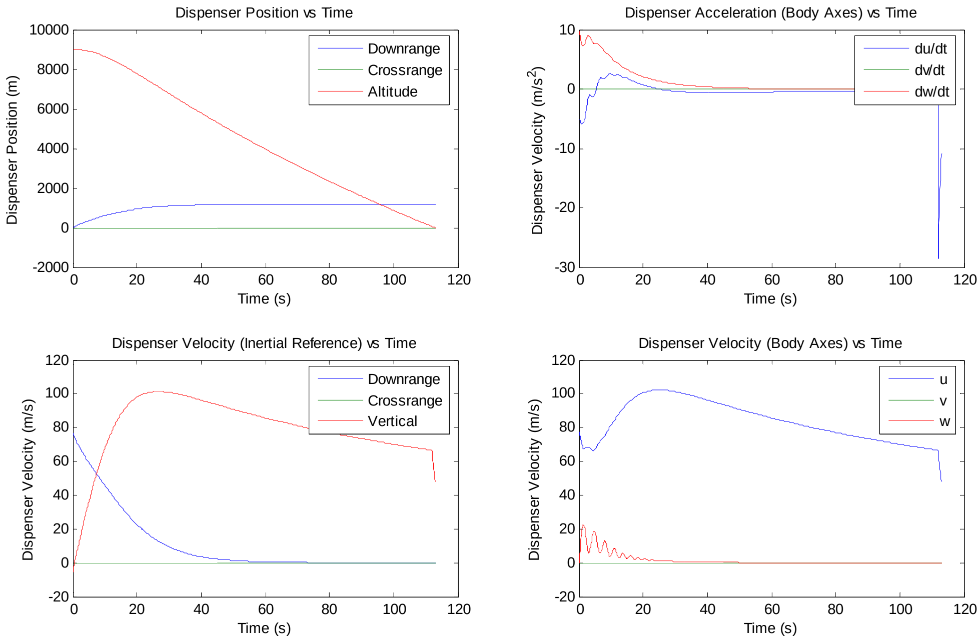

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (^{0})
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (^{0}/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (^{0}/s^2)
dp/dt
dq/dt
dr/dt
Time (s)

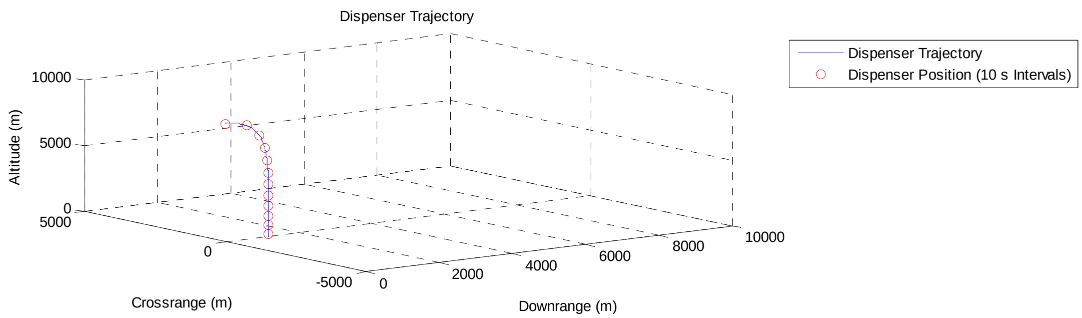

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (^{0})
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

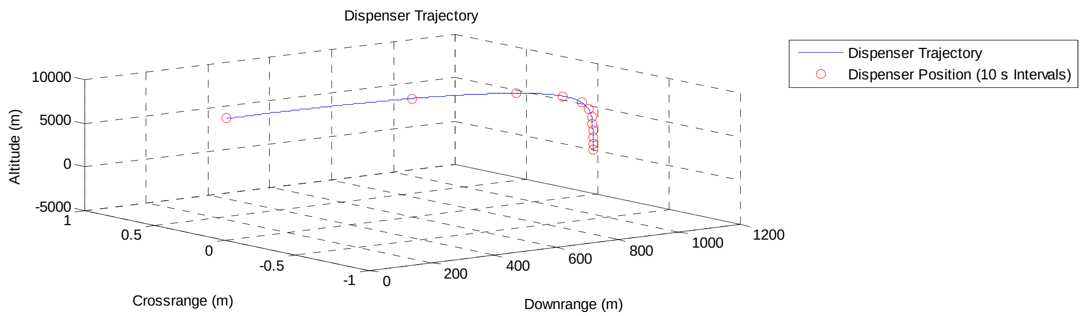

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

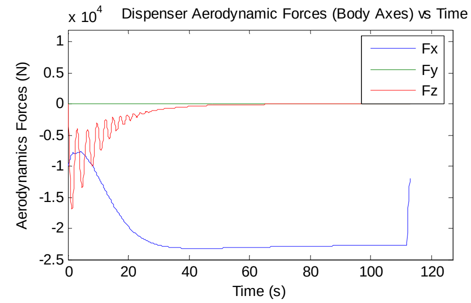

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

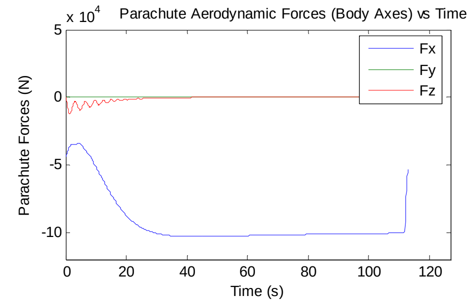
Test #2: Loaded Dispenser - 28' RS, No Harness

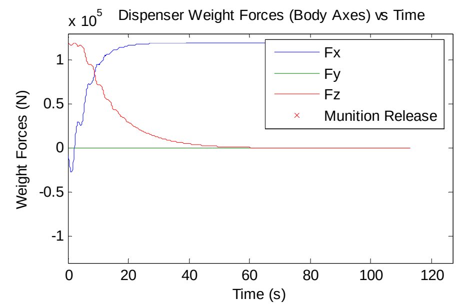


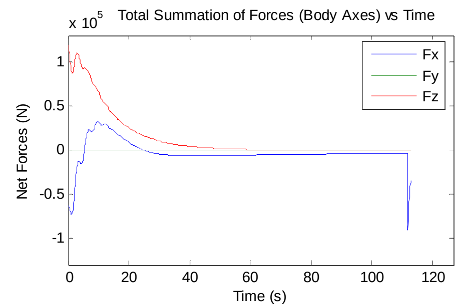


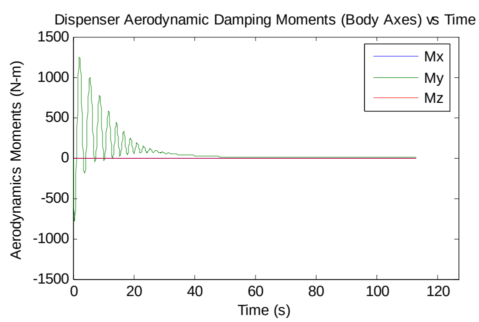


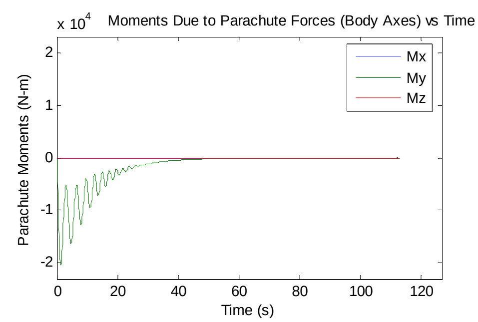

Dispenser Aerodynamic Forces (Body Axes) vs Time
x 10^4
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

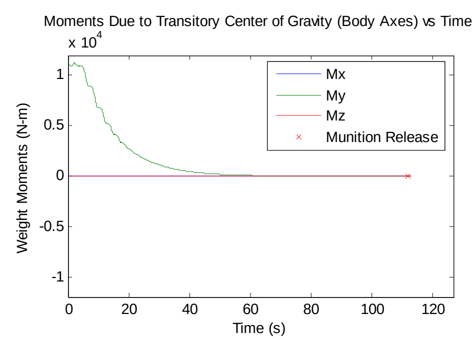

Parachute Aerodynamic Forces (Body Axes) vs Time
x 10^4
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

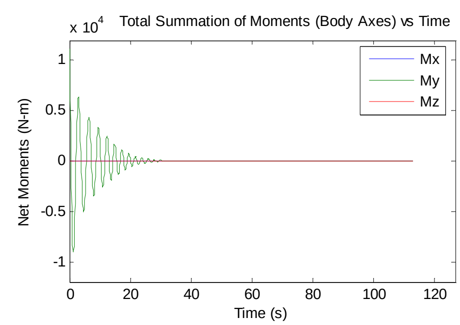

Dispenser Weight Forces (Body Axes) vs Time
x 10^5
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

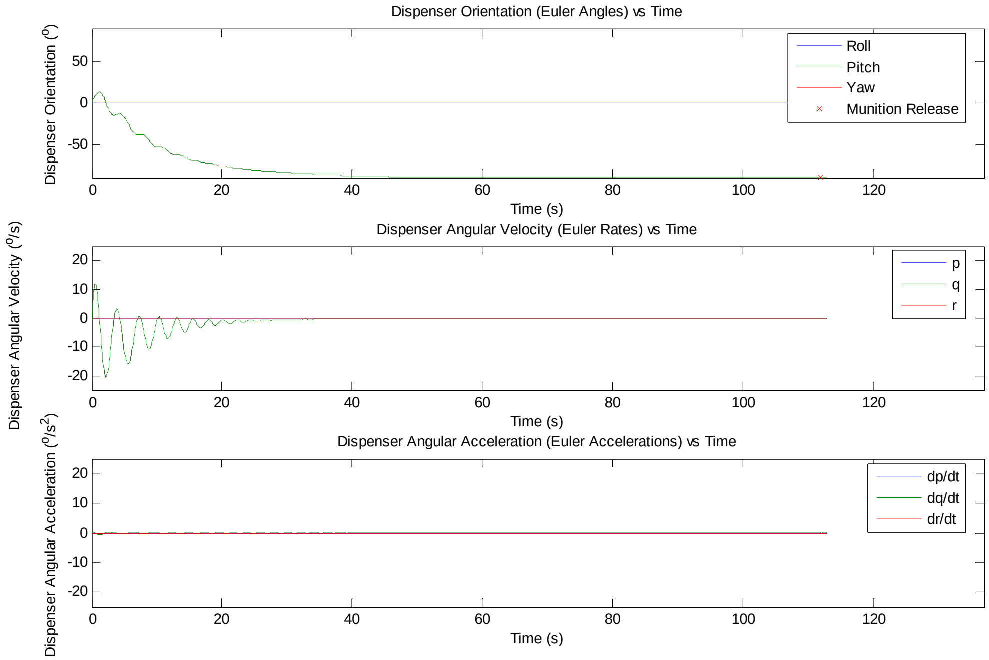

Total Summation of Forces (Body Axes) vs Time
x 10^5
Net Forces (N)
Time (s)
Fx
Fy
Fz

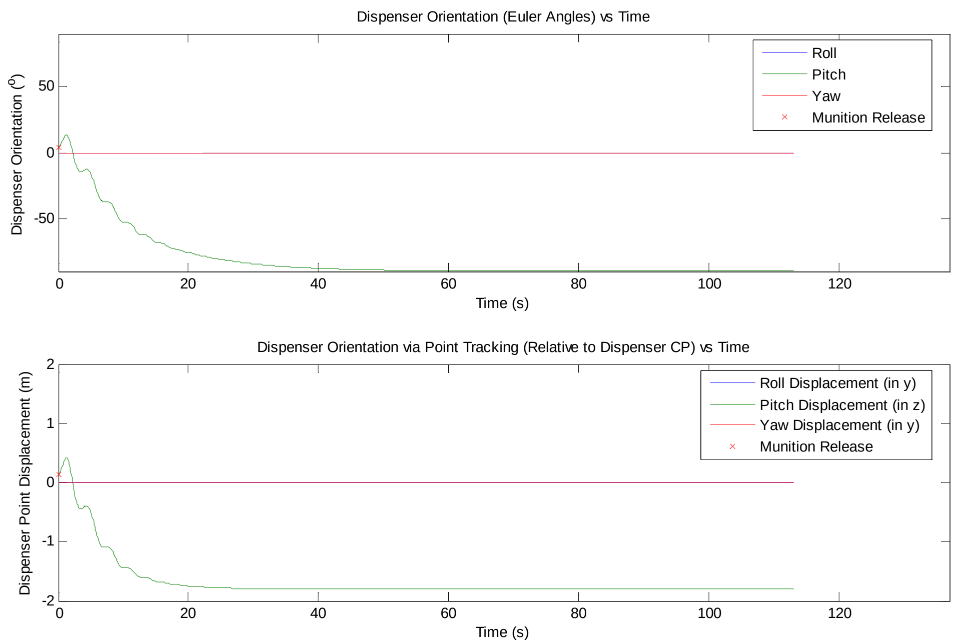

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

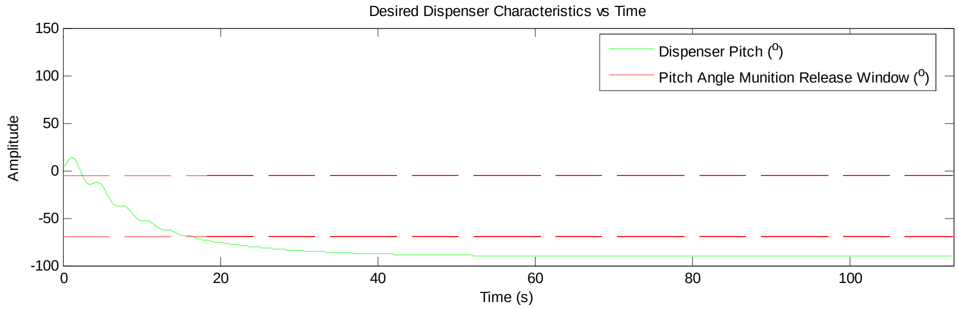

Moments Due to Parachute Forces (Body Axes) vs Time
x 10^4
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

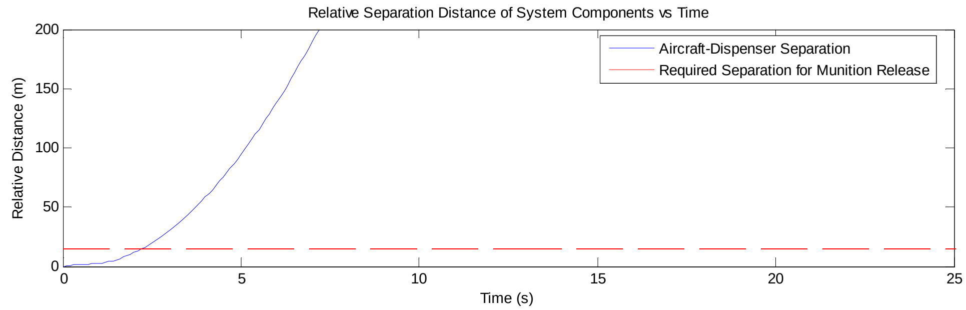

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release


Total Summation of Moments (Body Axes) vs Time
x 10^4
Net Moments (N-m)
Time (s)
Mx
My
Mz

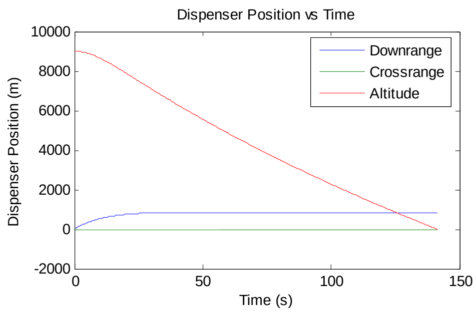

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

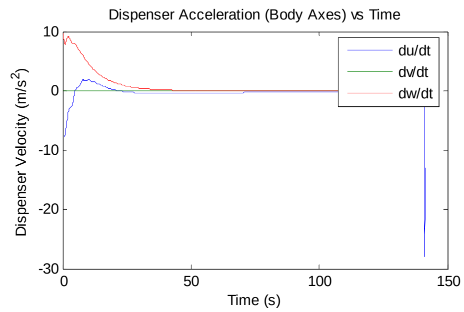

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

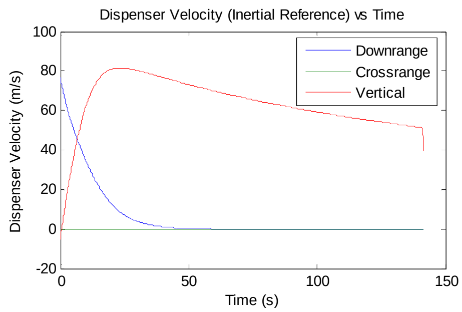

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
Time (s)
150
100
50
0
-50
-100
0
20
40
60
80
100

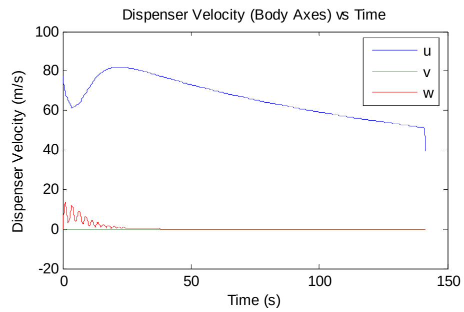

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
Time (s)
200
150
100
50
0
5
10
15
20
25

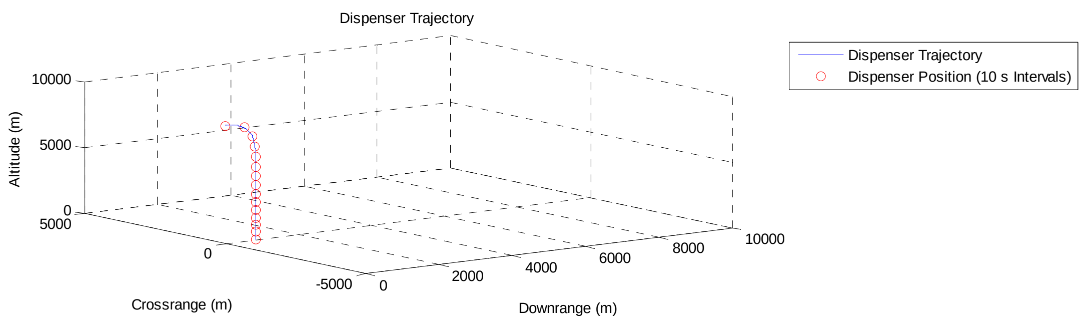
Test #3: Loaded Dispenser - 2 28' RS, No Harness

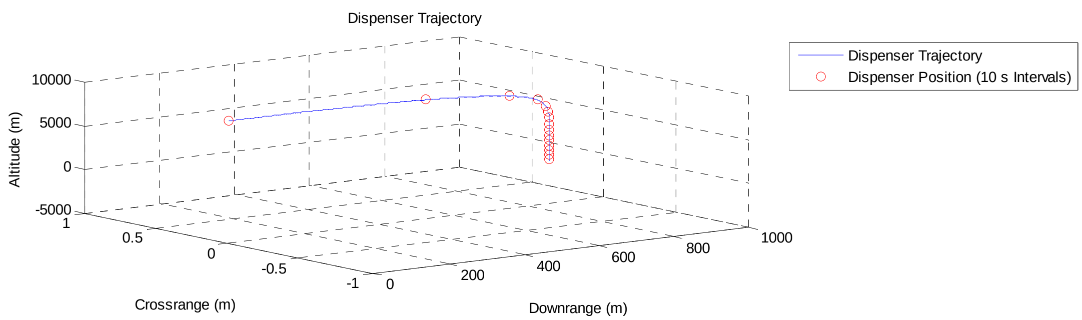


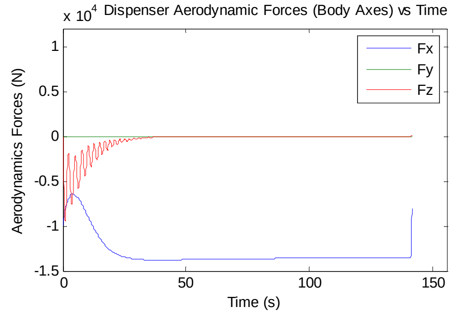


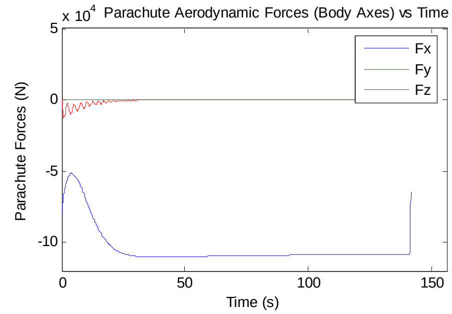


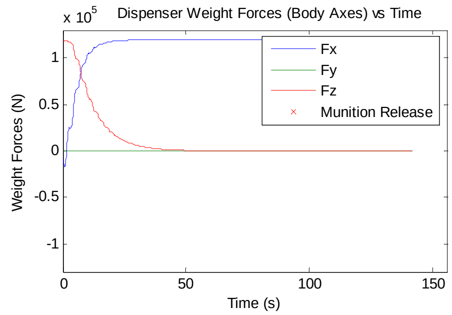


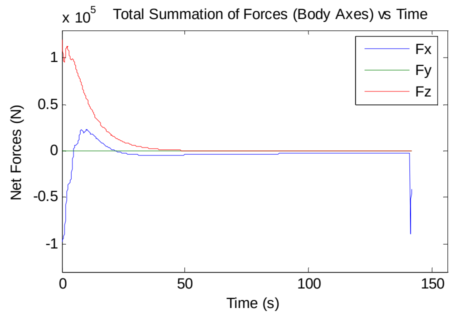


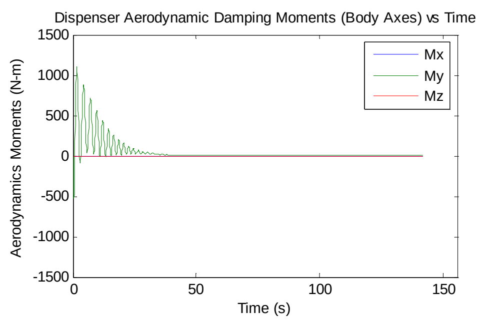


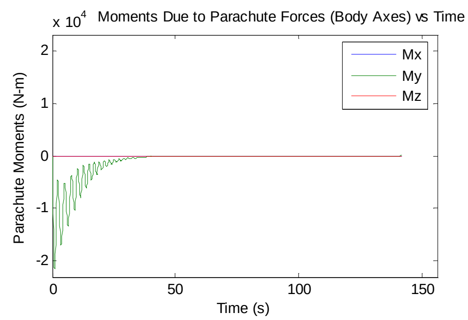

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

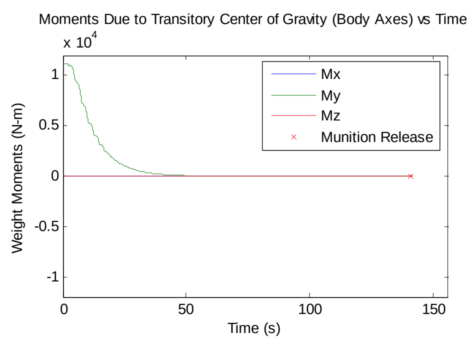

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

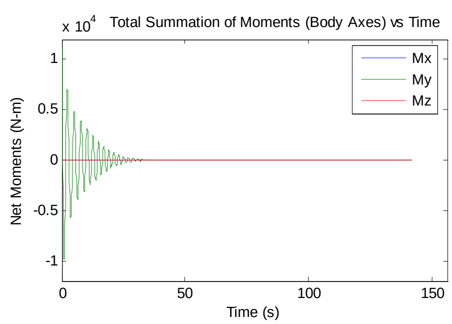

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

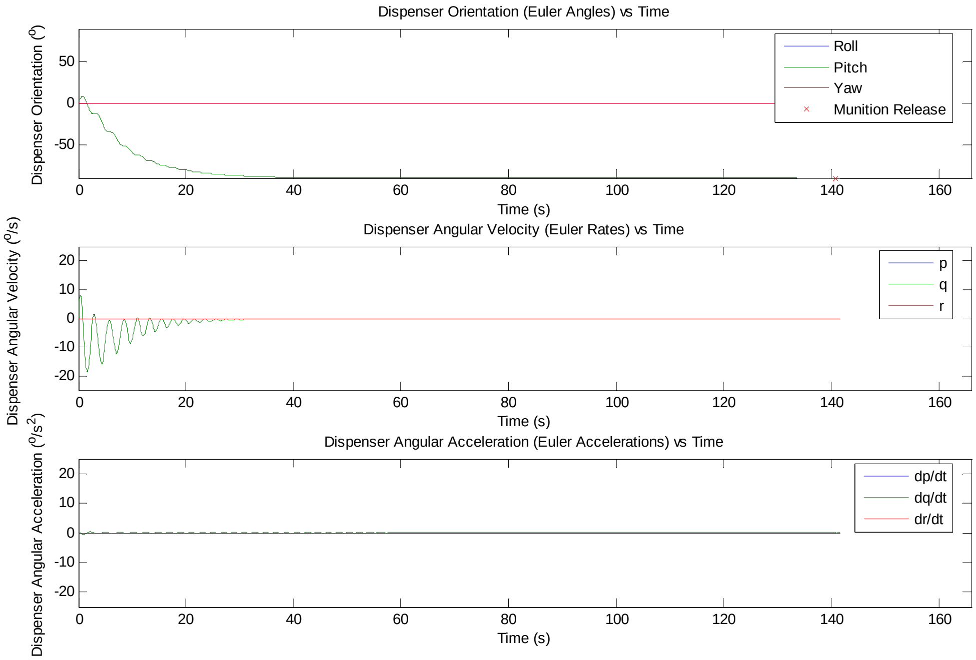

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

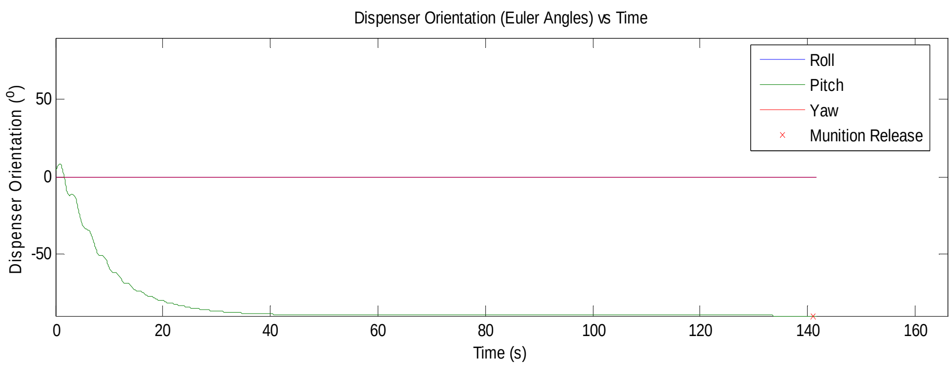

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

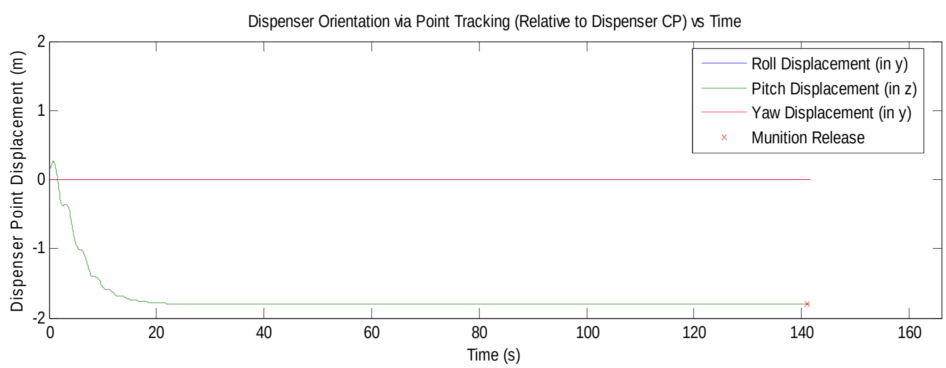

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

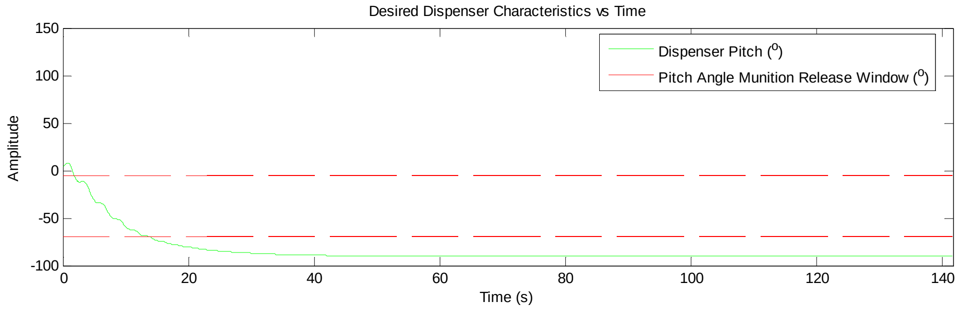

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

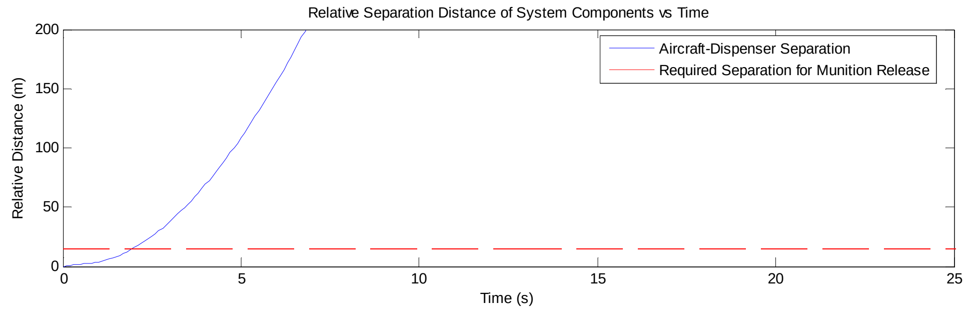

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

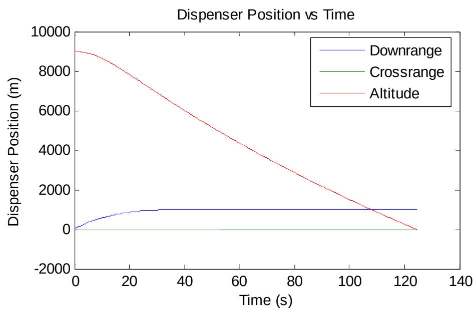

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)

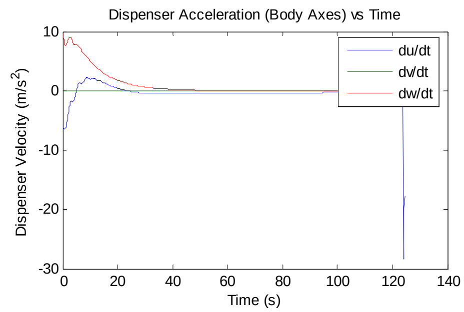

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

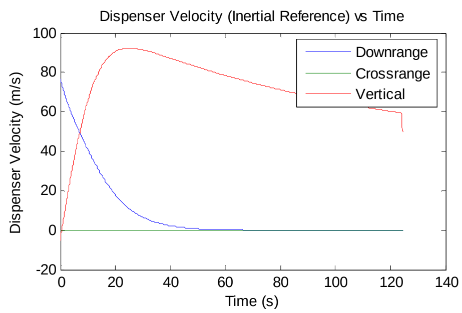

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
150
100
50
0
-50
-100
0
20
40
60
80
100
120
140
Time (s)

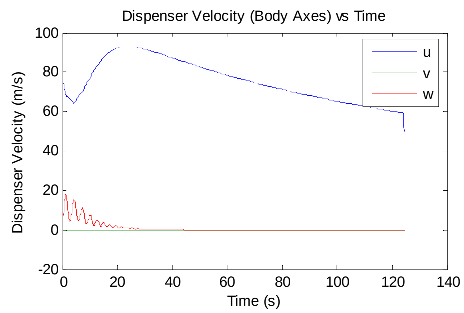

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
200
150
100
50
0
0
5
10
15
20
25
Time (s)

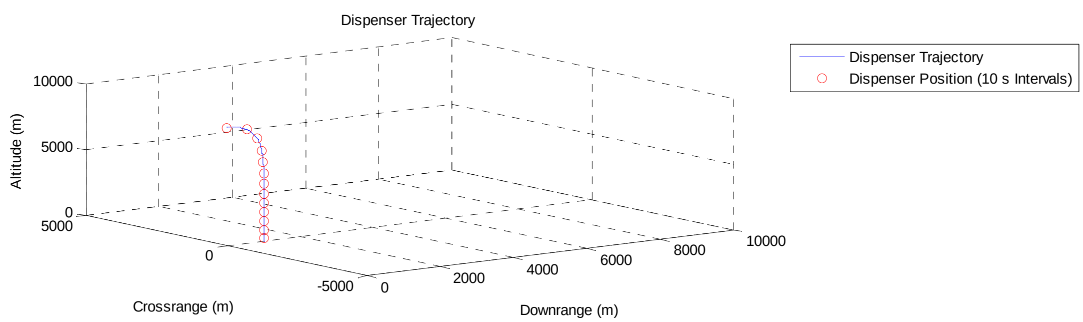
Test #4: Loaded Dispenser - 35' RS, No Harness

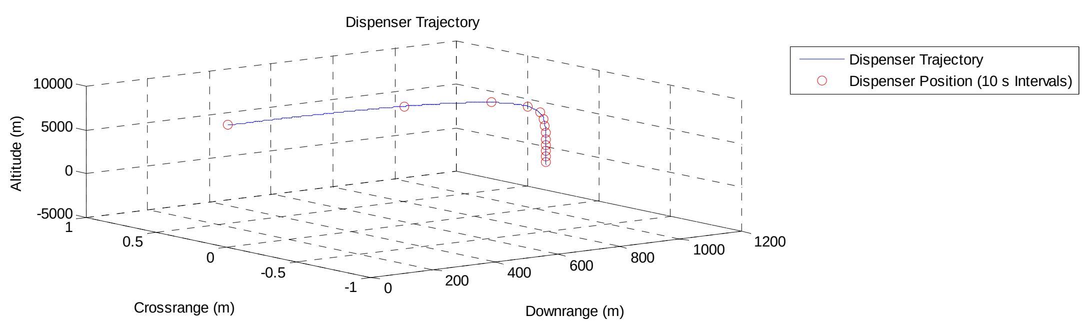


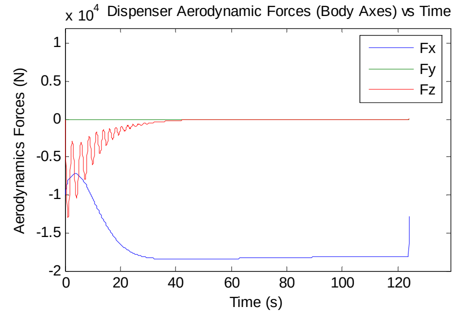


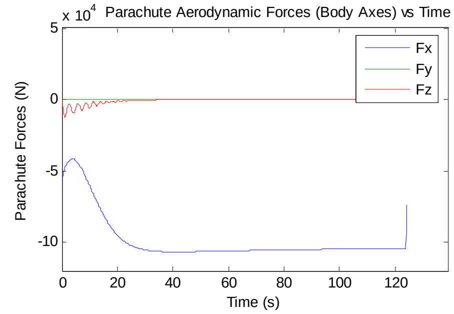


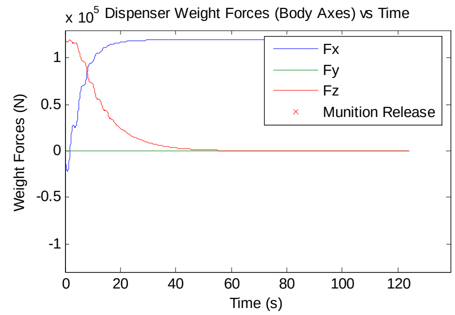


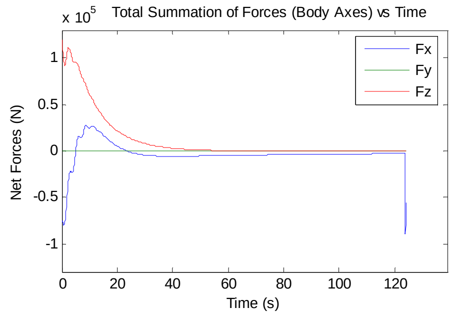


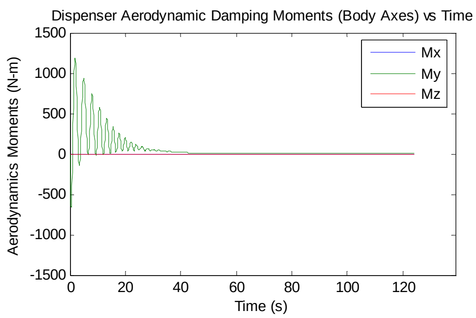


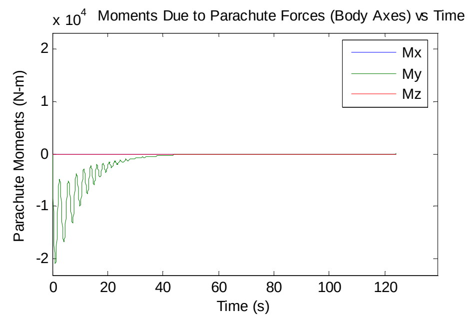

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

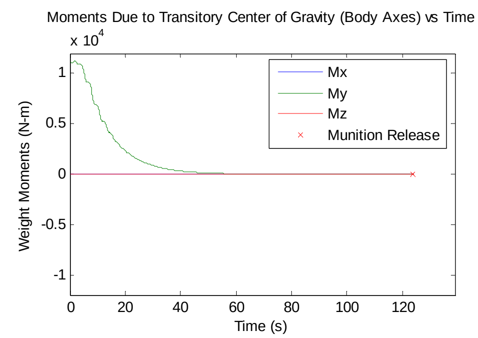

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

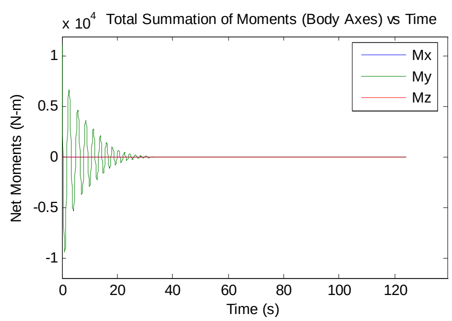

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

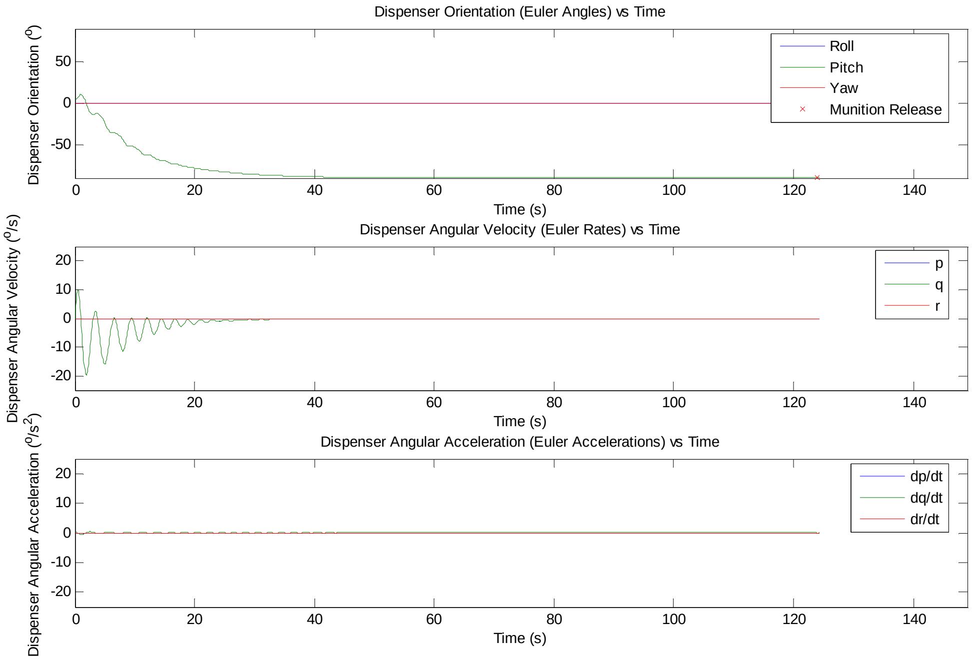

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

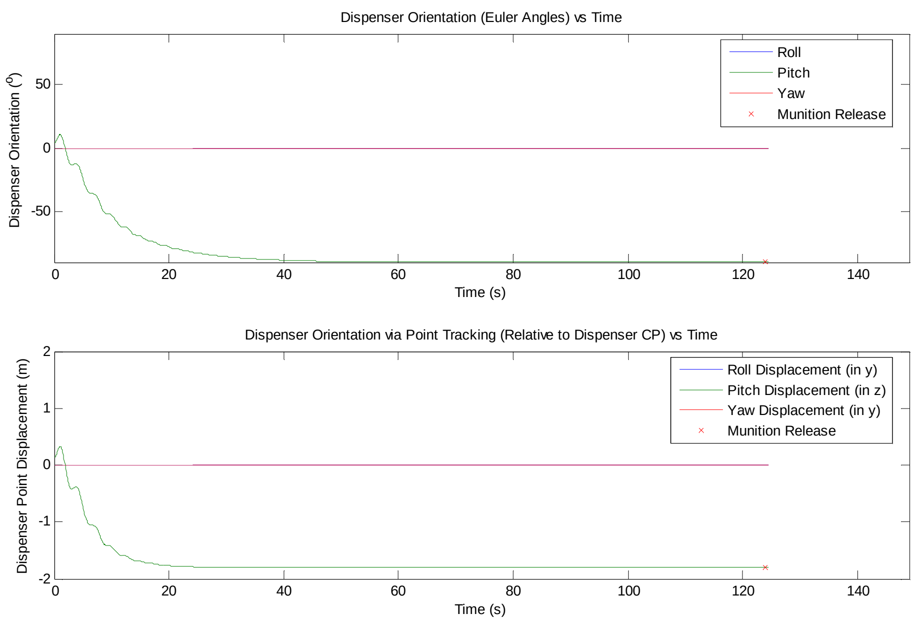

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

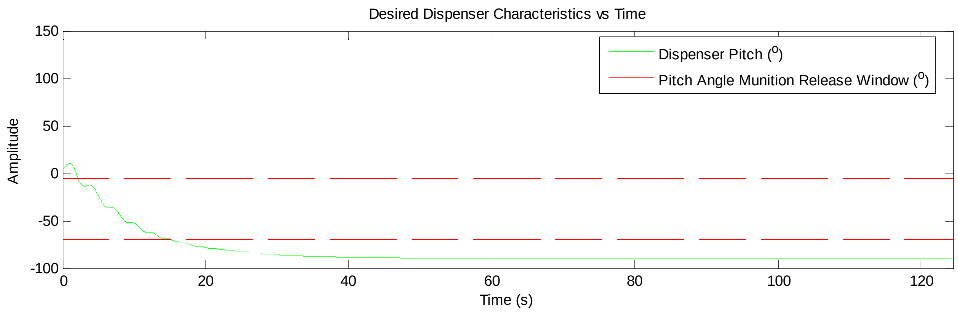

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

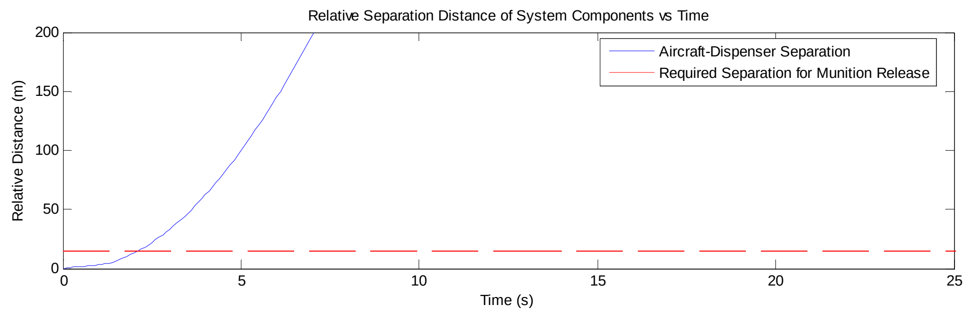

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release


x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

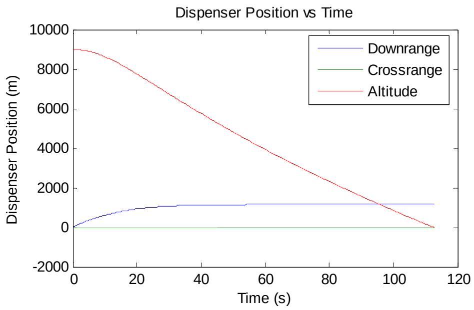

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

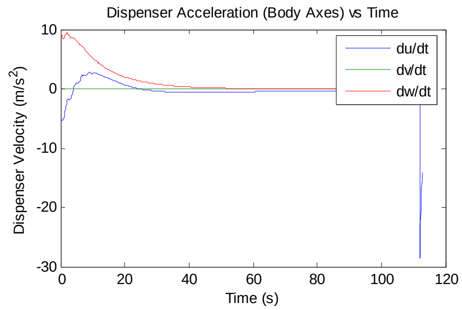

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

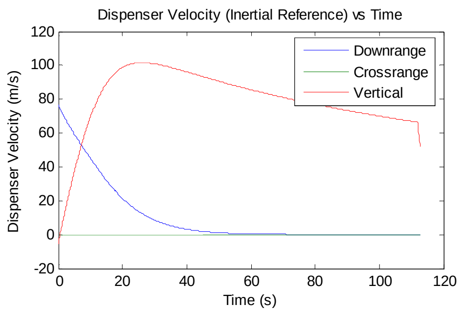

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
Time (s)
150
100
50
0
-50
-100
0
20
40
60
80
100
120

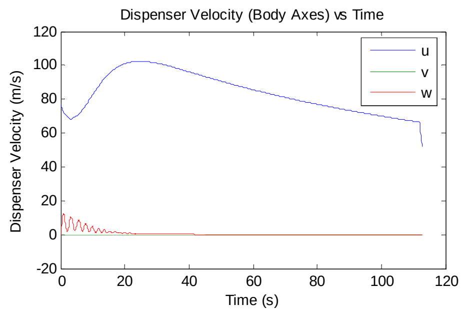

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
Time (s)
200
150
100
50
0
0
5
10
15
20
25

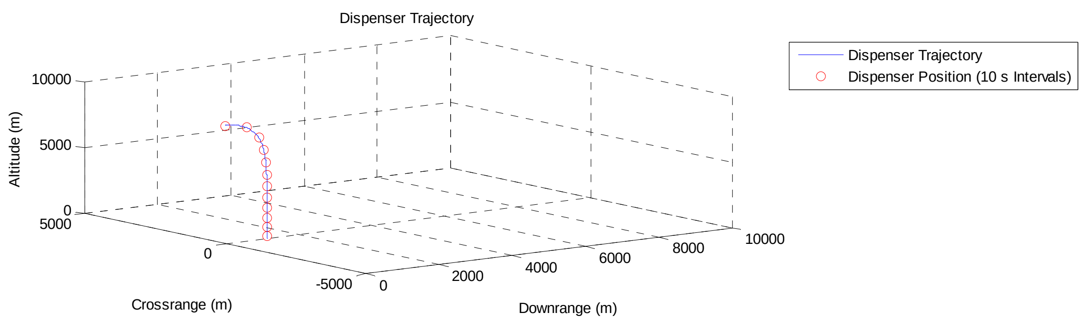
Test #5: Loaded Dispenser - 28' RS, Mid-Harness

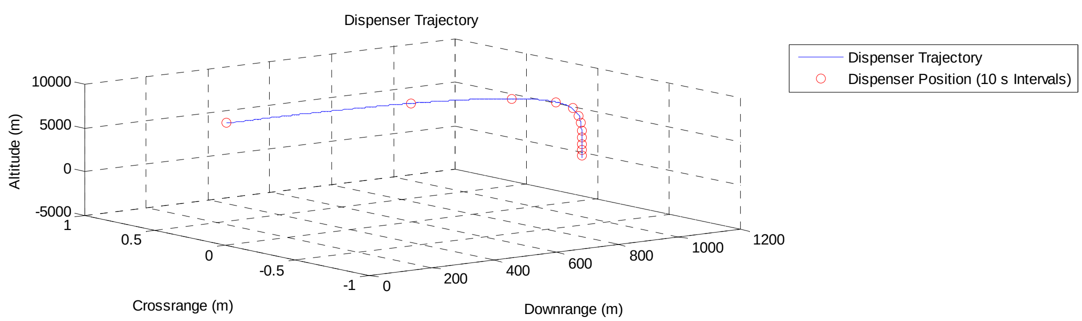


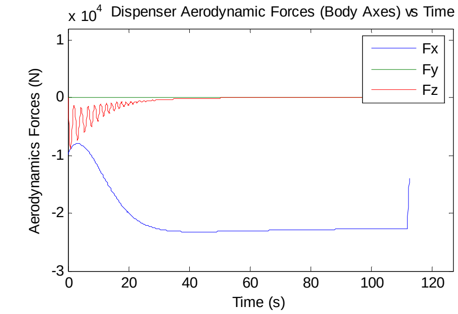


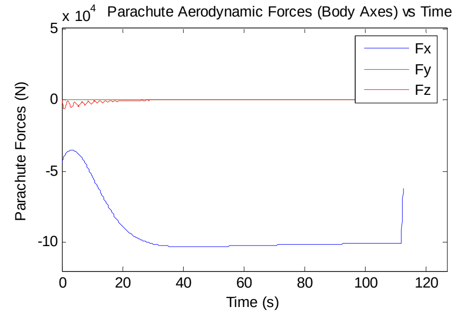


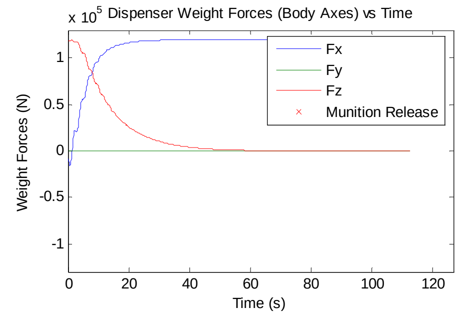


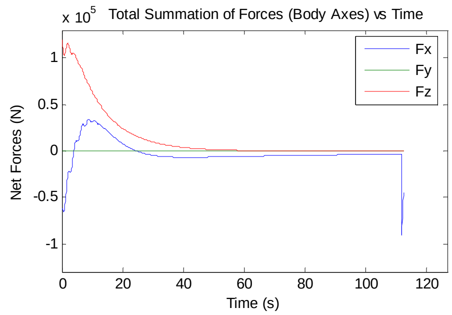


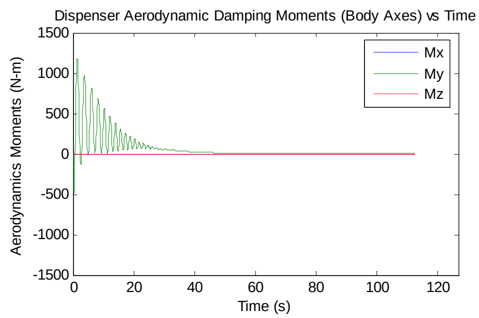


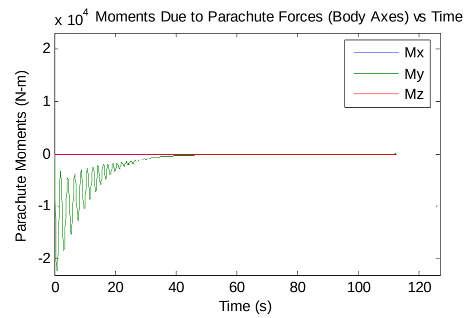

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
1
0
-1
-2
-3
0
20
40
60
80
100
120
Time (s)
Fx
Fy
Fz

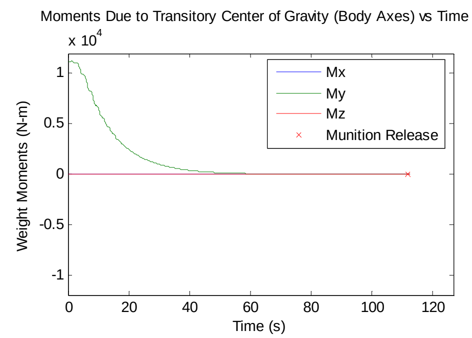

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
5
0
-5
-10
0
20
40
60
80
100
120
Time (s)
Fx
Fy
Fz

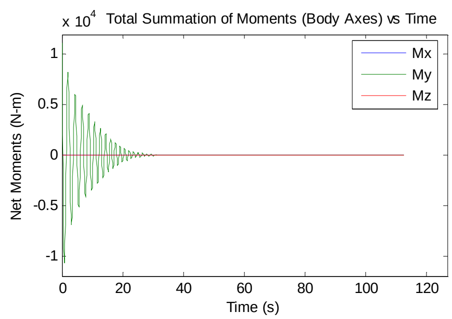

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
Time (s)
Fx
Fy
Fz
Munition Release

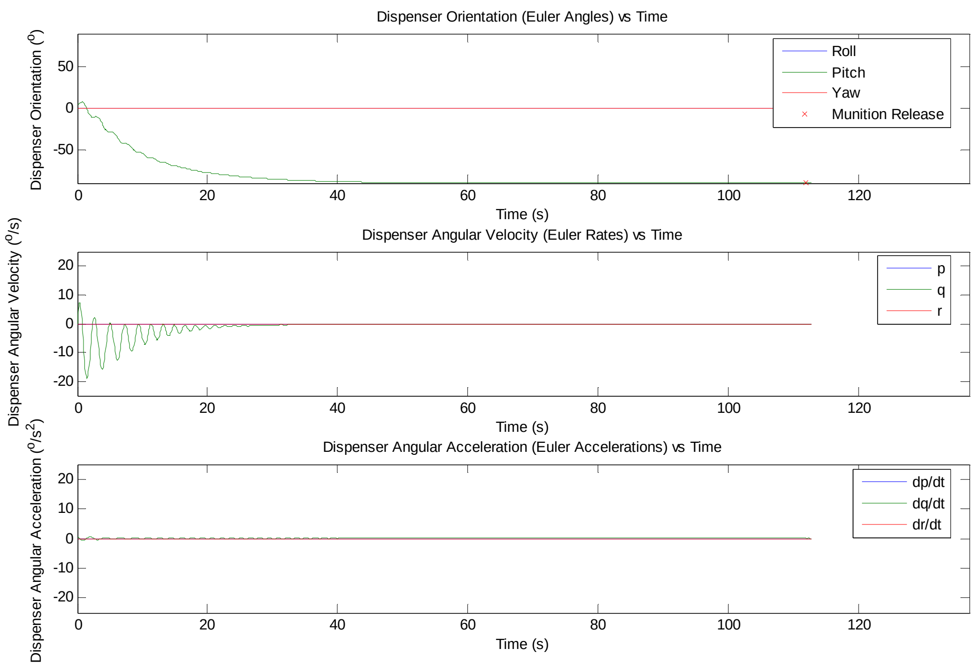

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
Time (s)
Fx
Fy
Fz

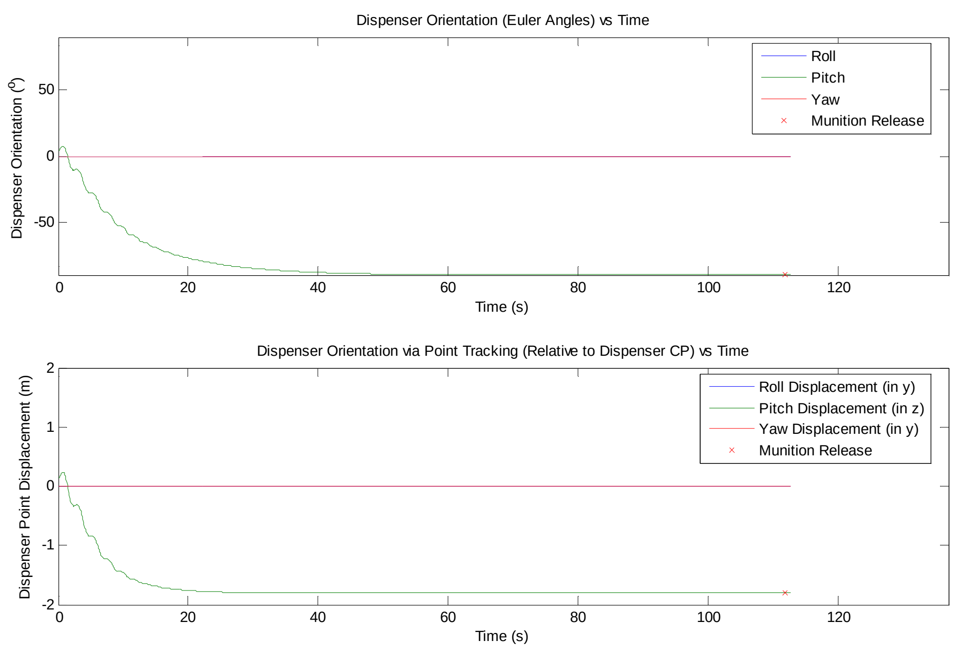

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
120
Time (s)
Mx
My
Mz

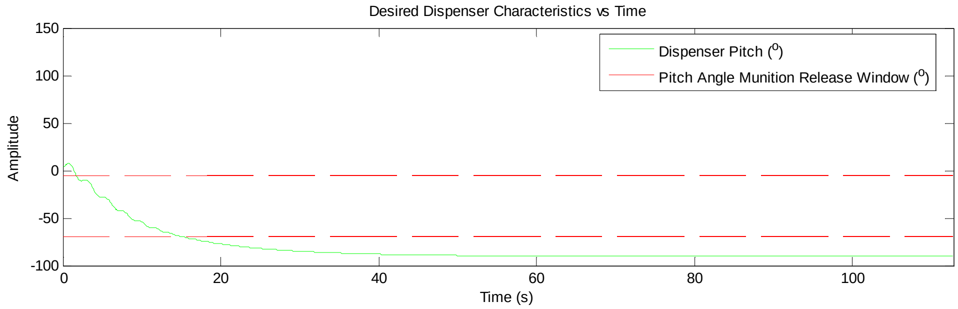

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
2
1
0
-1
-2
0
20
40
60
80
100
120
Time (s)
Mx
My
Mz

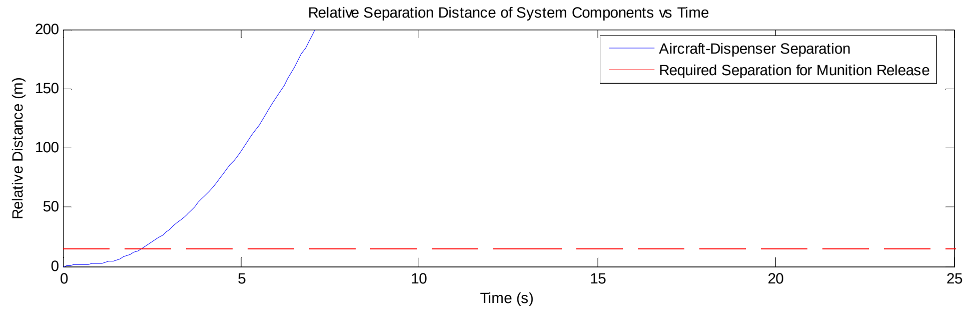

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
Time (s)
Mx
My
Mz
Munition Release


x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
1
0.5
0
-0.5
-1
0
20
40
60
80
100
120
Time (s)
Mx
My
Mz

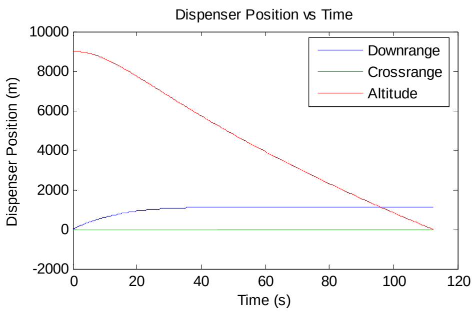

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

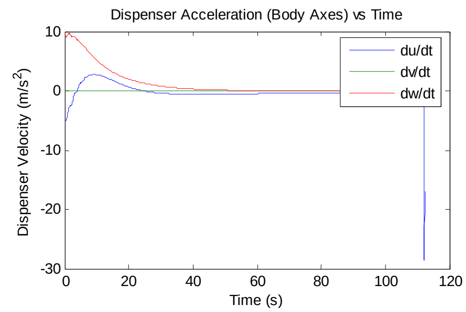

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

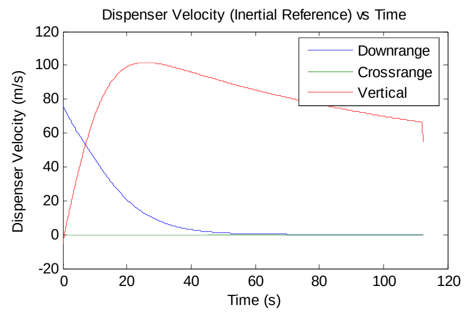

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
Time (s)
150
100
50
0
-50
-100
0
20
40
60
80
100

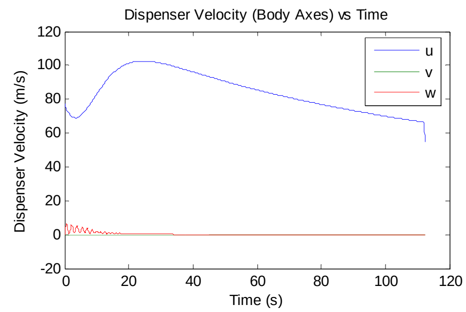

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
Time (s)
200
150
100
50
0
0
5
10
15
20
25

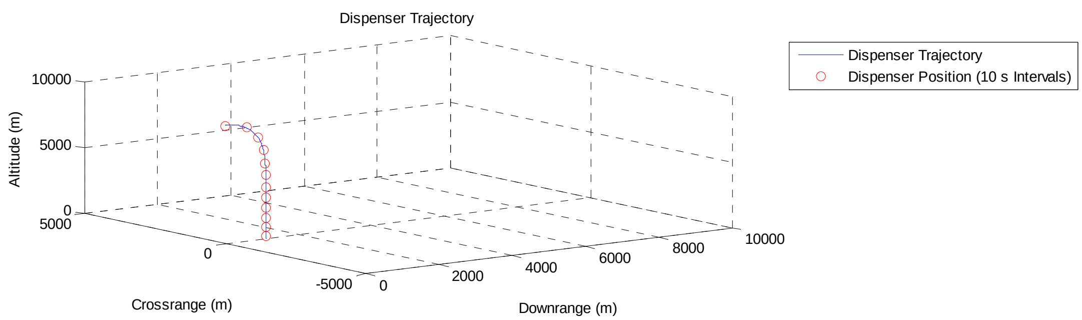
Test #6: Loaded Dispenser - 28' RS, Long-Harness

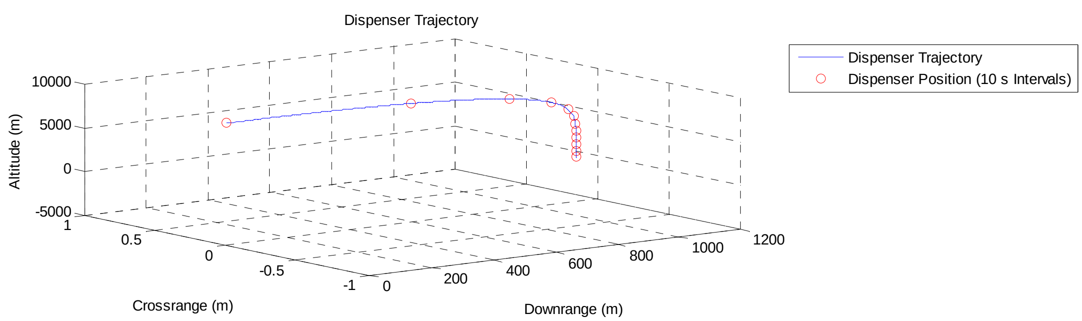


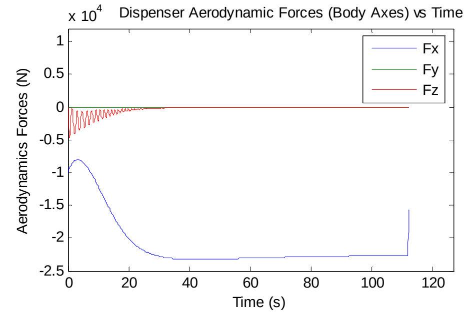


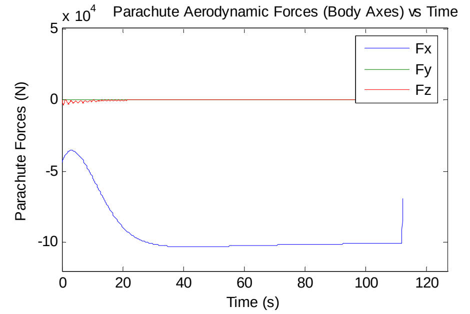


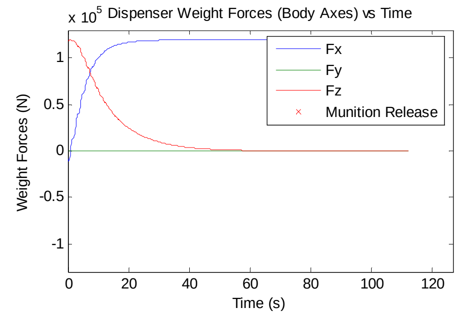


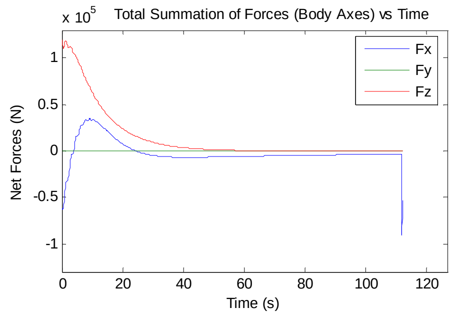


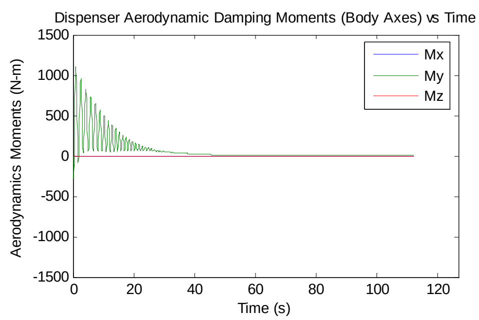


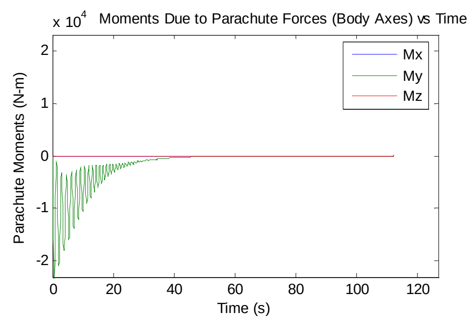

Dispenser Aerodynamic Forces (Body Axes) vs Time
x 10^4
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

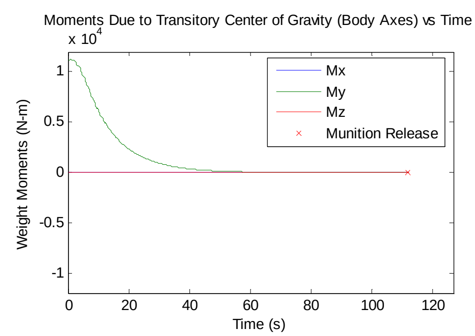

Parachute Aerodynamic Forces (Body Axes) vs Time
x 10^4
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

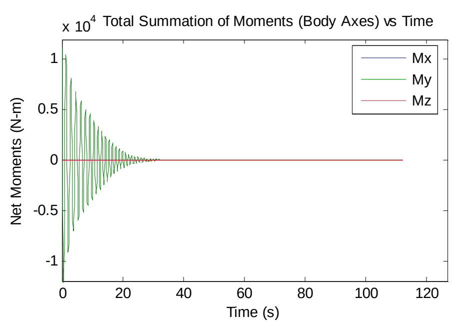

Dispenser Weight Forces (Body Axes) vs Time
x 10^5
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

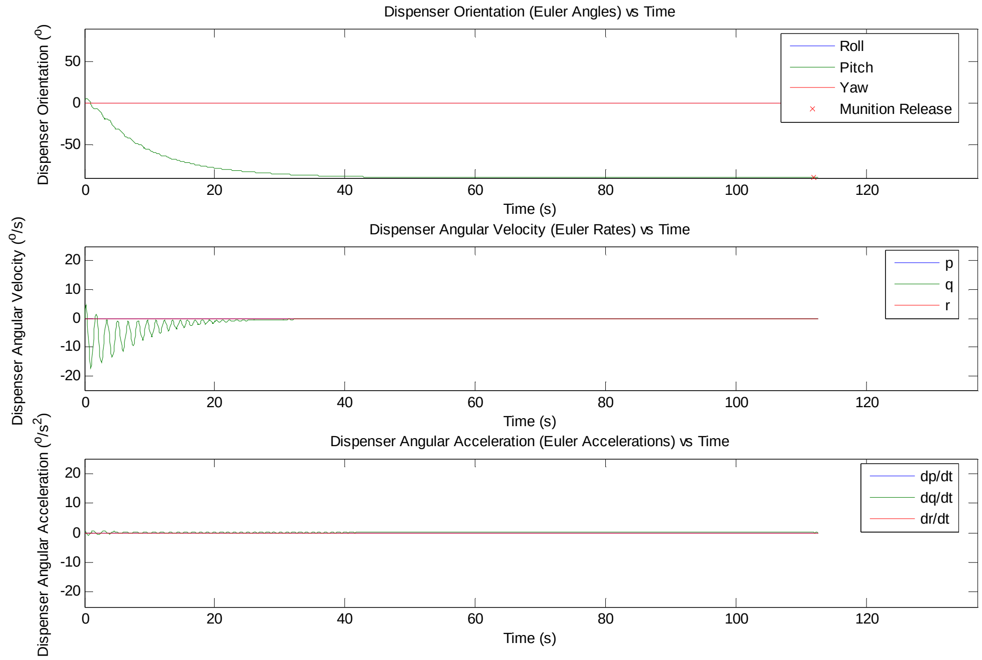

Total Summation of Forces (Body Axes) vs Time
x 10^5
Net Forces (N)
Time (s)
Fx
Fy
Fz

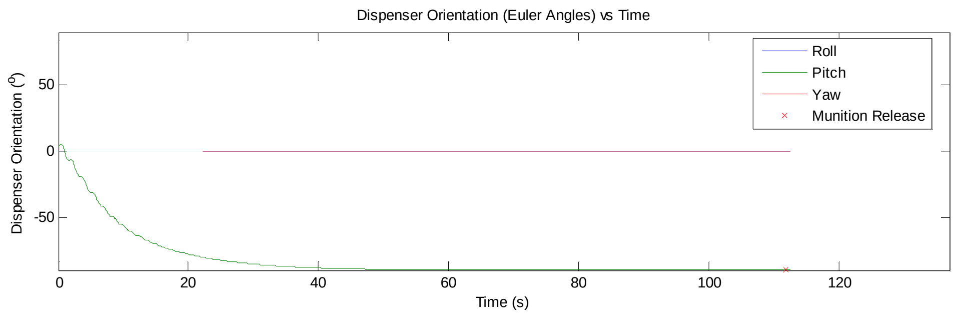

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

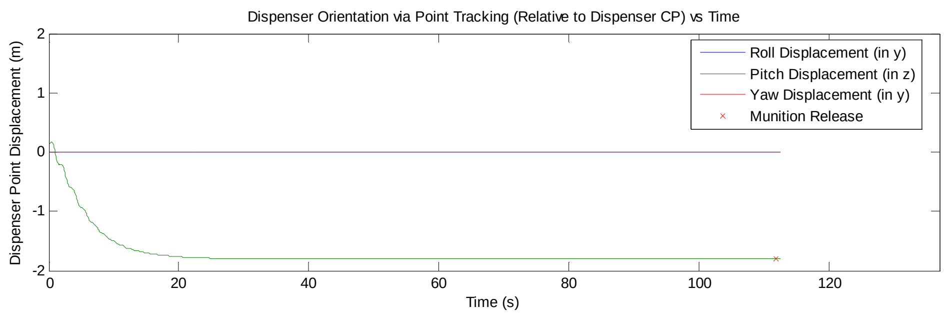

Moments Due to Parachute Forces (Body Axes) vs Time
x 10^4
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

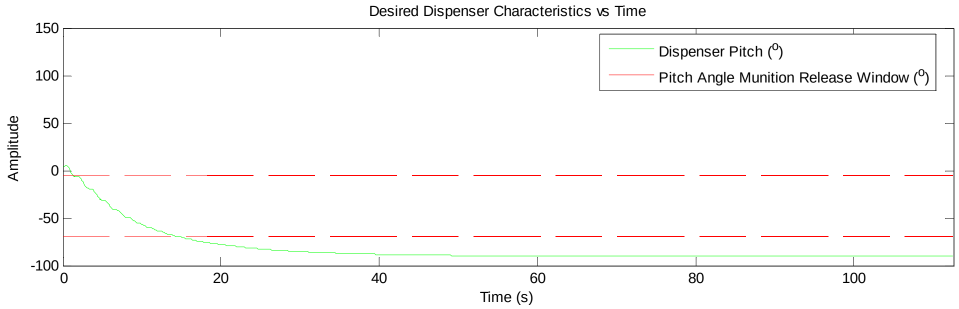

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

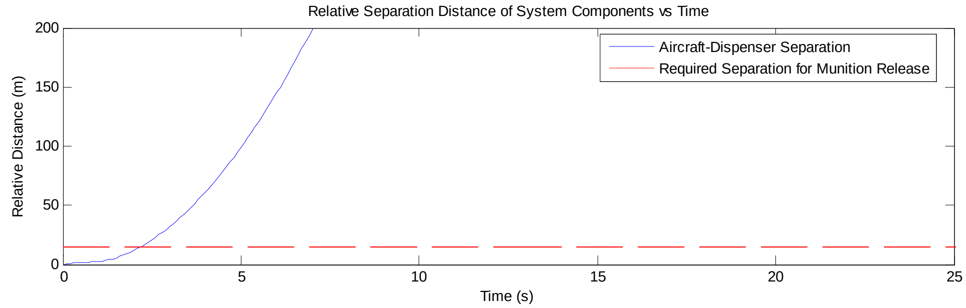

Total Summation of Moments (Body Axes) vs Time
x 10^4
Net Moments (N-m)
Time (s)
Mx
My
Mz


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

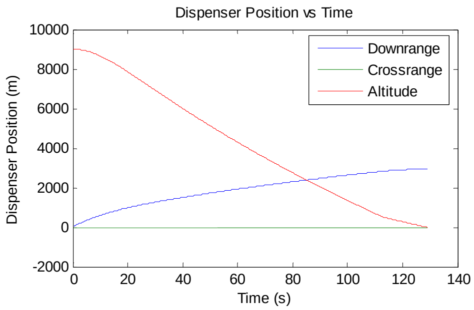

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

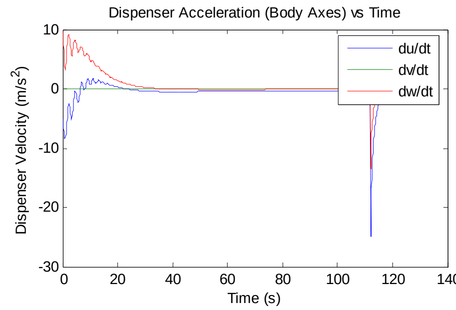

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

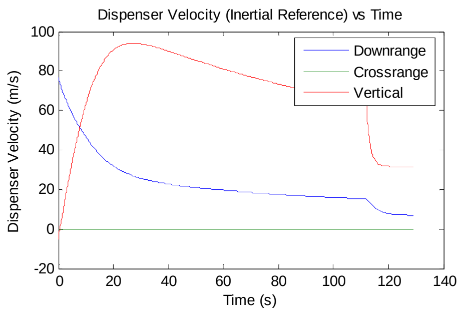

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
150
100
50
0
-50
-100
0
20
40
60
80
100
Time (s)

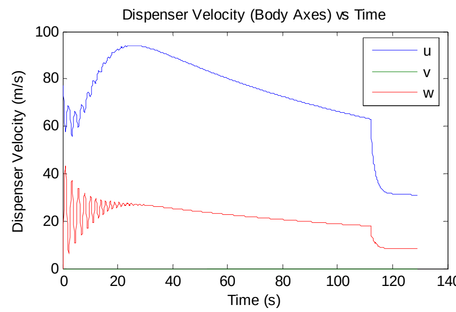

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
200
150
100
50
0
0
5
10
15
20
25
Time (s)

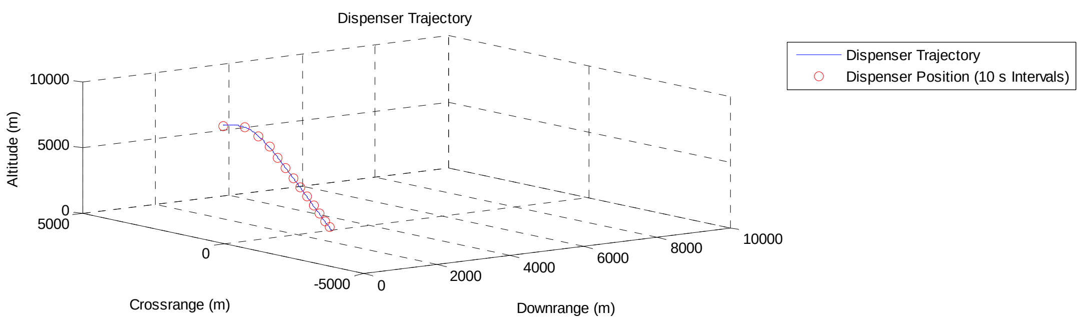
Test #7: Loaded Dispenser - 28' RS, Offset-Harness

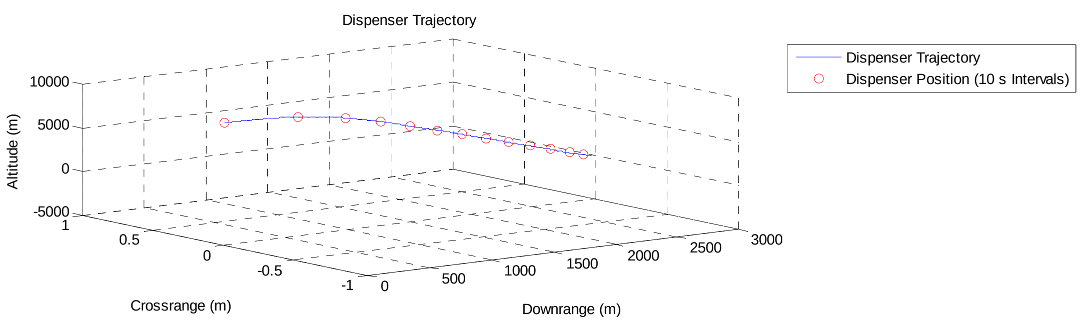


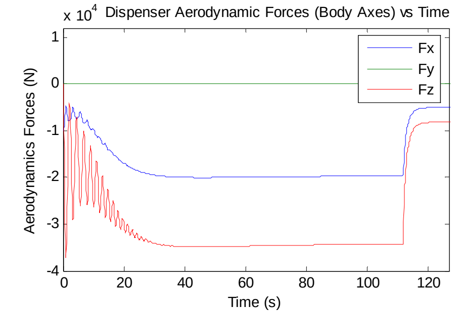


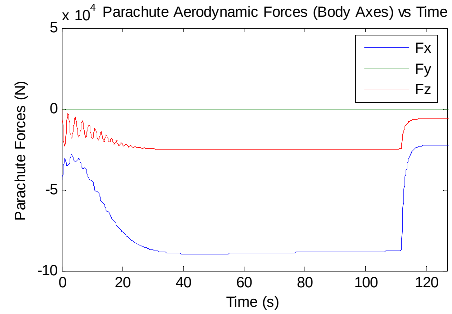


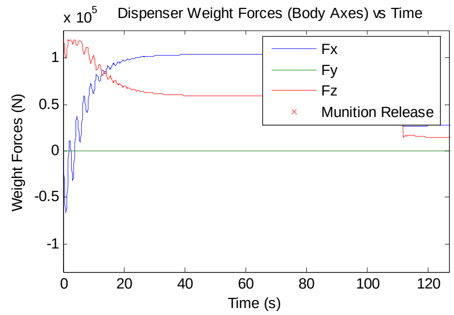


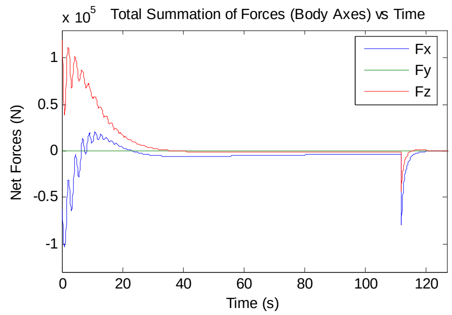


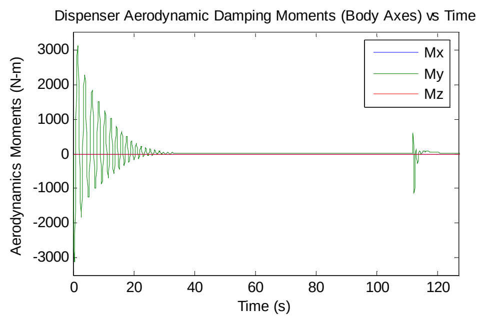



x 10^4
Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

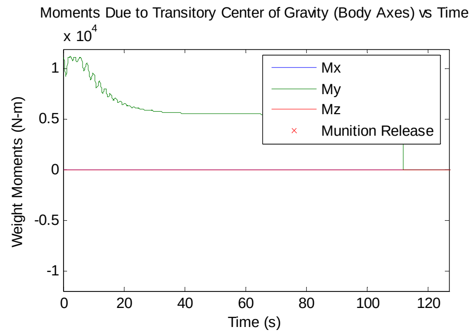

x 10^4
Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

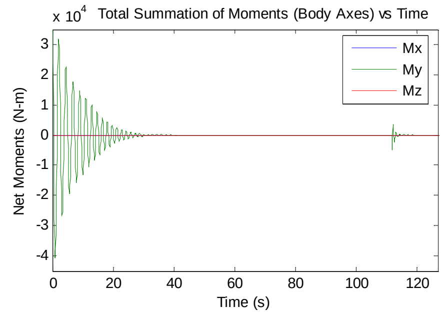

x 10^5
Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

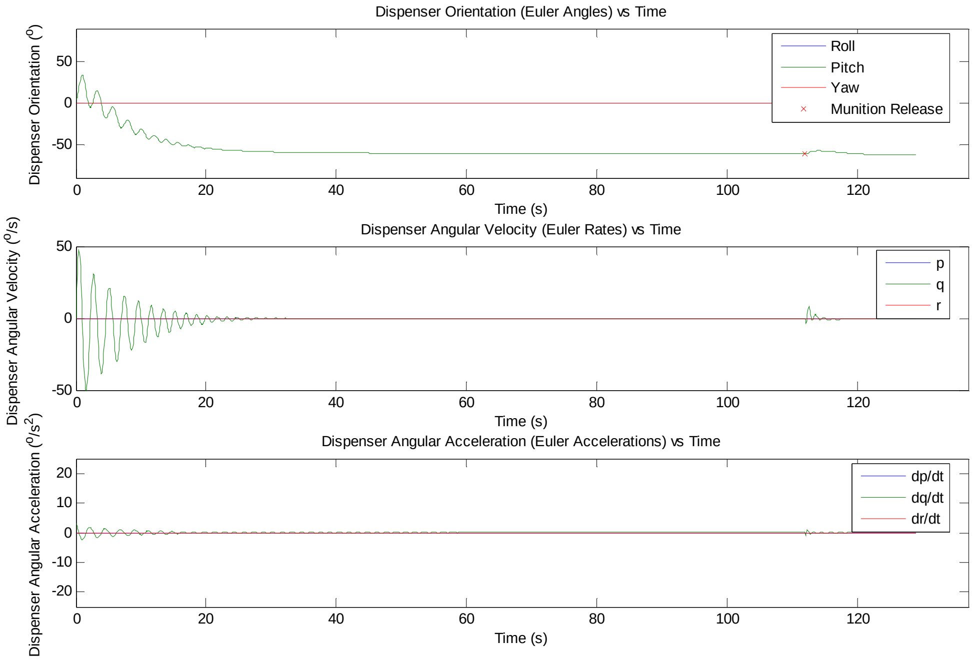

x 10^5
Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

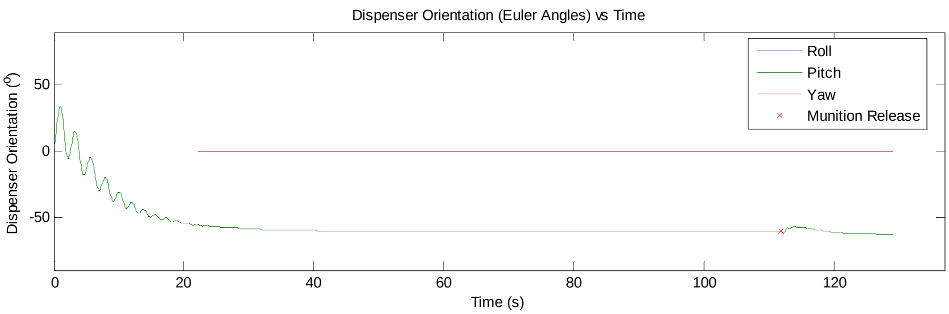

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

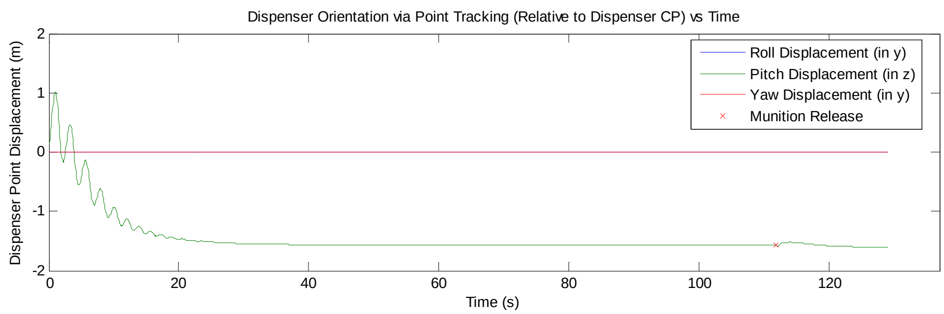

x 10^4
Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

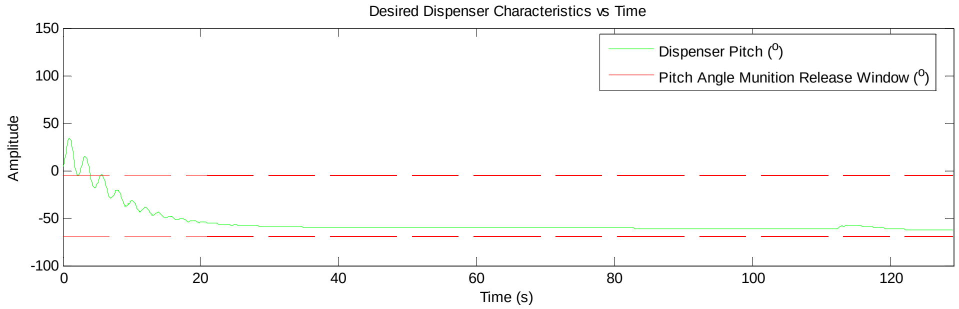

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

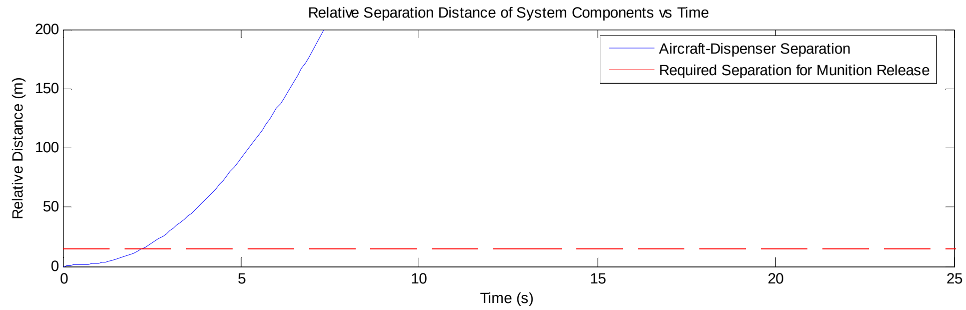

x 10^4
Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

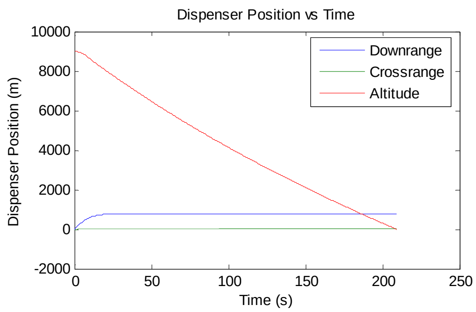

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)

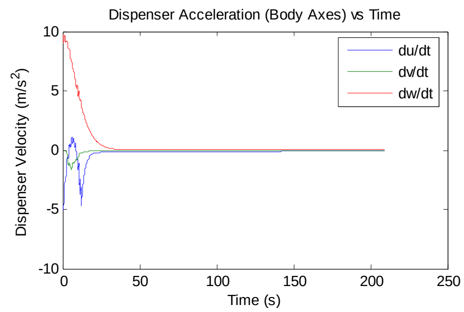

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Time (s)

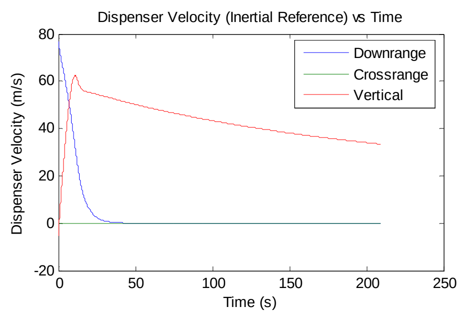

Desired Dispenser Characteristics vs Time
Dispenser Pitch (°)
Pitch Angle Munition Release Window (°)
Amplitude
150
100
50
0
-50
-100
0
20
40
60
80
100
120
Time (s)

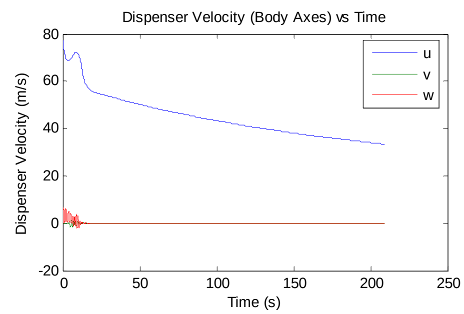

Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Required Separation for Munition Release
Relative Distance (m)
200
150
100
50
0
0
5
10
15
20
25
Time (s)

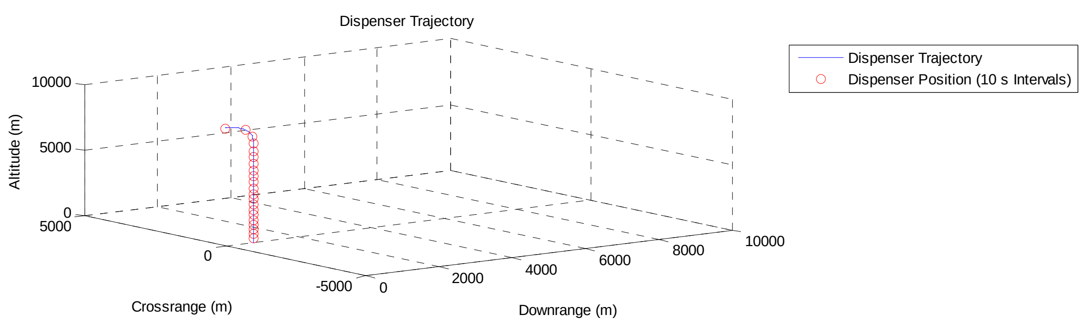
Test #8: Baseline Dispenser - Favorable Release

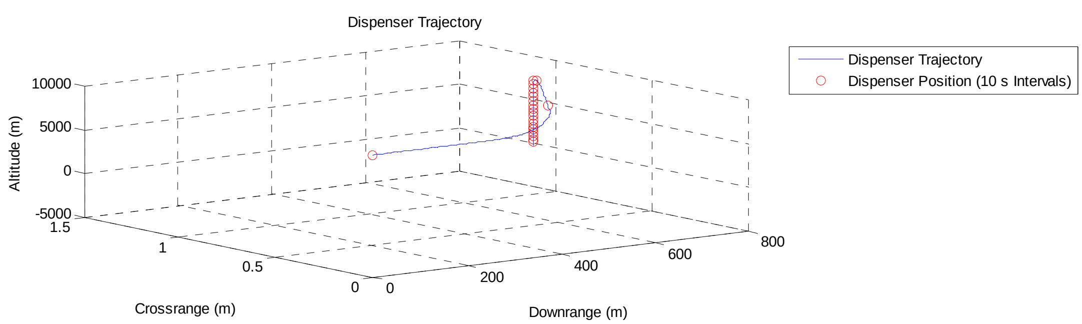


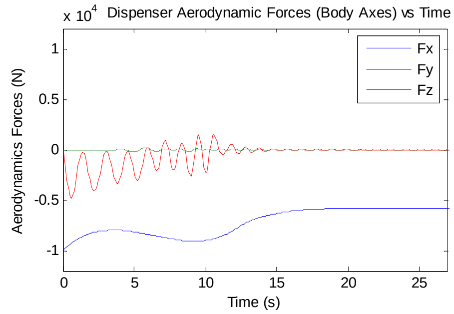


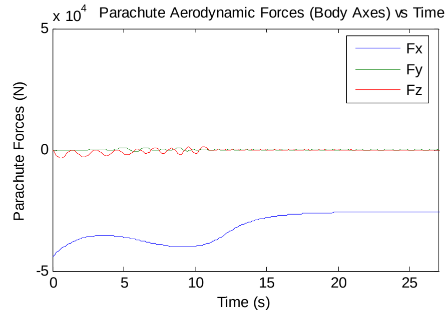


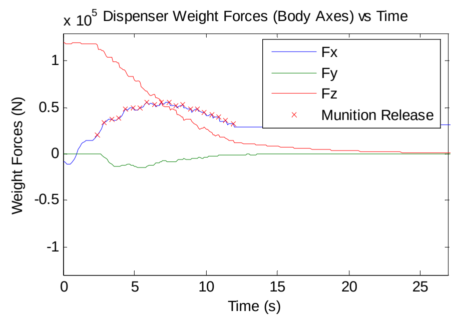


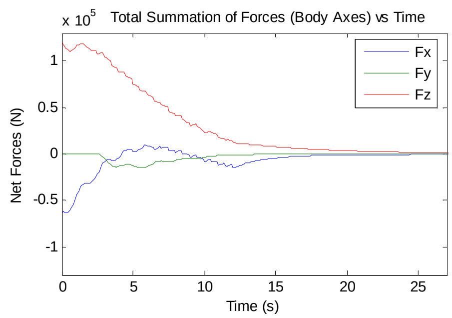


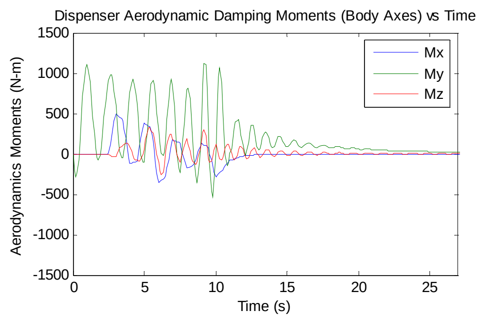


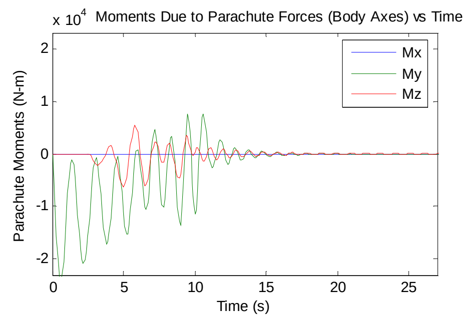

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

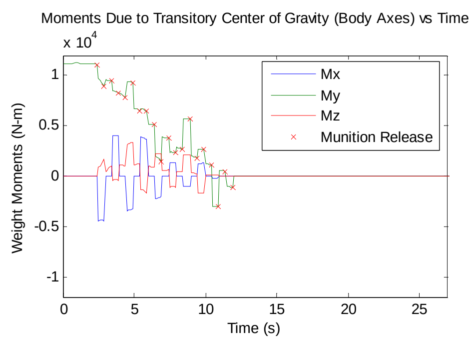

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

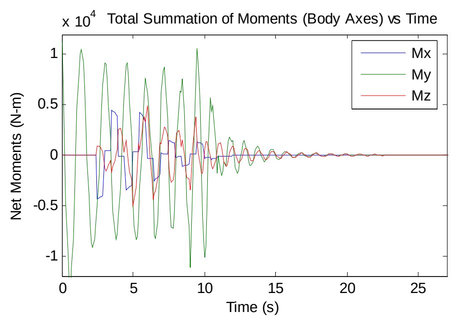

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

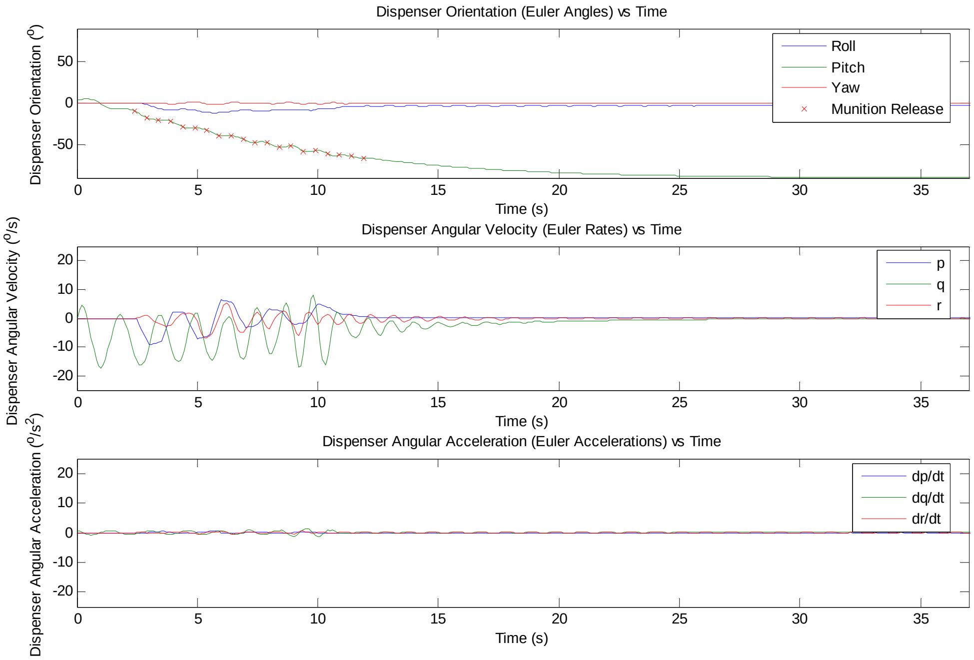

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

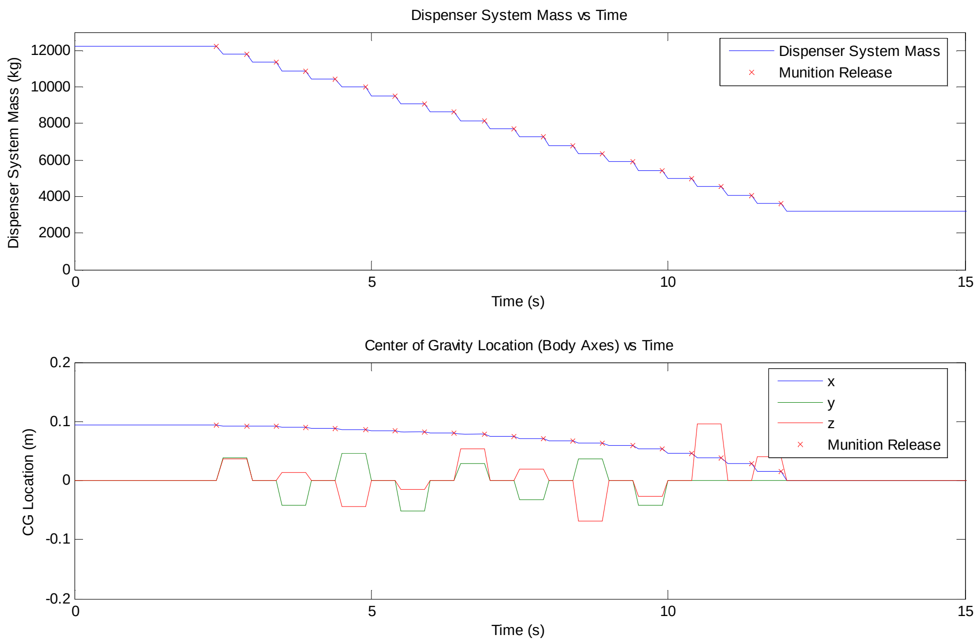

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

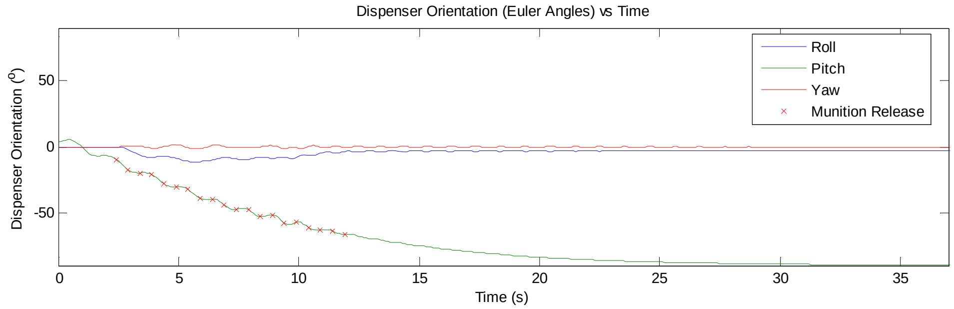

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz


Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

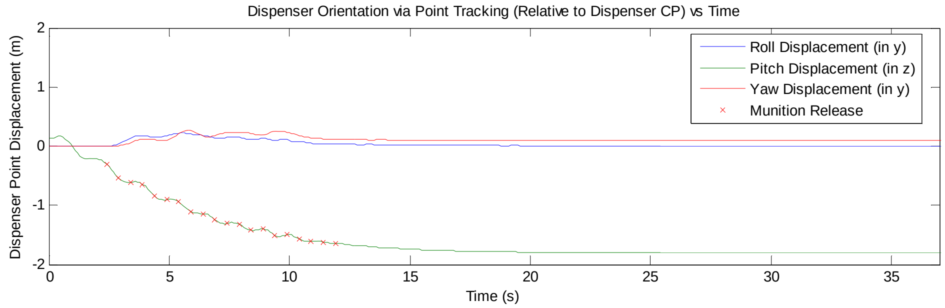

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

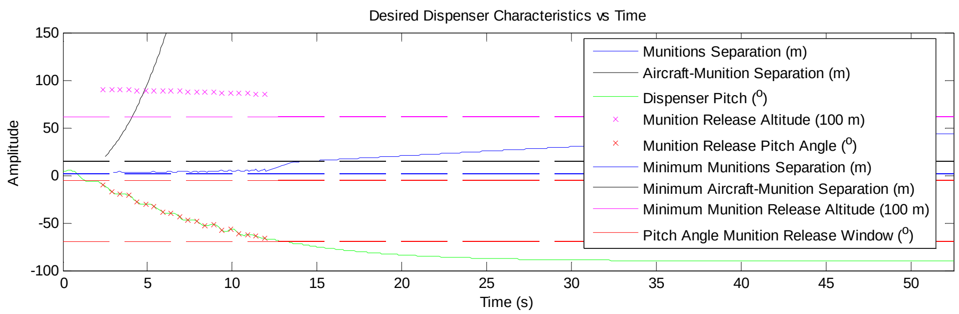

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release
Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release



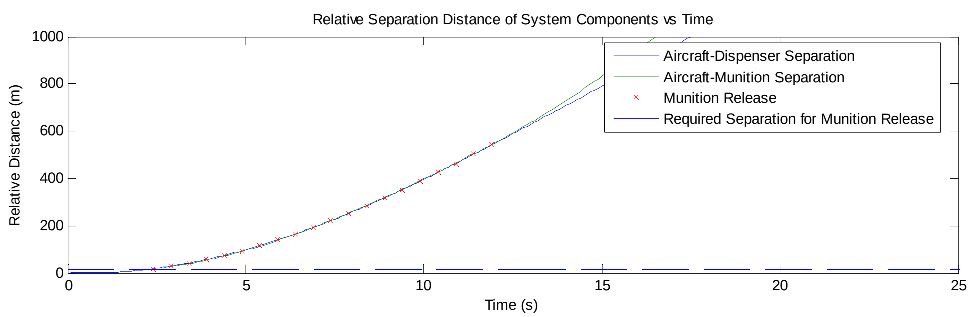
Dispenser Orientation (Euler Angles) vs Time
Roll
Pitch
Yaw
Munition Release
Dispenser Orientation (°)
Time (s)



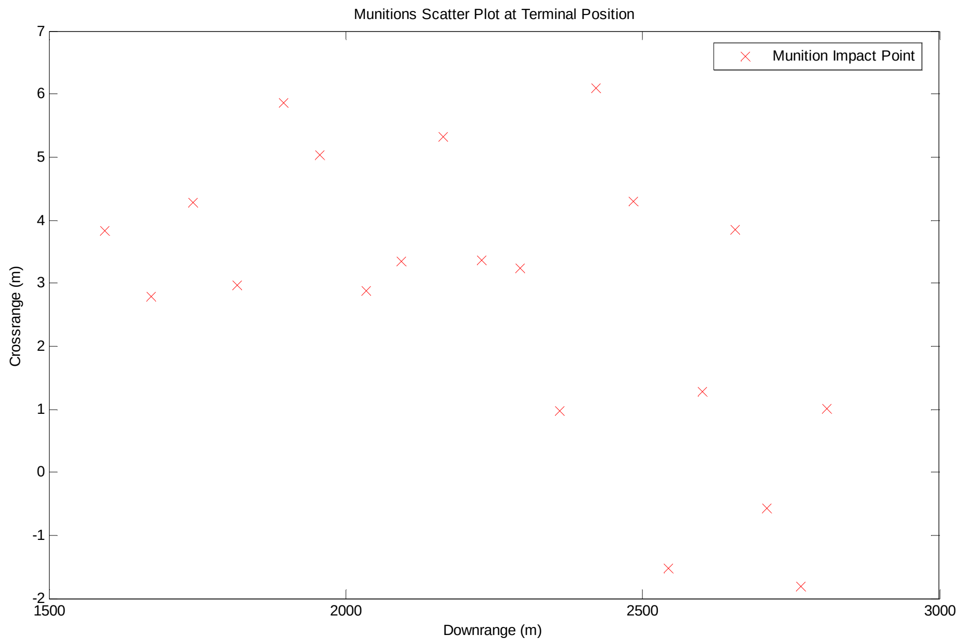
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Dispenser Point Displacement (m)
Time (s)



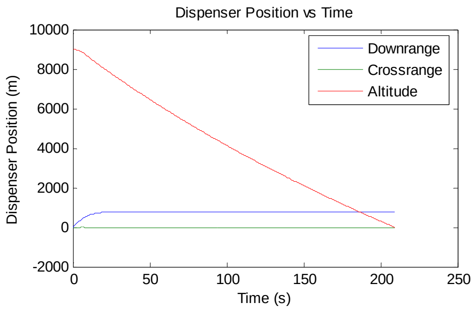
Desired Dispenser Characteristics vs Time
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
Amplitude
Time (s)

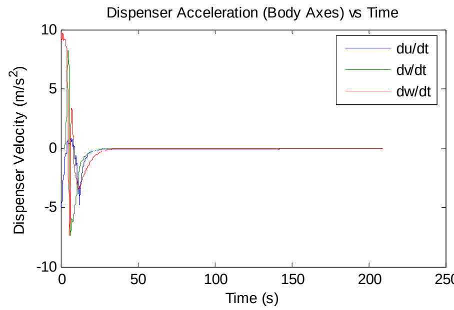


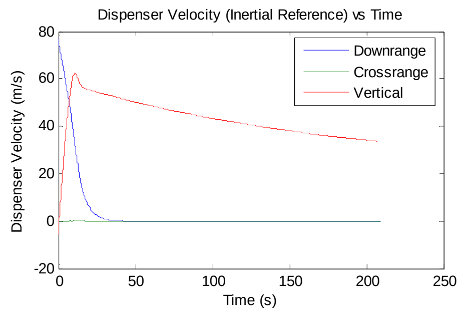
Relative Separation Distance of System Components vs Time
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release
Relative Distance (m)
Time (s)

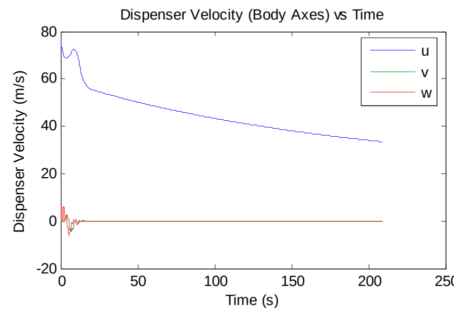

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
7
6
5
4
3
2
1
0
-1
-2
1500
2000
2500
3000

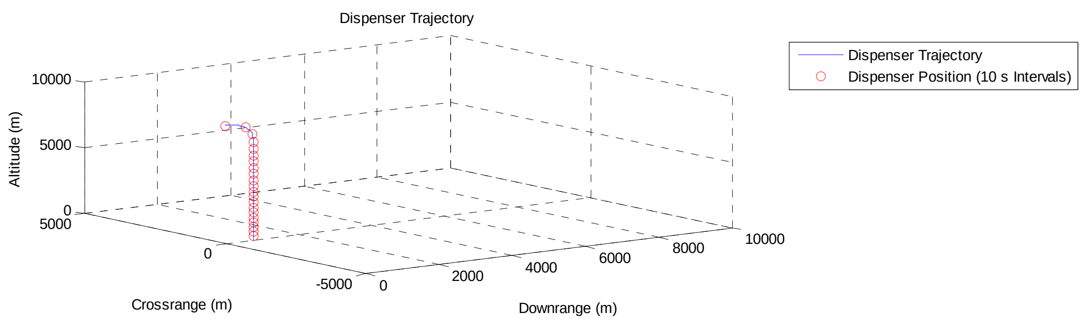
Test #9: Baseline Dispenser - Spiral Release

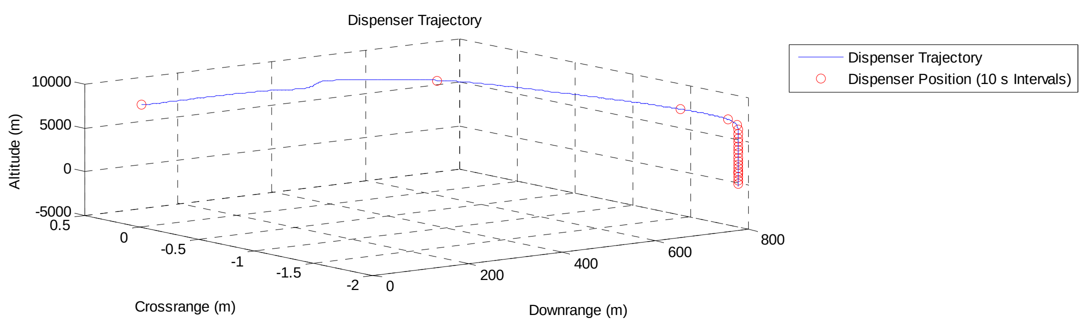


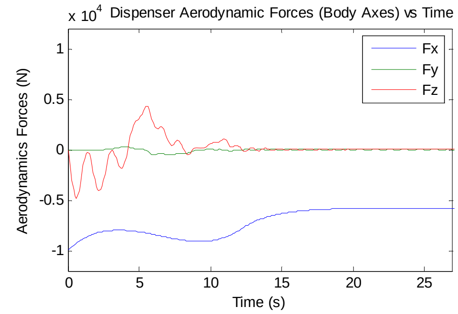


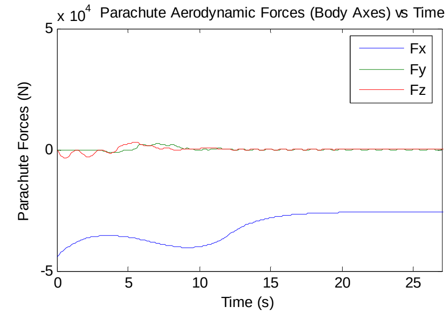


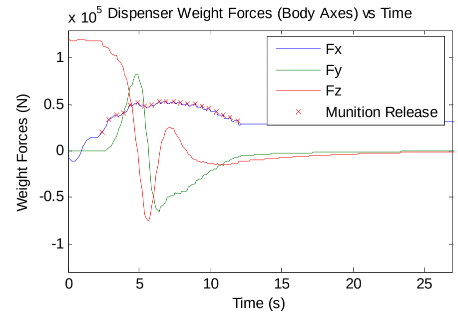


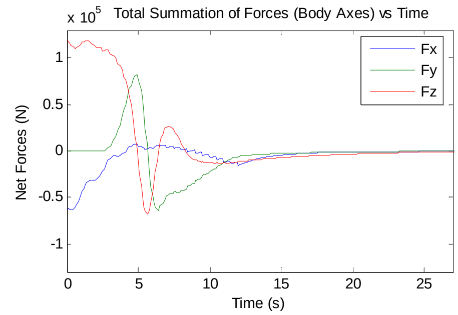


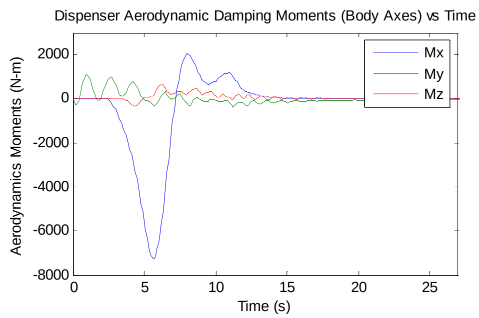


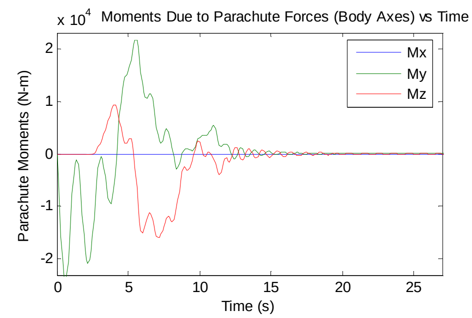

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

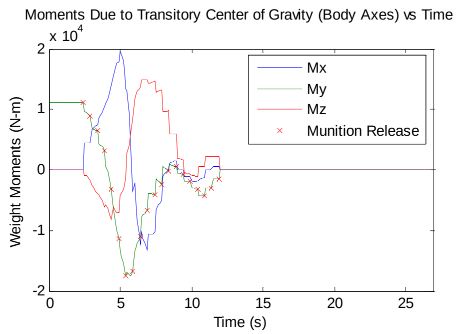

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

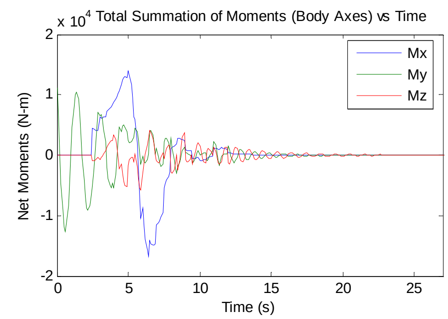

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

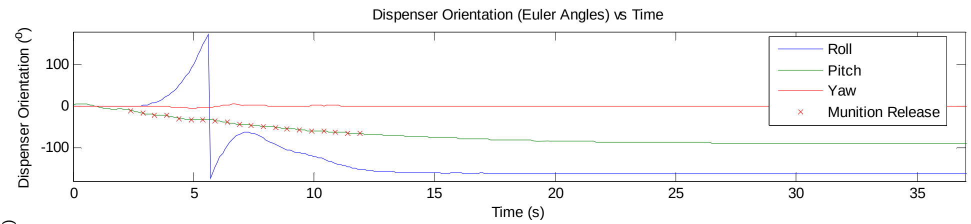

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

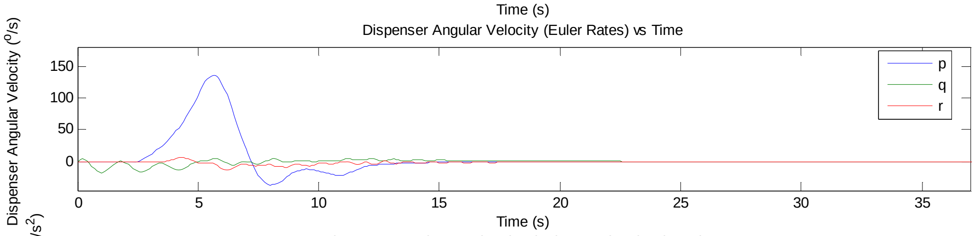

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

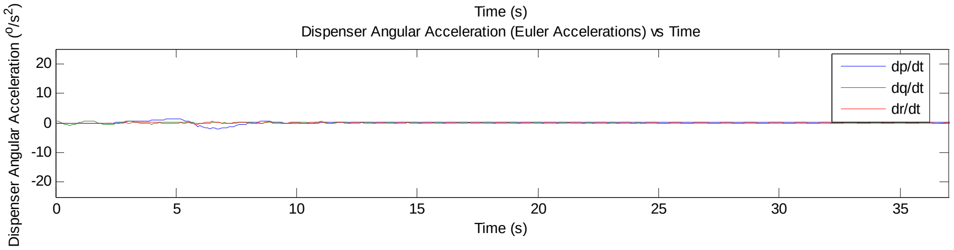

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

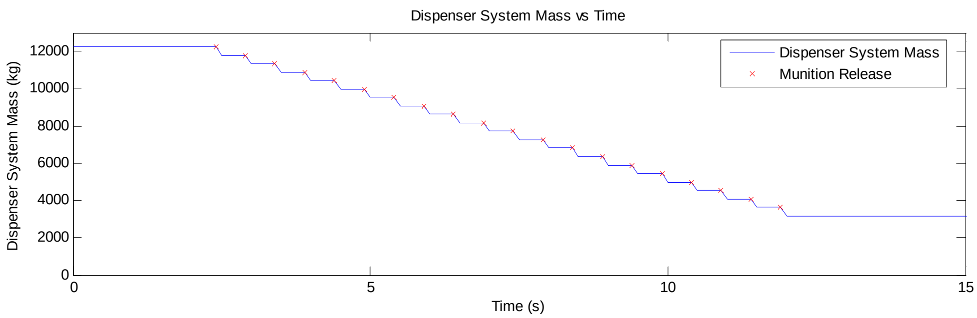

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

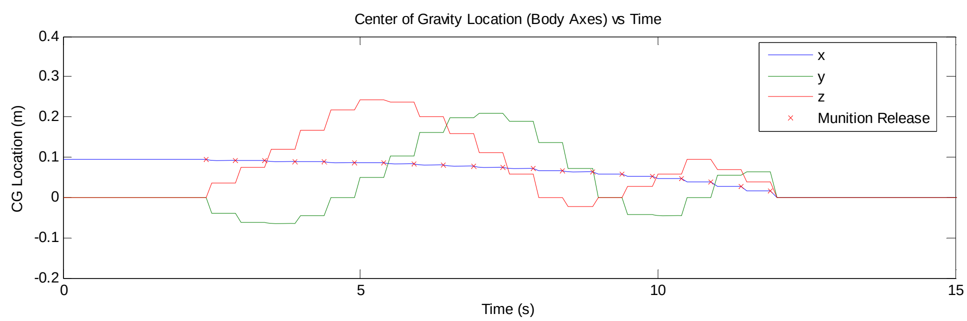

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

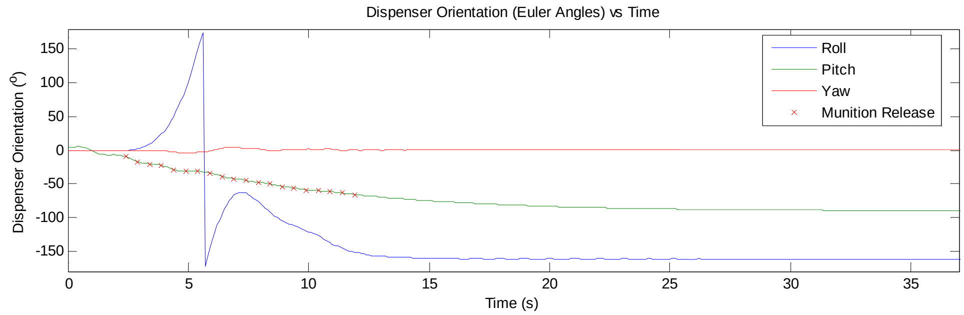

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

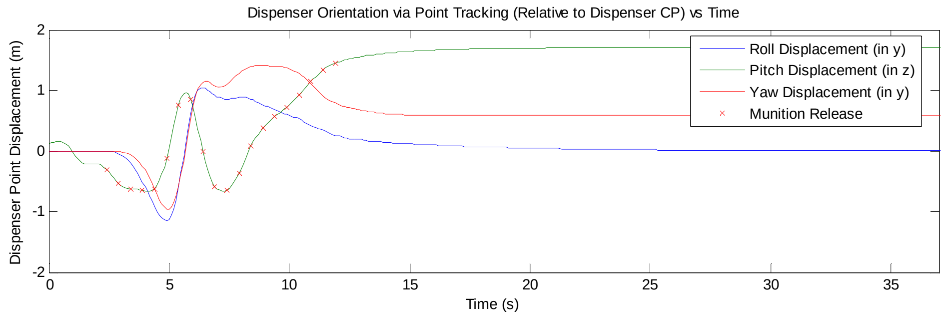

Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r

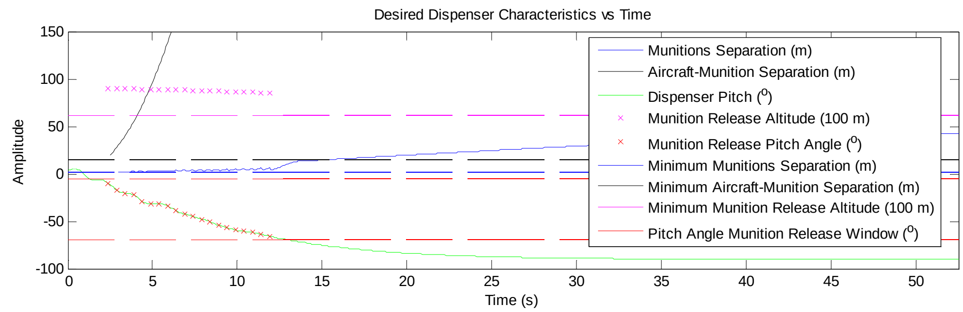

Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

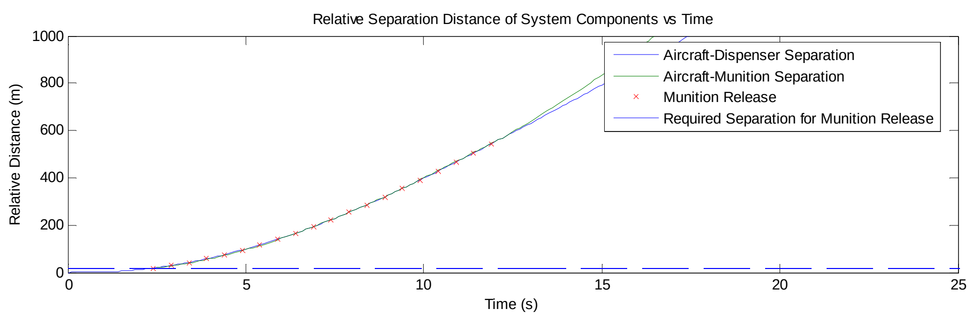

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

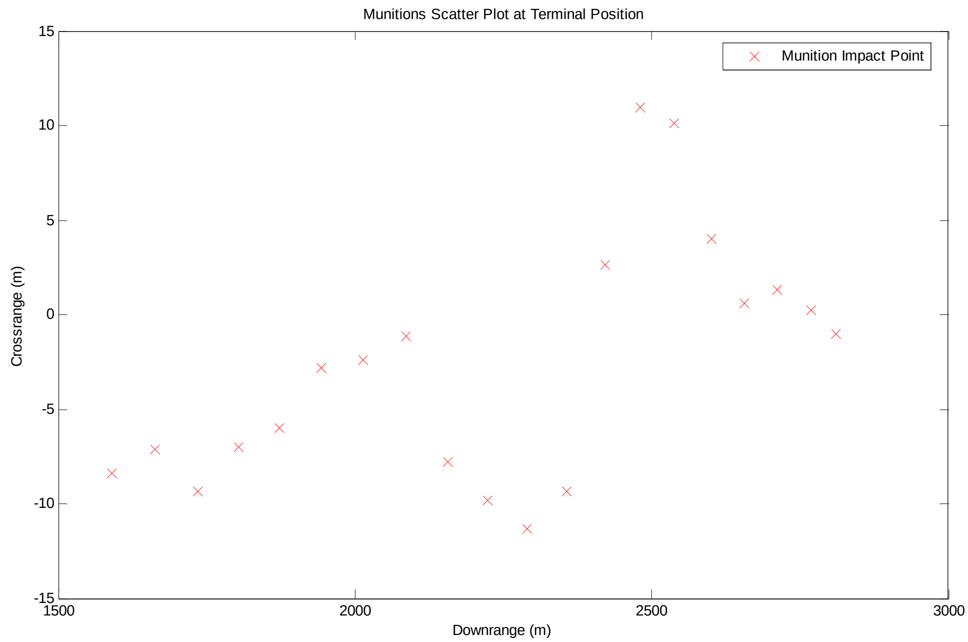

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
150
100
50
0
-50
-100
-150
0
5
10
15
20
25
30
35

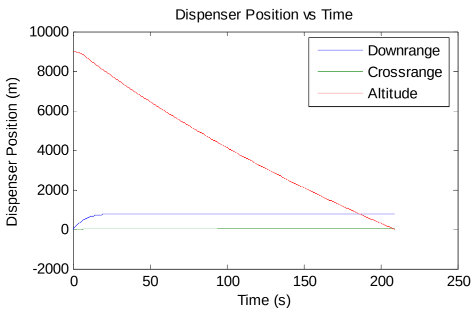

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
2
1
0
-1
-2
0
5
10
15
20
25
30
35

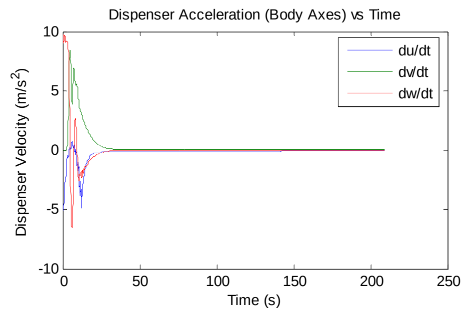

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
150
100
50
0
-50
-100
0
5
10
15
20
25
30
35
40
45
50

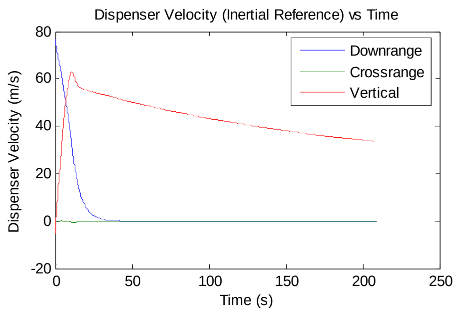

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release
1000
800
600
400
200
0
0
5
10
15
20
25

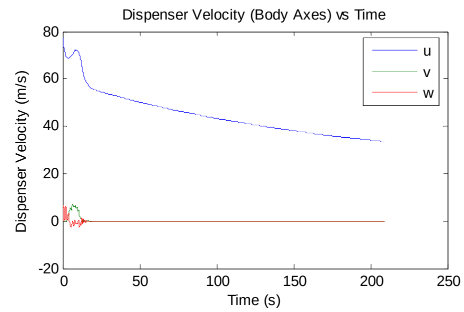

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
15
10
5
0
-5
-10
-15
1500
2000
2500
3000

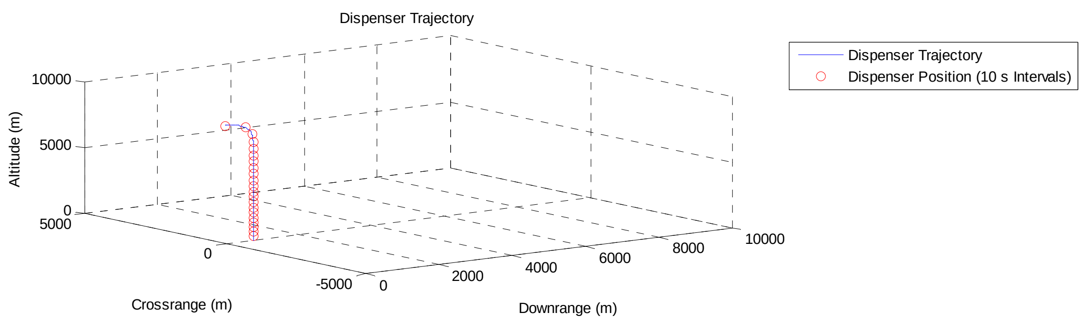
Test #10: Baseline Dispenser - Side-to-Side Release

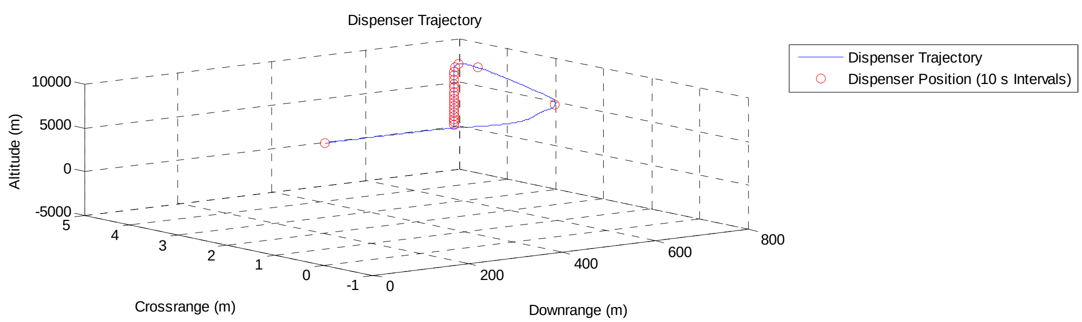


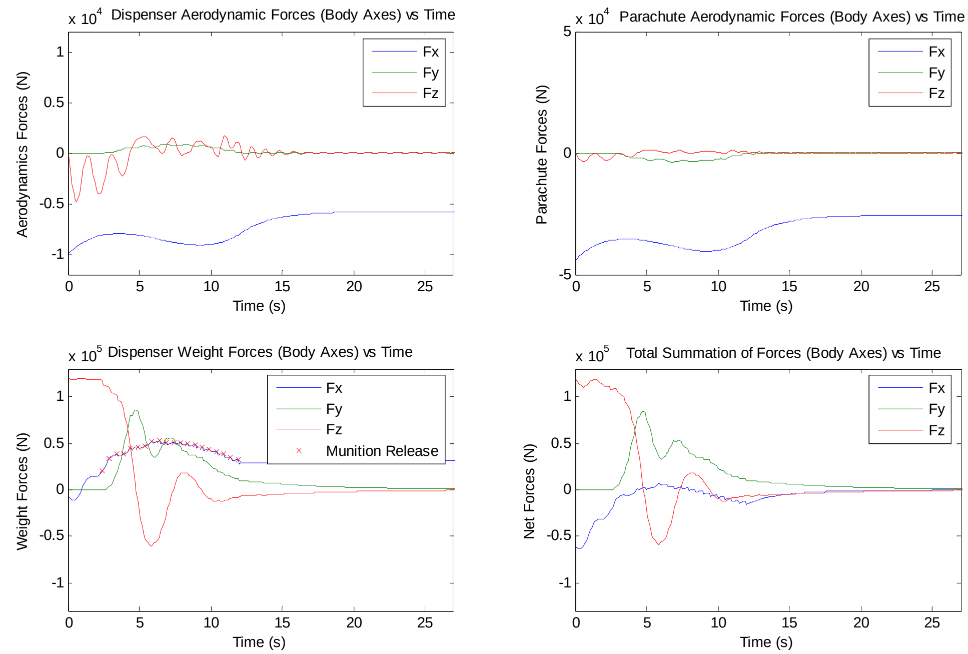


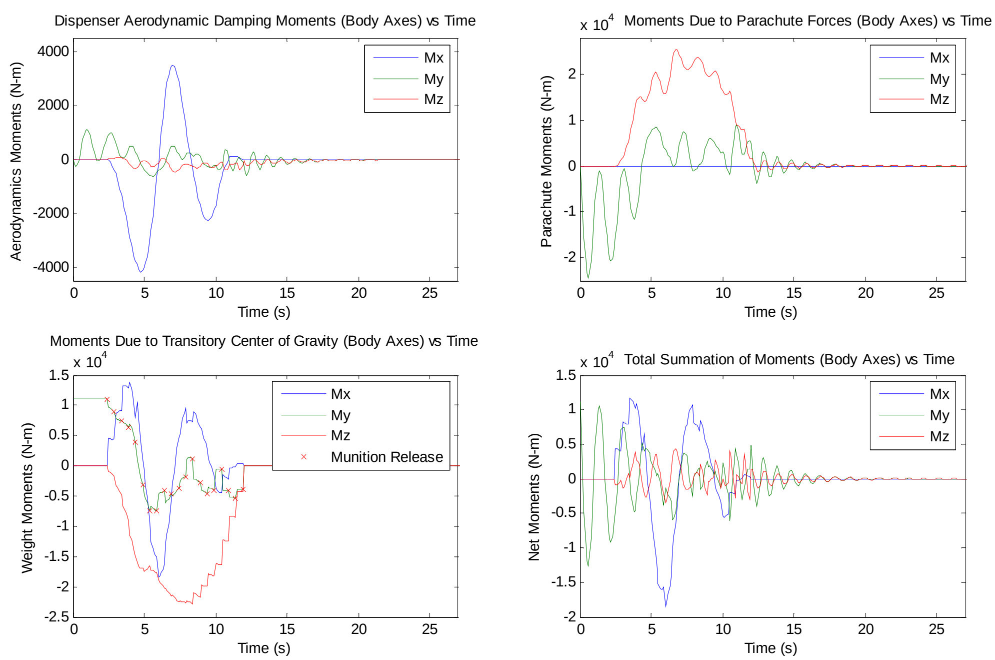


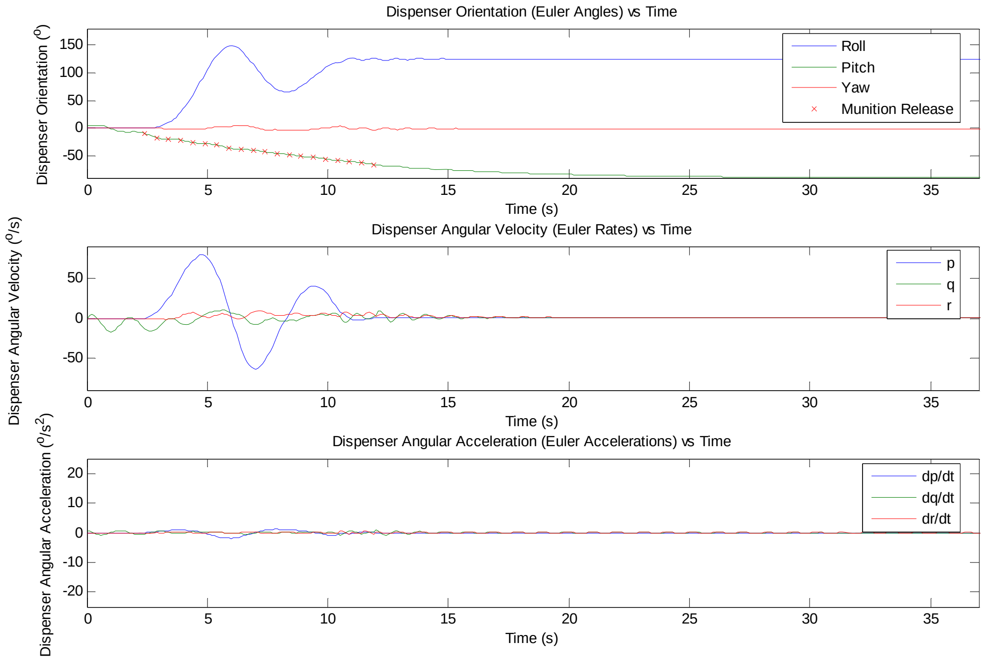


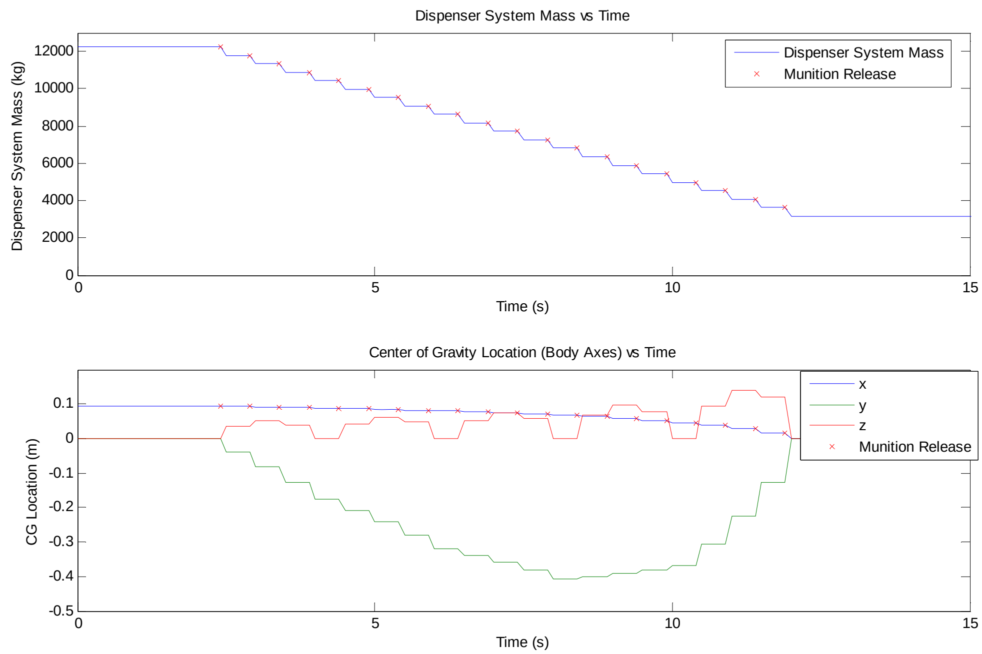


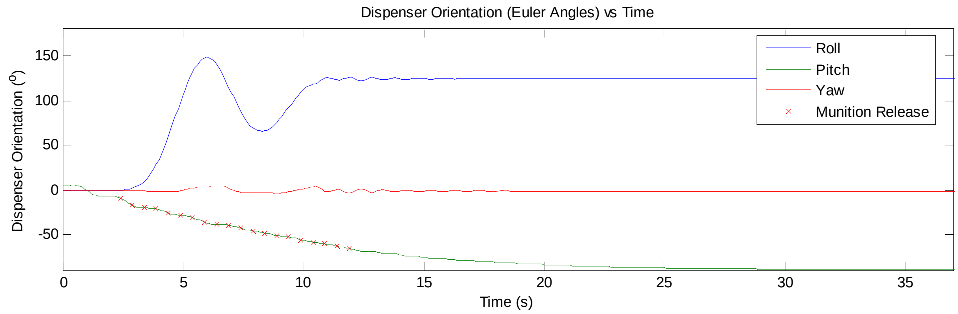


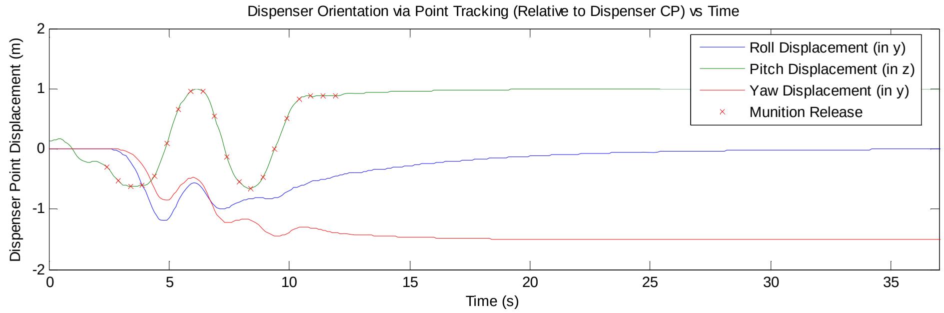

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz
x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz
x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release
x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

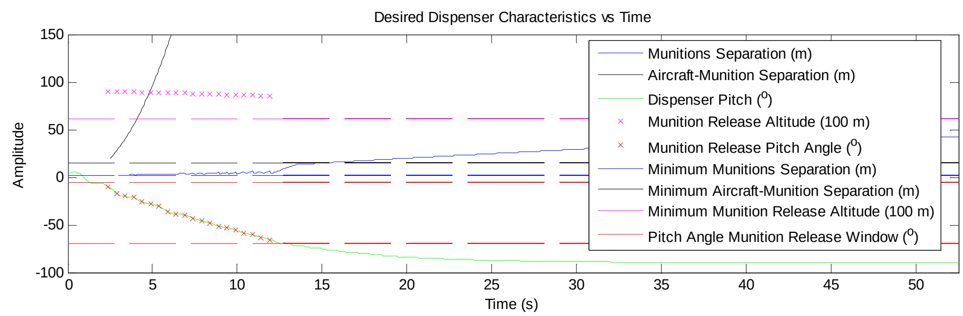

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz
x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz
Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release
x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

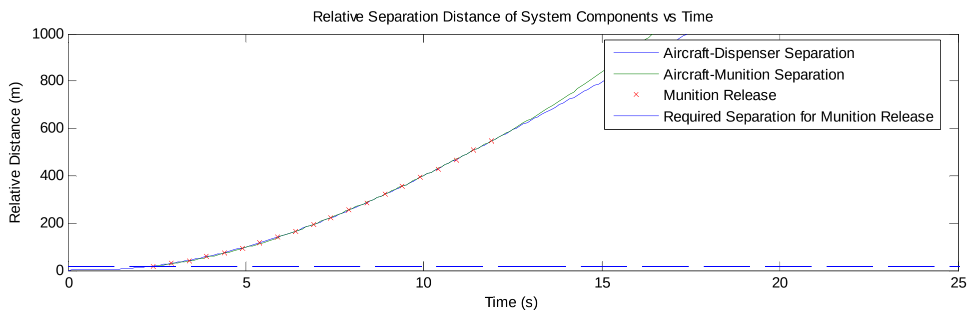

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

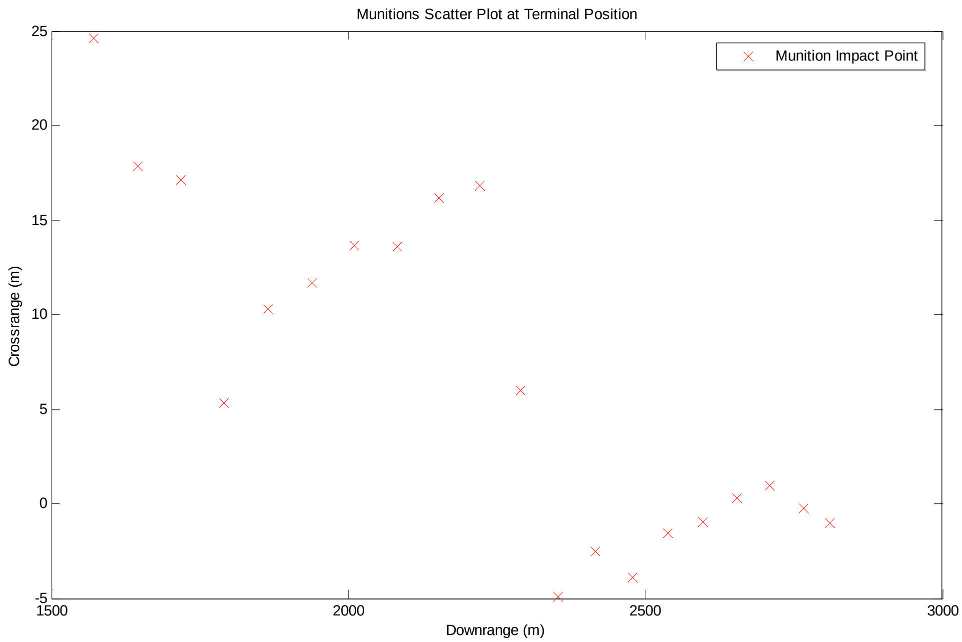

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Dispenser System Mass
Munition Release
Time (s)
Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release
Time (s)


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

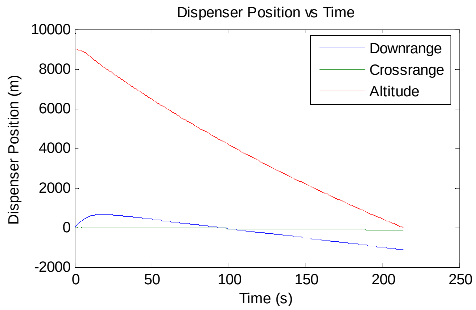

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

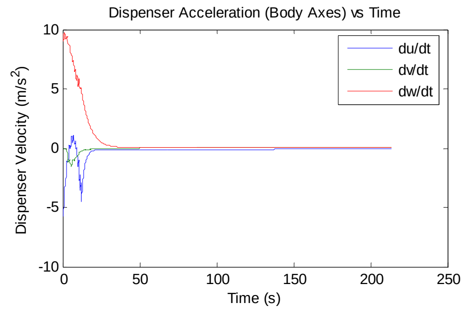

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

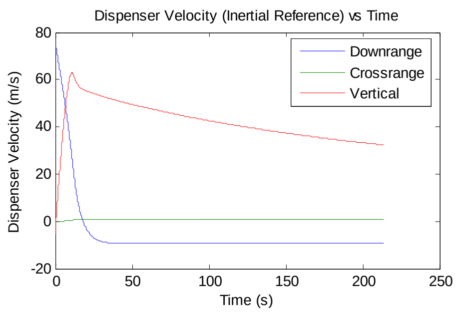

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

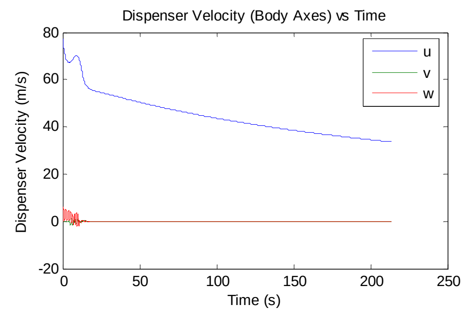

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
25
20
15
10
5
0
-5
1500
2000
2500
3000

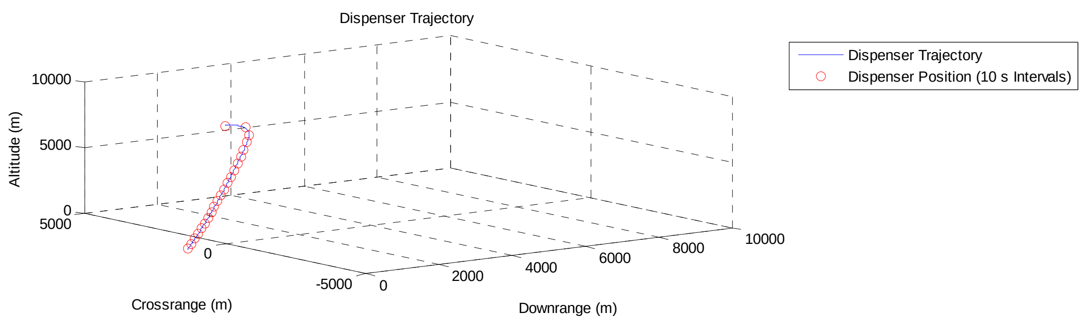
Test #11: Final Dispenser - Wind at 0

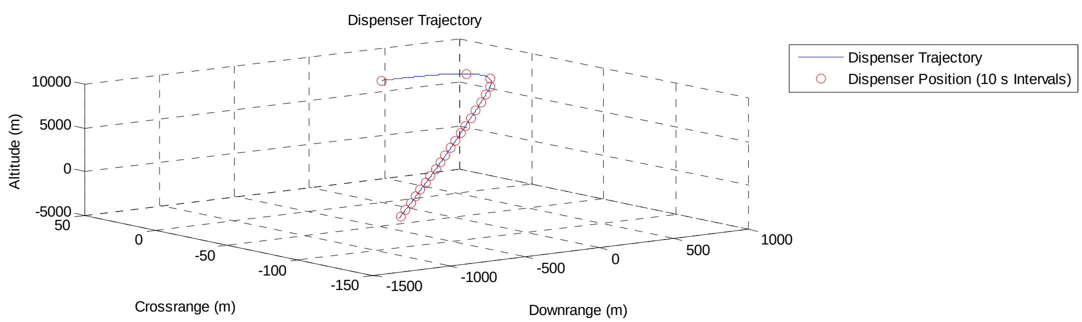


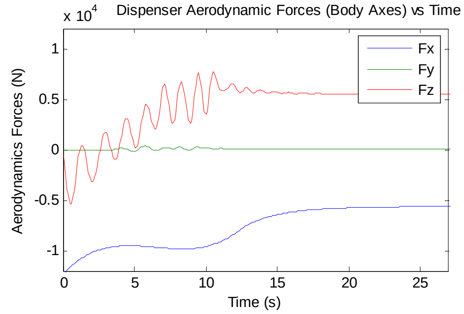


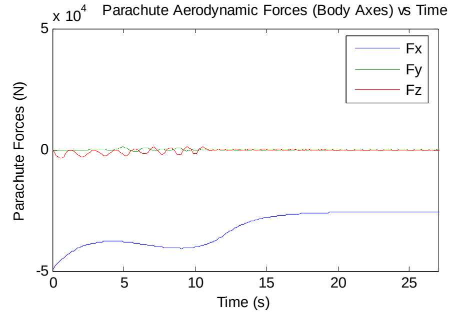


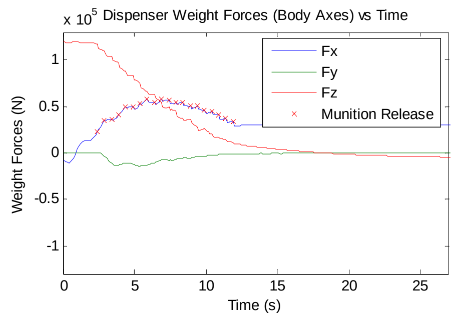


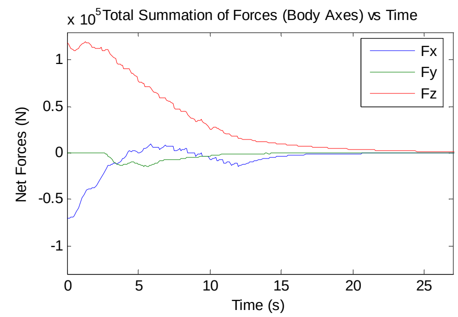


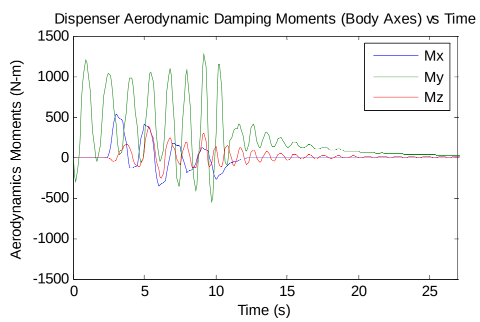


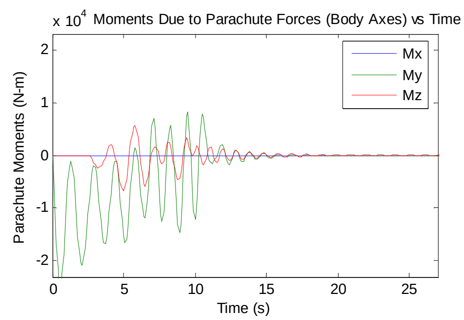

x 10^4
Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

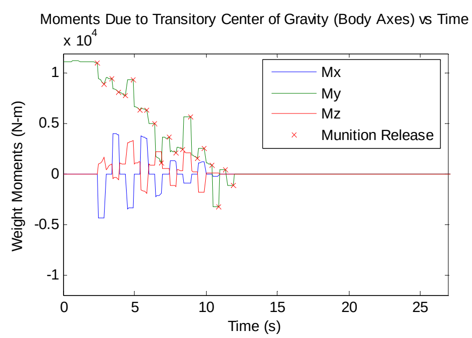

x 10^4
Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

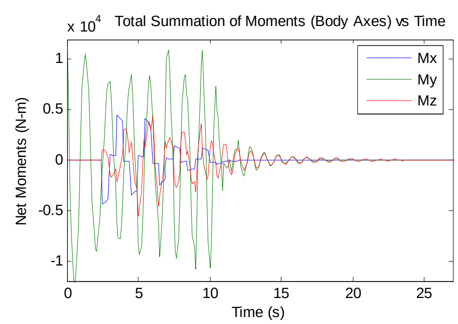

x 10^5
Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

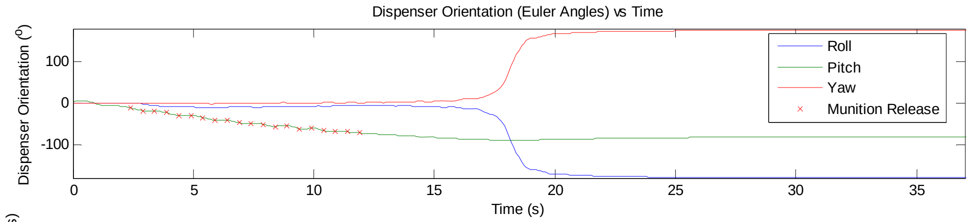

x 10^5
Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

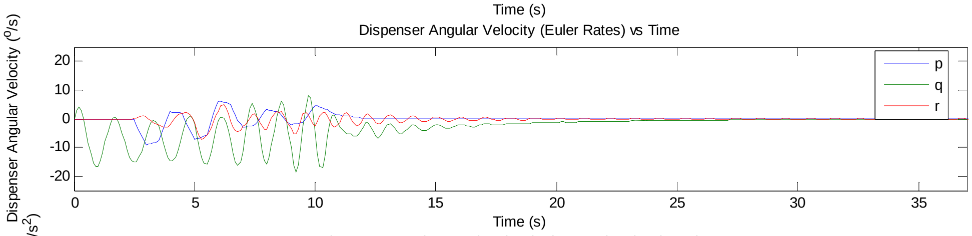

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

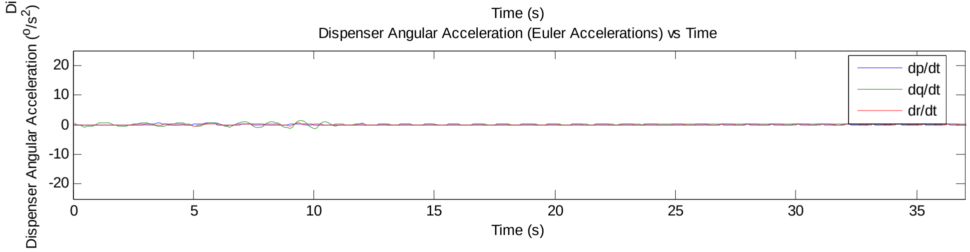

x 10^4
Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

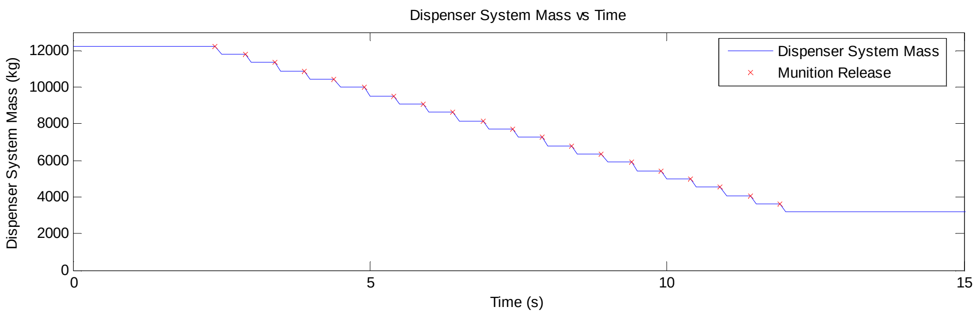

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

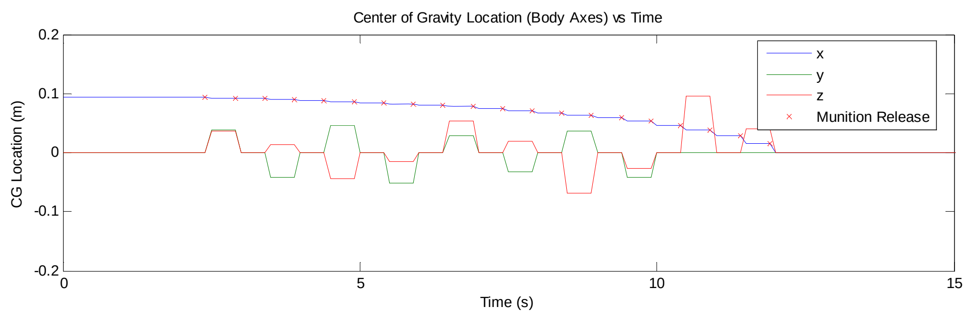

x 10^4
Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

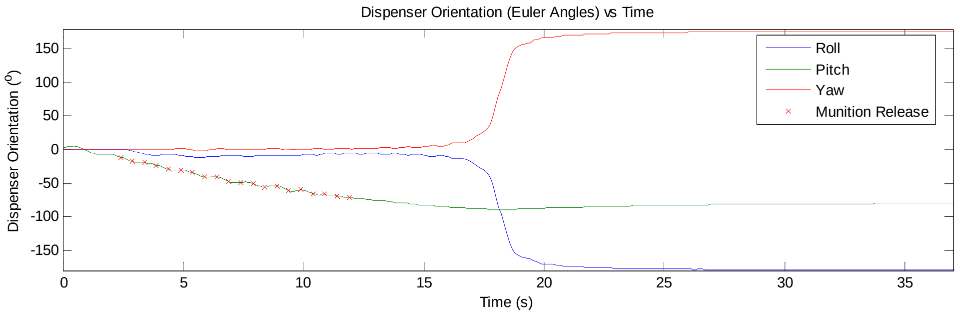

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

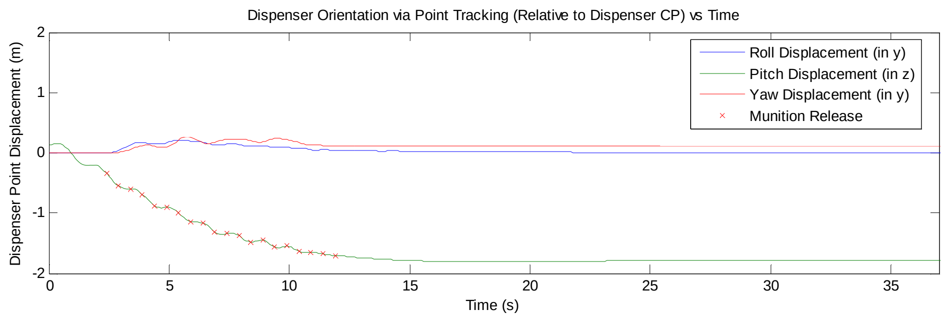

Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r

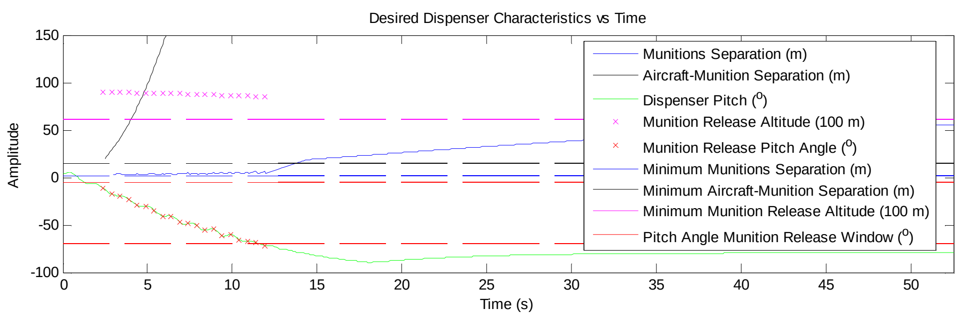

Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

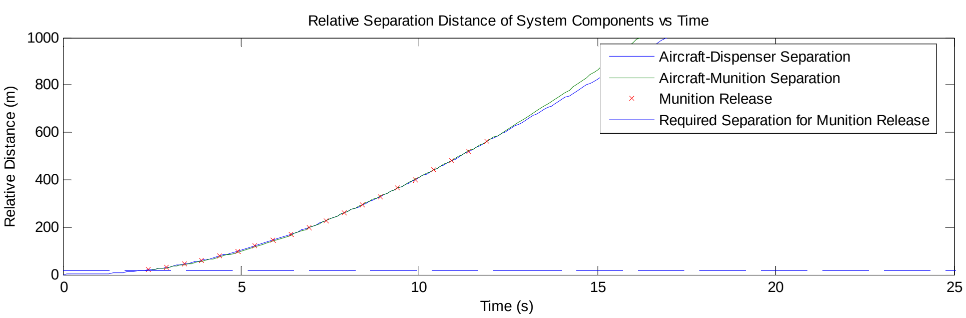

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

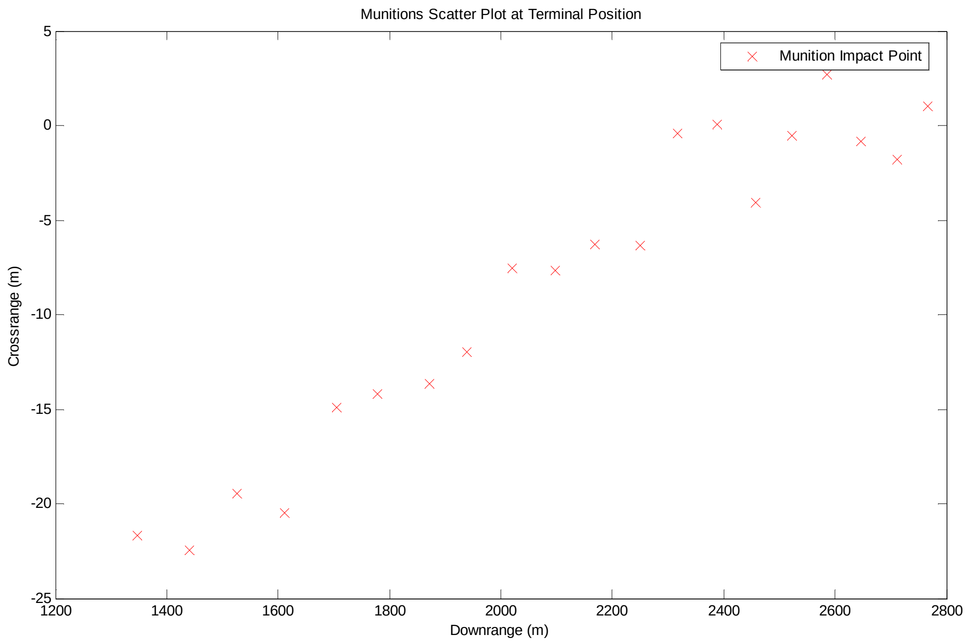

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

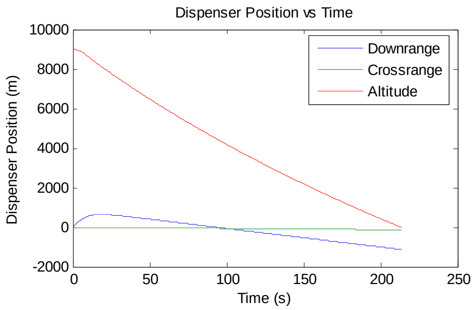

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

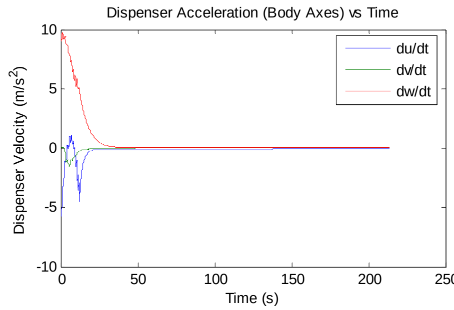

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

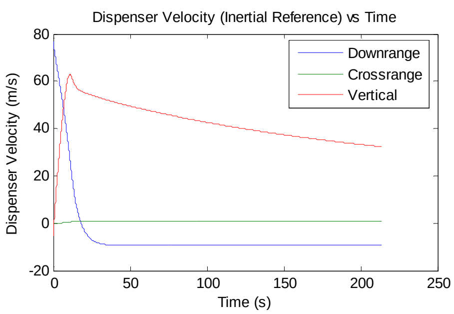

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

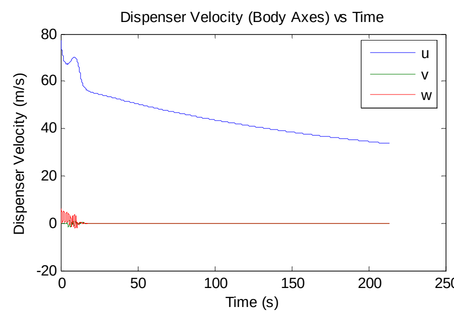

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
5
0
-5
-10
-15
-20
-25
1200
1400
1600
1800
2000
2200
2400
2600
2800

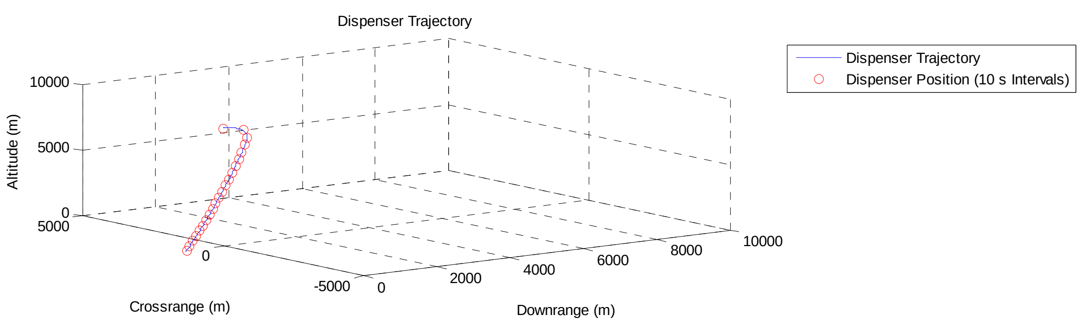
Test #12: Final Dispenser - Wind at 45

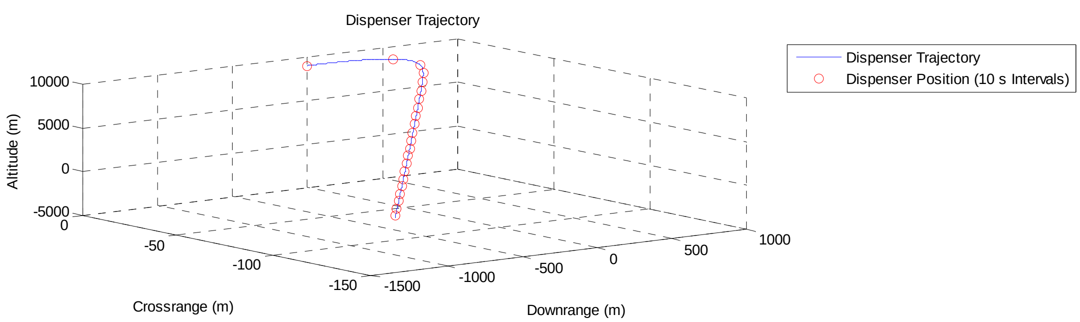


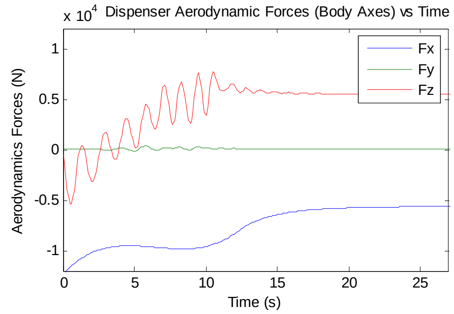


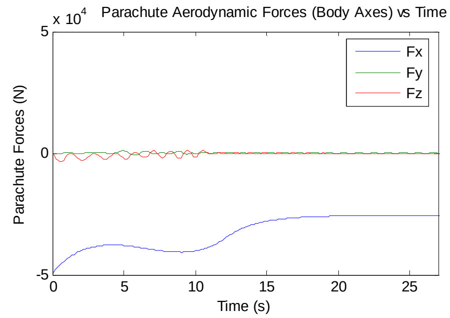


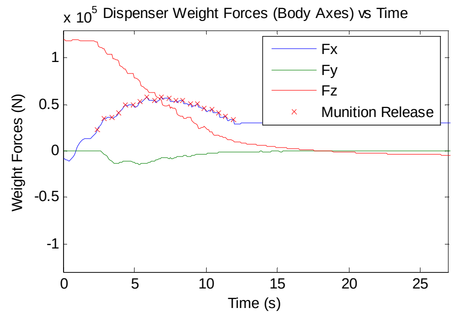


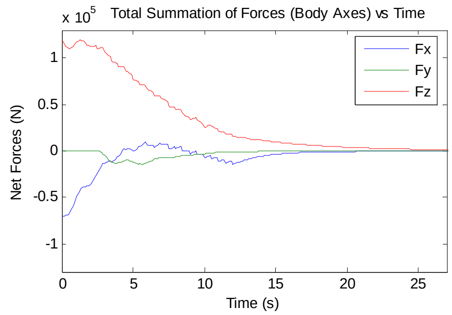


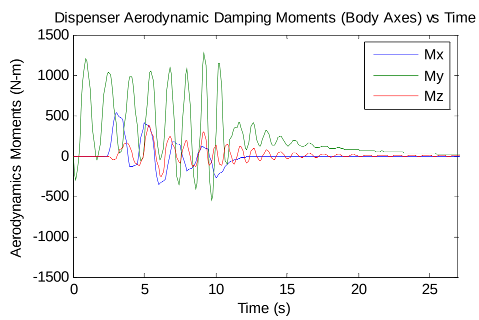


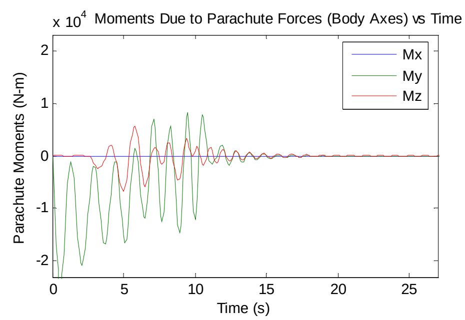

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

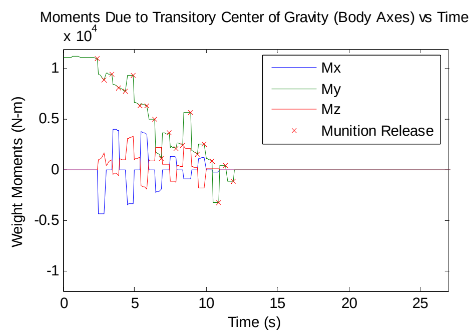

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

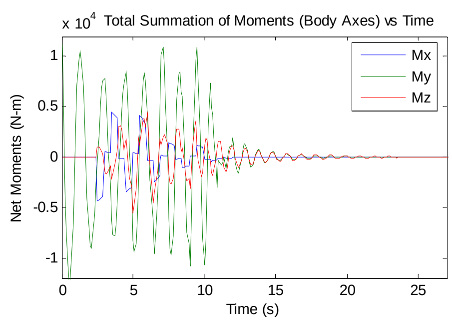

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

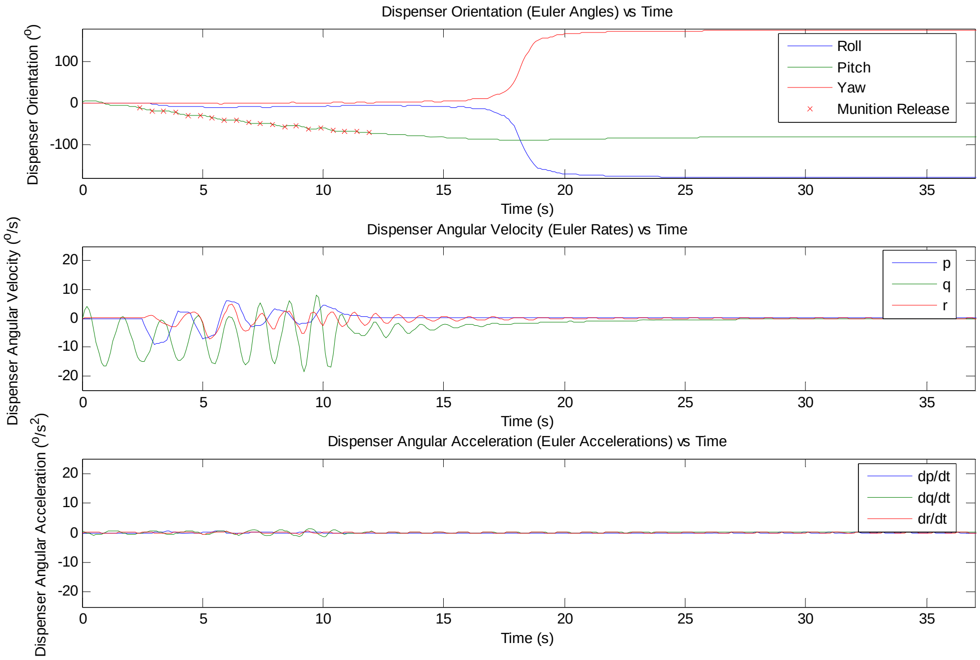

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

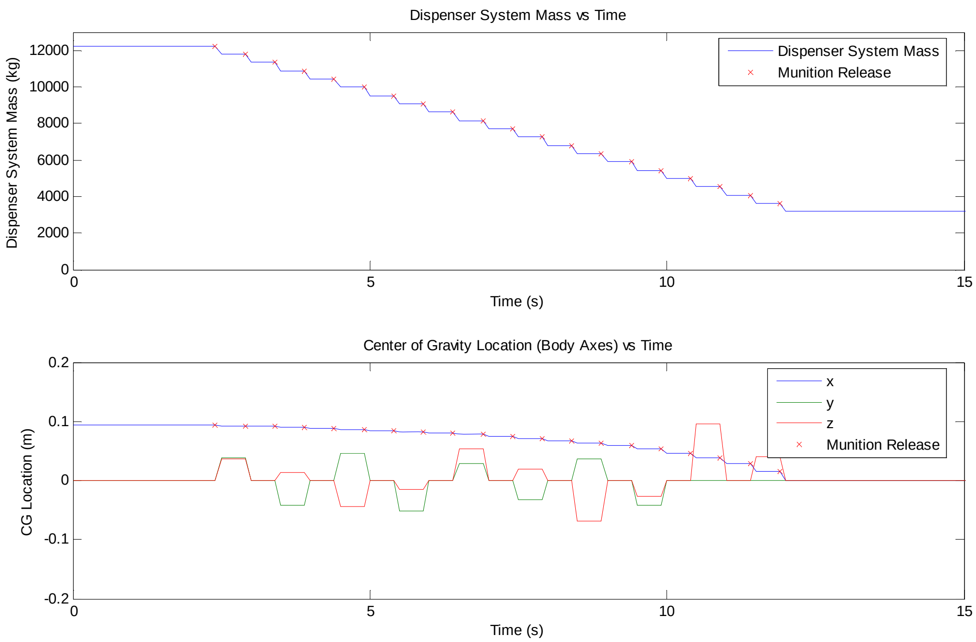

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

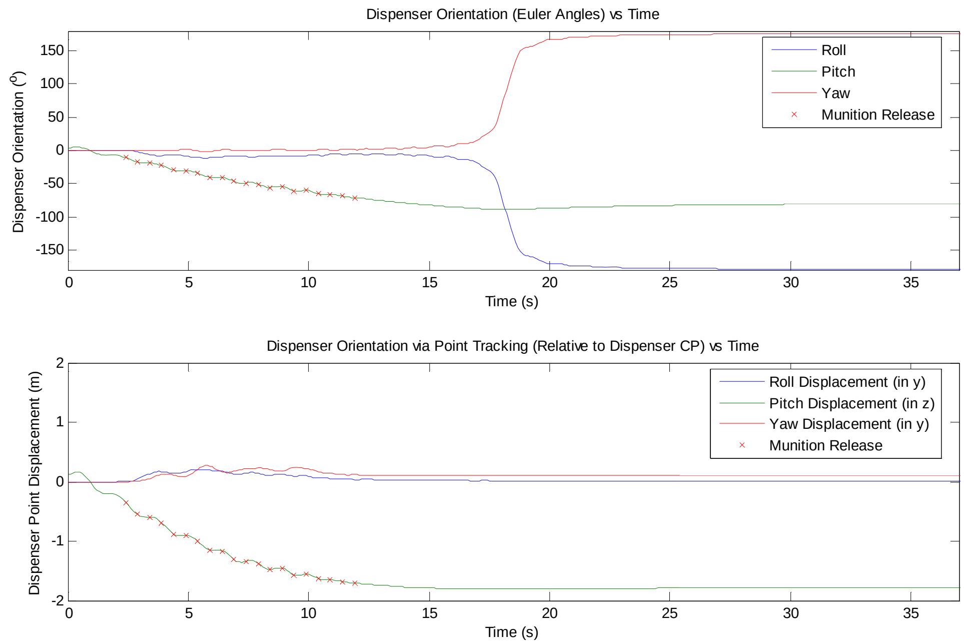

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

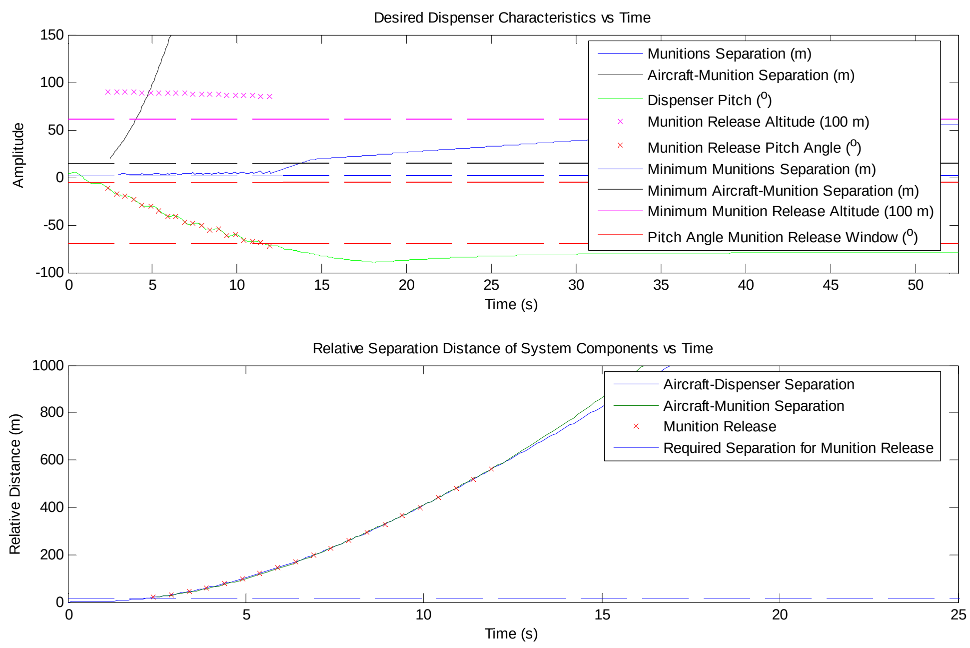

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

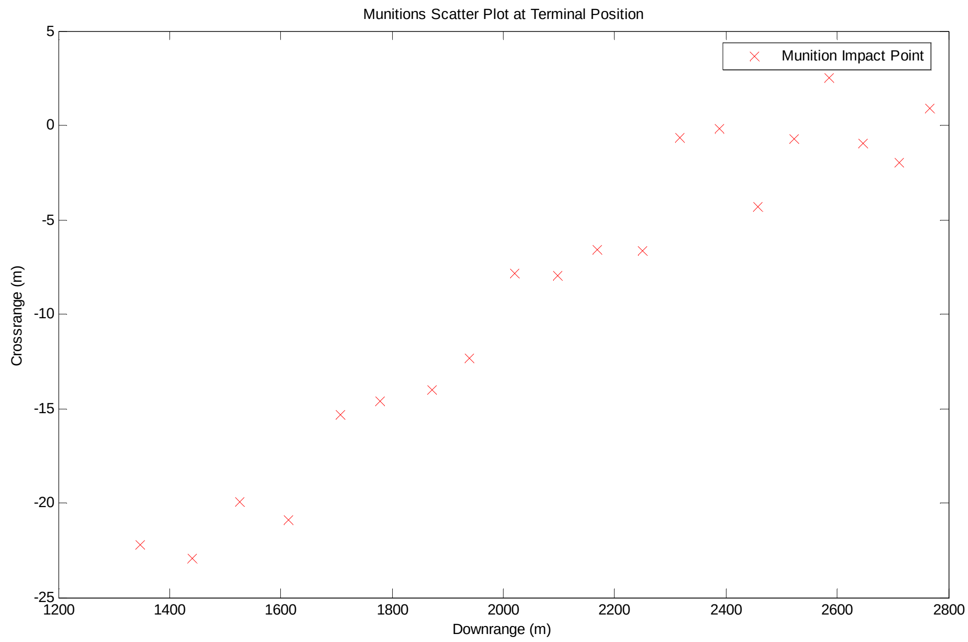

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

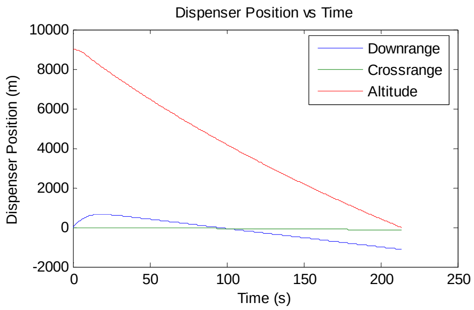

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release
Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release

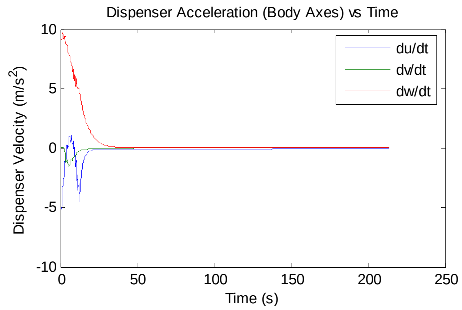

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

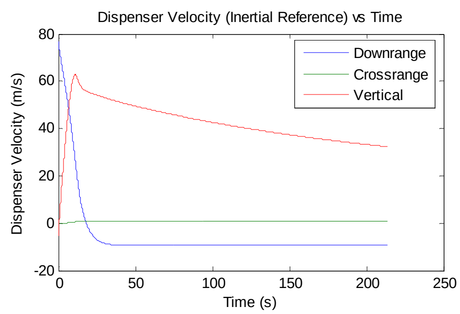

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
Relative Separation Distance of System Components vs Time
Relative Distance (m)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

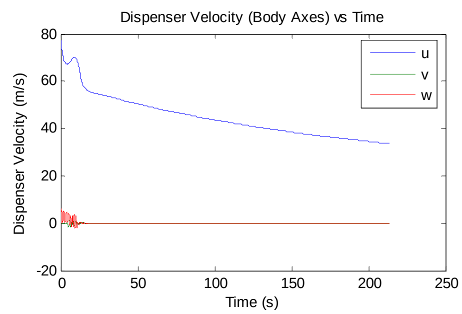

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
5
0
-5
-10
-15
-20
-25
1200
1400
1600
1800
2000
2200
2400
2600
2800

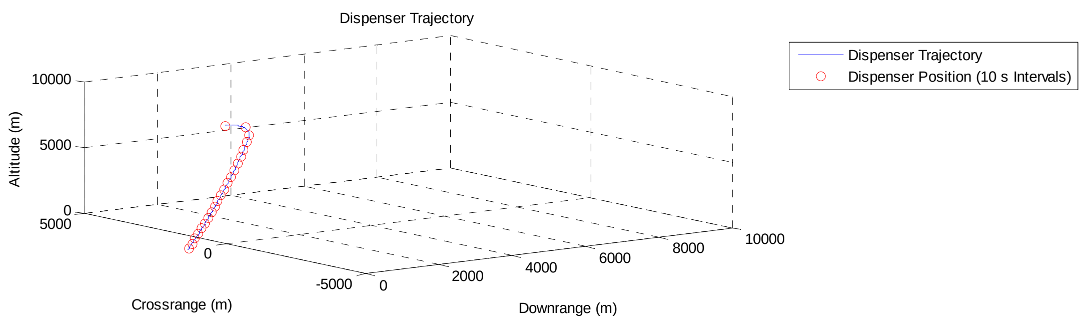
Test #13: Final Dispenser - Wind at 90

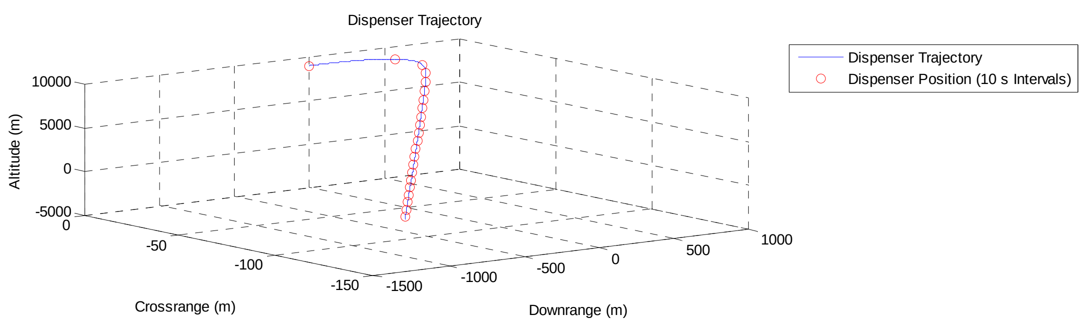


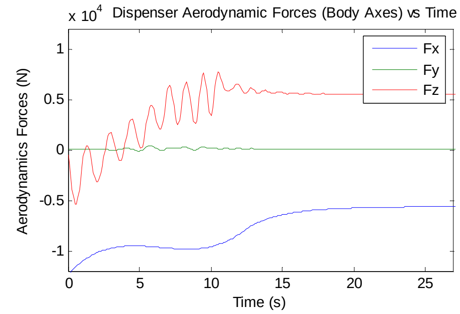


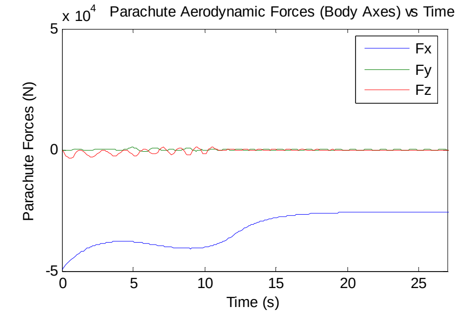


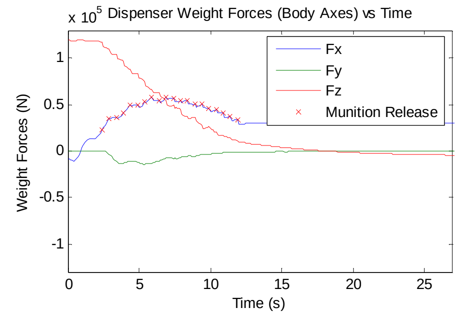


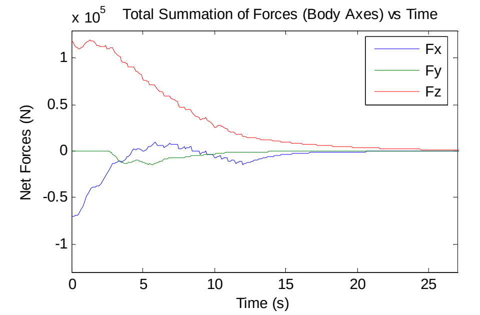


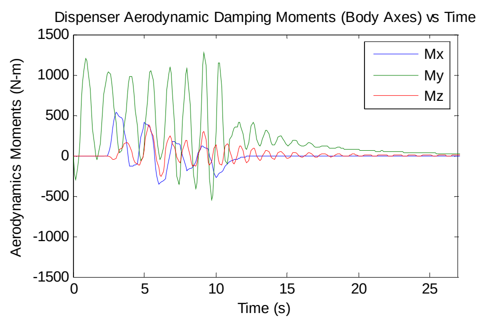


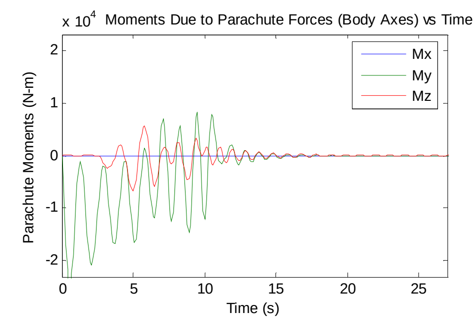

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

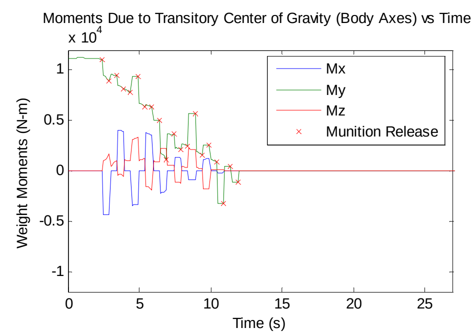

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

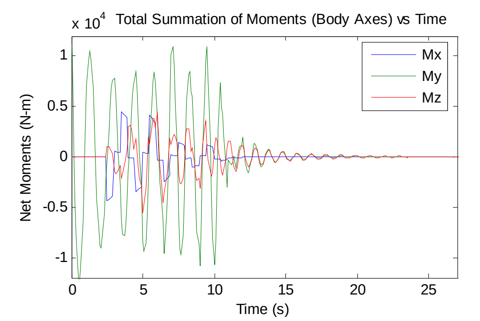

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

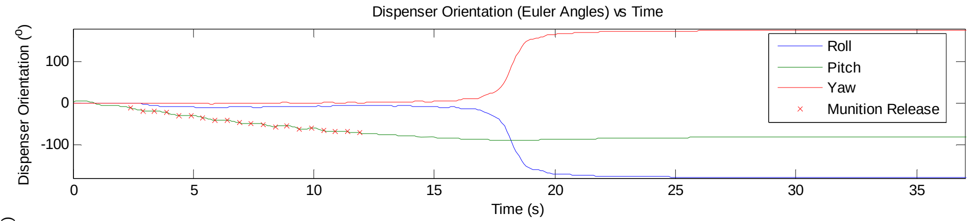

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

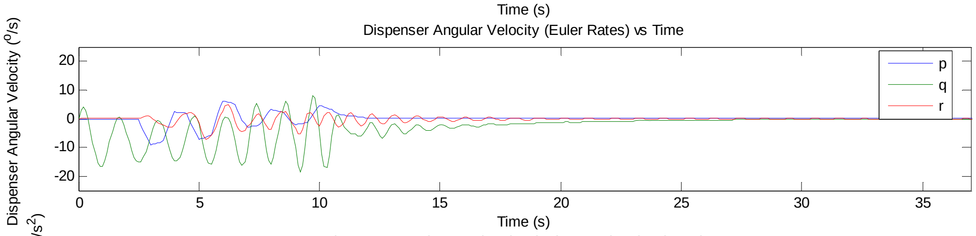

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

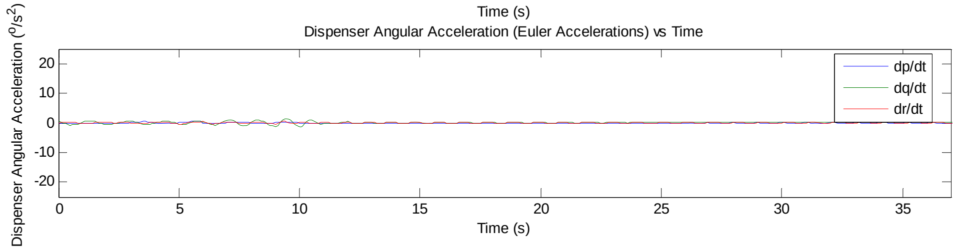

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

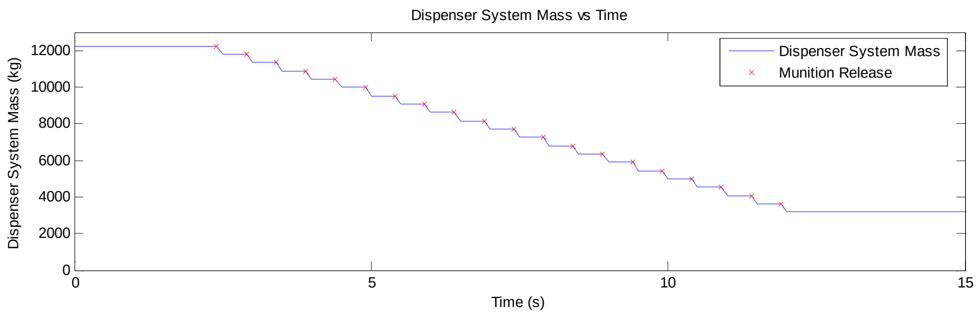

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

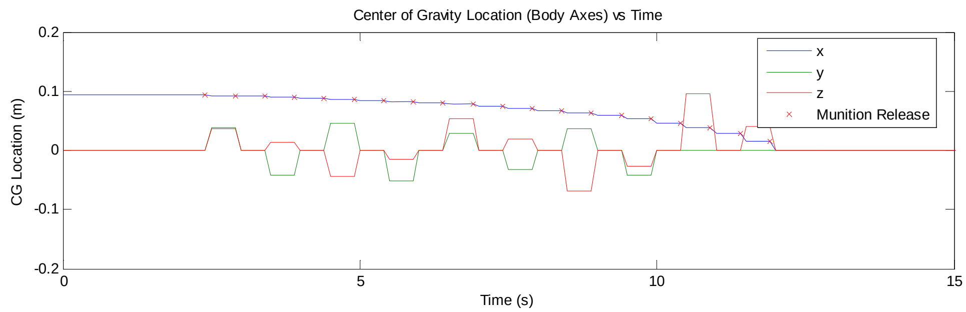

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

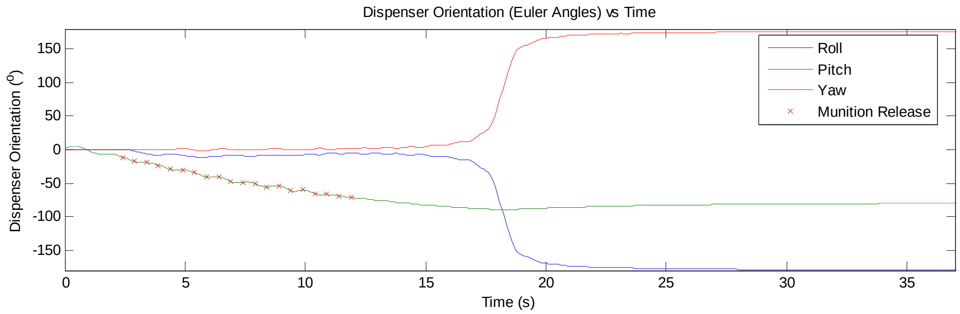

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

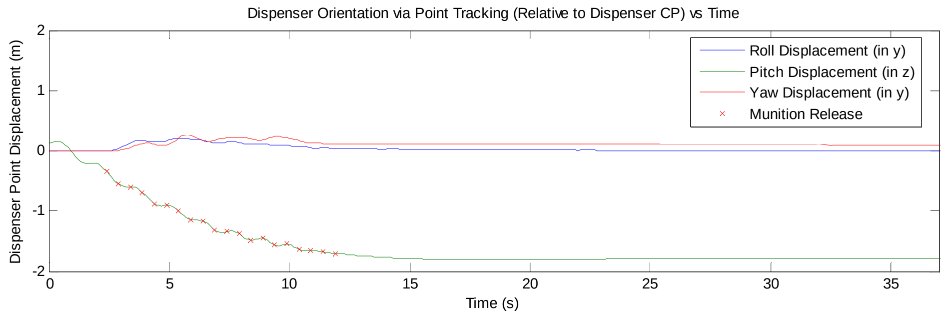

Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r

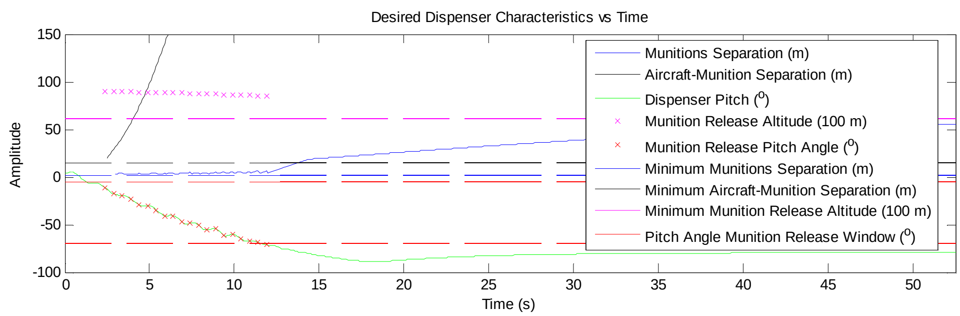

Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

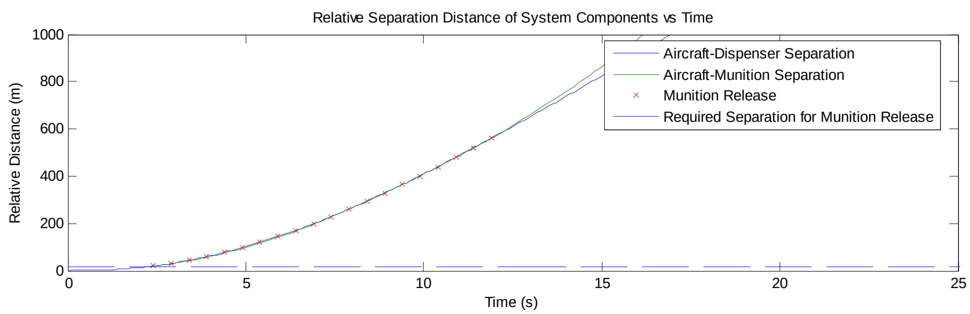

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

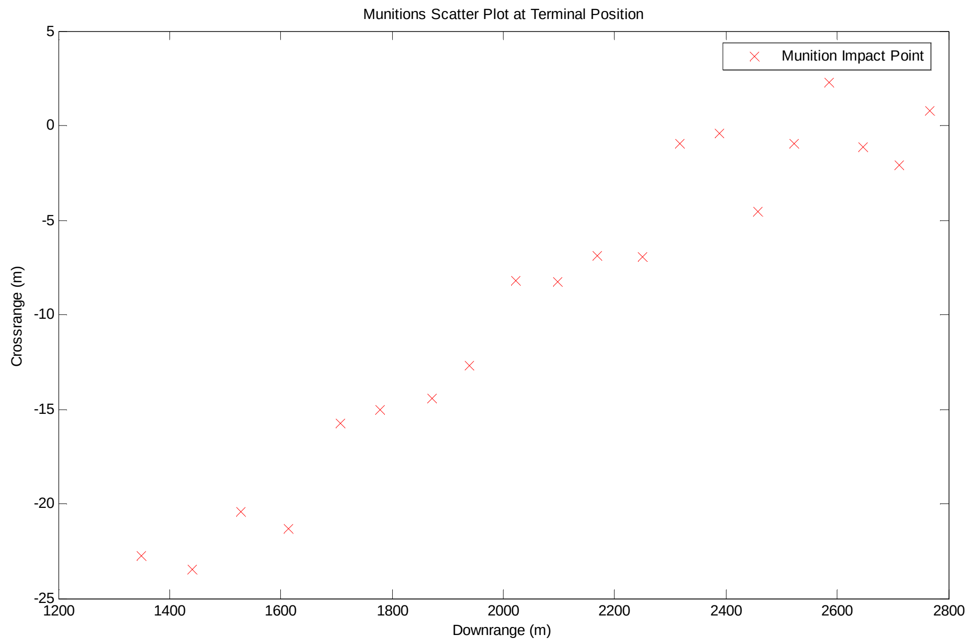

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

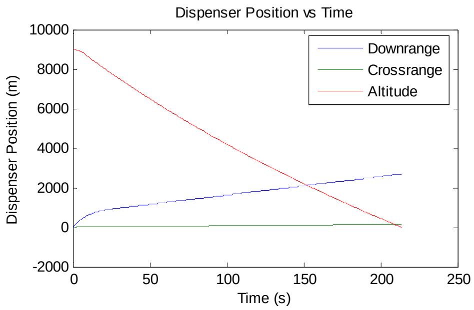

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

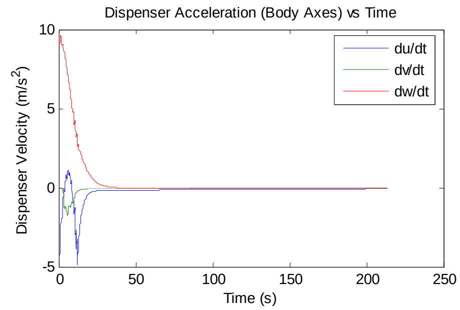

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

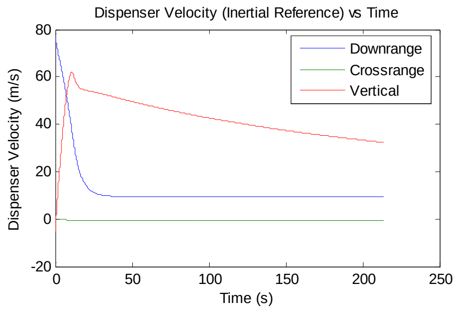

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

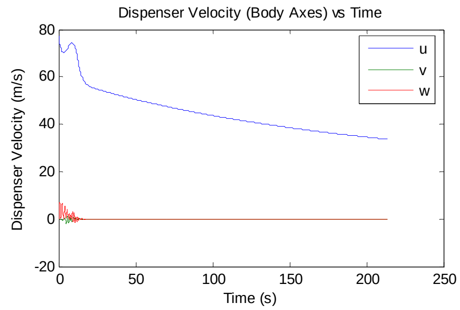

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
5
0
-5
-10
-15
-20
-25
1200
1400
1600
1800
2000
2200
2400
2600
2800

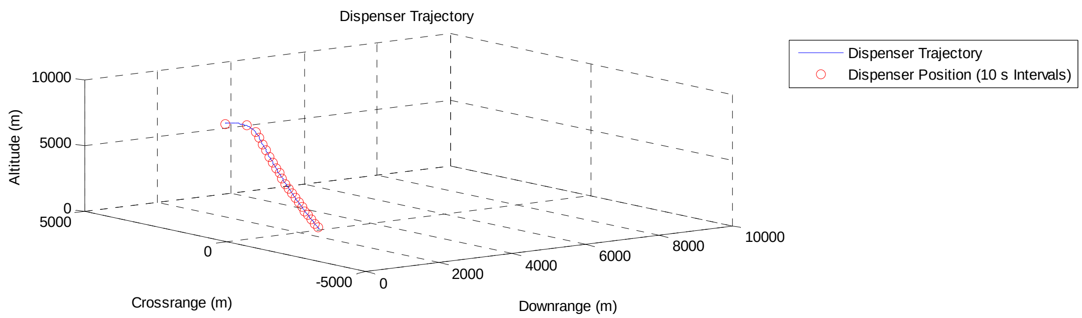
Test #14: Final Dispenser - Wind at 180

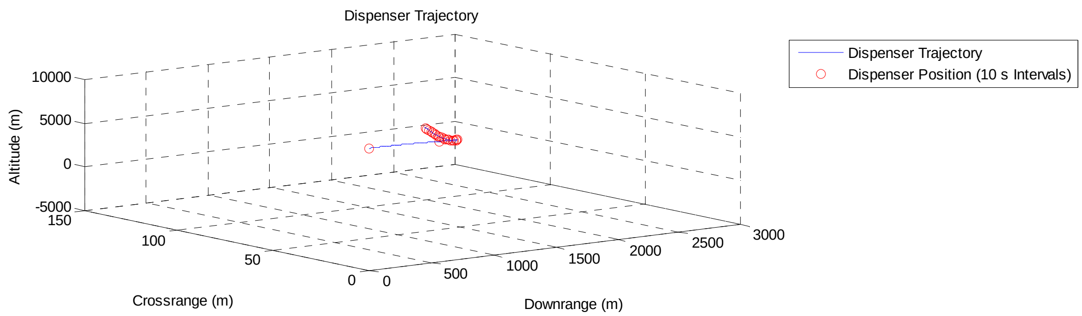


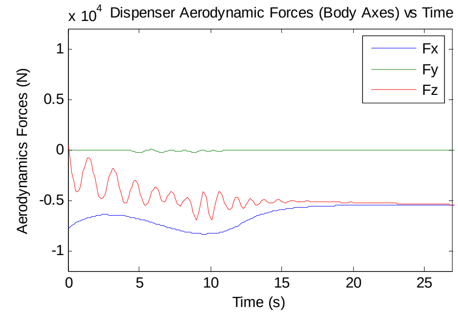


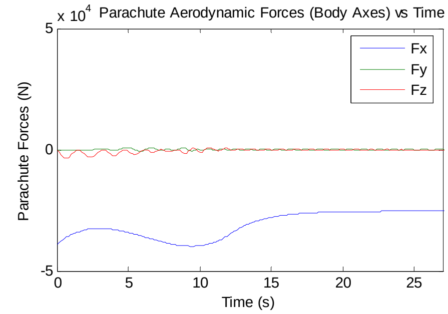


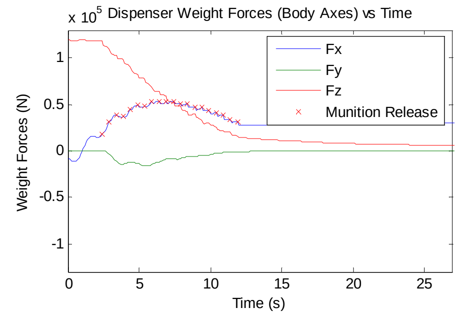


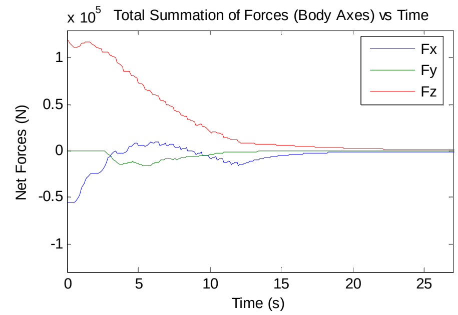


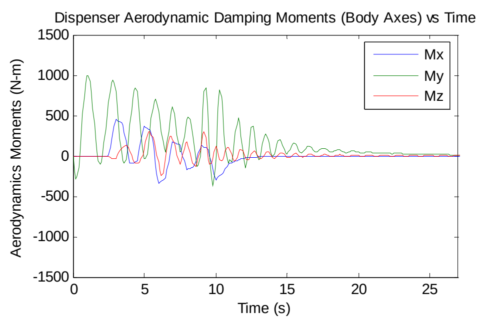


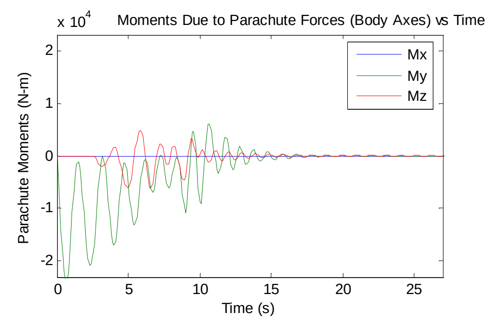

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

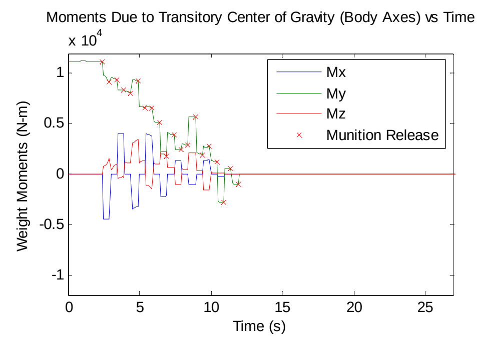

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

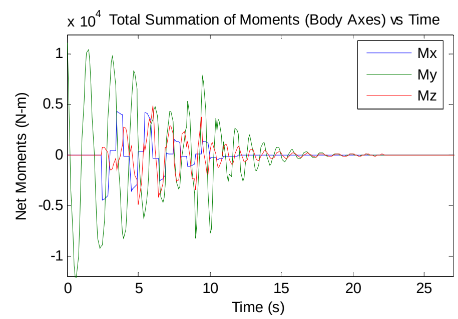

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

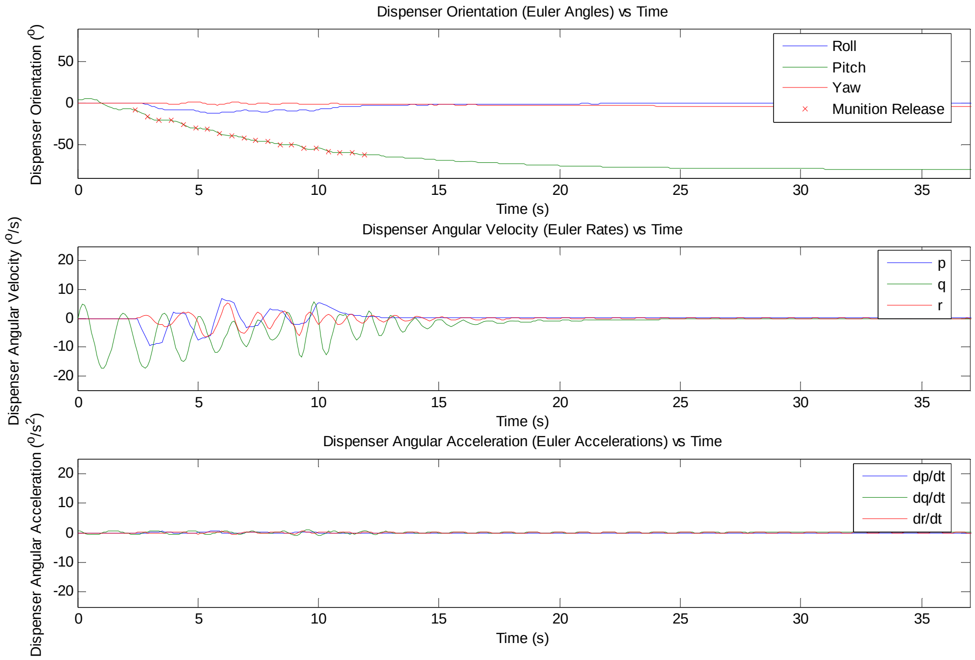

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

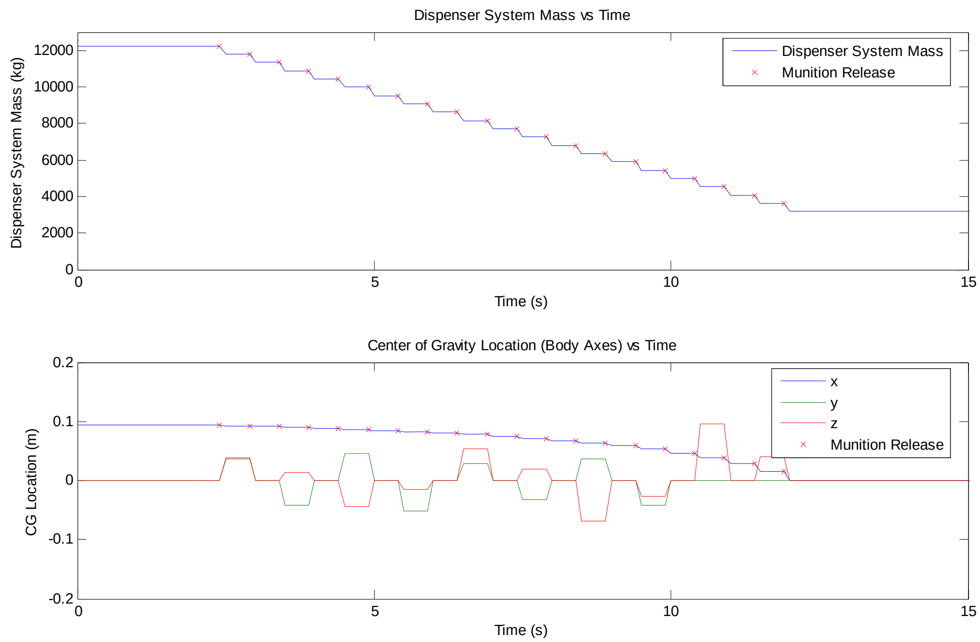

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

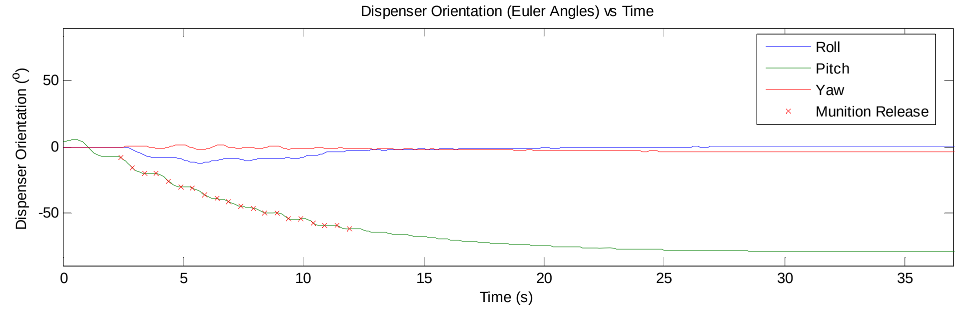

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

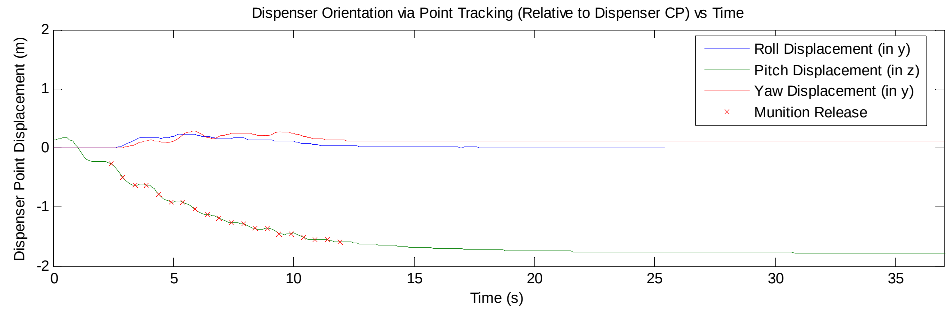

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

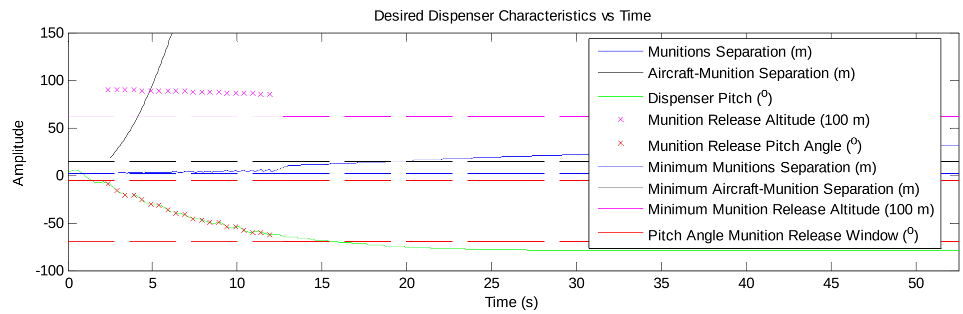

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

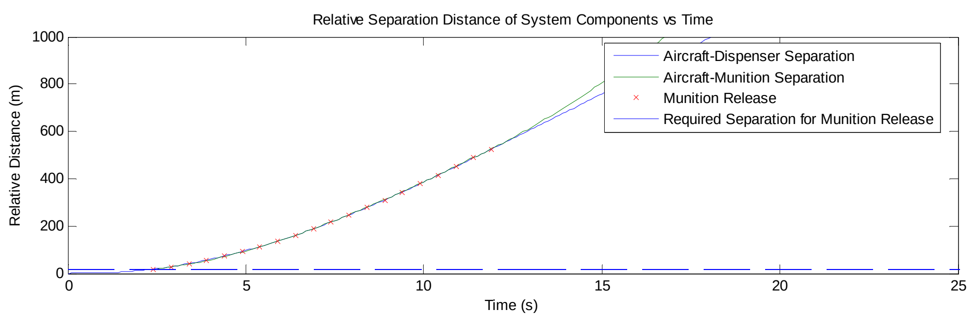

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

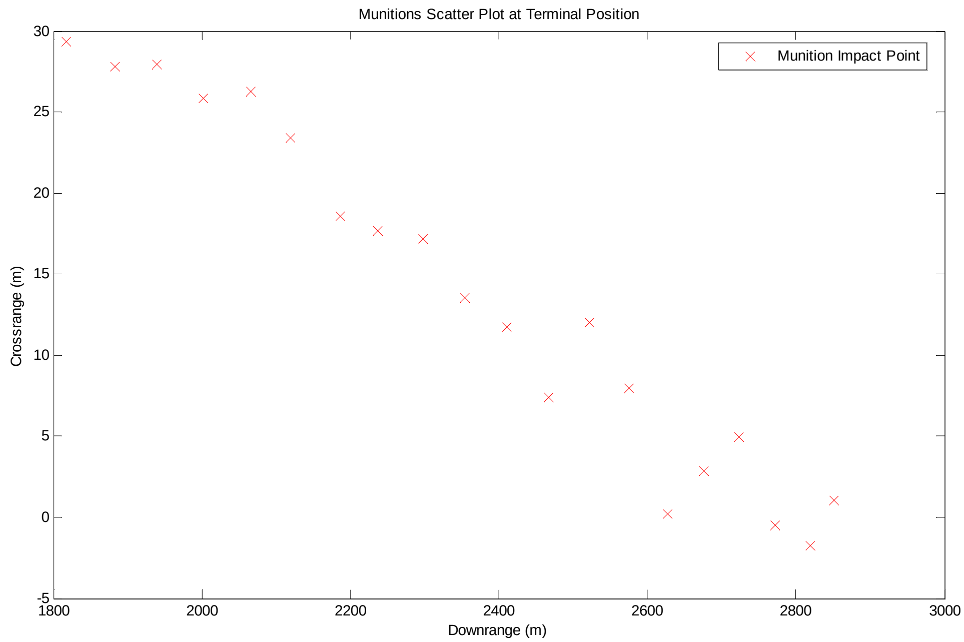

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Dispenser System Mass
Munition Release
Time (s)
Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release
Time (s)


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release


Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

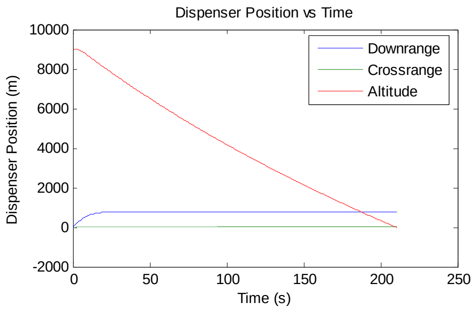

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

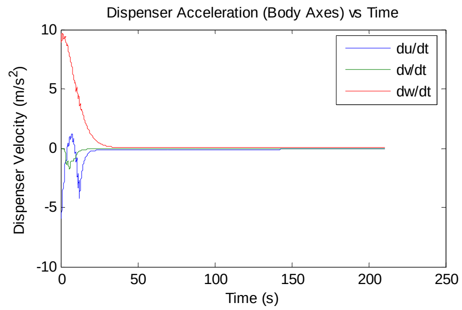

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

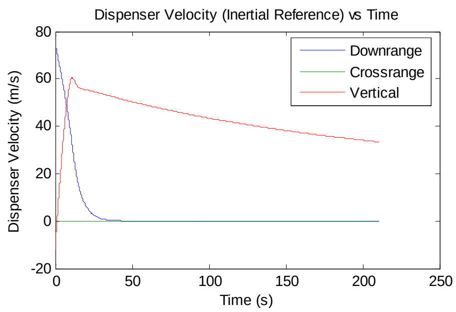


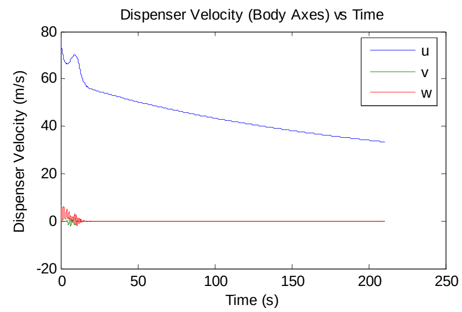
Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
30
25
20
15
10
5
0
-5
1800
2000
2200
2400
2600
2800
3000

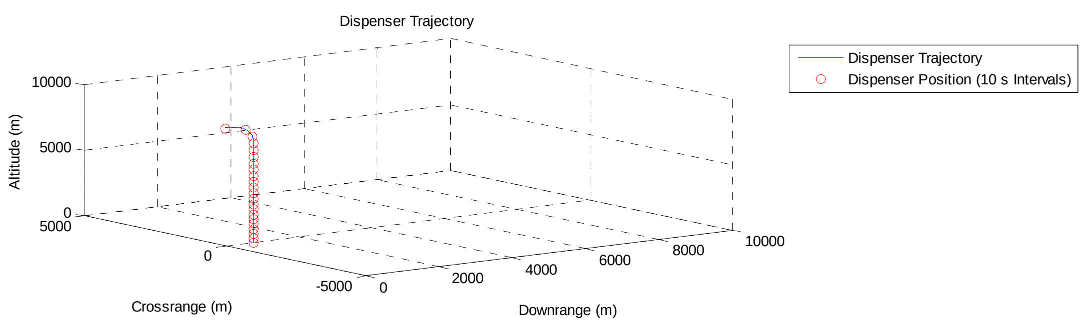
Test #15: Final Dispenser - Tip-Off Angle at 4+5

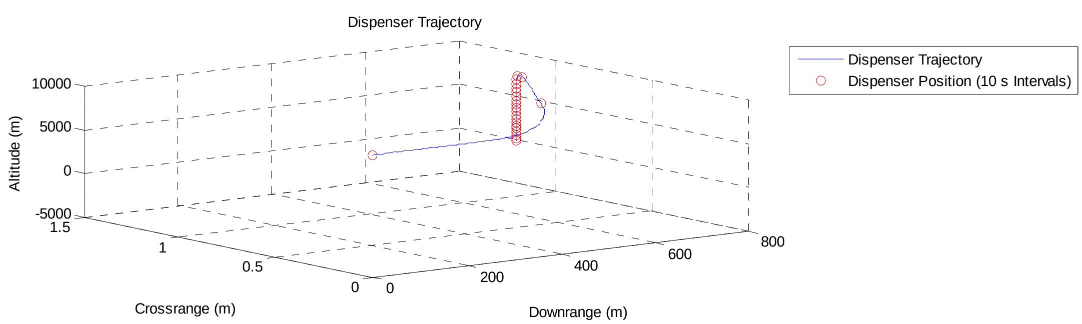


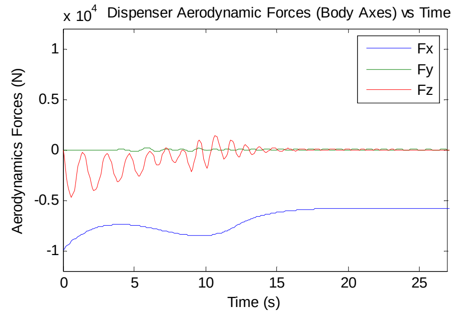


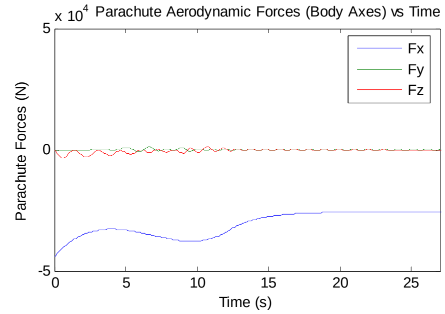


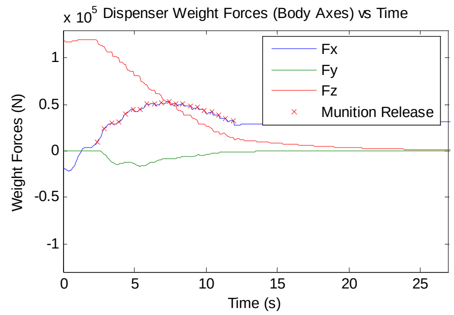


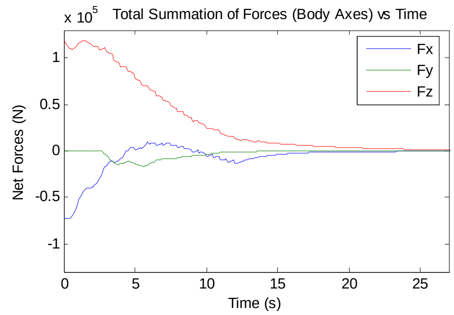


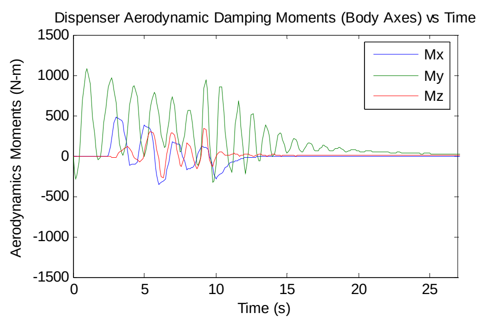


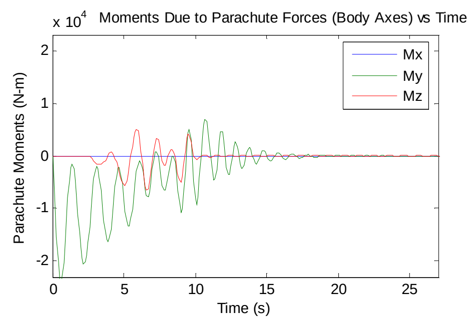

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

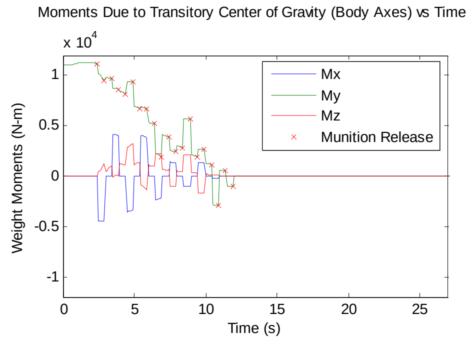

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

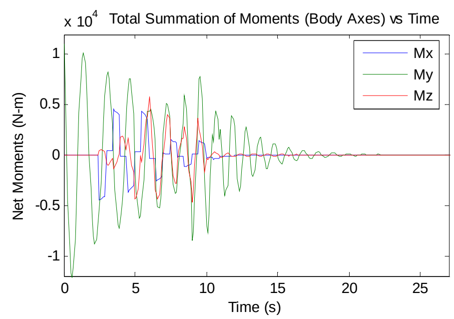

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

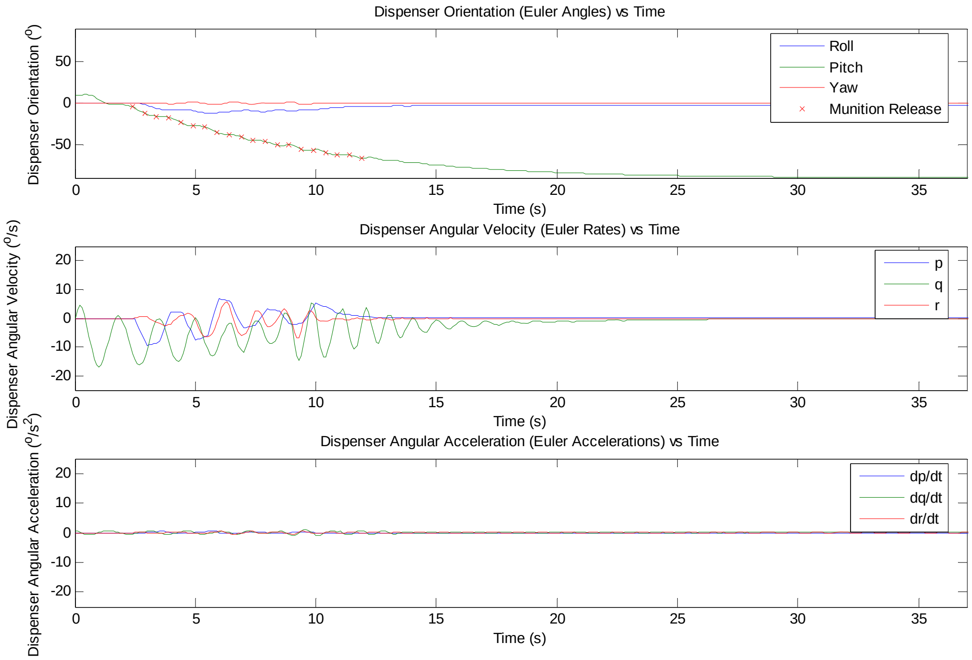

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

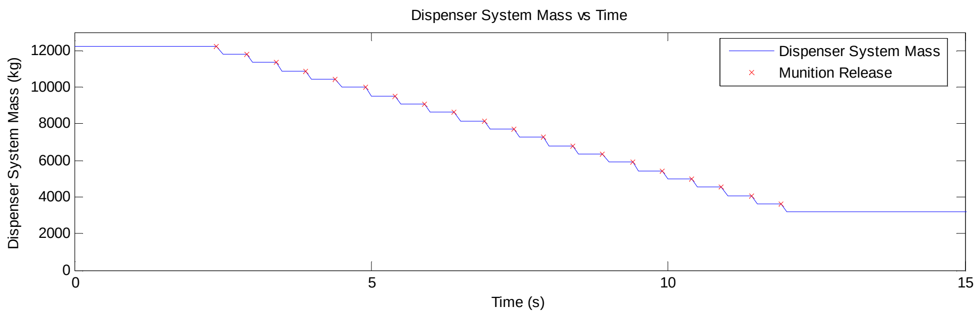

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

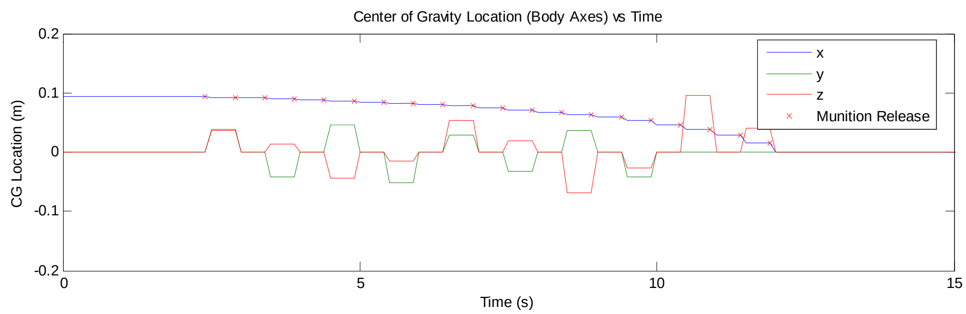

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

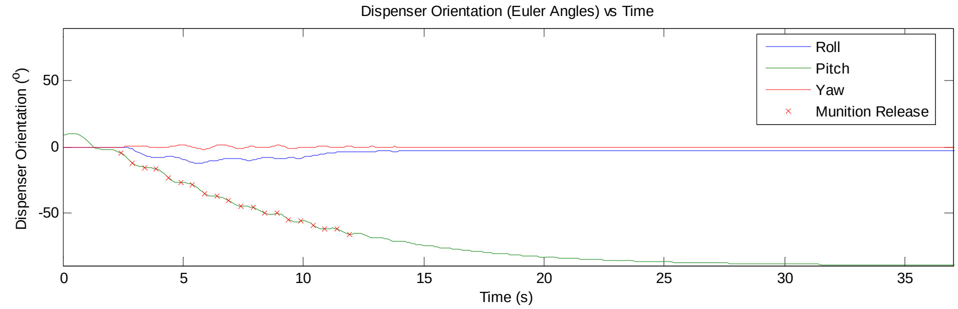

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

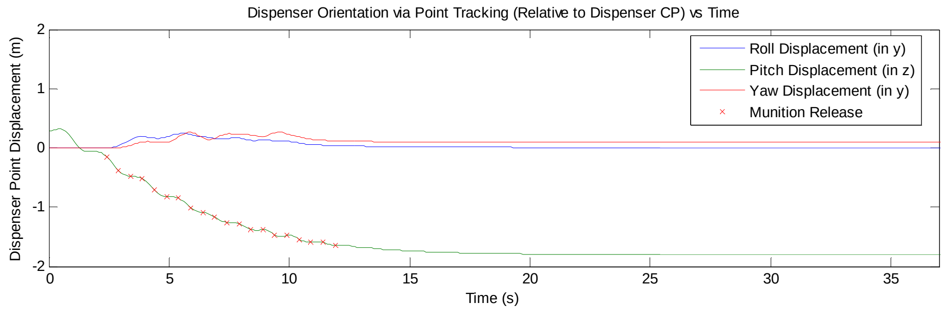

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

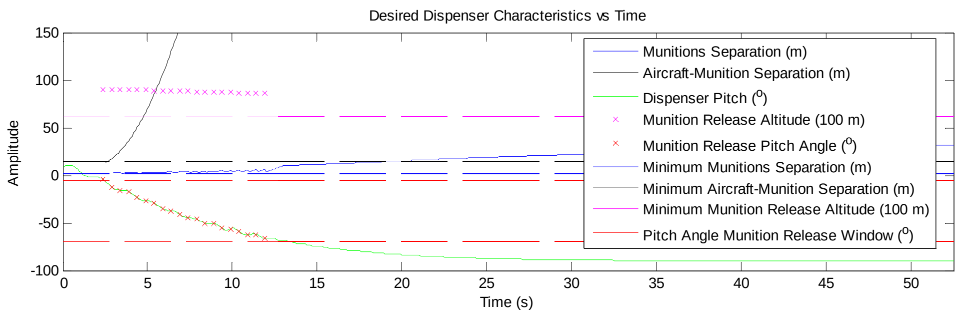

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

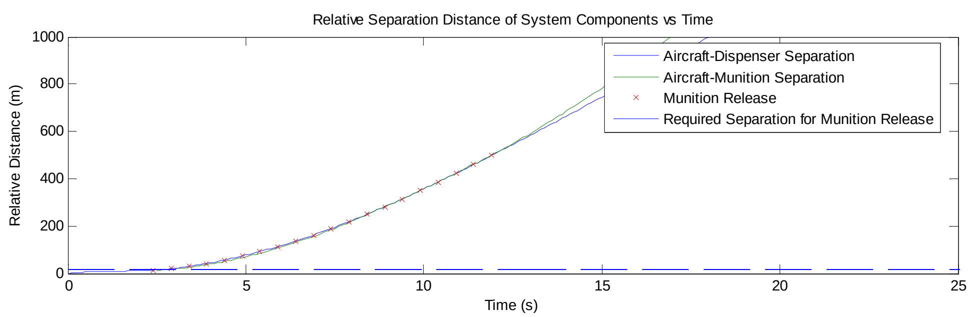

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Dispenser System Mass
Munition Release
Time (s)


Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release
Time (s)

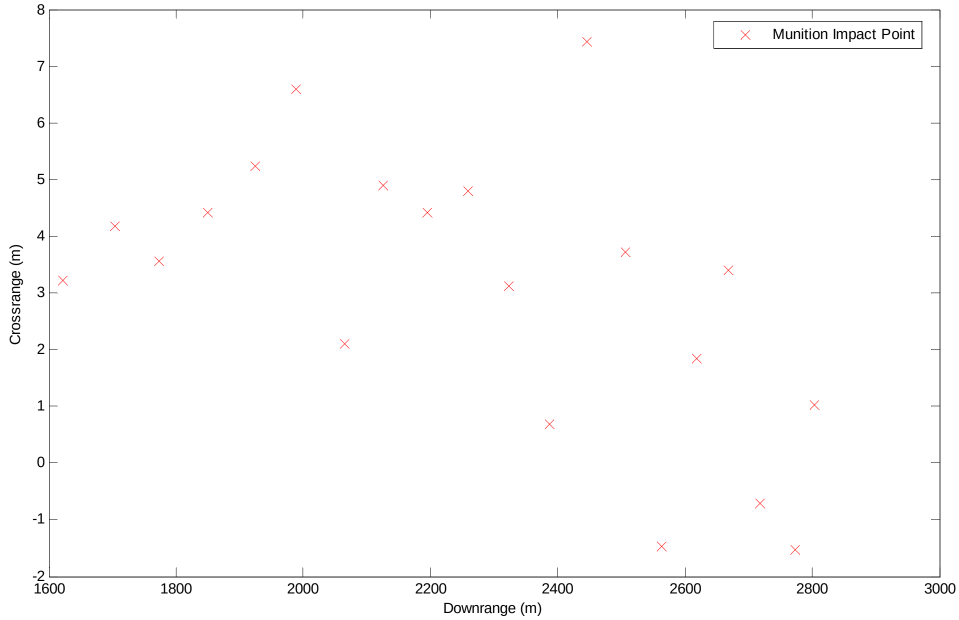

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (^{o})
Time (s)
Roll
Pitch
Yaw
Munition Release


Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

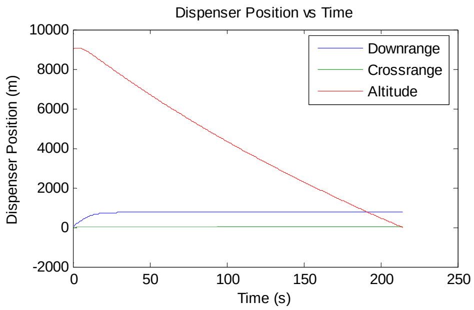

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (^{o})
Munition Release Altitude (100 m)
Munition Release Pitch Angle (^{o})
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (^{o})

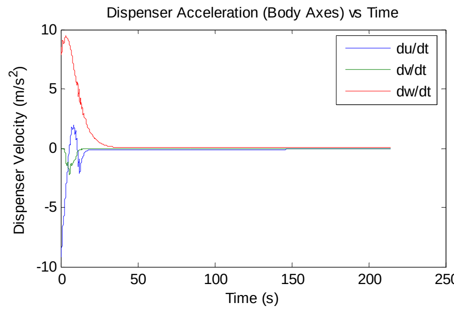

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

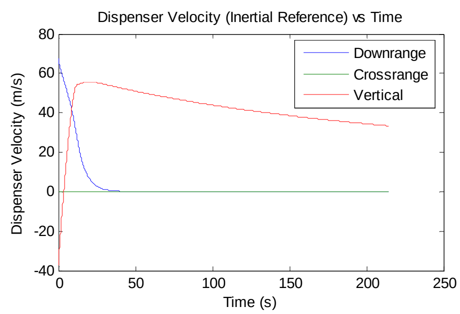
Munitions Scatter Plot at Terminal Position

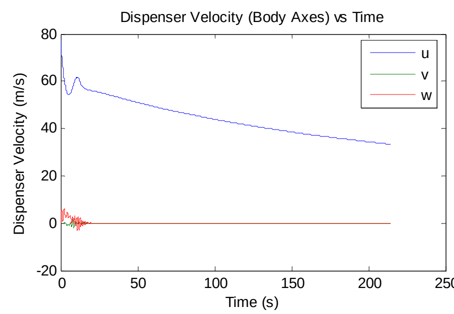


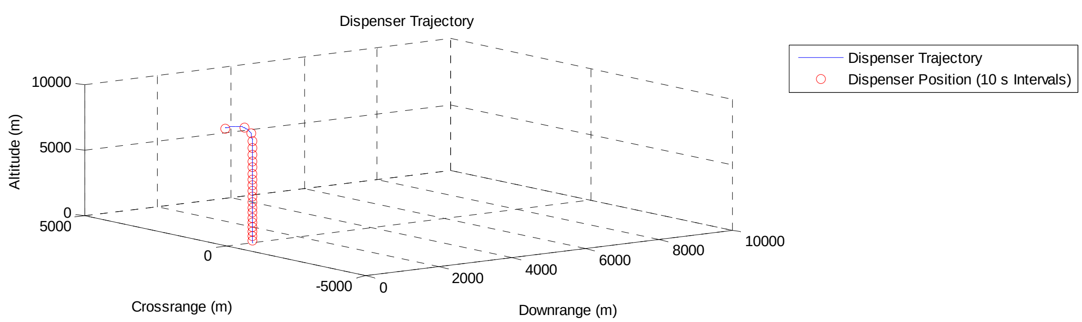
Test #16: Final Dispenser - Tip-Off Angle at 4+25

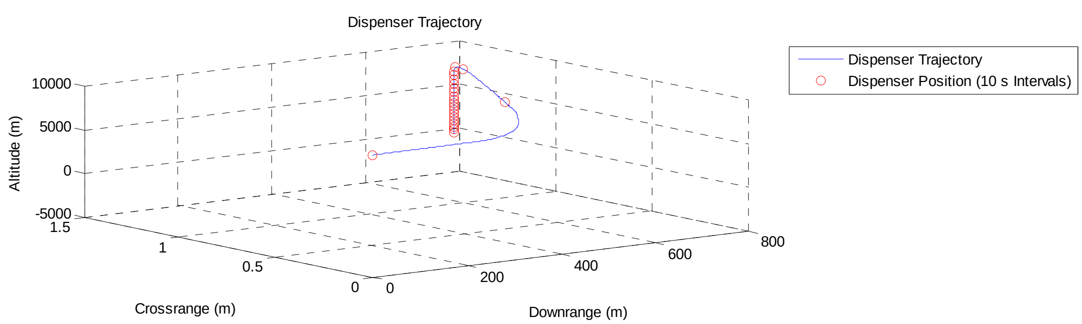


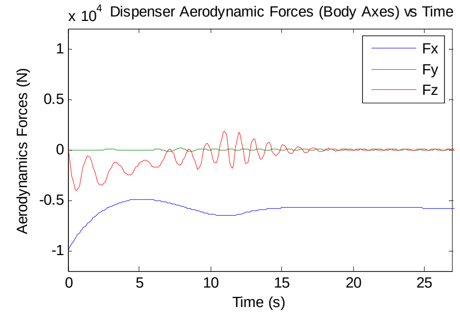


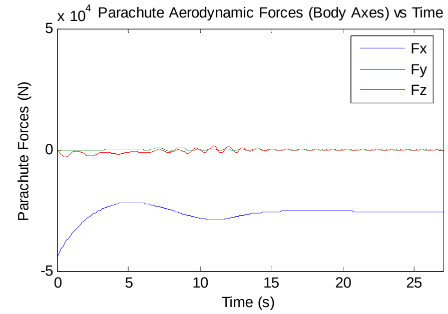


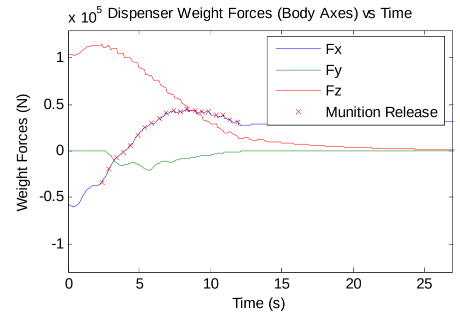


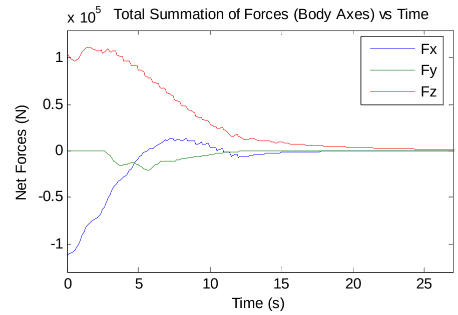


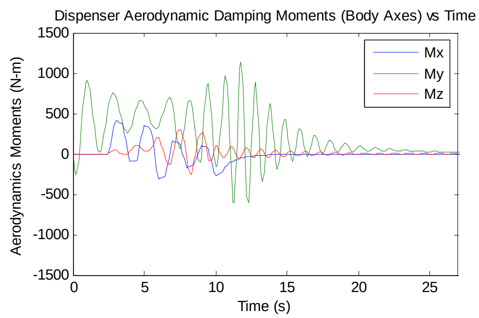


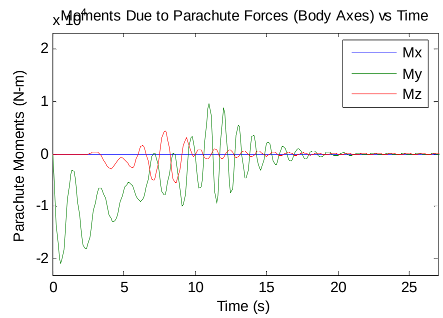

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

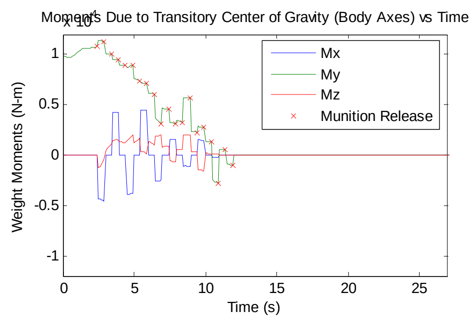

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

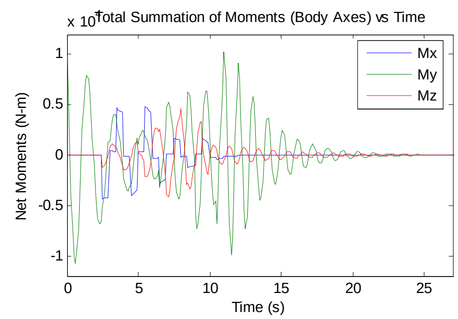

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

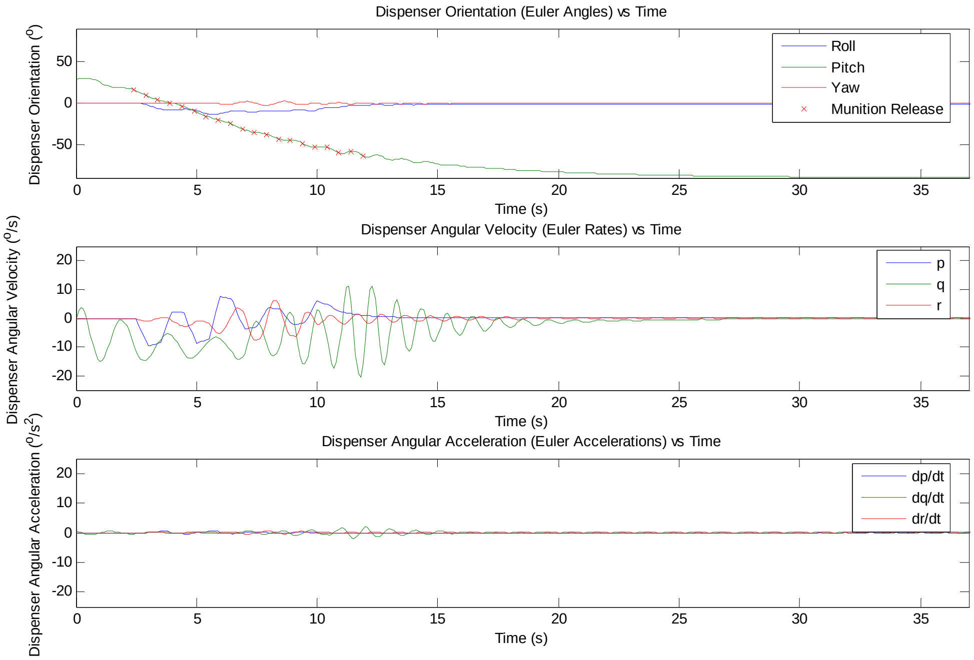

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

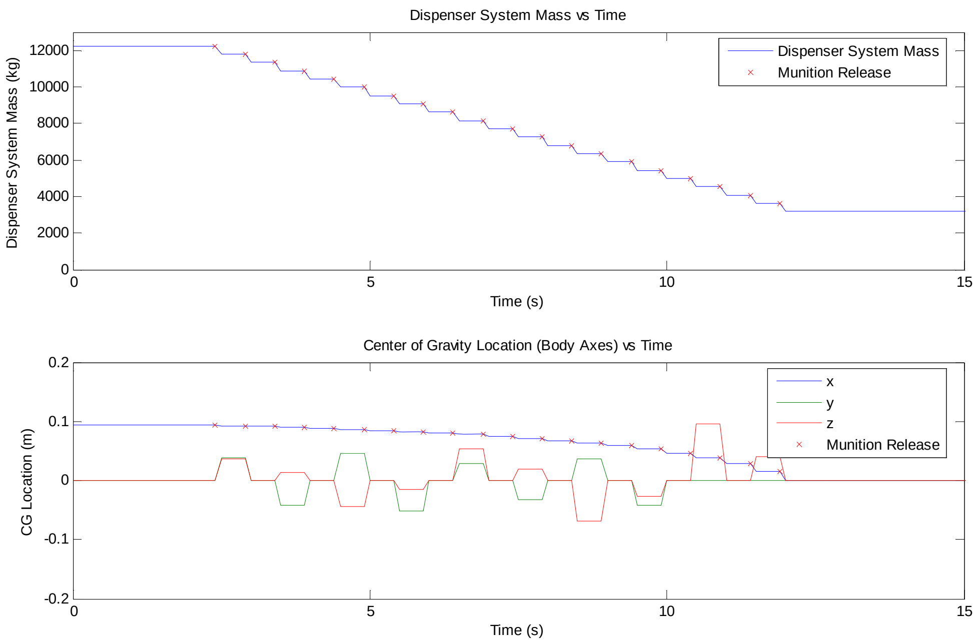

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

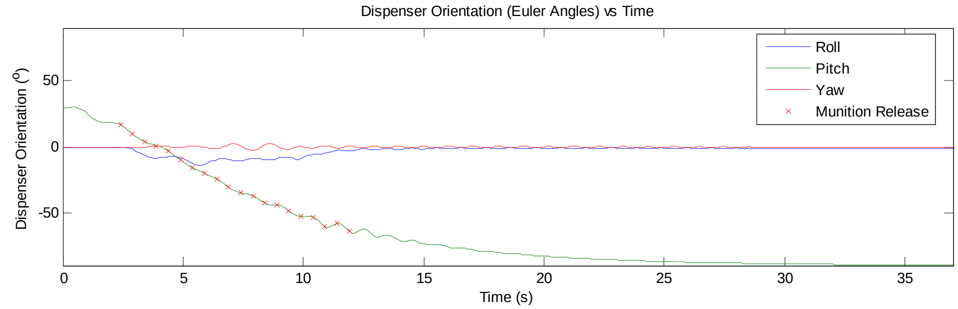

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

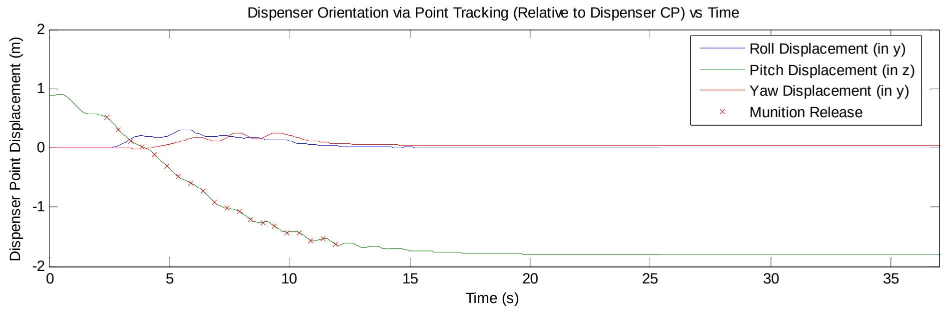

x 10^5 Moments Due to Transitory Center of Gravity (Body Axes) vs Time
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

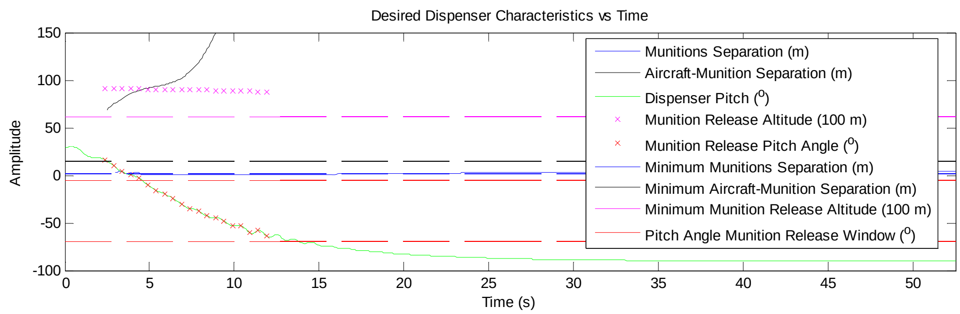

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

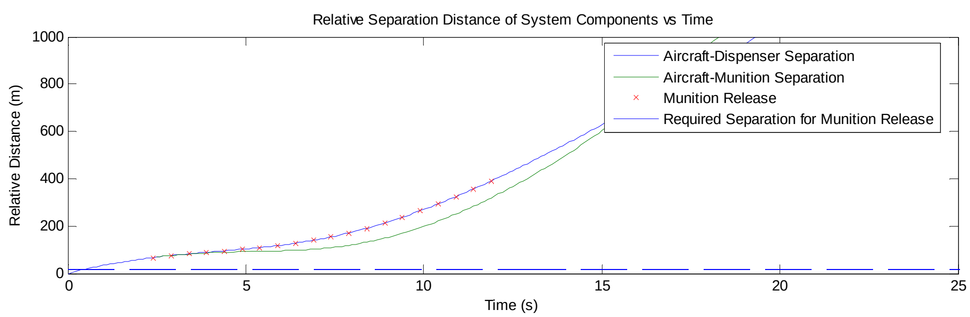

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

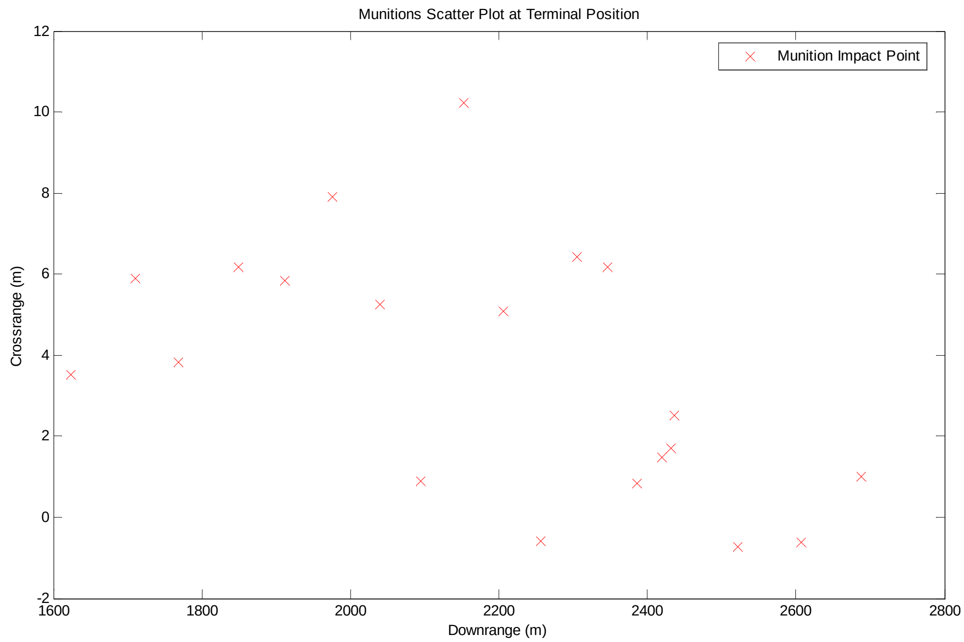

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Dispenser System Mass
Munition Release
Time (s)
Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release
Time (s)


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (^{o})
Time (s)
Roll
Pitch
Yaw
Munition Release

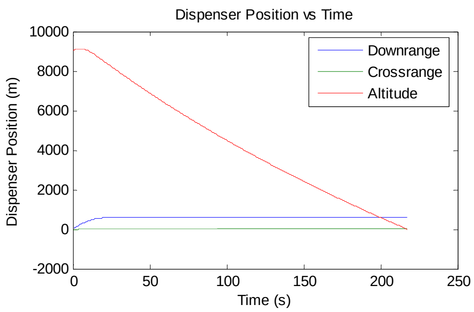

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

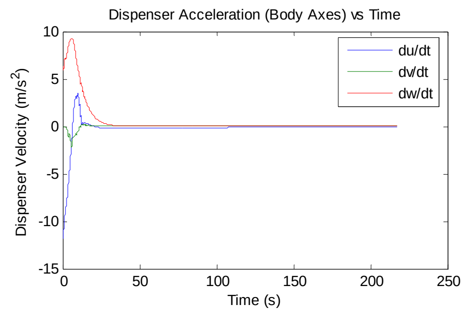

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (^{o})
Munition Release Altitude (100 m)
Munition Release Pitch Angle (^{o})
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (^{o})

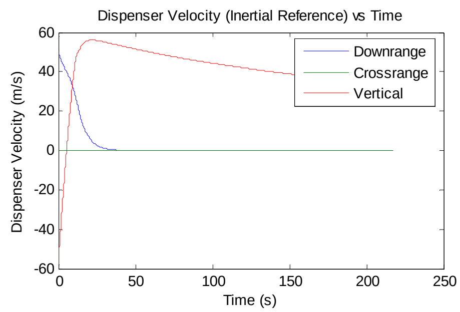

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

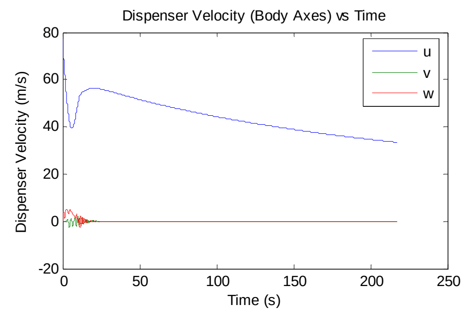

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
12
10
8
6
4
2
0
-2
1600
1800
2000
2200
2400
2600
2800

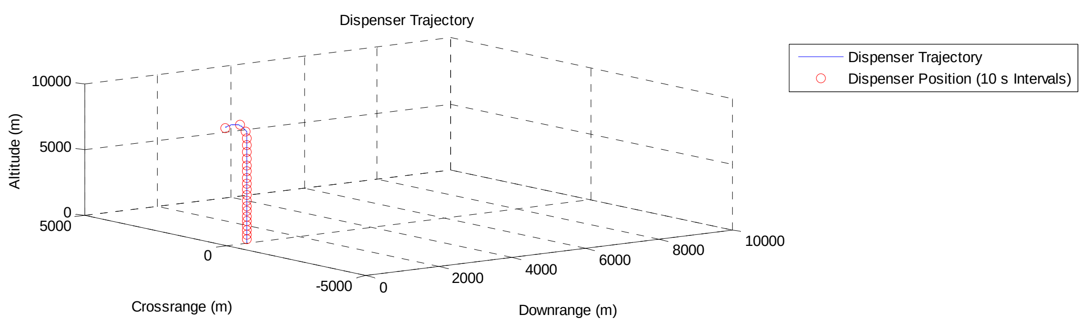
Test #17: Final Dispenser - Tip-Off Angle at 4+45

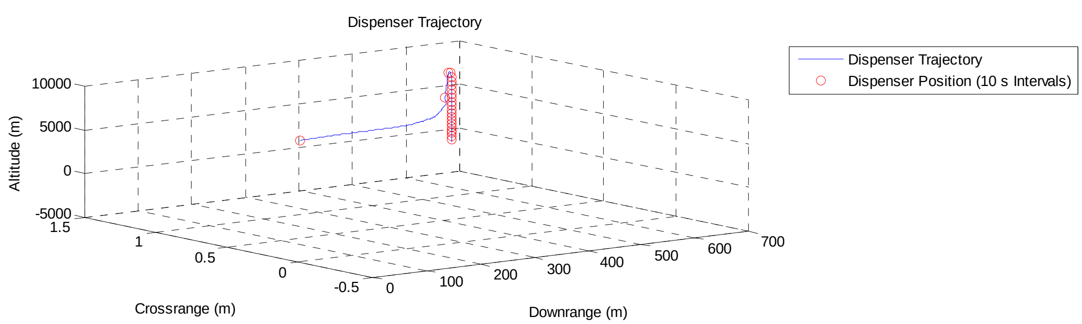


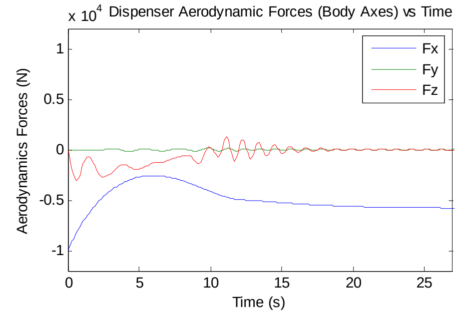


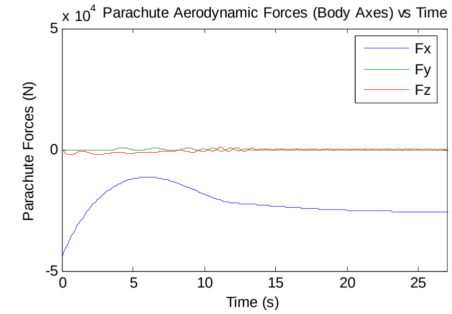


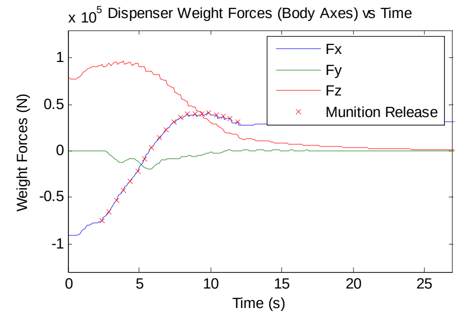


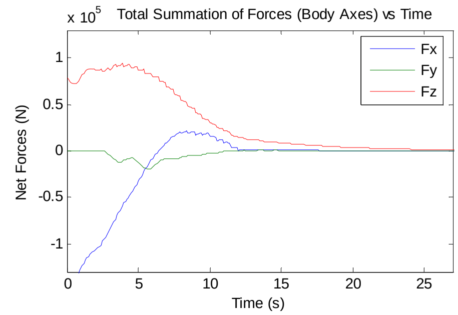


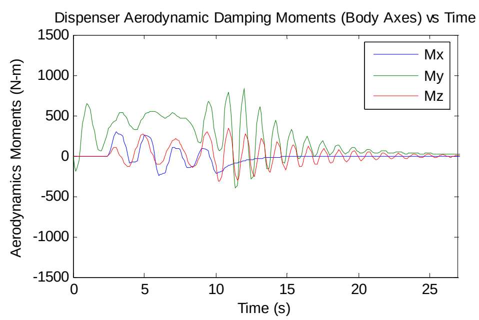


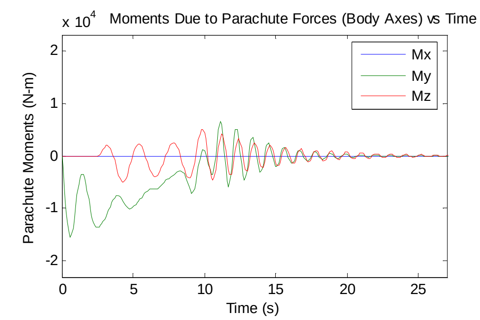

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Fx
Fy
Fz
Aerodynamics Forces (N)
Time (s)

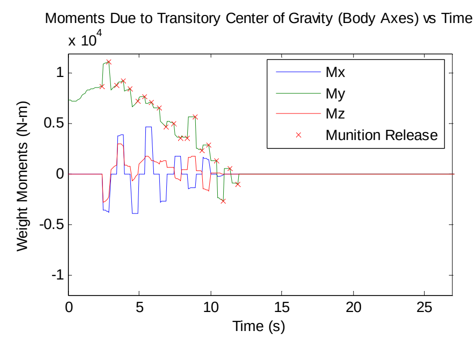

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Fx
Fy
Fz
Parachute Forces (N)
Time (s)

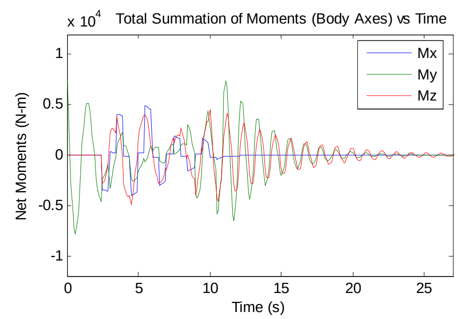

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Fx
Fy
Fz
Munition Release
Weight Forces (N)
Time (s)

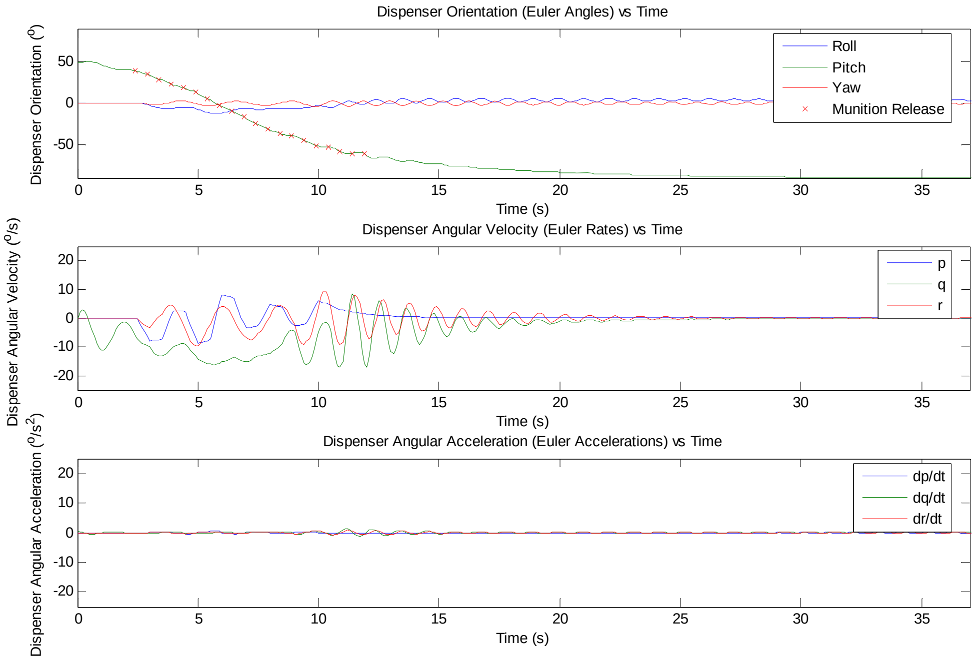

x 10^5 Total Summation of Forces (Body Axes) vs Time
Fx
Fy
Fz
Net Forces (N)
Time (s)

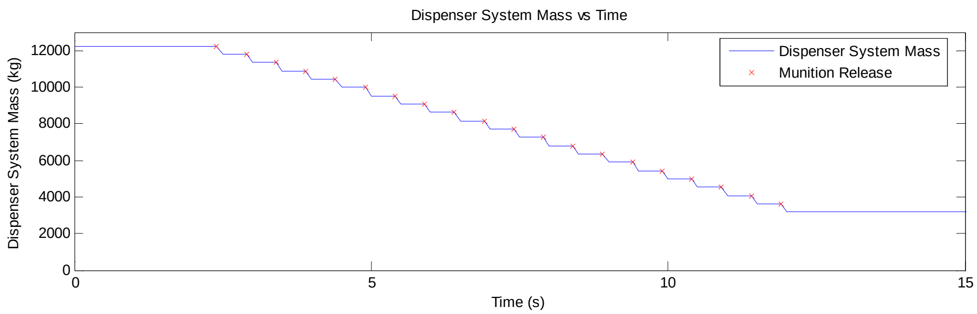

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Mx
My
Mz
Aerodynamics Moments (N-m)
Time (s)

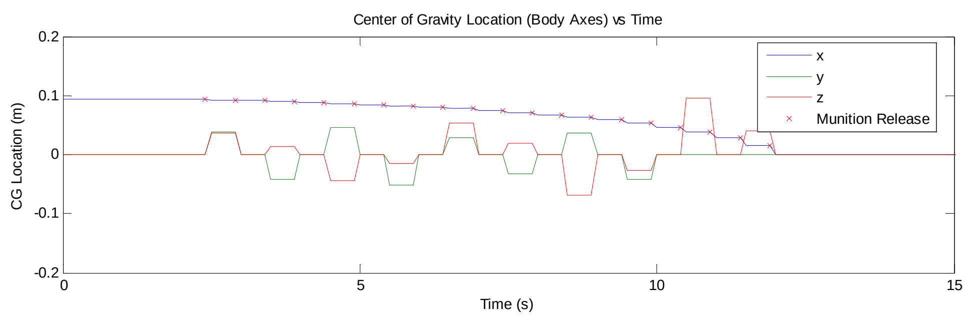

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Mx
My
Mz
Parachute Moments (N-m)
Time (s)

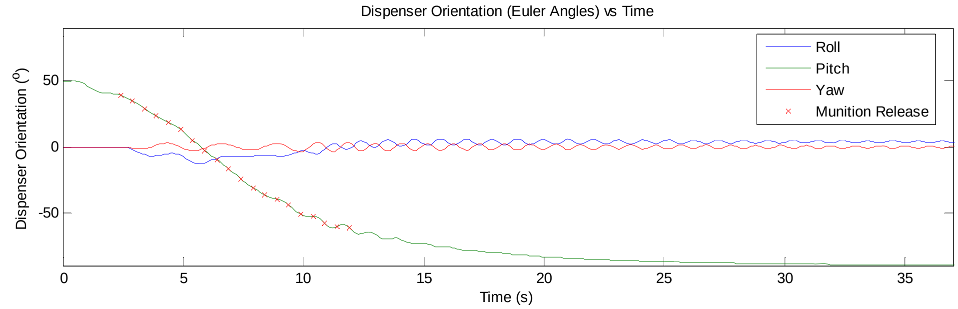

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Mx
My
Mz
Munition Release
Weight Moments (N-m)
Time (s)

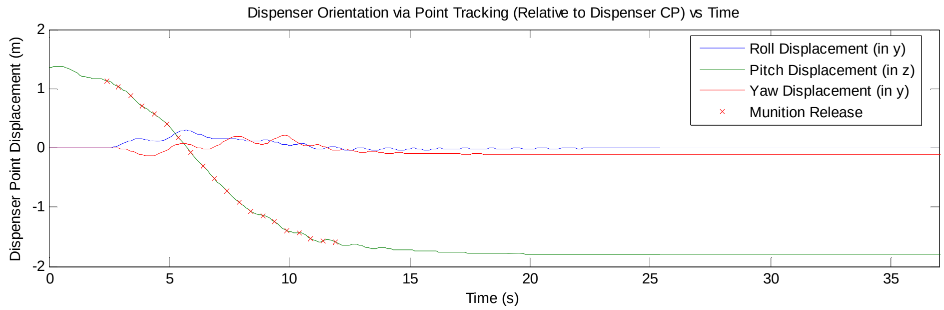

x 10^4 Total Summation of Moments (Body Axes) vs Time
Mx
My
Mz
Net Moments (N-m)
Time (s)

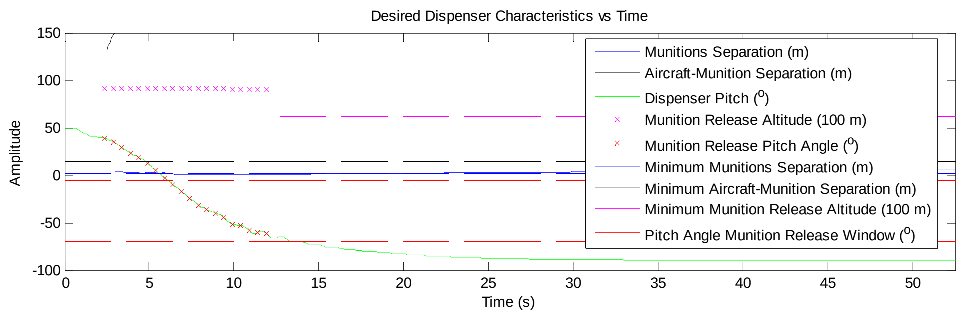

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

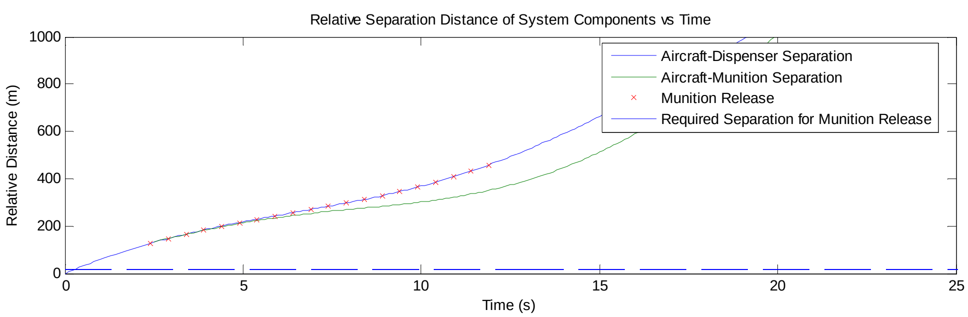

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

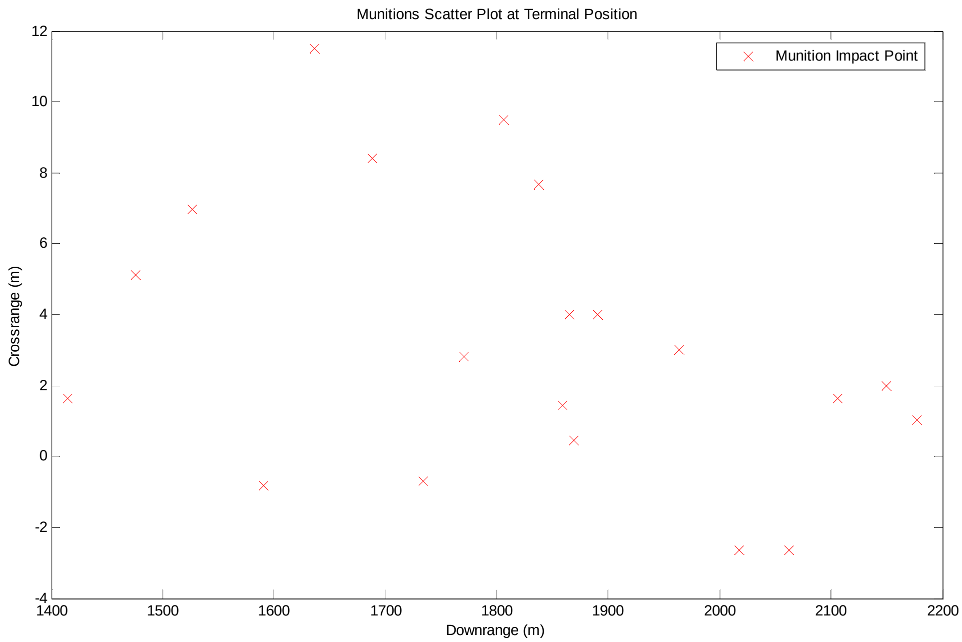

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
50
0
-50
0
5
10
15
20
25
30
35


Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
2
1
0
-1
-2
0
5
10
15
20
25
30
35

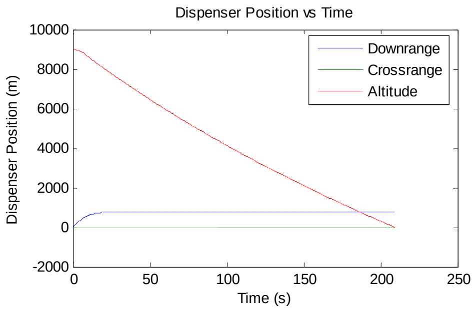

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
150
100
50
0
-50
-100
0
5
10
15
20
25
30
35
40
45
50

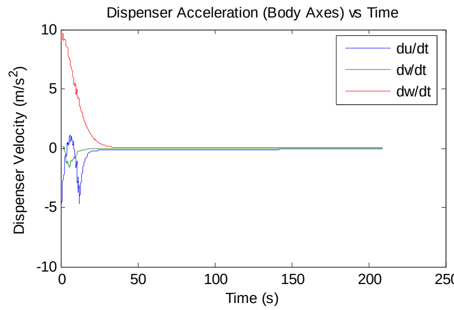

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release
1000
800
600
400
200
0
0
5
10
15
20
25

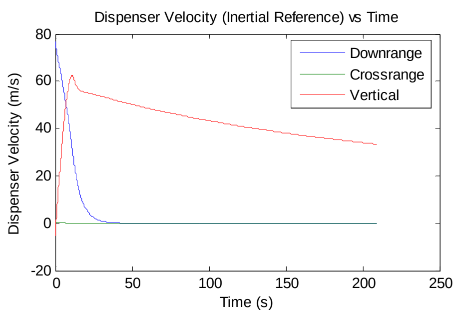


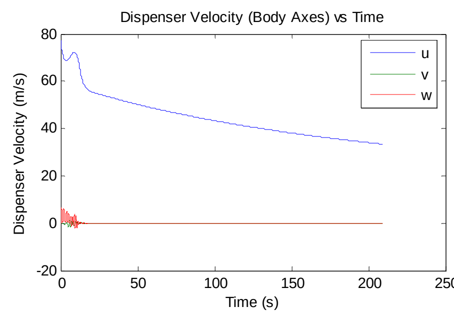
Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
12
10
8
6
4
2
0
-2
-4
1400
1500
1600
1700
1800
1900
2000
2100
2200

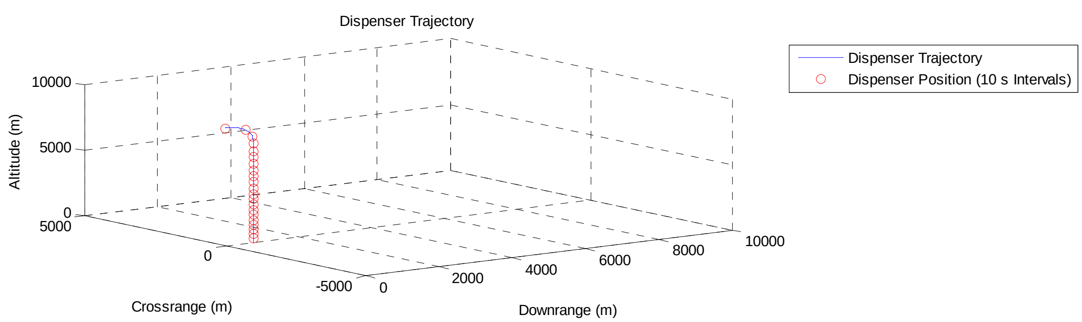
Test #18: Final Dispenser - Force in Y

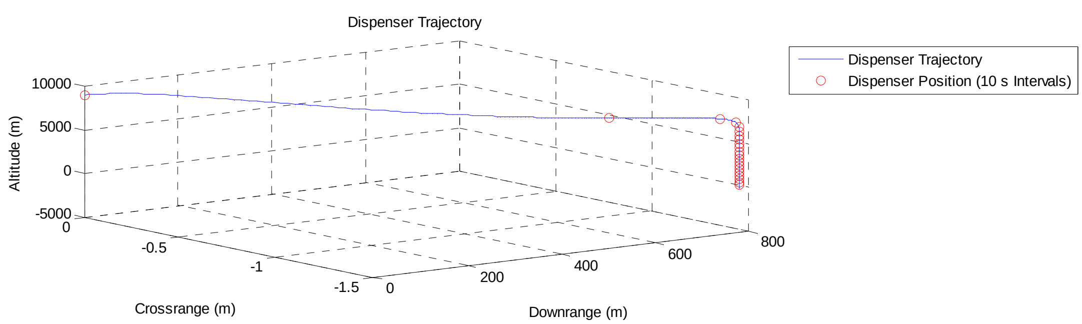


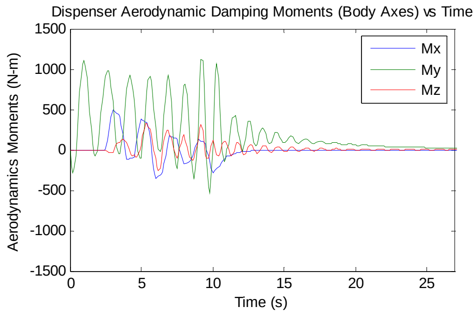


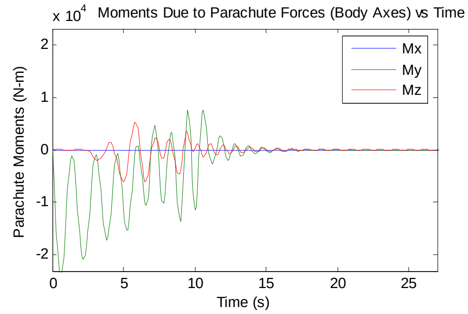


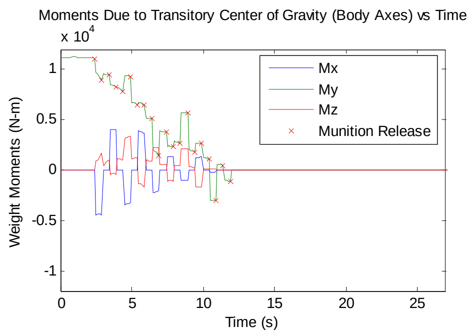


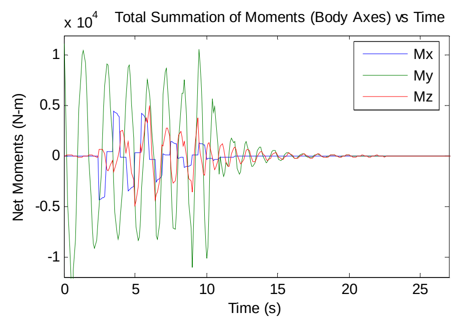


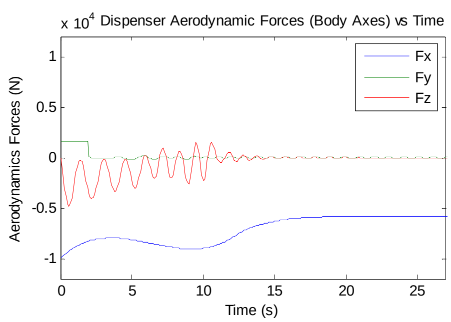


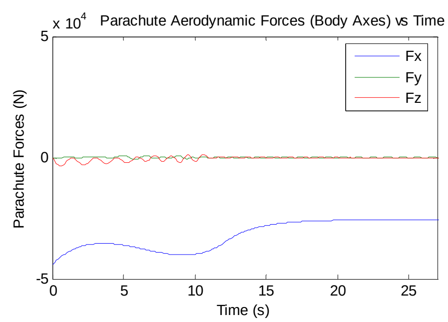

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

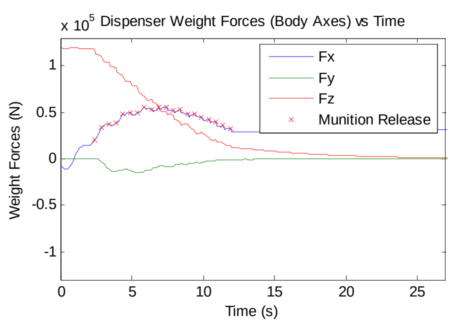

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

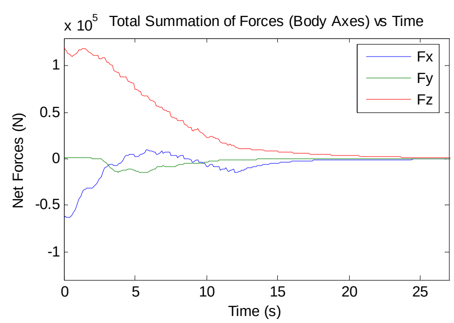

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

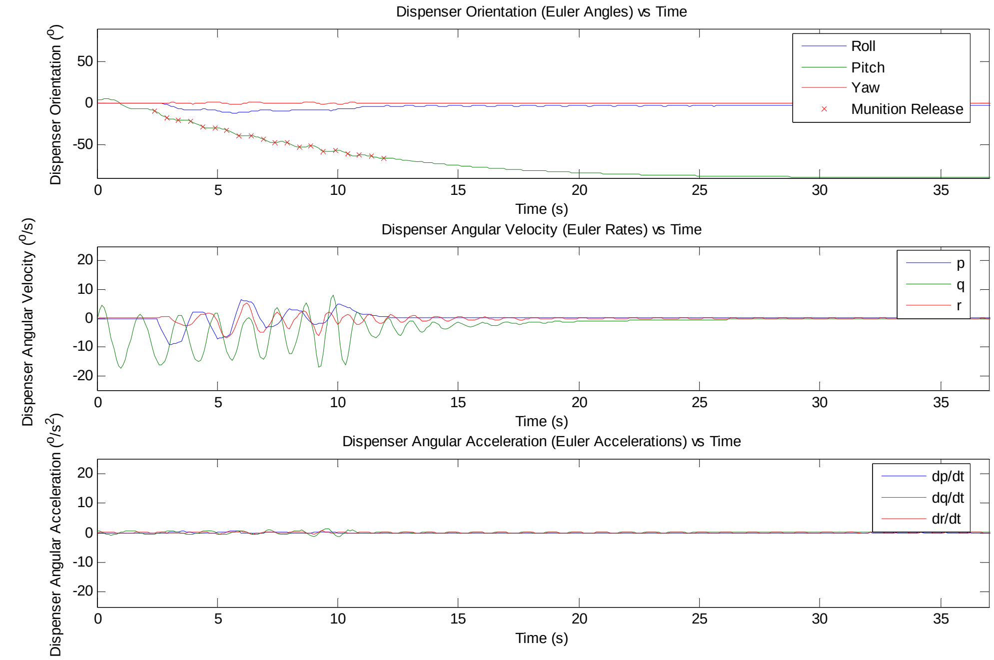

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

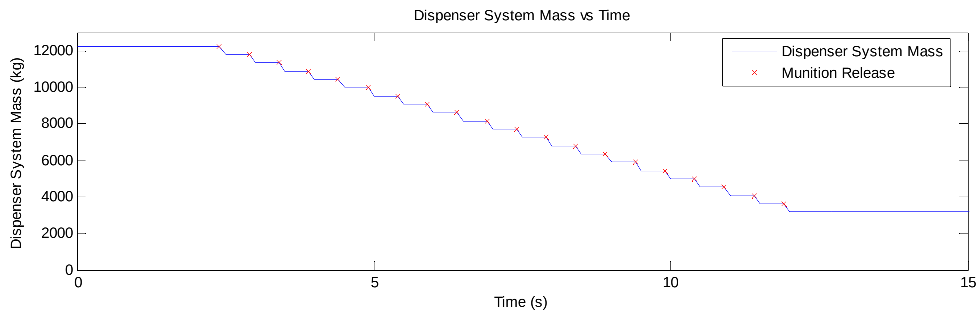

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

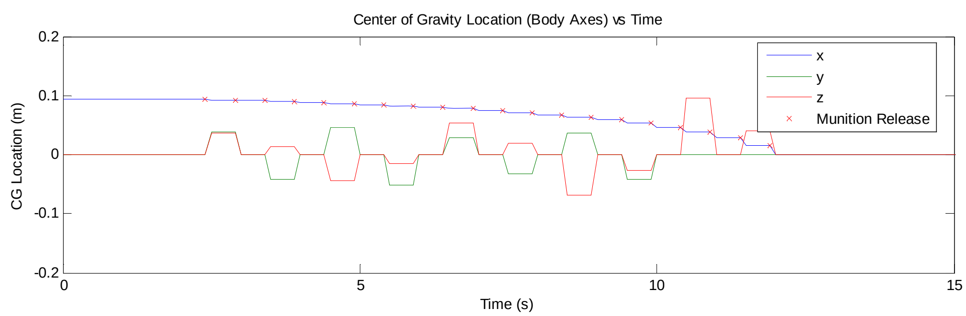

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

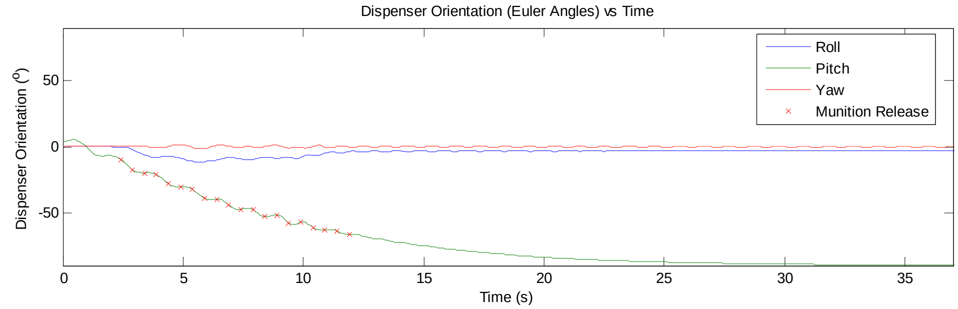

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

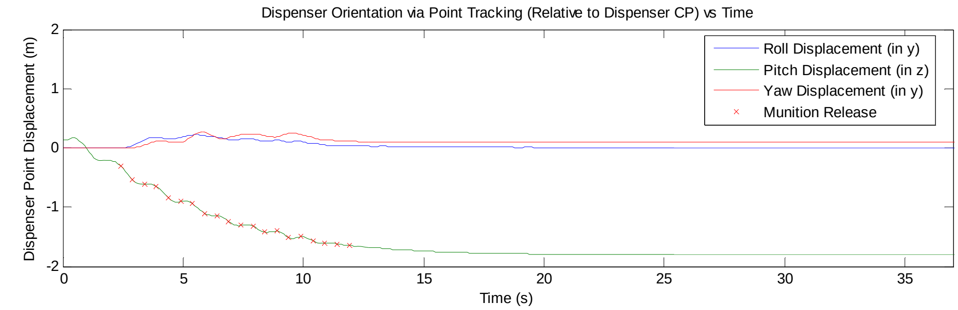

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

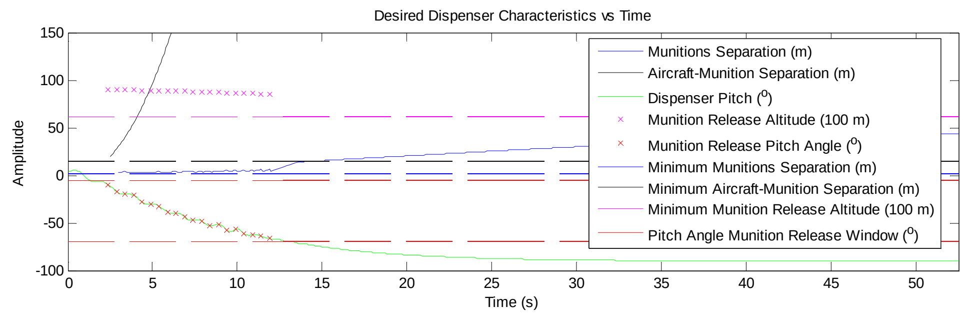

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Roll
Pitch
Yaw
Munition Release
Time (s)
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Time (s)
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt
Time (s)

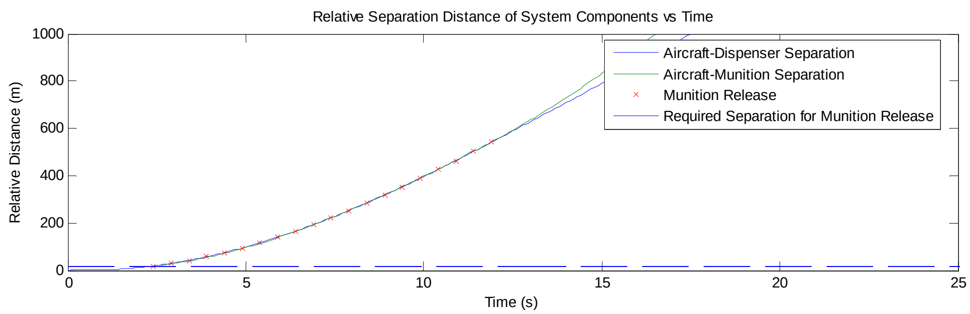

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Dispenser System Mass
Munition Release
Time (s)

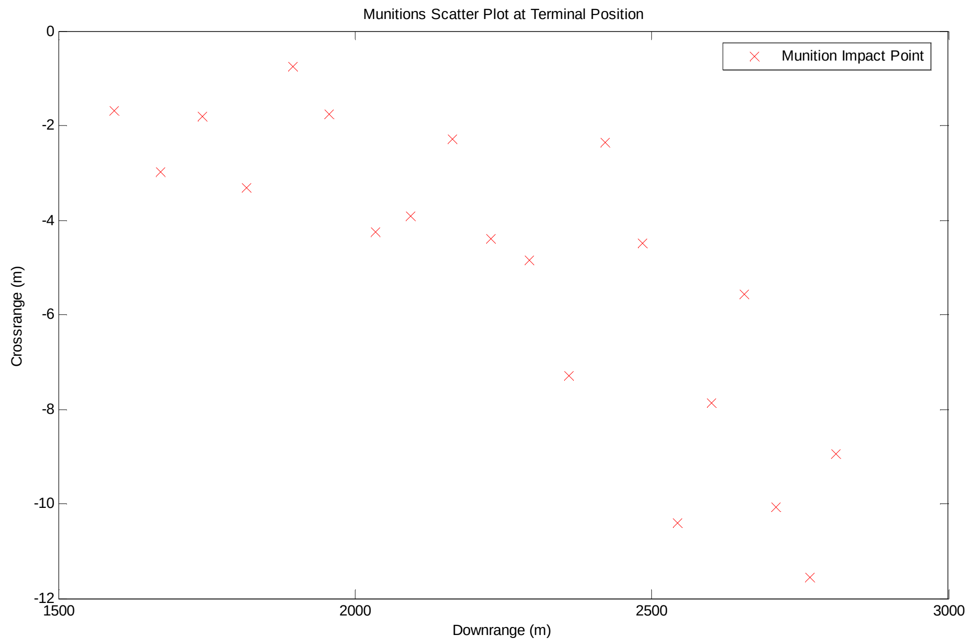

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
x
y
z
Munition Release
Time (s)


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
50
0
-50
0
5
10
15
20
25
30
35


Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
2
1
0
-1
-2
0
5
10
15
20
25
30
35

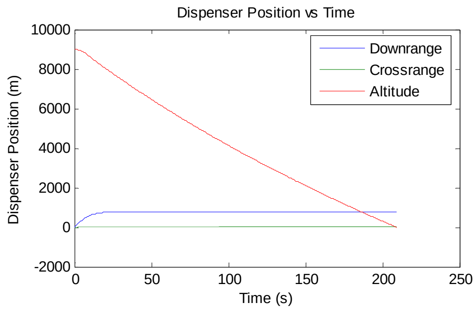

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
150
100
50
0
-50
-100
0
5
10
15
20
25
30
35
40
45
50

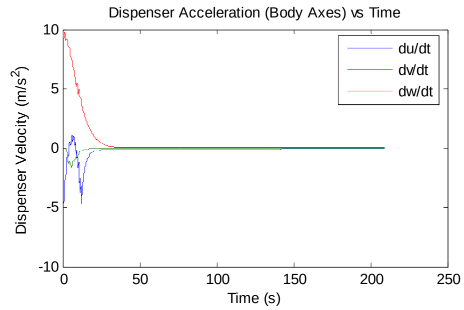

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release
1000
800
600
400
200
0
0
5
10
15
20
25

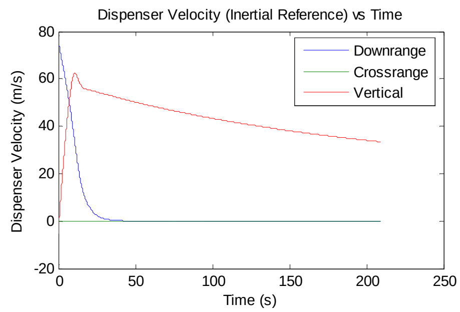


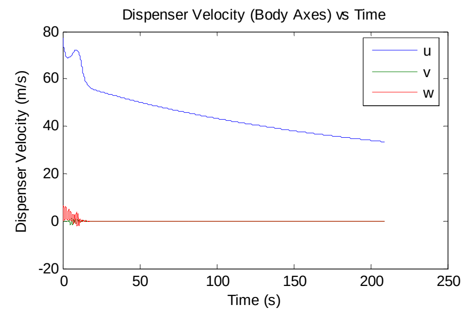
Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
0
-2
-4
-6
-8
-10
-12
1500
2000
2500
3000

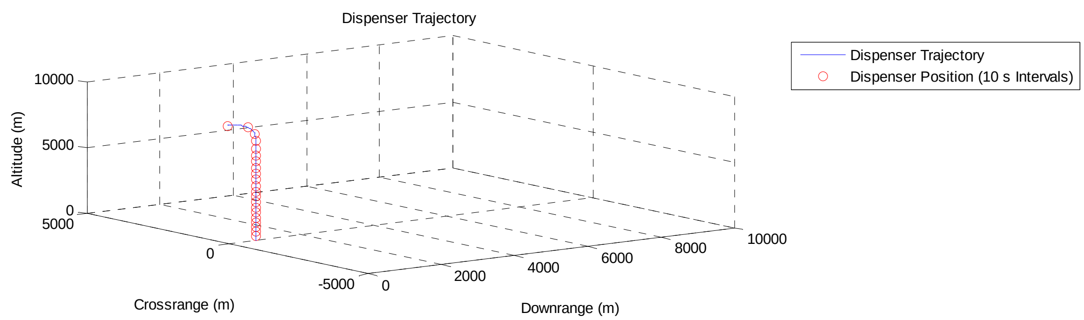
Test #19: Final Dispenser - Force in +Z

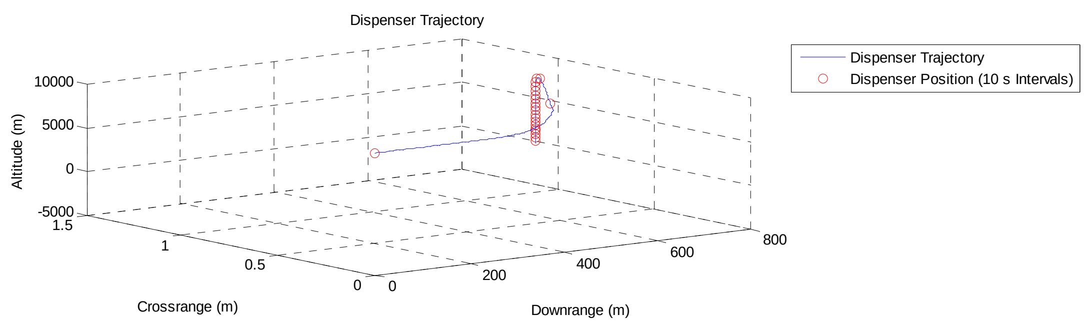


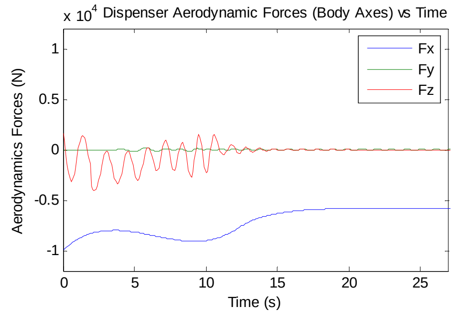


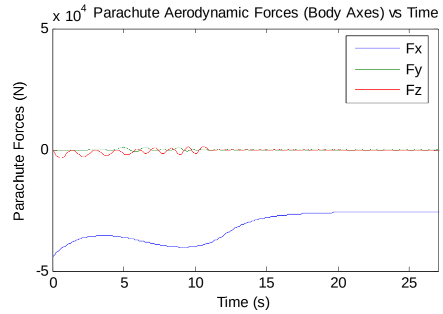


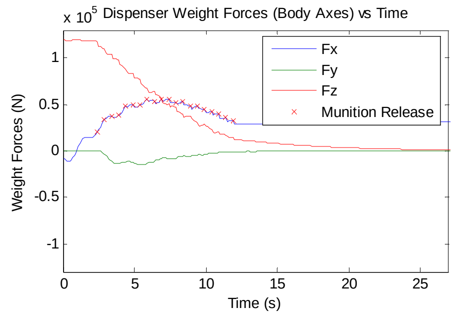


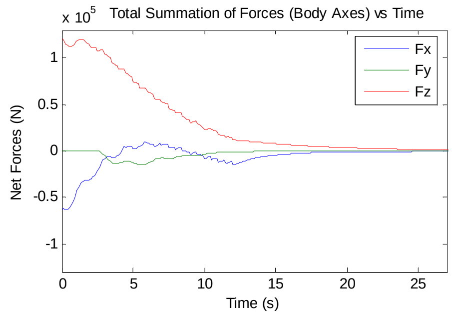


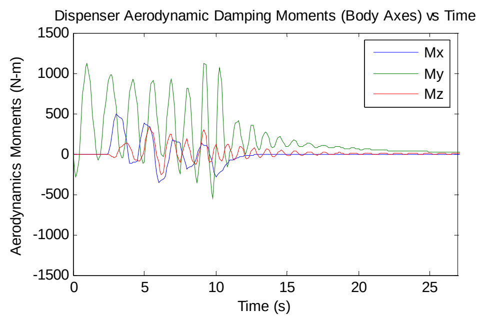


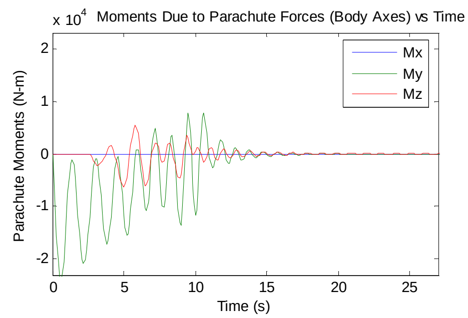

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

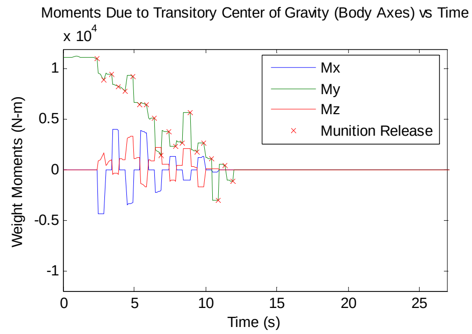

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

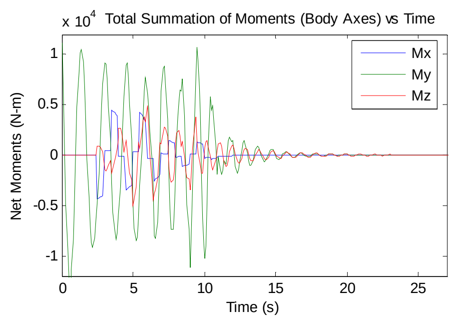

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

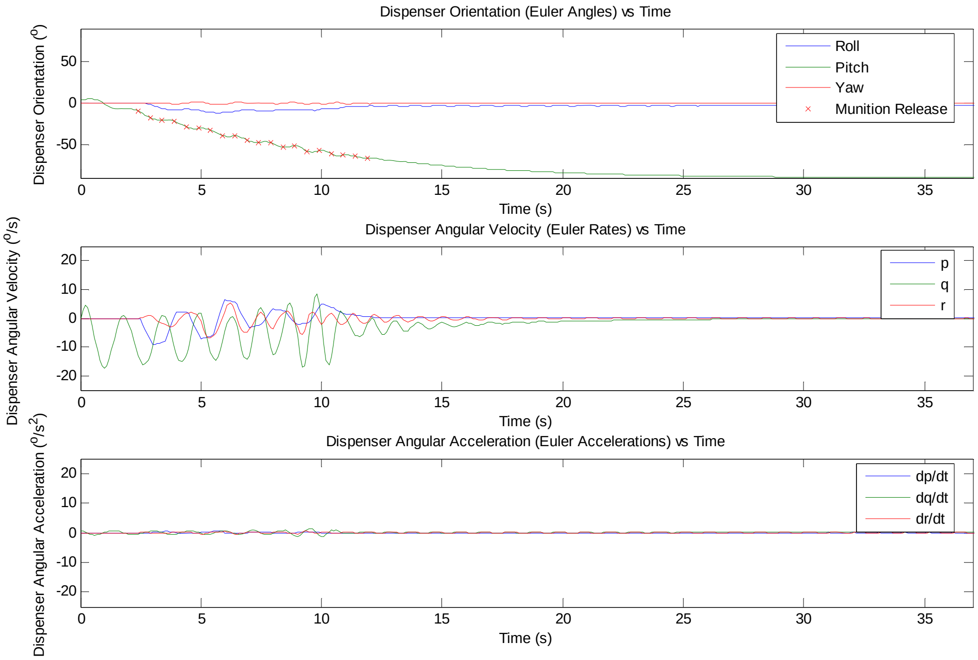

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

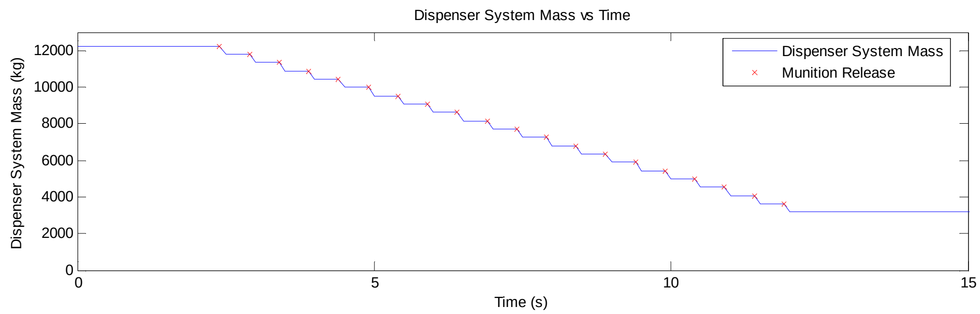

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

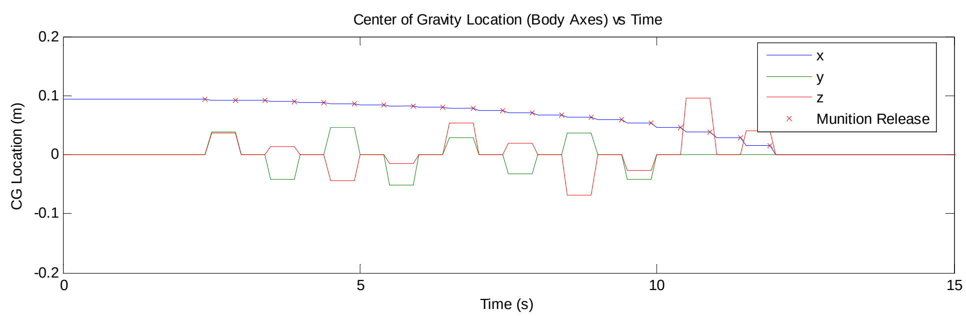

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

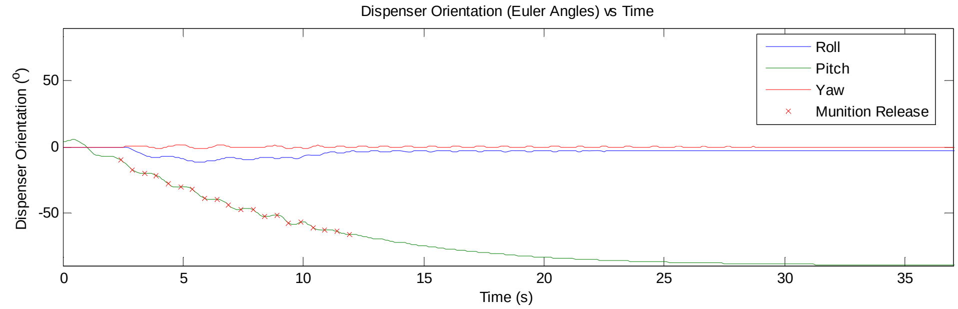

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

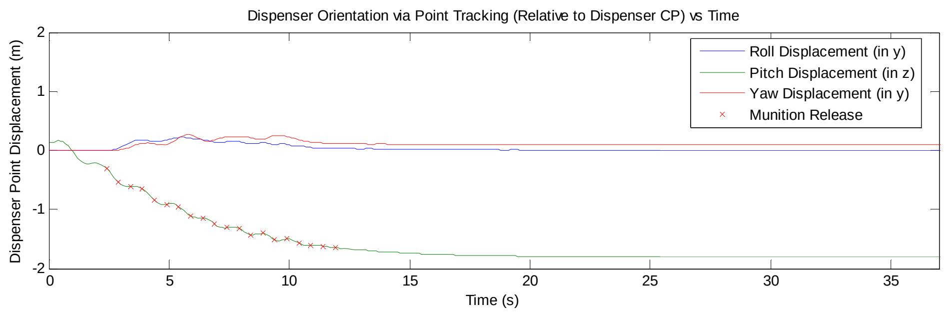

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

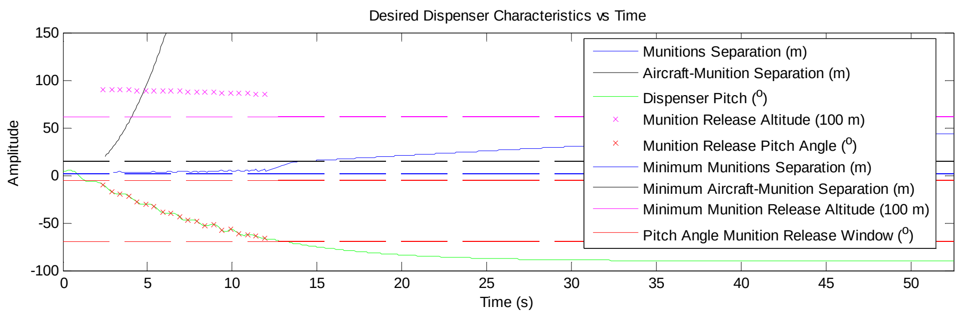

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

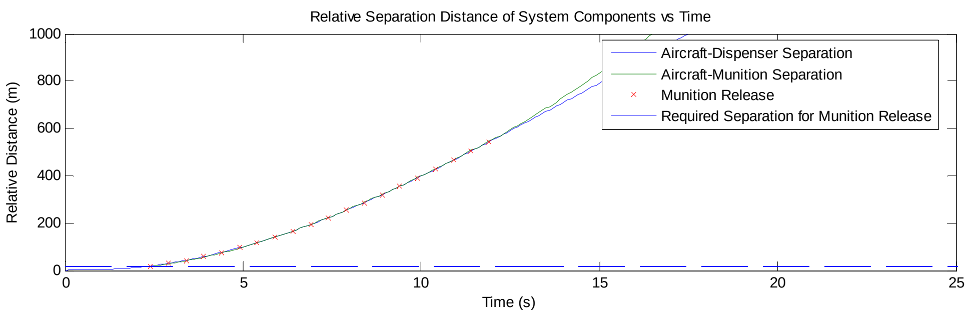

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

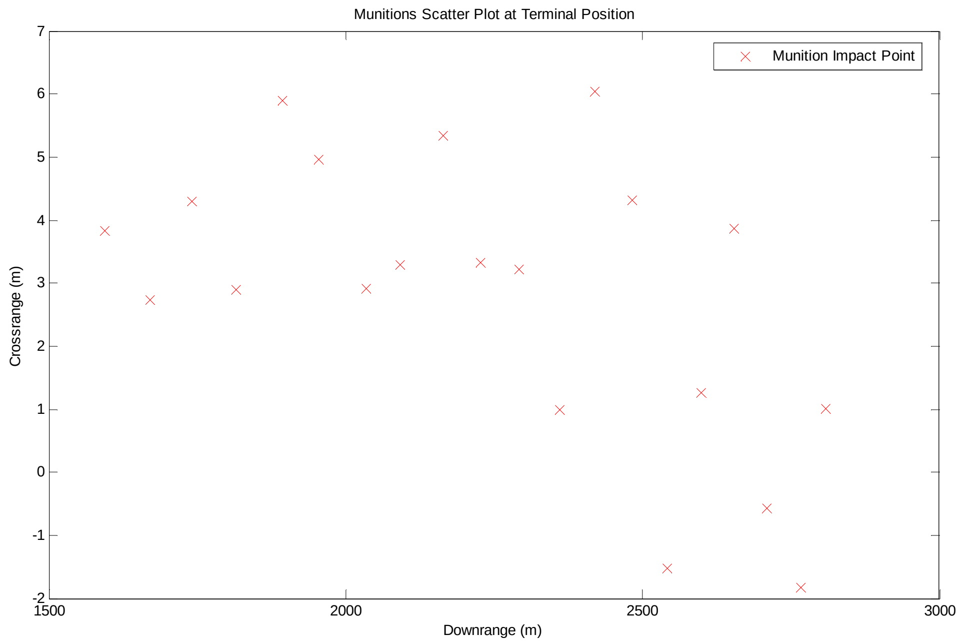

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

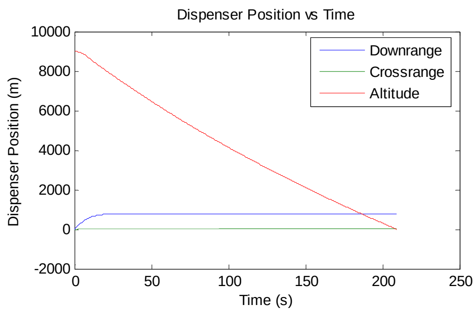

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

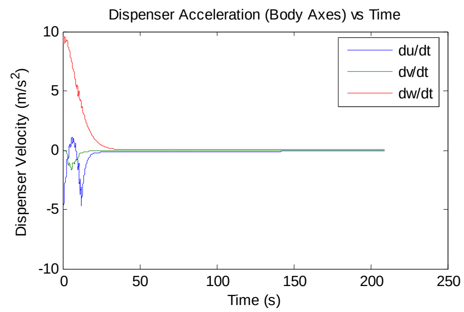

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

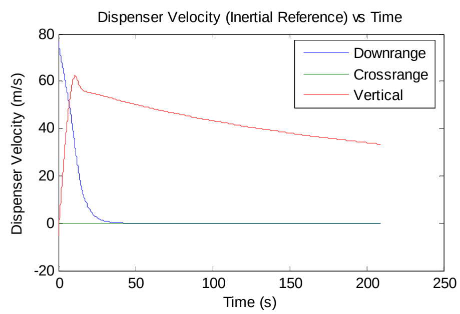

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

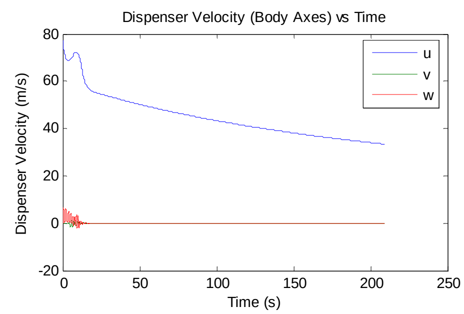

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
7
6
5
4
3
2
1
0
-1
-2
1500
2000
2500
3000

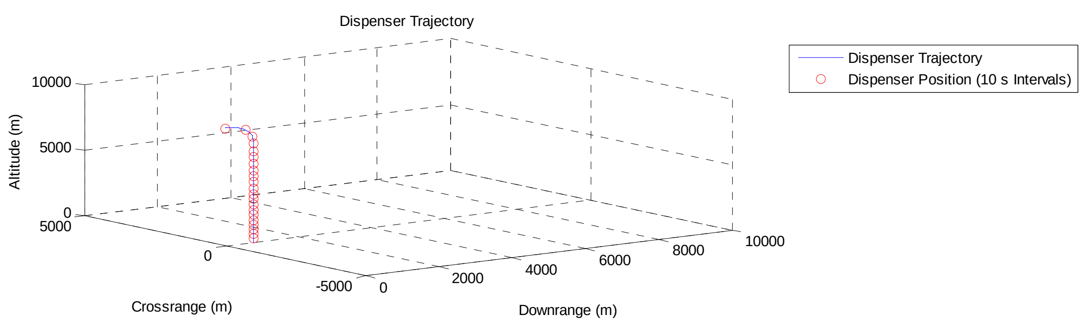
Test #20: Final Dispenser - Force in -Z

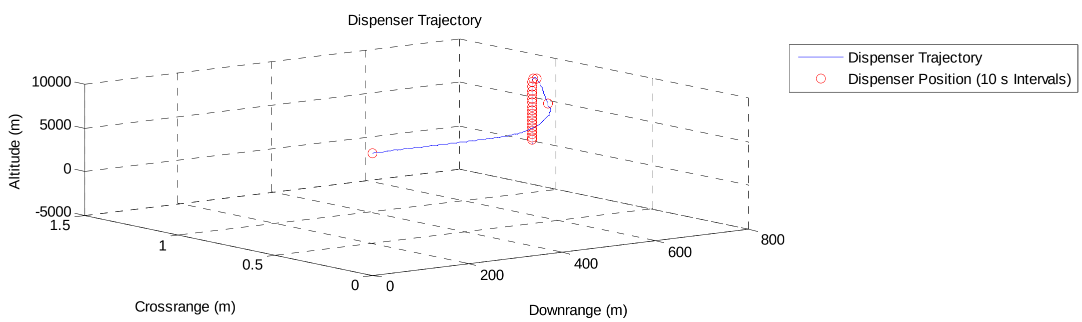


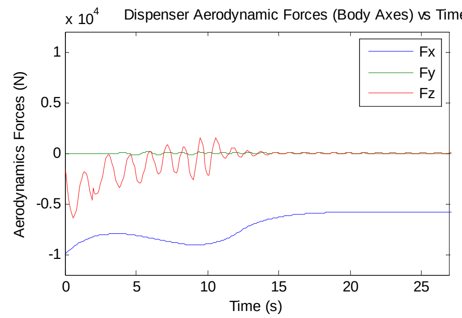


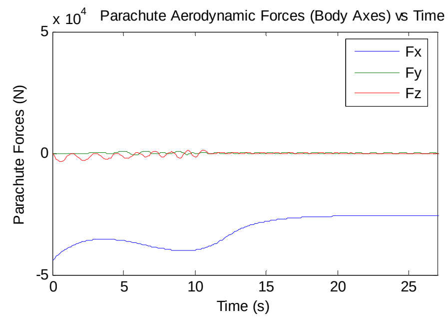


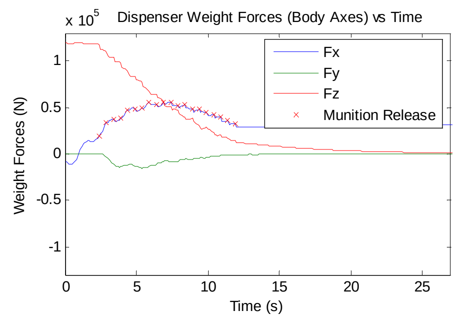


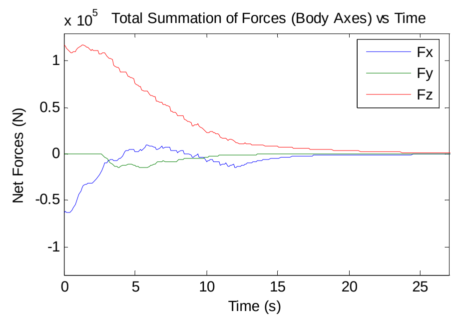


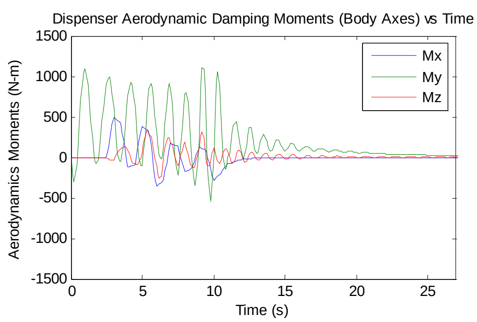


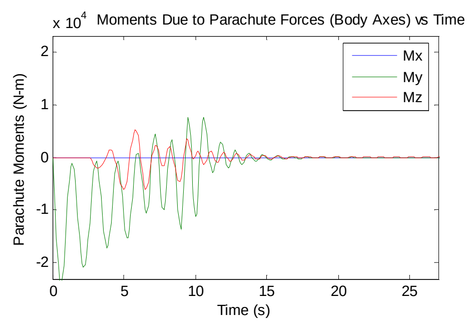

x 10^4
Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

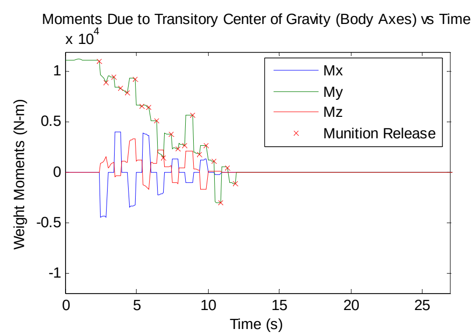

x 10^4
Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

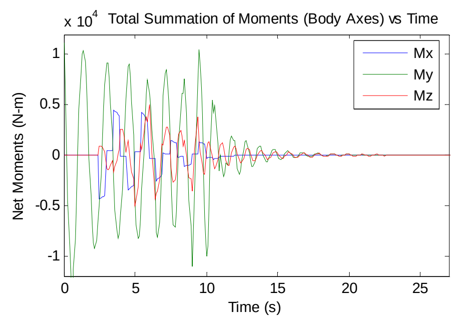

x 10^5
Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

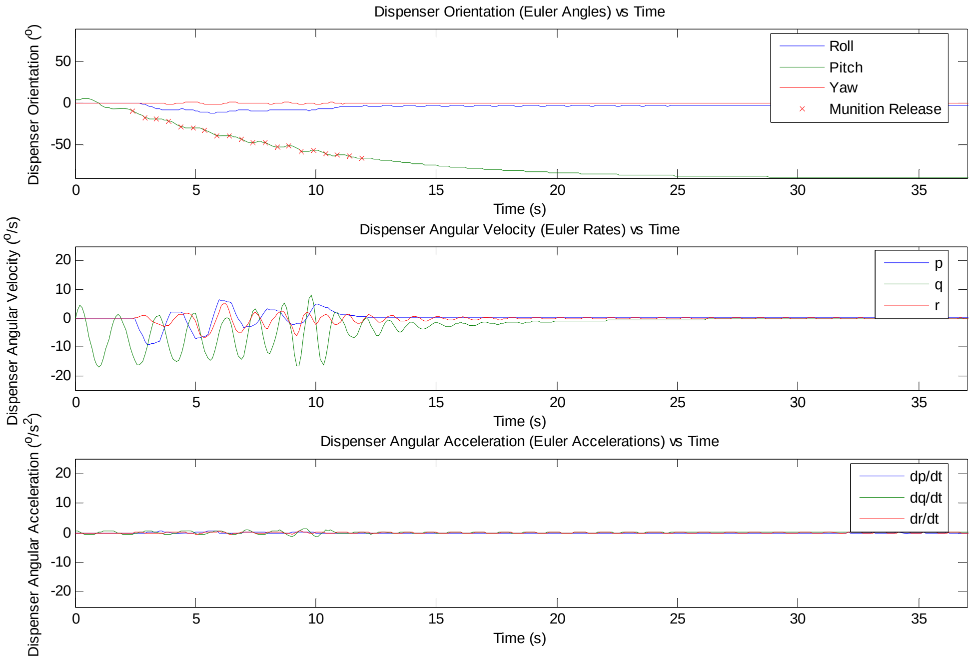

x 10^5
Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

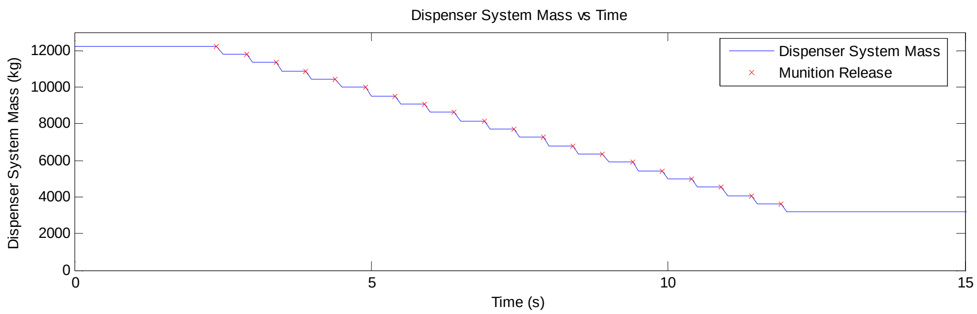

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

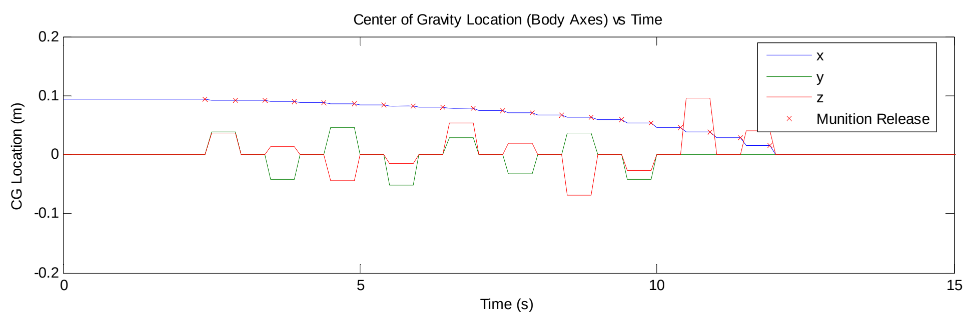

x 10^4
Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

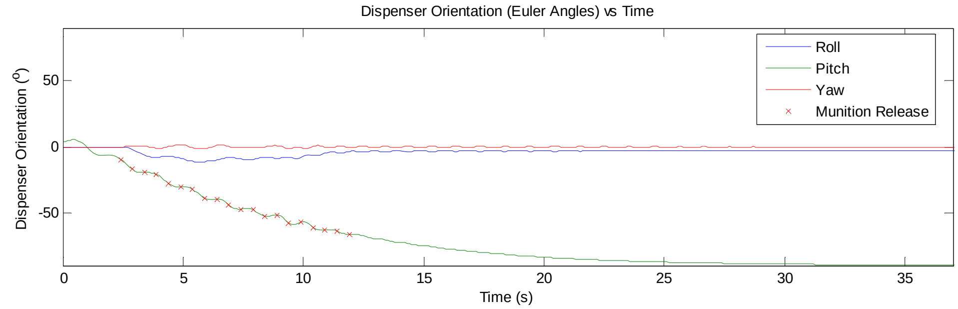

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

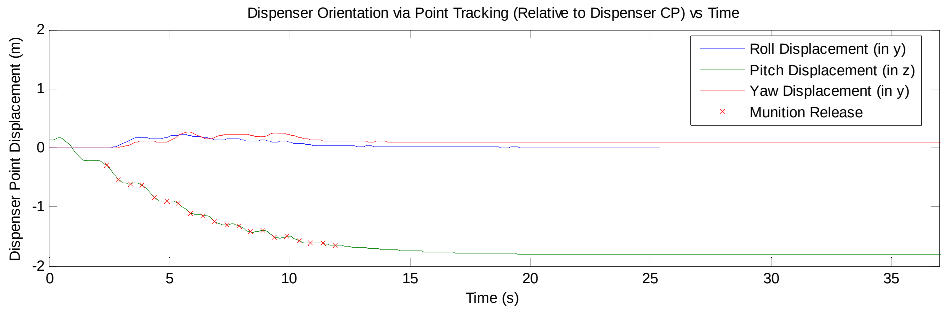

x 10^4
Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

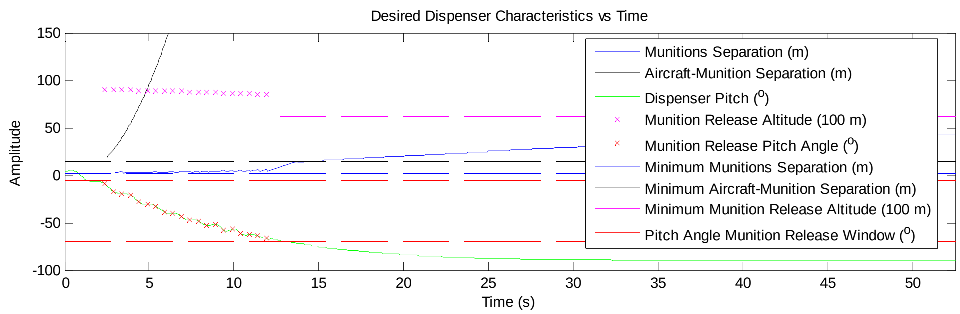

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

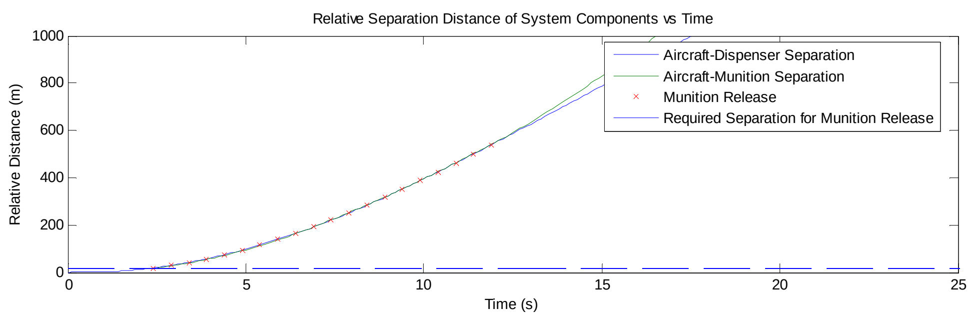

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

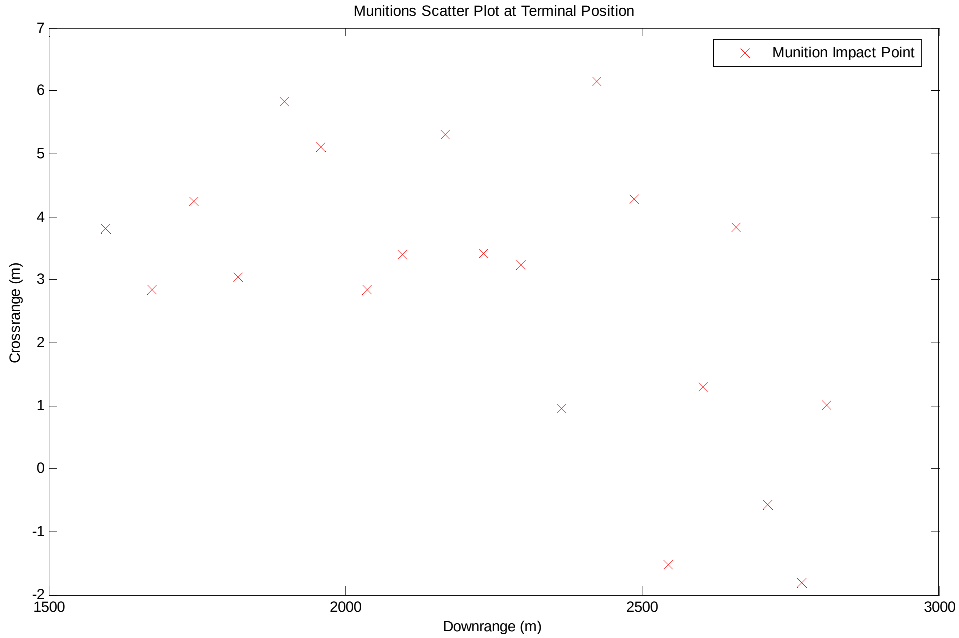

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (^{o})
Time (s)
Roll
Pitch
Yaw
Munition Release

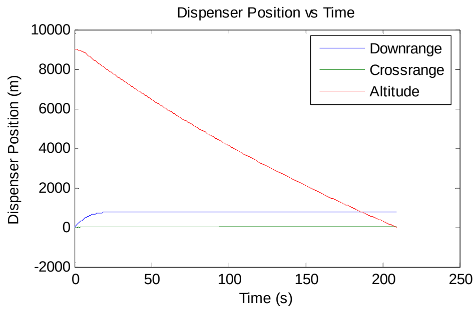

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

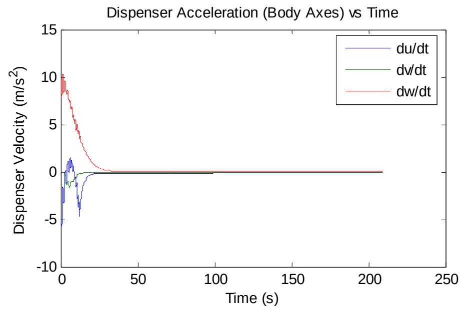

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (^{o})
Munition Release Altitude (100 m)
Munition Release Pitch Angle (^{o})
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (^{o})

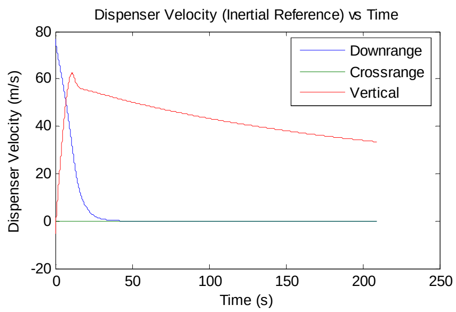

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

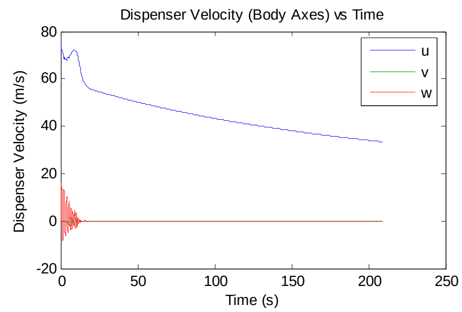

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
7
6
5
4
3
2
1
0
-1
-2
1500
2000
2500
3000

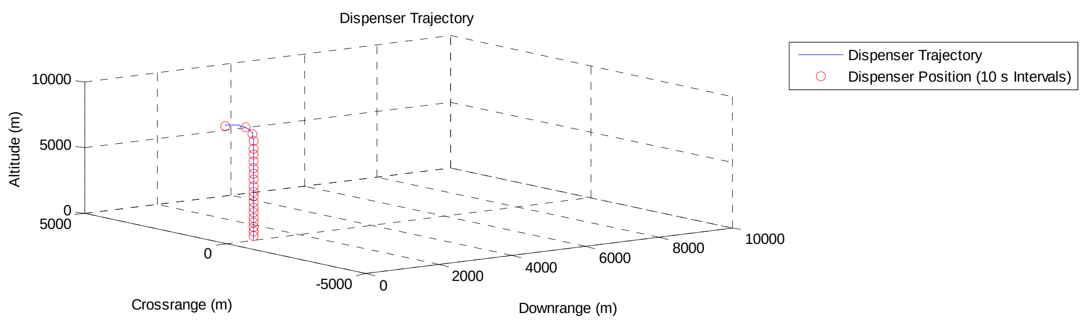
Test #21: Final Dispenser - Moment about Y

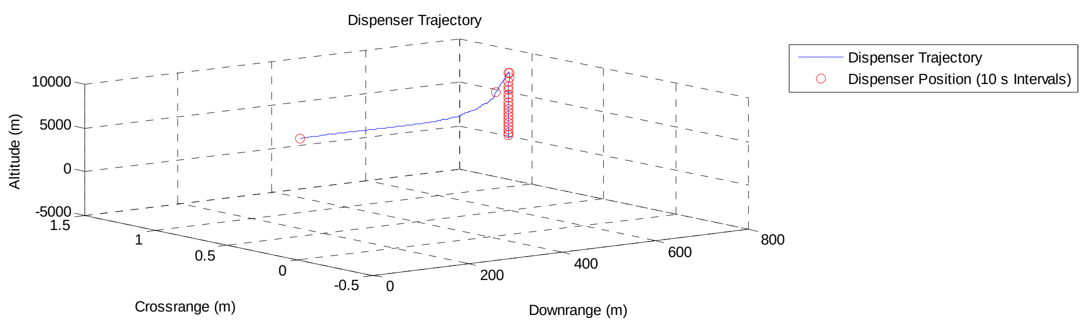


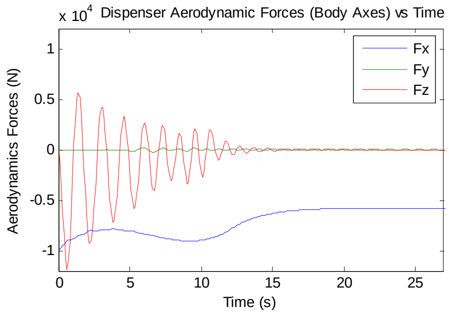


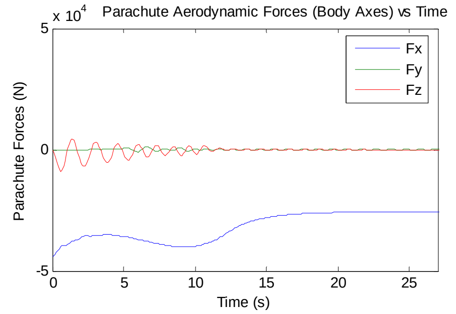


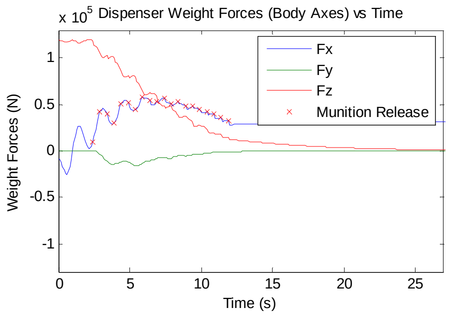


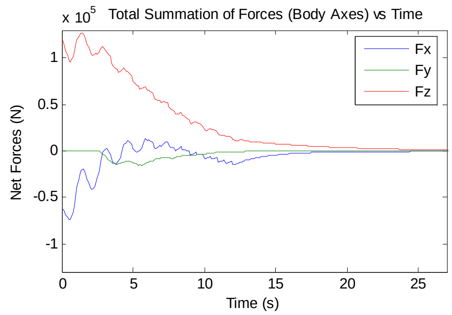


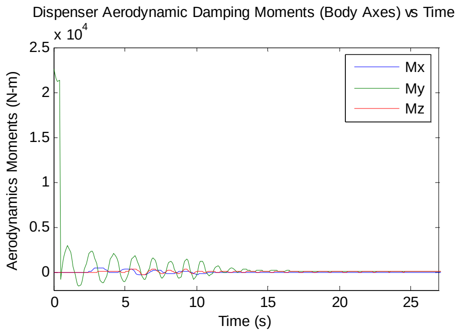


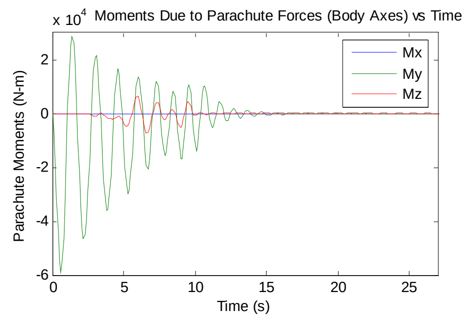

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

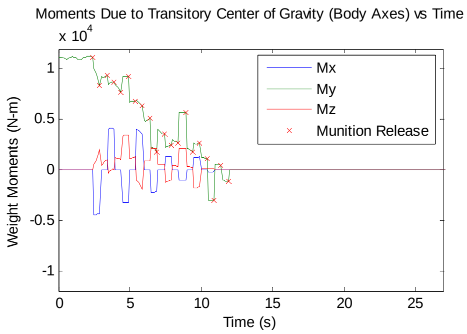

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

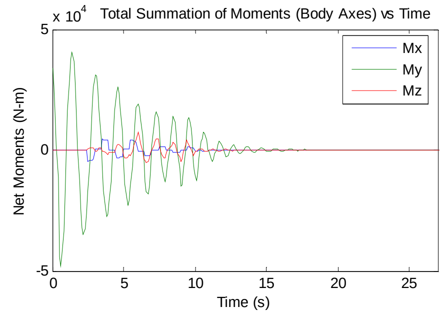

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

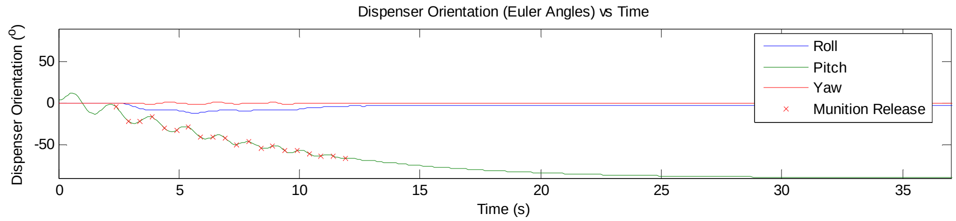

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

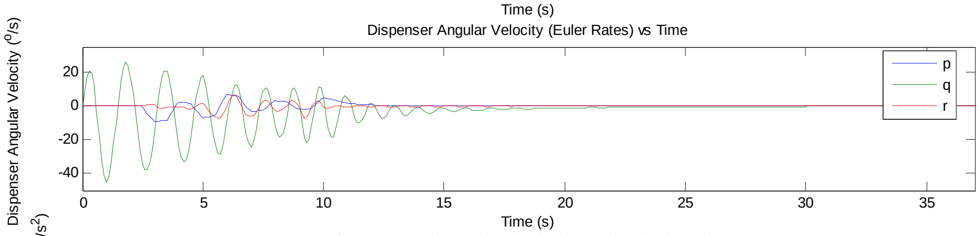

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
x 10^4
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

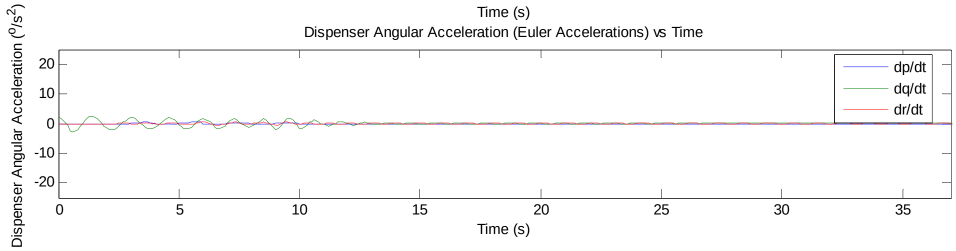

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

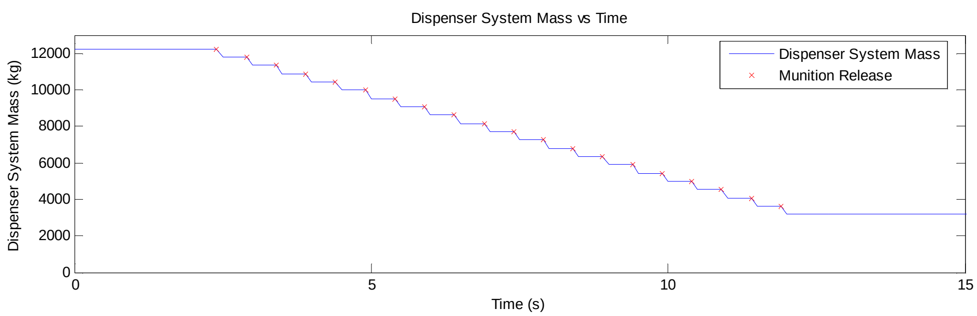

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

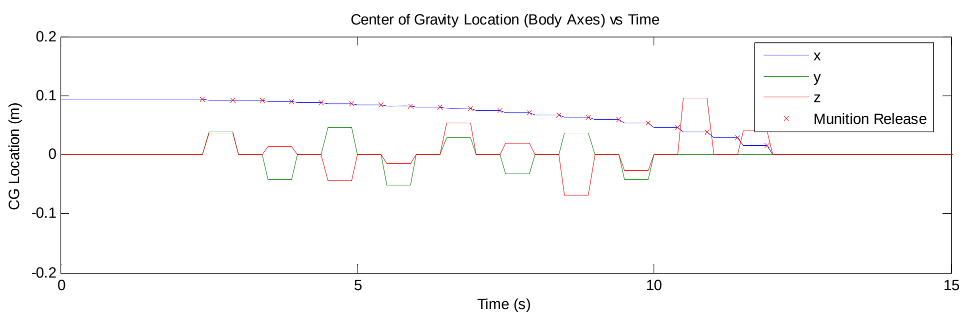

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

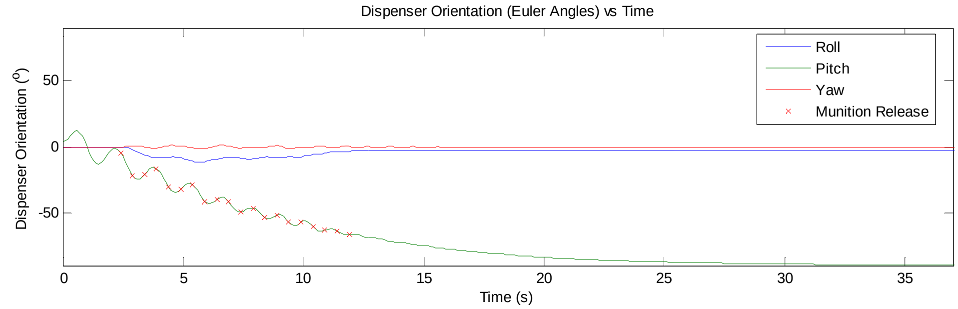

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

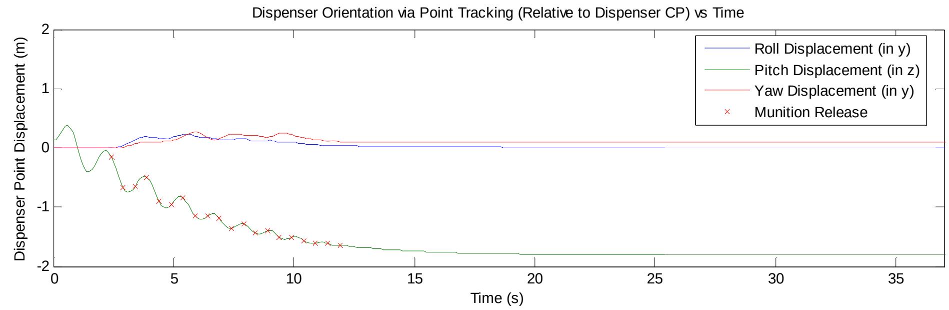

Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
Time (s)
p
q
r

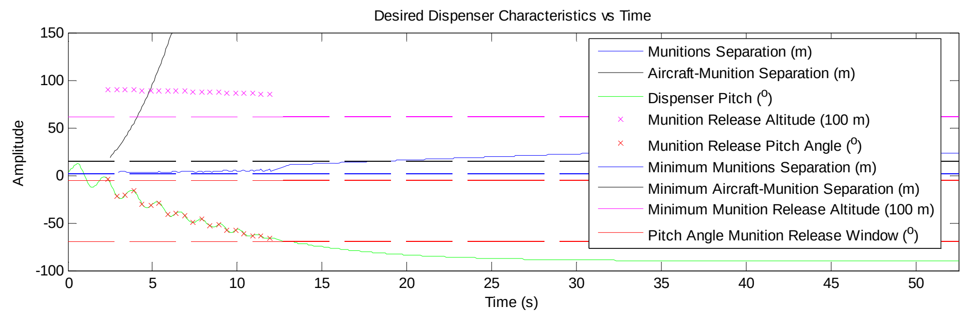

Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
Time (s)
dp/dt
dq/dt
dr/dt

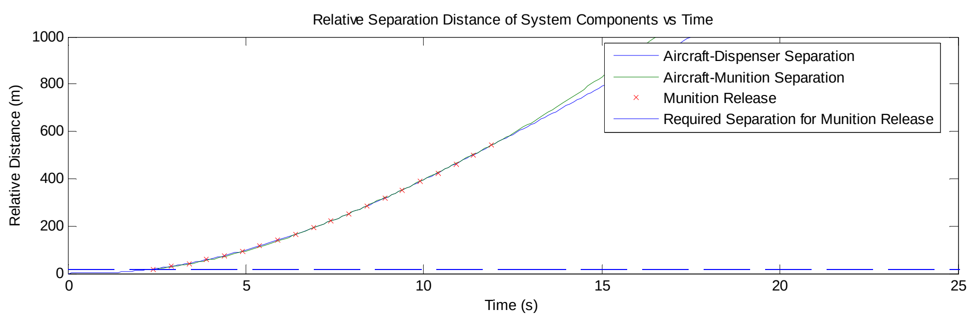

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release

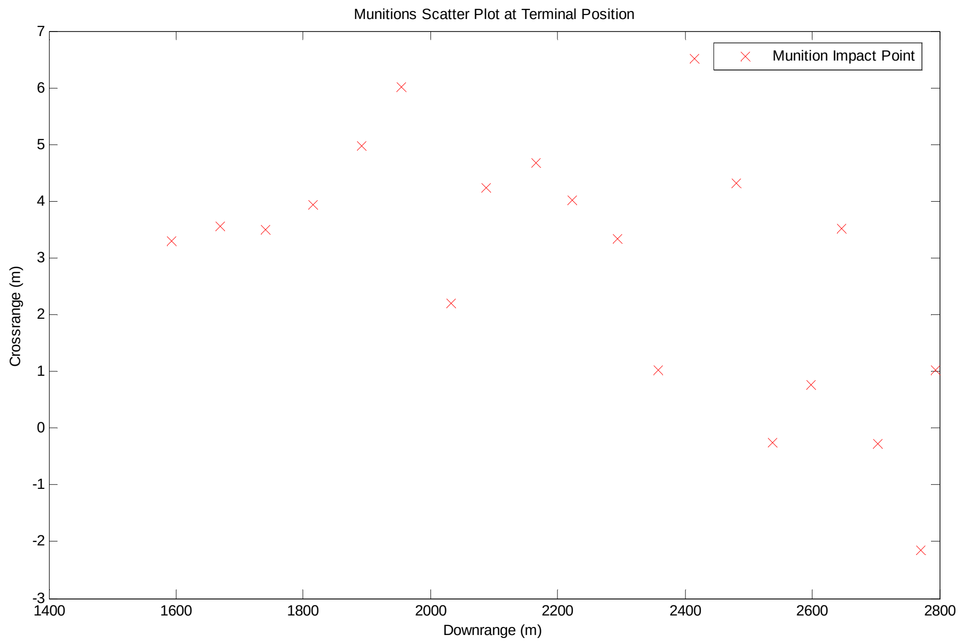

Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (o)
Time (s)
Roll
Pitch
Yaw
Munition Release

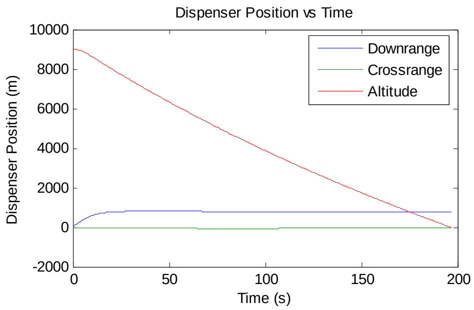

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

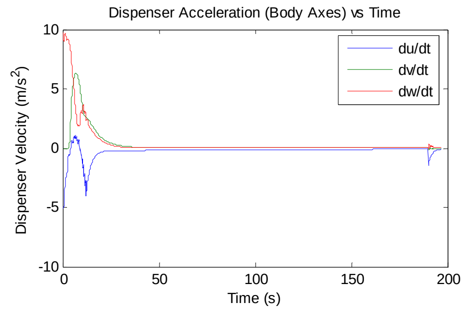

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (o)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (o)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (o)

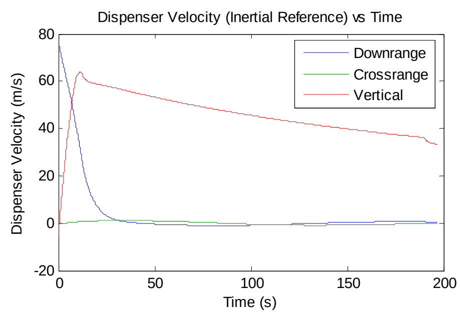

Relative Separation Distance of System Components vs Time
Relative Distance (m)
Time (s)
Aircraft-Dispenser Separation
Aircraft-Munition Separation
Munition Release
Required Separation for Munition Release

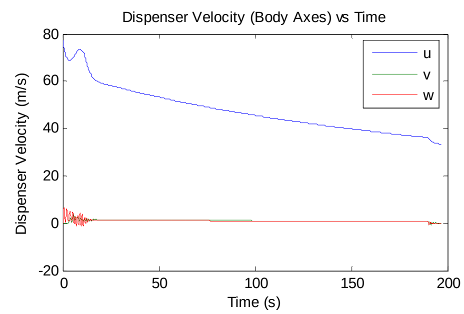

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
7
6
5
4
3
2
1
0
-1
-2
-3
1400
1600
1800
2000
2200
2400
2600
2800

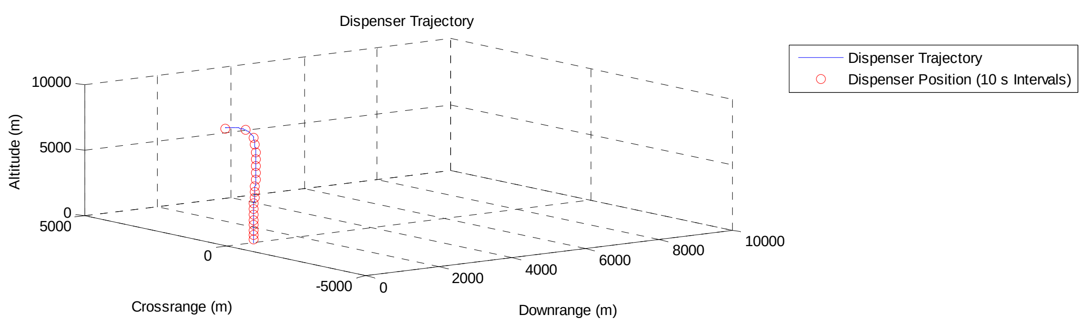
Test #22: Final Dispenser - Munition 5 Failure

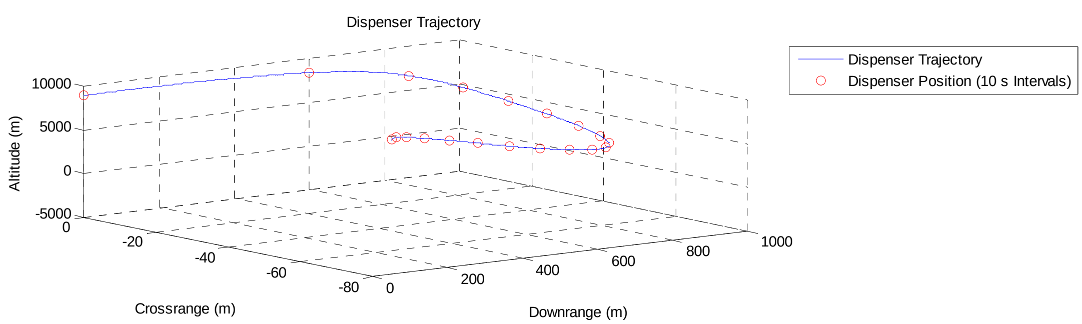


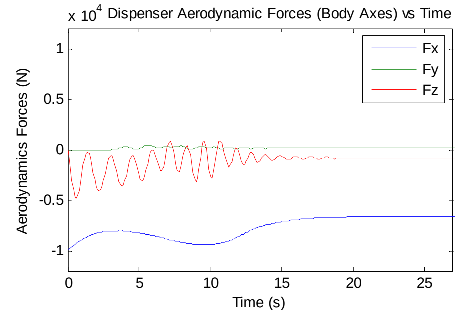


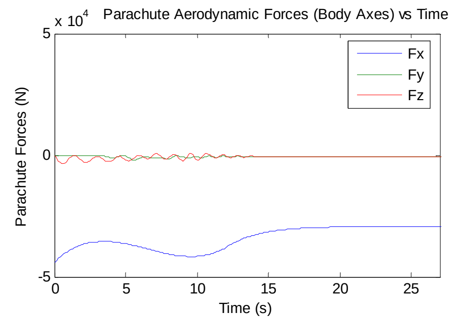


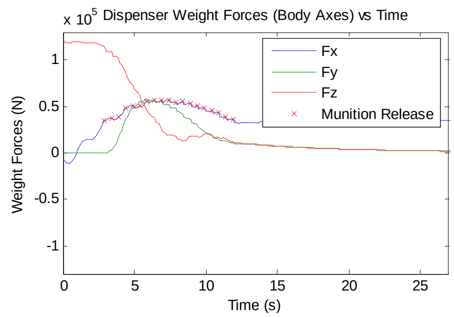


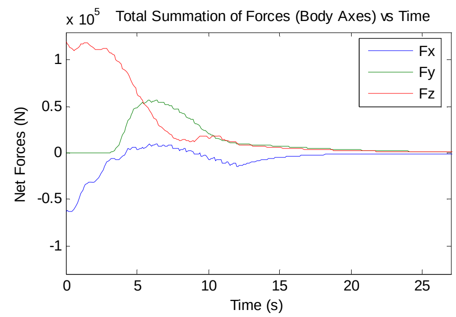


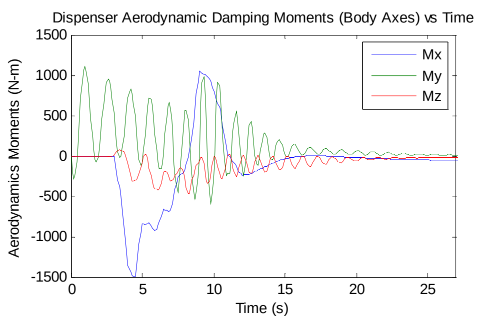


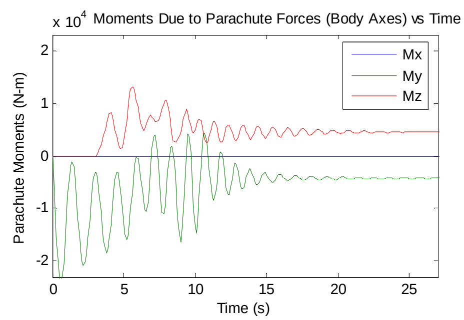

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

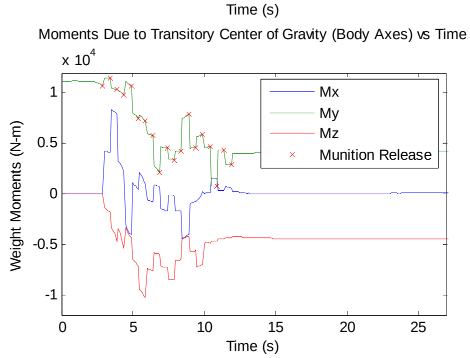

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

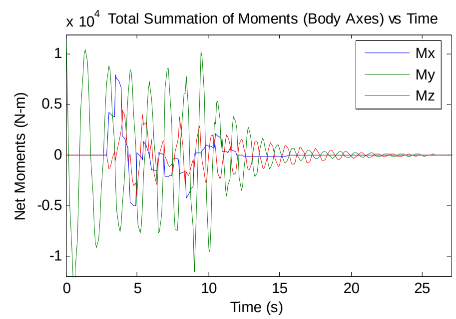

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

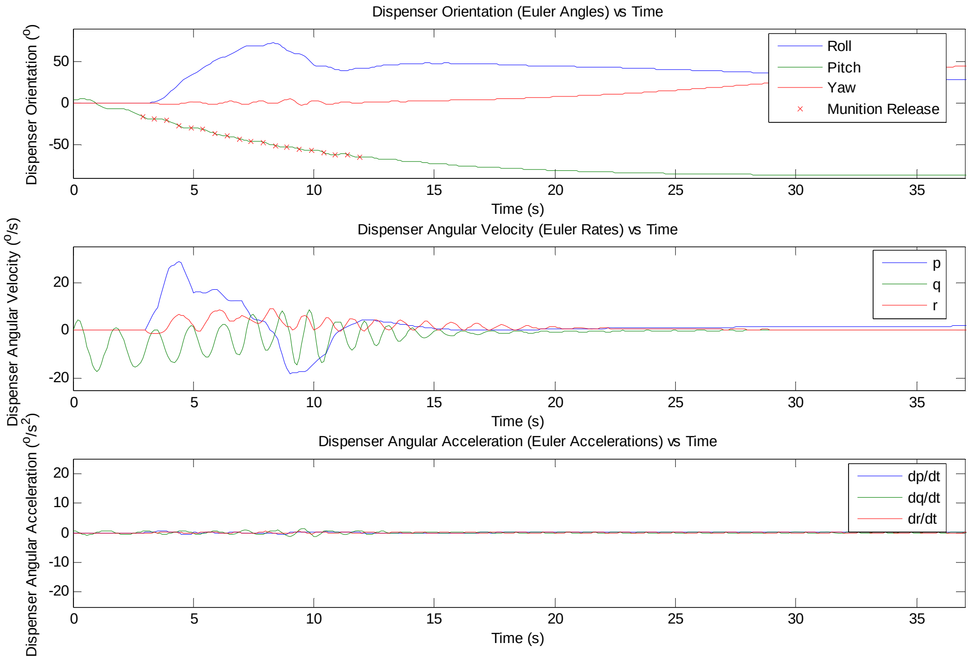

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

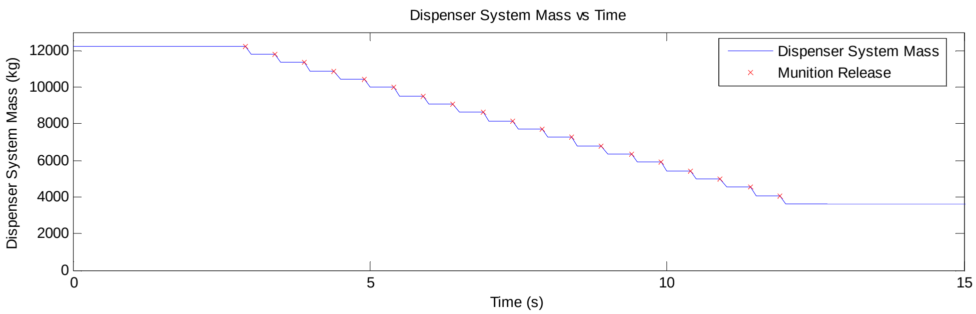

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

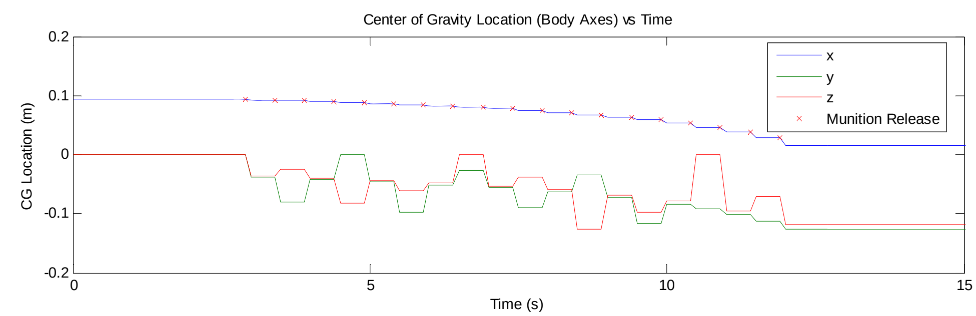

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

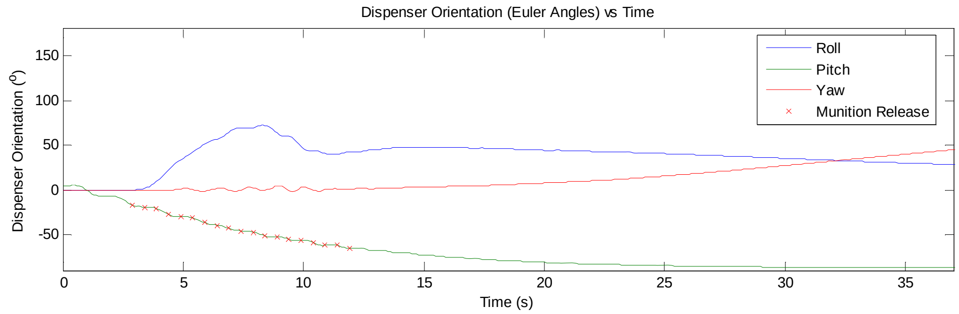

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

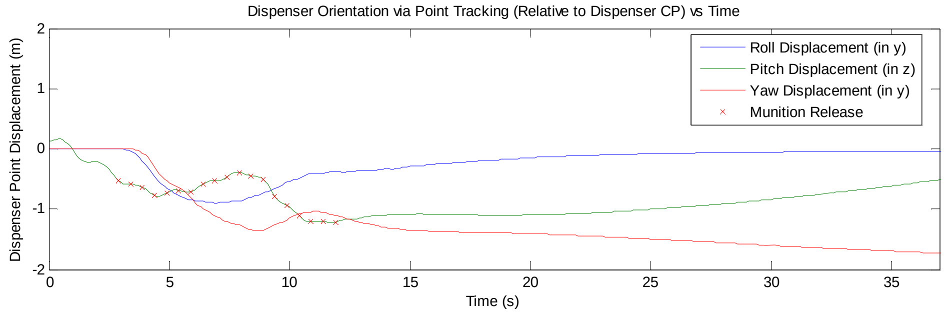

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

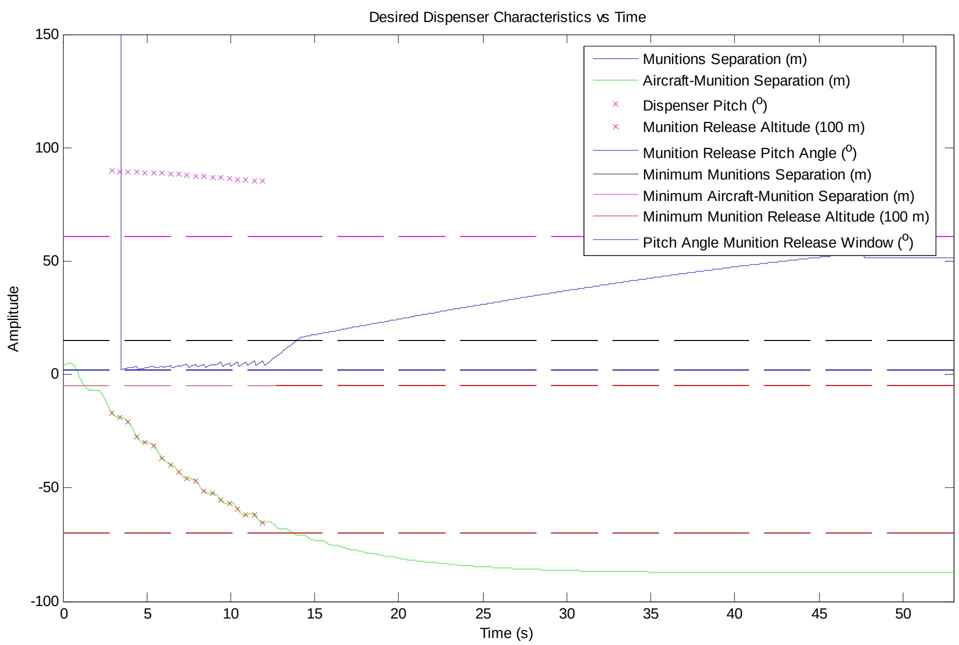

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

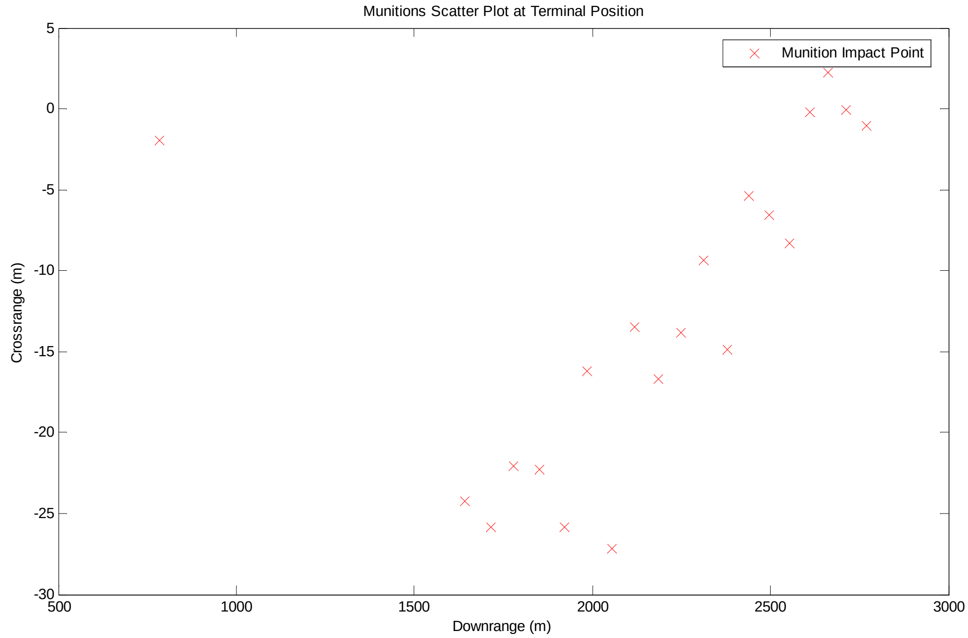

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release


Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release

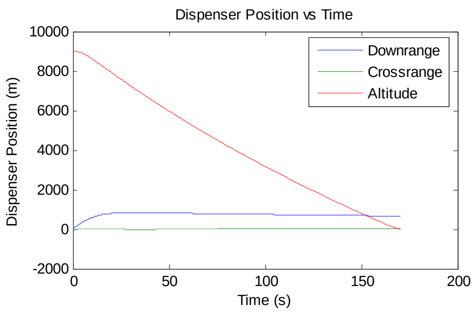

Dispenser Orientation (Euler Angles) vs Time
Roll
Pitch
Yaw
Munition Release
Dispenser Orientation (°)
Time (s)

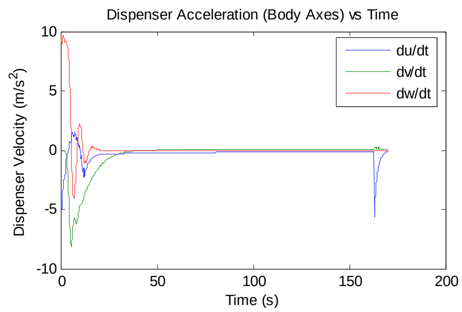

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release
Dispenser Point Displacement (m)
Time (s)

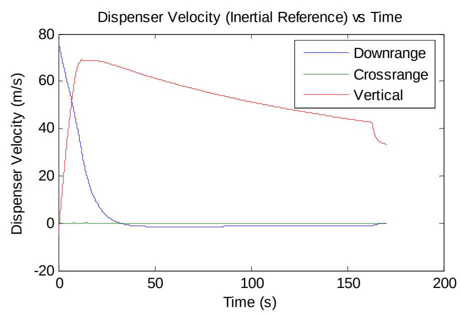

Desired Dispenser Characteristics vs Time
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)
Amplitude
Time (s)

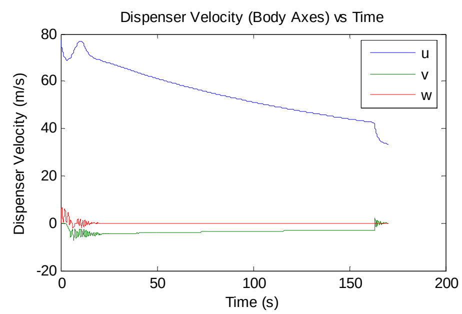

Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
5
0
-5
-10
-15
-20
-25
-30
500
1000
1500
2000
2500
3000

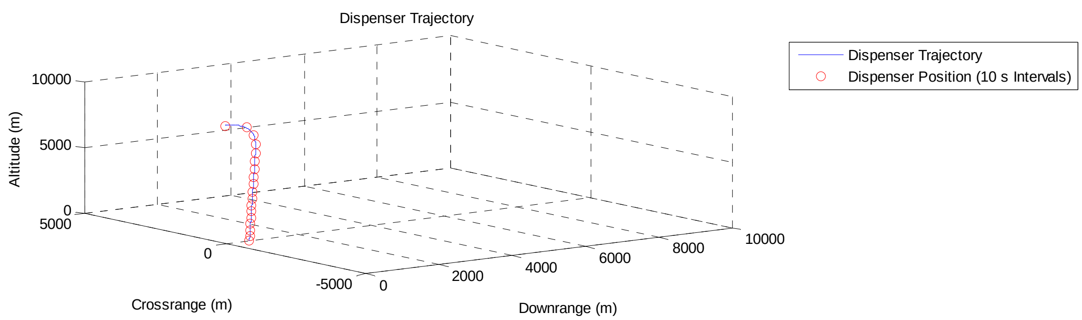
Test #23: Final Dispenser - Munitions 1,6,11,16 Failure

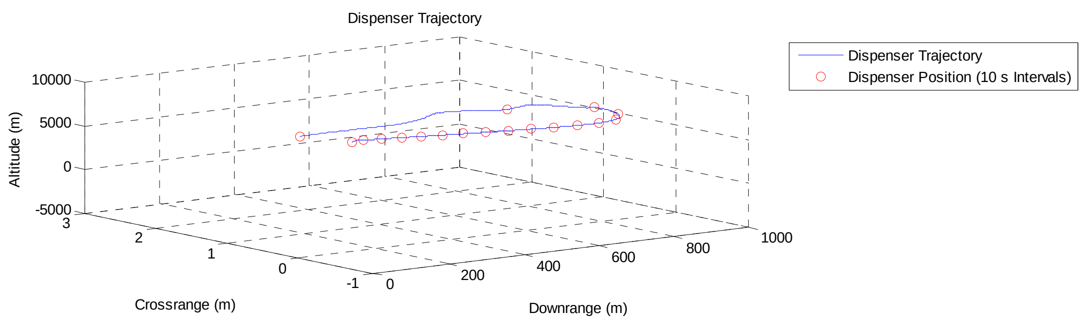


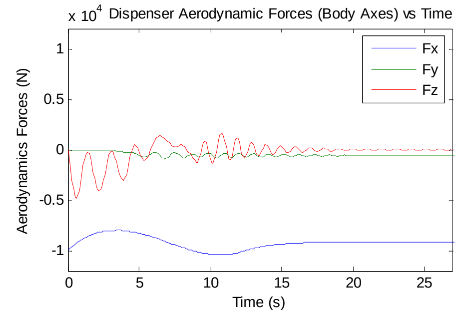


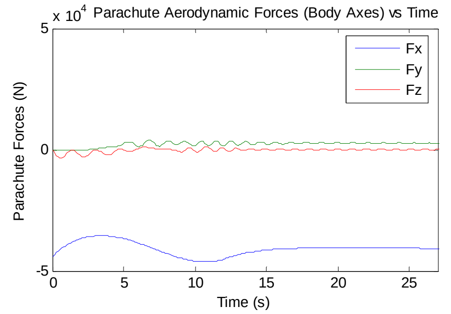


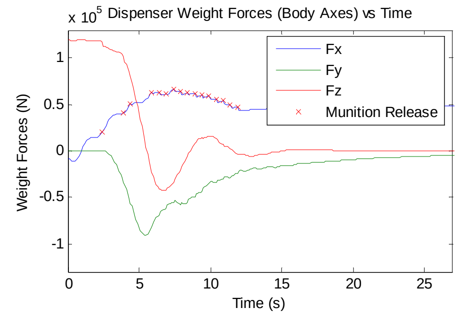


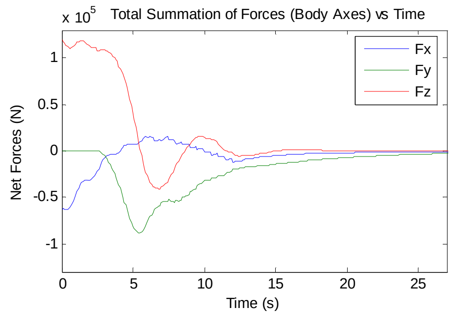


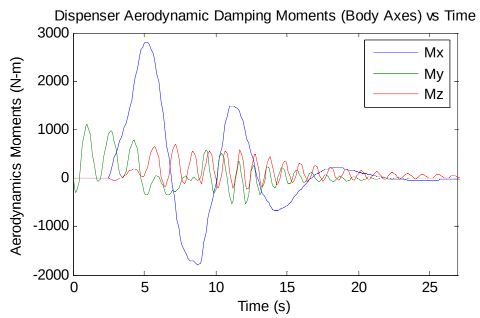


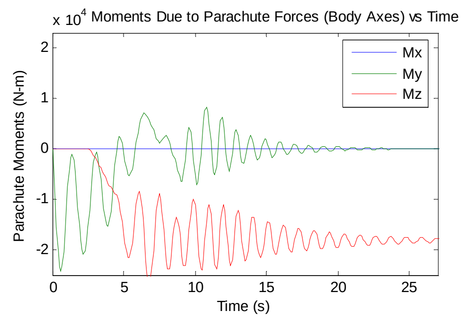

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

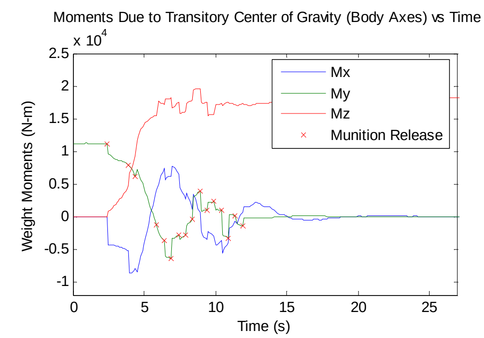

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

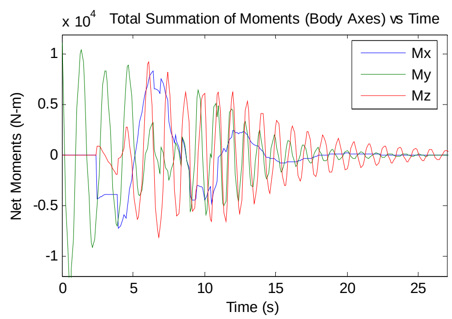

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

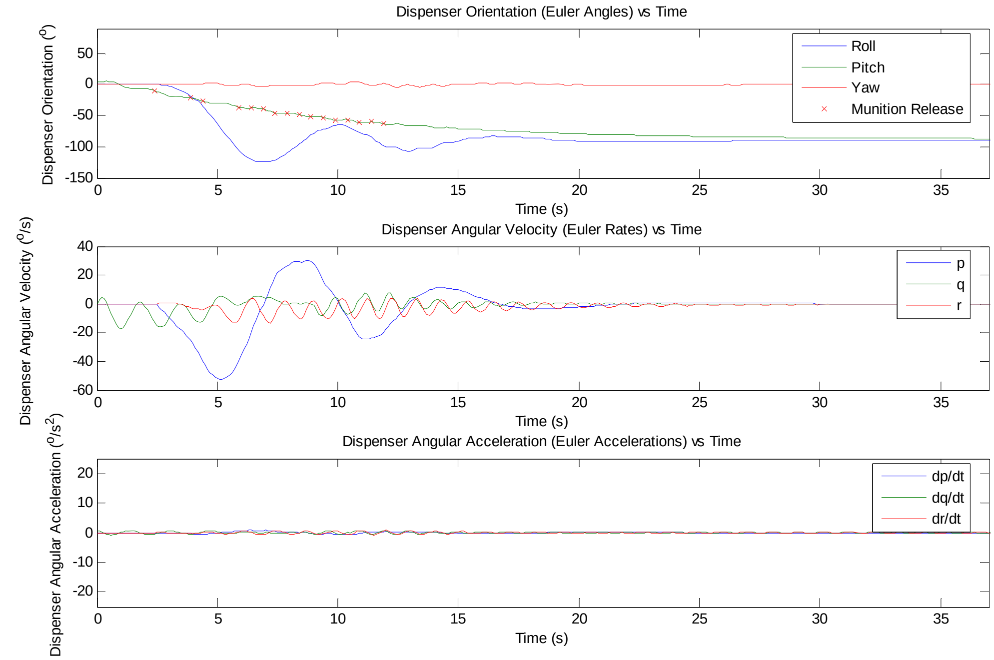

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

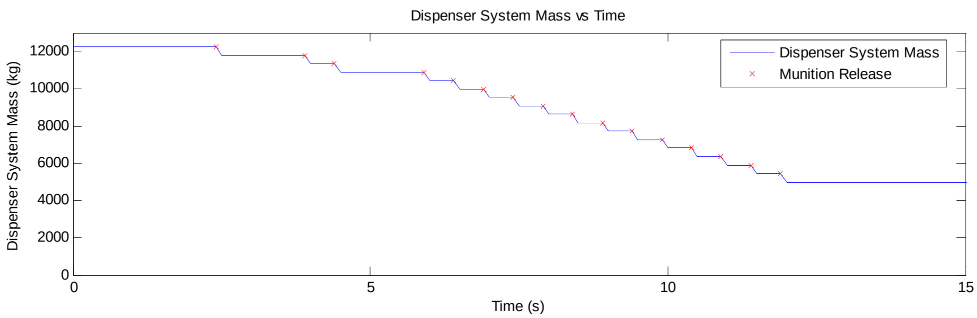

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

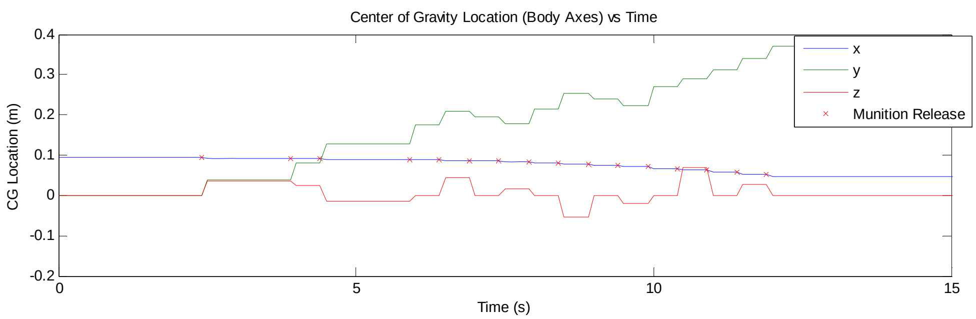

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

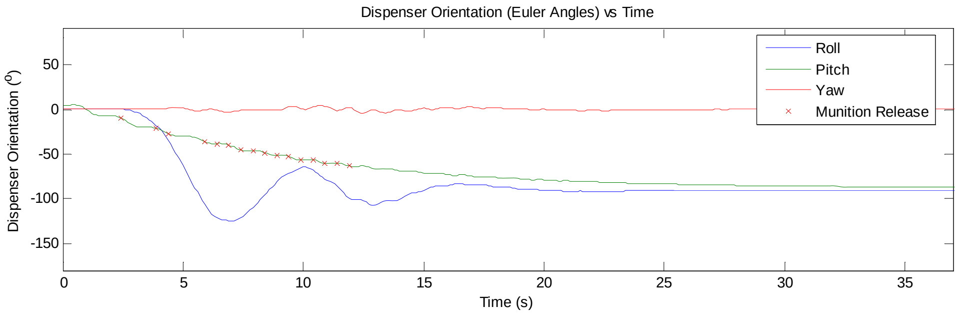

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

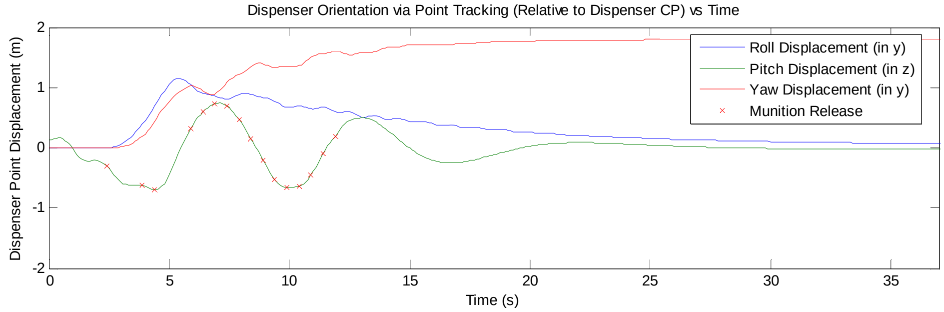

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

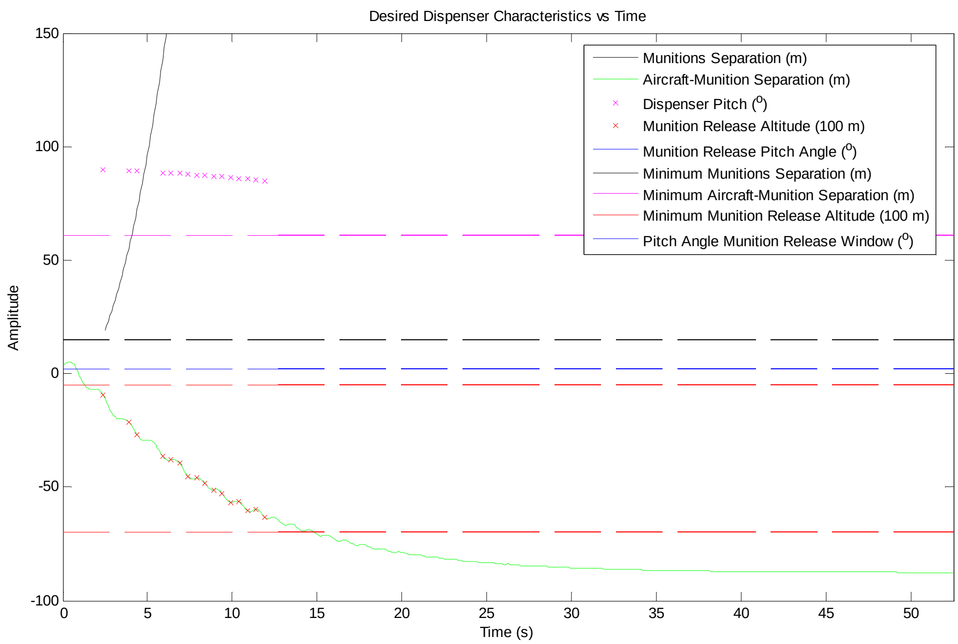

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

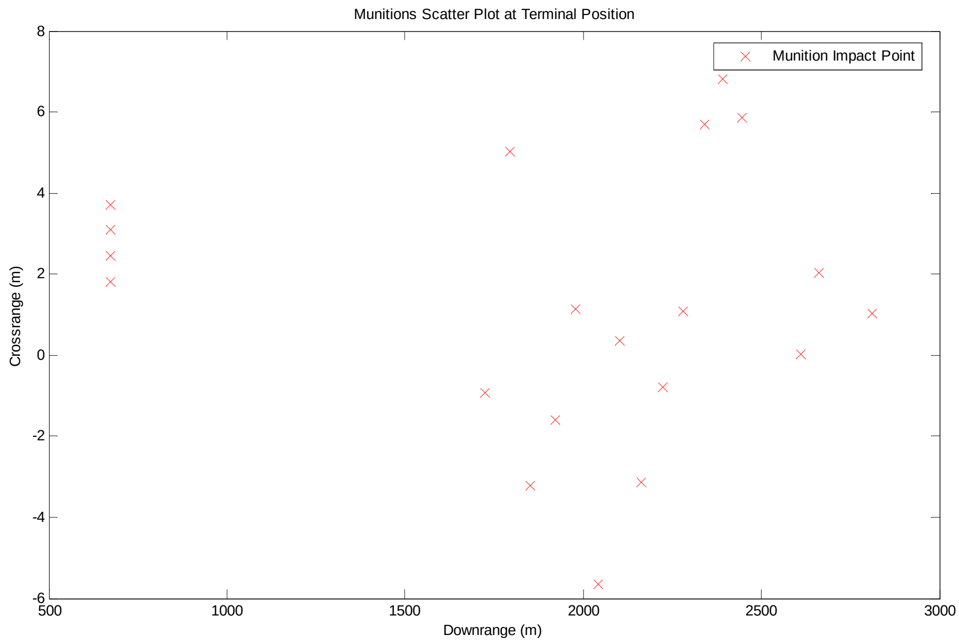

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release


Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release

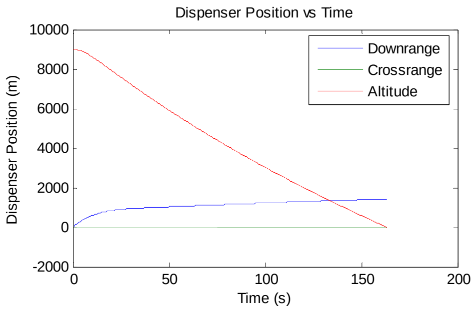

Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release

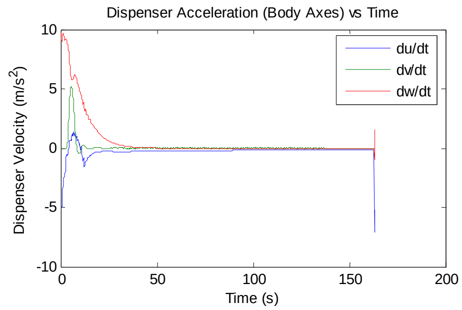

Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)

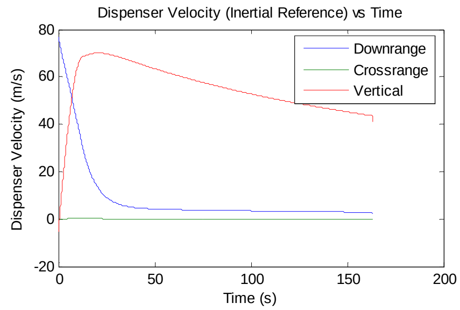


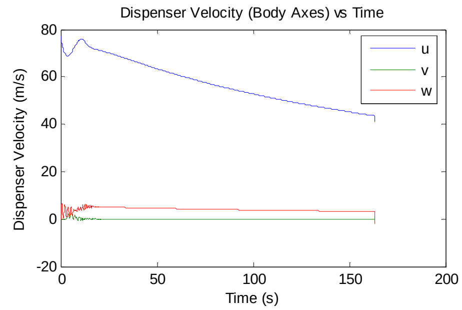
Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
8
6
4
2
0
-2
-4
-6
500
1000
1500
2000
2500
3000

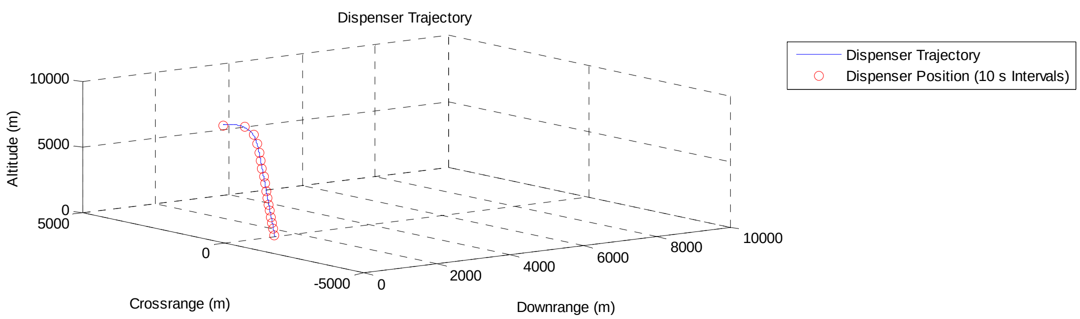
Test #24: Final Dispenser - Munitions 1,2,3,4,5 Failure

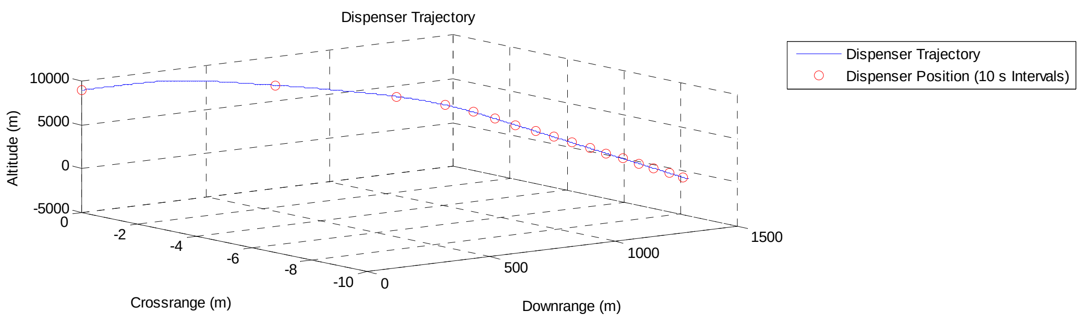


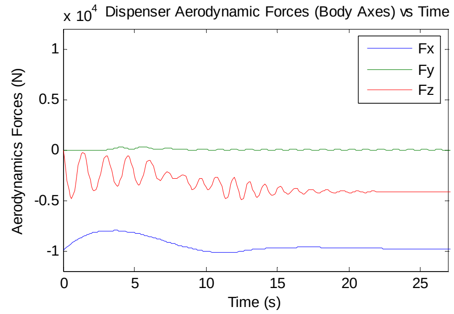


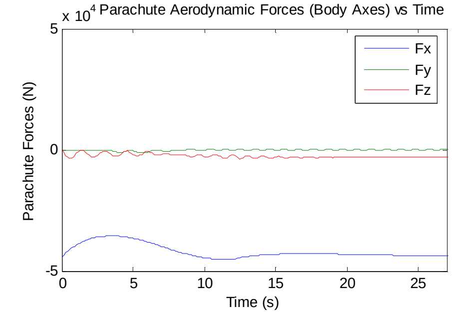


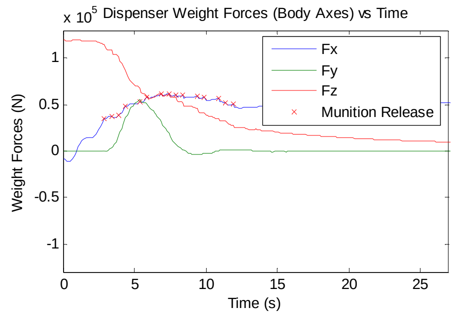


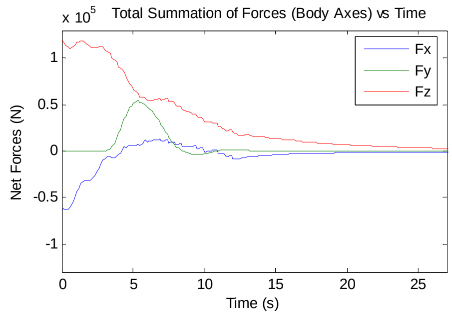


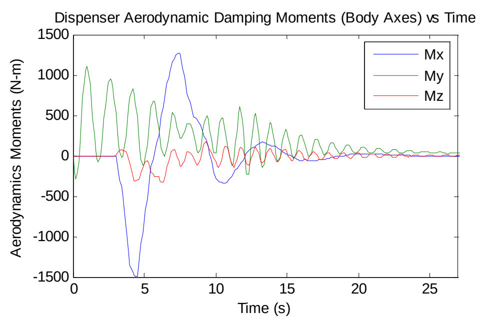


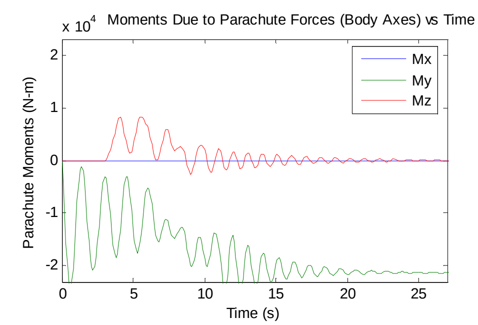

x 10^4 Dispenser Aerodynamic Forces (Body Axes) vs Time
Aerodynamics Forces (N)
Time (s)
Fx
Fy
Fz

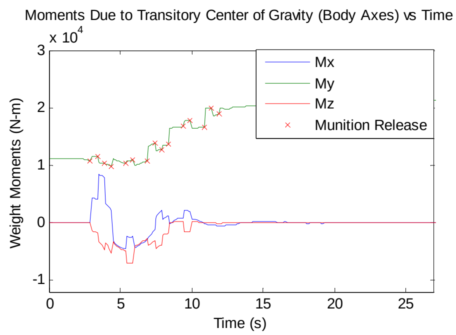

x 10^4 Parachute Aerodynamic Forces (Body Axes) vs Time
Parachute Forces (N)
Time (s)
Fx
Fy
Fz

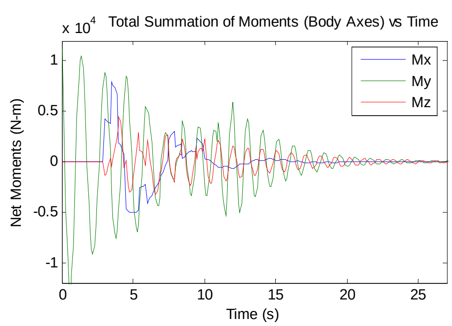

x 10^5 Dispenser Weight Forces (Body Axes) vs Time
Weight Forces (N)
Time (s)
Fx
Fy
Fz
Munition Release

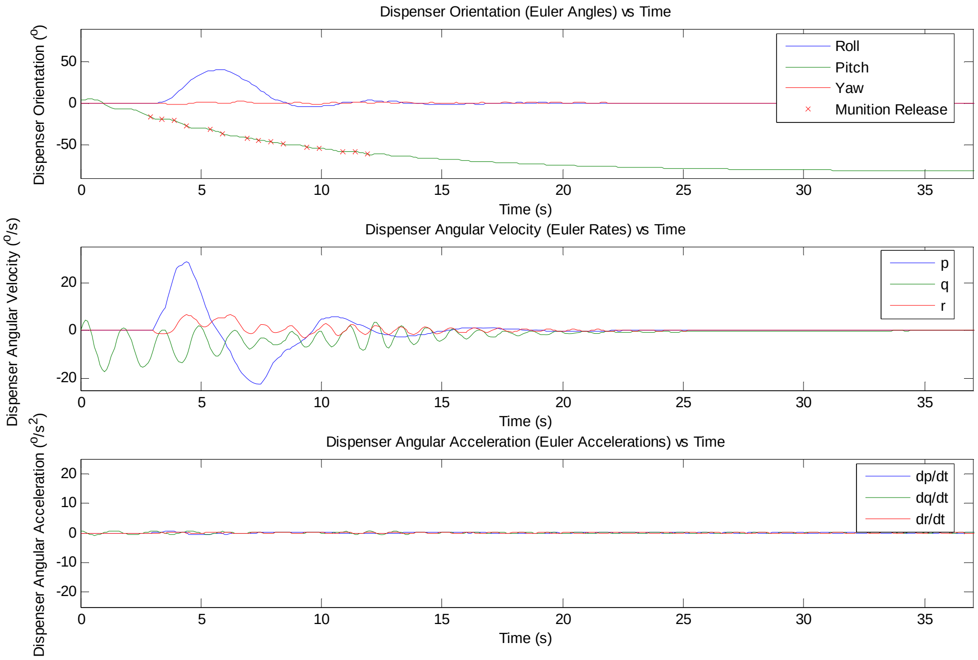

x 10^5 Total Summation of Forces (Body Axes) vs Time
Net Forces (N)
Time (s)
Fx
Fy
Fz

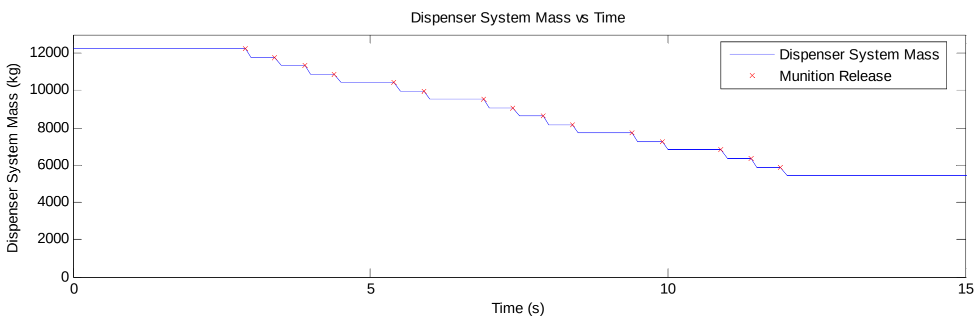

Dispenser Aerodynamic Damping Moments (Body Axes) vs Time
Aerodynamics Moments (N-m)
Time (s)
Mx
My
Mz

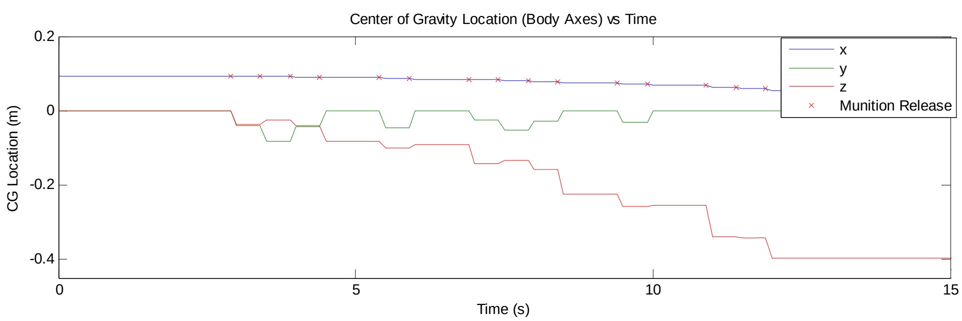

x 10^4 Moments Due to Parachute Forces (Body Axes) vs Time
Parachute Moments (N-m)
Time (s)
Mx
My
Mz

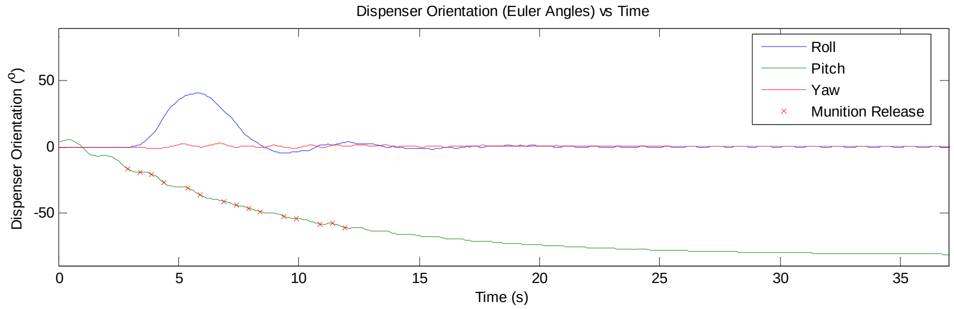

Moments Due to Transitory Center of Gravity (Body Axes) vs Time
x 10^4
Weight Moments (N-m)
Time (s)
Mx
My
Mz
Munition Release

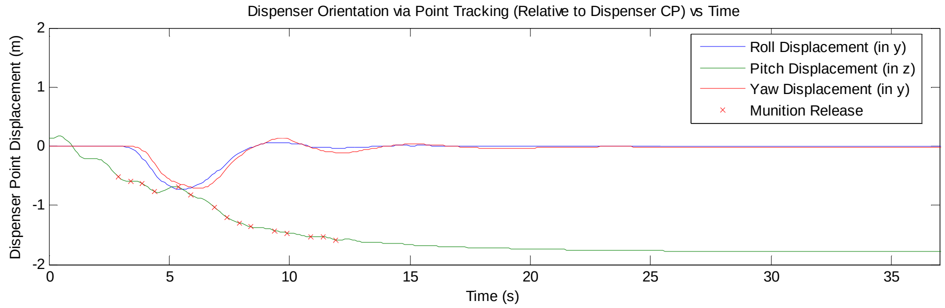

x 10^4 Total Summation of Moments (Body Axes) vs Time
Net Moments (N-m)
Time (s)
Mx
My
Mz

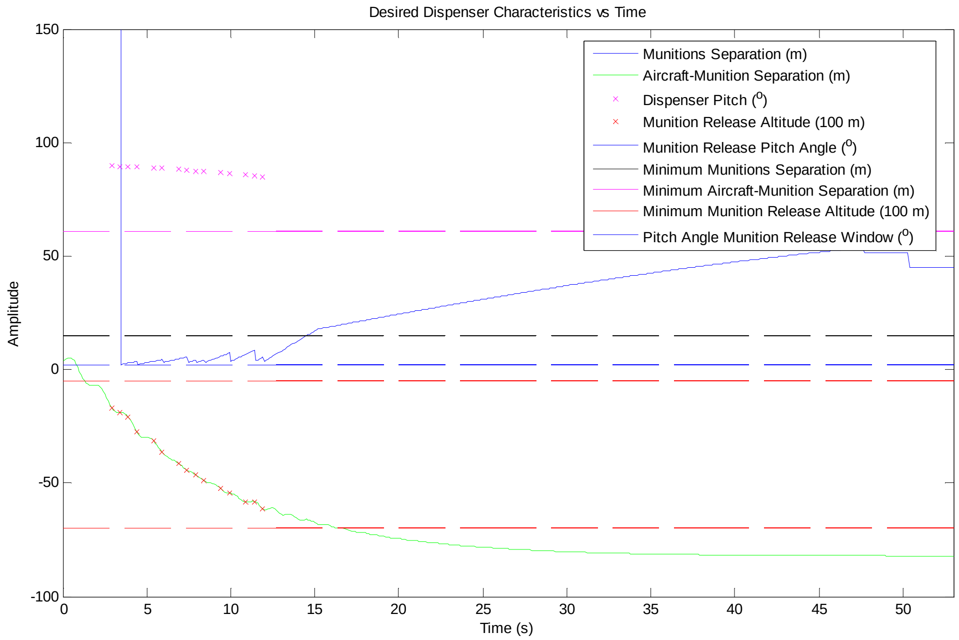

Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release
Dispenser Angular Velocity (Euler Rates) vs Time
Dispenser Angular Velocity (°/s)
p
q
r
Dispenser Angular Acceleration (Euler Accelerations) vs Time
Dispenser Angular Acceleration (°/s²)
dp/dt
dq/dt
dr/dt

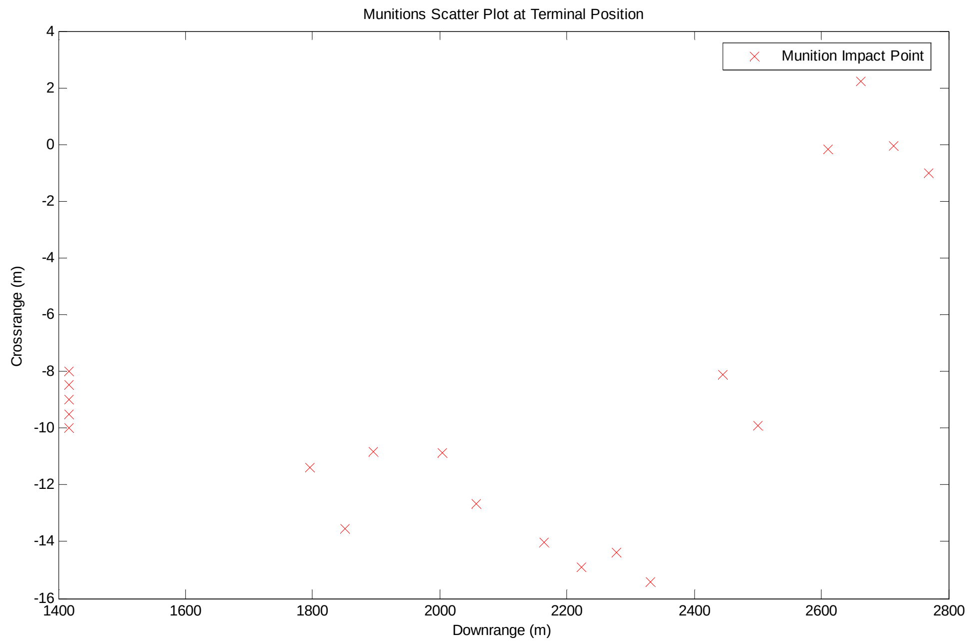

Dispenser System Mass vs Time
Dispenser System Mass (kg)
Time (s)
Dispenser System Mass
Munition Release


Center of Gravity Location (Body Axes) vs Time
CG Location (m)
Time (s)
x
y
z
Munition Release


Dispenser Orientation (Euler Angles) vs Time
Dispenser Orientation (°)
Time (s)
Roll
Pitch
Yaw
Munition Release


Dispenser Orientation via Point Tracking (Relative to Dispenser CP) vs Time
Dispenser Point Displacement (m)
Time (s)
Roll Displacement (in y)
Pitch Displacement (in z)
Yaw Displacement (in y)
Munition Release


Desired Dispenser Characteristics vs Time
Amplitude
Time (s)
Munitions Separation (m)
Aircraft-Munition Separation (m)
Dispenser Pitch (°)
Munition Release Altitude (100 m)
Munition Release Pitch Angle (°)
Minimum Munitions Separation (m)
Minimum Aircraft-Munition Separation (m)
Minimum Munition Release Altitude (100 m)
Pitch Angle Munition Release Window (°)


Munitions Scatter Plot at Terminal Position
Munition Impact Point
Crossrange (m)
Downrange (m)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
1400
1600
1800
2000
2200
2400
2600
2800

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1. Type of Product:

CD-ROM

2. Operating System/Version:

Windows XP

3. New Product or Replacement:

New

4. Type of File:

Both

5. Language/Utility Program:

Microsoft Word and Excel, Adobe Acrobat, MATLAB, Simulink, Windows Media Player

6. # of Files/# of Products:

37/1

7. Character Set:

ASCII

8. Disk Capacity:

700MB

9. Compatibility:

PC

10. Disk Size:

4 3/4"

11. Title:

Simulation of Weapons Release from Cargo Aircraft:
Thesis, Appendices, Simulation Files, and Test Results

12. Performing Organization:

AFIT/EN
2950 Hobson Way
WPAFB OH 45433-7765

13. Performing Report #:

AFIT/GAE/ENY/06M-33

14. Contract #:

N/A

15. Program Element #:

N/A

16. Sponsor/Monitor:
AFRL/MNAV
Attn: Mr. Eric B. Werkowitz
101 W Eglin Blvd, Suite 143
Eglin AFB FL 32542-6810

17. Sponsor/Monitor # Acronym:

AFRL/MNAV

18. Sponsor/Monitor #:

N/A

19. Project #:

N/A

20. Task #:

N/A

21. Work Unit #:

N/A

22. Date:
17 Mar 06

23. Classification of Product:
U

24. Security Classification Authority:

25. Declassification/Downgrade Schedule:

26. Distribution/Availability:
A: Approved for public release; distribution unlimited

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27. Abstract: The purpose of this study is to develop a computer simulation capable of providing an accurate flight history of an airdropped munitions dispenser system in order to conduct proof of concept testing. The simulation is intended to serve as an adaptable tool for the development and testing of any cargo aircraft based weapons dispenser system. The simulation allows the user to conduct low-cost, time efficient, and effective tests of various design concepts in determining their operational feasibility and performance envelope. The munitions dispenser system is intended to provide a retrofit combat capability to the USAF C-17 aircraft, delivering massive amounts of precision guided ordinance where needed, when needed, while remaining outside the threat envelope. The dispenser concept was developed and modified through use of the simulation by determining the most favorable parachute system, harness configuration, and munition release sequence which ensure the desired behavior and performance of the twenty-munition dispenser system. The developed dispenser system was subjected to various adverse flight conditions, disturbances, and system malfunctions to determine the dispenser's reaction to such inputs. Overall, the developed dispenser configuration has proven to be a viable weapons release platform for a cargo aircraft.

28. Classification of Abstract: U	**29. Limitation of Abstract:** UL
30. Subject Terms: Air Drop Operations, Air Launched, Cargo Aircraft Bombing, Cargo Parachutes, Degrees of Freedom, Dispensers, Equations of Motion, Free Flight, Munitions, Simulation	**30a. Classification of Subject Terms:** U

31. Required Peripherals:

N/A

32. # of Physical Records:	**33. # of Logical Records:**	**34. # of Tracks:**
35. Record Type:	**36. Color:**	**37. Recording System:**
38. Recording Density:	**39. Parity:**	**40. Playtime:**

41. Playback Speed:	**42. Video:**	**43. Text:**	**44. Still Photos:**	**45. Audio:**

46. Other:

47. Documentation/Supplemental Information:
Includes readme file for execution of MATLAB/Simulink munitions dispenser simulation programs.

48. Point of Contact and Telephone Number:
Dr. Milton E. Franke (AFIT/ENY)
2950 Hobson Way
WPAFB OH 45433-7765
(937)255-3636, ext 4720; e-mail: milton.franke@afit.edu

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1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
23 Mar 06	**Master's Thesis**	Sep 2004 – Mar 2006

4. TITLE AND SUBTITLE

Simulation of Weapons Release from Cargo Aircraft

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Wilson, Paul, M., Second Lieutenant, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/GAE/ENY/06-M33

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFRL/MNAVI
Attn: Mr. Eric B. Werkowitz
101 W. Eglin Blvd., Suite 143
Eglin AFB FL 32542-6810 DSN: 872-8541

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The purpose of this study is to develop a computer simulation capable of providing an accurate flight history of an airdropped munitions dispenser system in order to conduct proof of concept testing. The simulation is intended to serve as an adaptable tool for the development and testing of any cargo aircraft based weapons dispenser system. The simulation allows the user to conduct low-cost, time efficient, and effective tests of various design concepts in determining their operational feasibility and performance envelope.

The munitions dispenser system is intended to provide a retrofit combat capability to the USAF C-17 aircraft, delivering massive amounts of precision guided ordinance where needed, when needed, while remaining outside the threat envelope. The dispenser concept was developed and modified through use of the simulation by determining the most favorable parachute system, harness configuration, and munition release sequence which ensure the desired behavior and performance of the twenty-munition dispenser system. The developed dispenser system was subjected to various adverse flight conditions, disturbances, and system malfunctions to determine the dispenser's reaction to such inputs. Overall, the developed dispenser configuration has proven to be a viable weapons release platform for a cargo aircraft.

15. SUBJECT TERMS

Air Drop Operations, Air Launched, Cargo Aircraft Bombing, Cargo, Parachutes, Degrees of Freedom, Dispensers, Equations of Motion, Free Flight, Munitions, Simulation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
REPORT	ABSTRACT	c. THIS PAGE			Dr. Milton E. Franke (AFIT/ENY)
U	**U**	**U**	**UU**	210	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-3636, ext 4720; e-mail: Milton.franke@afit.edu

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