A Validation of FlightStream for Store-Separation Modeling

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This work intends to validate the capability of FlightStream®, a classical aerodynamics flow solver, to accurately predict pressure trends and trajectory data for store-separation events, where proximity flow interaction is a key contributor to the dynamics of the store. A modified generic wing-pylon-store configuration from the AEDC/Eglin wind tunnel tests was modeled and results, including pressure coefficient distribution, trajectory and attitude data, as well as the forces experienced during carriage at M = 0.3, were compared to data obtained in an equivalent ANSYS Fluent simulation. Two configurations were analyzed, the full wing-pylon-store outfit and the store alone. Pressure coefficient data showed strong correlation in trend, with FlightStream slightly over-predicting the magnitude. Trajectory data showed that most trends were adequately captured, with some slight disagreements. Disagreements were observed in angular displacements for both full and store only configurations. Forces and moments were generally in agreement in order of magnitude and trend for the full wing-pylon-store configuration.

I. Nomenclature

M = mach number
F_x = force in the x direction
F_y = force in the y direction
F_z = force in the z direction
M_x = moment in the x direction
M_y = moment in the y direction
M_z = moment in the z direction
Cp = pressure coefficient
T/C = thickness to chord
R = radius
X = x component
L = length of store
phi = roll angle
theta = pitch angle
psi = yaw angle
I_{xx} = roll moment of inertia
I_{yy} = pitch moment of inertia
I_{zz} = yaw moment of inertia
CFD = computationl fluid dynamics
6DOF = six degrees of freedom

II. Introduction

Store-separation modeling is a critically important topic in the realm of aerodynamics simulation. Some very strange events have been known to occur when a store is released from an aircraft, including airframe strikes, going along non-intuitive trajectories, and in some cases not going anywhere at all for uncomfortably long times. Hundreds of stores await flight testing and ultimately certification in part because of the CFD studies required to ensure that these bizarre behaviors and unanticipated outcomes do not occur for a full complement of flight conditions. While CFD solvers can generally resolve the complex proximity flows involved in store-separation events, classical approaches to aerodynamics

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harness potential flow and the mature development of boundary layer theory to capture loads far more efficiently than CFD solvers. The classical aerodynamics solver used in this work is FlightStream®. This paper seeks to validate the capability of a classical panel-type aerodynamics solver to capture accurate pressure distributions, aerodynamic loads, and trajectory data of an external store in a separation event for a generic wing-pylon-store configuration at sea level and low sub-sonic speed.

The wing-pylon-store model used in this analysis is consistent with the AEDC/Eglin wind tunnel tests, however a full-scale model was opted for rather than the scaled version. Physical characteristics of the model are also consistent with those used in the motion definition for the AEDC/Eglin tests. Ejector forces were not used in this validation study. By not using ejector forces, the full effect of proximity interaction of the wing and pylon are observed. This work does not directly compare against the experimental data obtained in the wind tunnel tests.

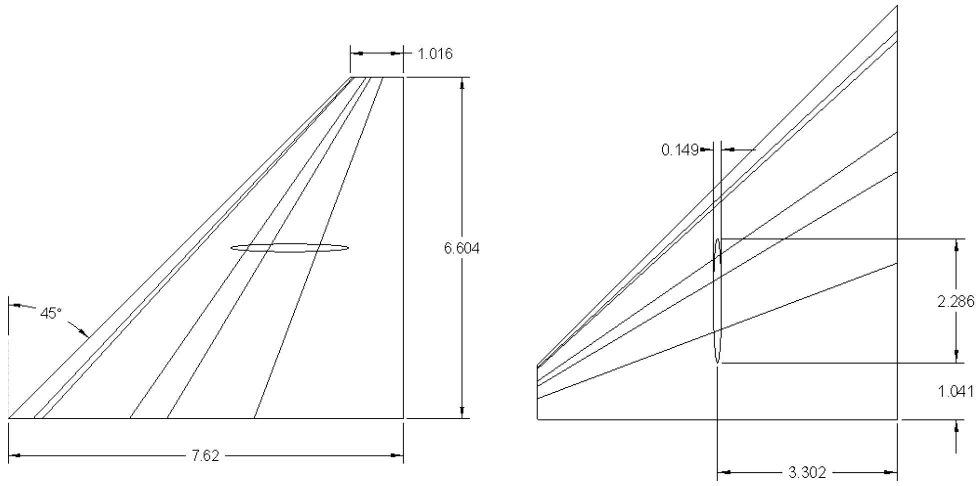
This work is subdivided into analyses of two different configurations: a full wing-pylon-store outfit, and the store alone. Both configurations are tested at carriage position and in a transient gravity drop.

III. Geometric Model

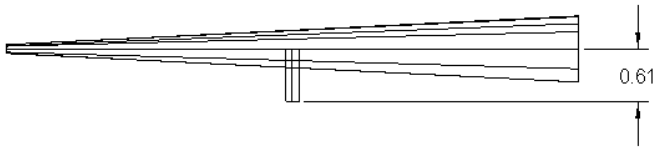
The geometry for this work was modified from the AEDC/Eglin model to be full-scale, as the analysis done is not being compared to the wind tunnel data. The motion definition used in the wind tunnel experiment was for a full scale model, with the wind tunnel model being 1:20 scale. All units of measurement are in meters.

A. Wing and Pylon

The wing is a tapered swept-back clipped delta wing, similar to that of the F-16. The airfoil selected is the NACA 64A010, with a T/C of 0.1. The pylon is a generic ellipse sized to longitudinal and lateral dimensions to have reasonable curvature. Dimensions are detailed in the figure below.



(a) Top view of the wing and pylon **(b) Bottom view of the wing and pylon**

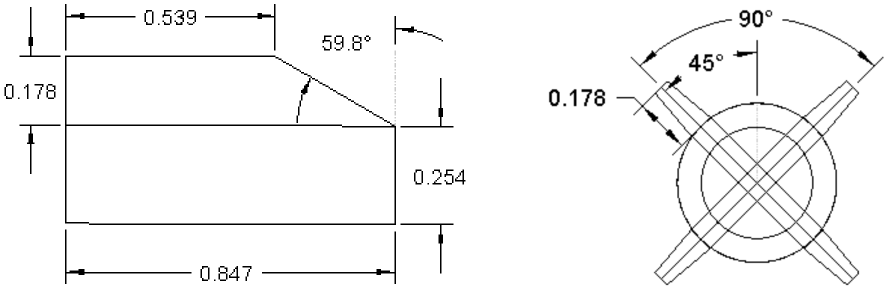


(c) Front view of the wing and pylon

Fig. 1 Wing and pylon dimensions

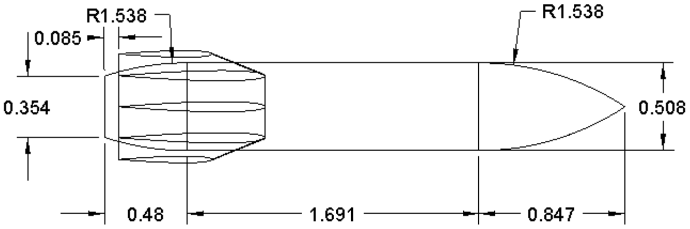
B. Finned Store

The store used is a generic axisymmetric finned-store with a base cut aft end. FlightStream allows for base regions to be accounted for, making the base cut aft end more favorable than a smooth one. In the wind tunnel experiment, the store is connected at its aft end to a boom, which moved the store based on its motion definition. For simplicity, the store was modeled without the boom. This aided in the transient simulation where mass properties would need to be assigned to the store for its motion definition. For the fins, the NACA 0010 symmetric airfoil was selected. The fin is split into two sections, one with no taper or sweep which is only partially exposed to the flow, and another with taper and sweep which is exposed to the flow. Dimensions are detailed in the figure below.



(a) Side view of fin

(b) Front view of store



(c) Side view of store

Fig. 2 Store and fin dimensions

C. Wing-Pylon-Store

The wing-pylon-store configuration with the store in carriage positions allows a small gap between the pylon and store. In reality, there will be lugs from which the store is suspended, but this modeling approach is consistent with the AEDC/Eglin model. The centerline of the store is equidistant from the root chord and the pylon centerline.

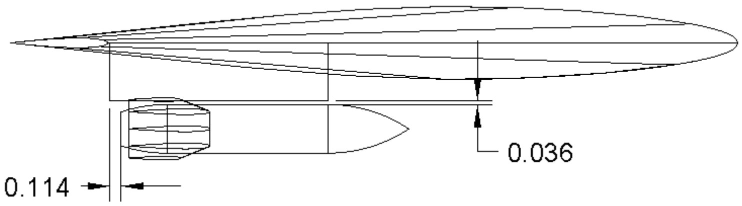


Fig. 3 Side view of store positioning

IV. Configurations and Physical Characteristics

Two configurations were tested, a full wing-pylon-store outfit and the store alone. This was done to validate results from FlightStream against Fluent, and also to show how significant an effect proximity flow interaction such as from wing and pylon have on the pressure, trajectory and loads of the store. For the transient simulations, the following physical characteristics were used in the motion definition of the store. The coordinate system for all simulations is consistent with the stability frame, as seen in the figure below.

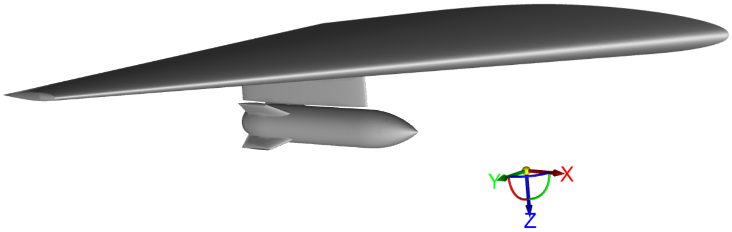


Fig. 4 Coordinate system orientation

Table 1 Store physical characteristics

Property	Value
Mass (kg)	906.87
Distance to Center of Gravity (m)	1.416 aft of store nose
Moment of Inertia I_{xx} (kg m^2)	27.12
Moment of Inertia I_{yy} (kg m^2)	488.1
Moment of Inertia I_{zz} (kg m^2)	488.1

V. FlightStream Setup

For FlightStream, the wing-pylon-store geometry was meshed using OpenVSP, an open source aircraft geometry tool developed by NASA. The mesh produced is an unstructured surface mesh, which FlightStream is designed to use. Below is a figure showing the mesh used in both configurations.

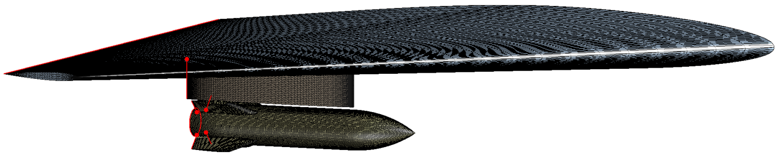


Fig. 5 Mesh used in FlightStream setup

Mesh for the store and pylon was made more dense than that of wing, due to how close the store and pylon are positioned. Trailing edges were marked, and wake termination nodes set on the wing, pylon, and store as seen in the figure. The base of the store was marked a base region. For both wing-pylon-store and store alone configurations, the same mesh was used. To omit the wing and pylon, only the store was initialized. The same mesh was used for both steady-state and transient simulations as well.

A. Steady-State Simulation

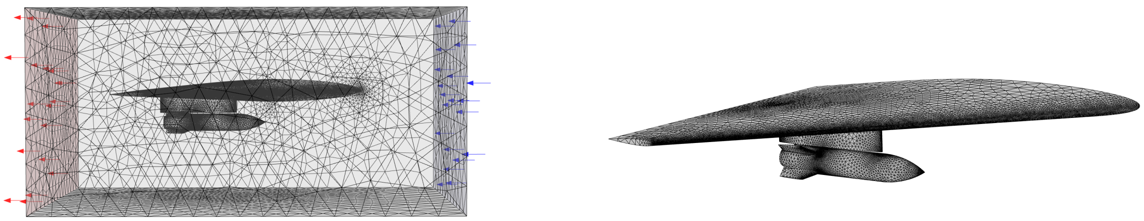
For the steady-state simulation for both configurations, in which pressure coefficient profiles and carriage loads were determined, the number of iterations was set to 1000, with residual convergence set to 1e-5.

B. Transient Simulation

For the transient simulation, in which trajectory and attitude data was obtained for a gravity drop, the number of time steps was set to 50, with time stepping iterations of 0.01 s. This results in 0.5 seconds of flow time. For each time stepping iteration, 200 solver iterations were performed. The embedded 6DOF solver was utilized to define the motion of the store.

VI. Fluent Setup

Geometry was exported from OpenVSP as a CAD file, and imported into Fluent meshing. Rather than creating a mesh of the geometry itself, a volume mesh is created around the geometry and the geometry omitted. What is left is the fluid domain around the geometry. For the store-only configuration, the same procedure was done without the wing and pylon. Below is a figure showing the volume mesh of the fluid domain, and the surface mesh created by the geometry.



(a) Volume mesh of wing-pylon-store

(b) Surface mesh of wing-pylon-store

Fig. 6 Mesh of wing-pylon-store

Mesh density was increased for areas in proximity to other boundaries, such as the store and pylon and store and fins. This is useful for observing proximity flow interaction. The k-epsilon turbulence model was chosen for this simulation

A. Steady-State Simulation

For the steady-state simulation for both configurations, in which pressure coefficient profiles and carriage loads were determined, the number of iterations was set to 200, with residual convergence set to 1e-6.

B. Transient Simulation

For the transient simulation, in which trajectory and attitude data was obtained for a gravity drop, the number of time steps was set to 50, with time stepping iterations of 0.01 s. This results in 0.5 seconds of flow time. For each time stepping iteration, 20 solver iterations were performed. The embedded 6DOF solver was used to define the motion of the store boundary. To move the mesh according to this motion definition, a rigid body dynamic mesh was defined for the store.

VII. Results

A. Pressure Coefficient Profile

The pressure coefficient was observed along the length of the store at various angular positions looking aft from the nose, starting at 0 degrees at the intersection of the store and pylon, counterclockwise positive.

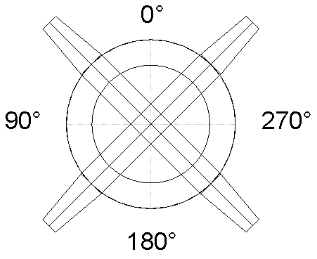
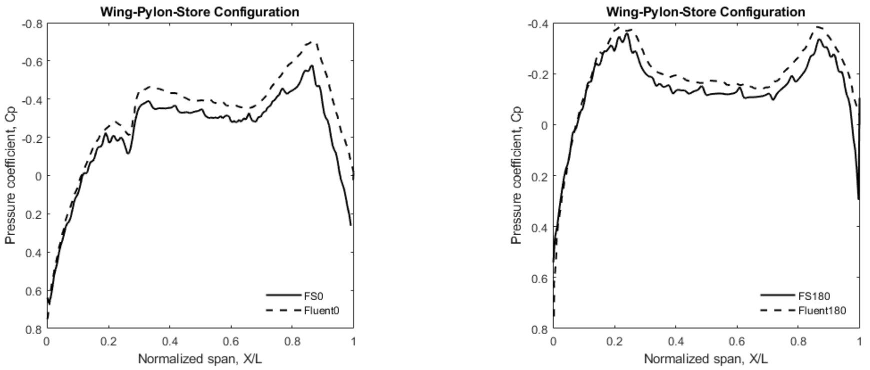
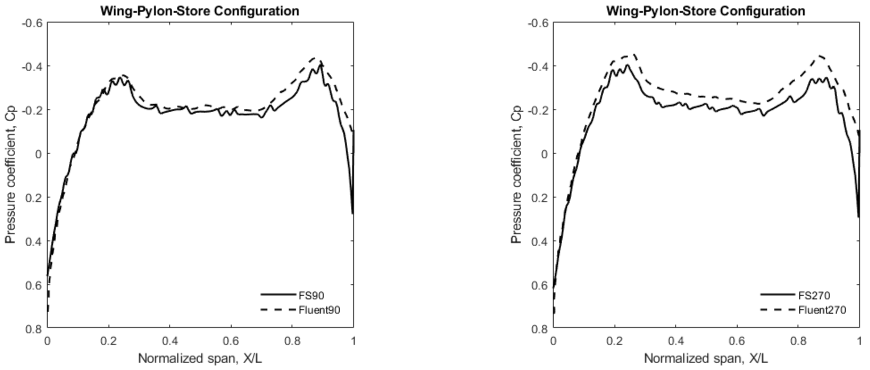


Fig. 7 Angular positions on store



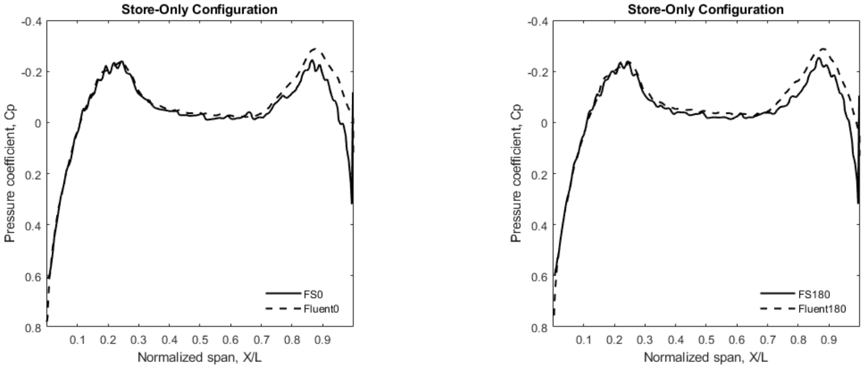
(a) 0 degrees **(b) 180 degrees**



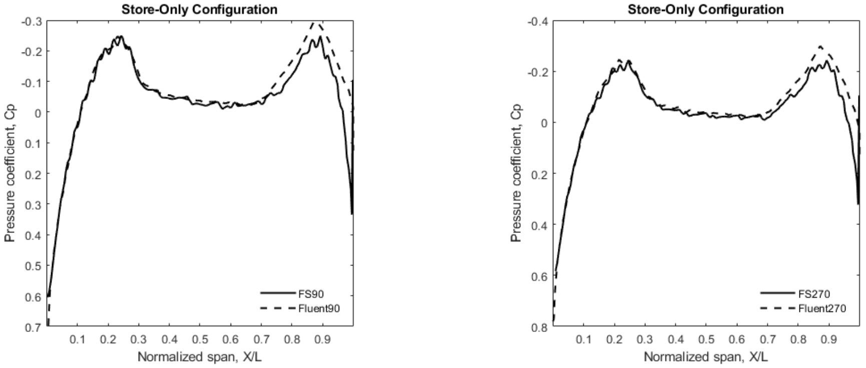
(c) 90 degrees **(d) 270 degrees**

Fig. 8 Cp profiles for wing-pylon-store configuration

For the wing-pylon-store configuration, pressure coefficient profile along the store is in good agreement between FlightStream and Fluent, with FlightStream slightly overpredicting in magnitude. The magnitude and trend lines up very well along the nose, and all the nuances in trend for the position of pylon-store flow interaction, 0 degrees, are observed by FlightStream. For the inboard and outboard positions, a change in magnitude for the Fluent curve is observed. This is due to the wing having more influence on the inboard side.



(a) 0 degrees **(b) 180 degrees**

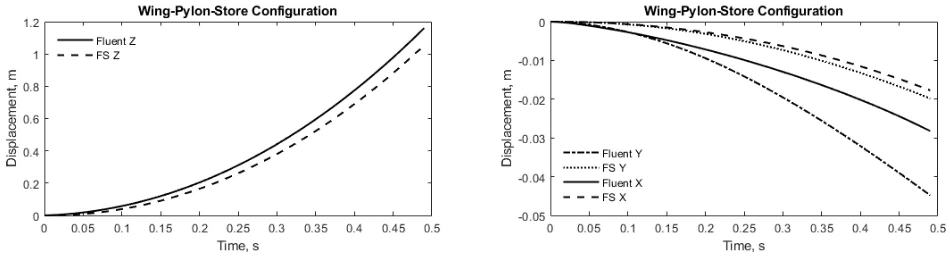


(c) 90 degrees **(d) 270 degrees**

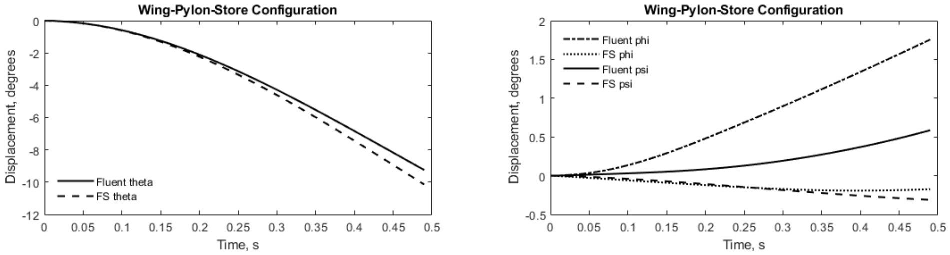
Fig. 9 Cp profiles for store-only configuration

The store-only configuration coefficient of pressure profiles are also in good agreement. Similar to the wing-pylon-store configuration, these profiles are in very good agreement along the nose. In this configuration, they are also in very good agreement along the span of the store. Toward the aft end there is observed a change in magnitude versus the Fluent profiles.

B. Linear and Angular Displacement



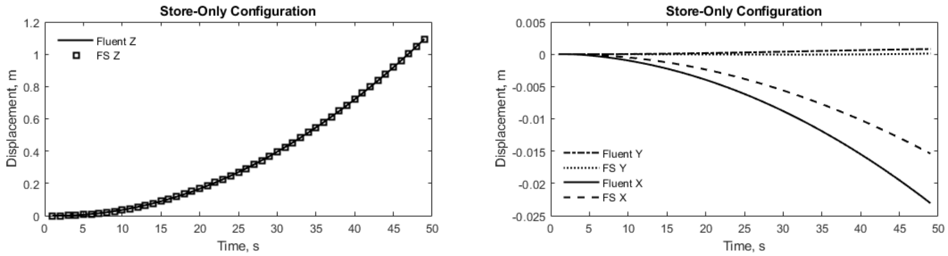
(a) Z displacement **(b) X, Y displacement**



(c) Pitch displacement **(d) Roll, Yaw displacement**

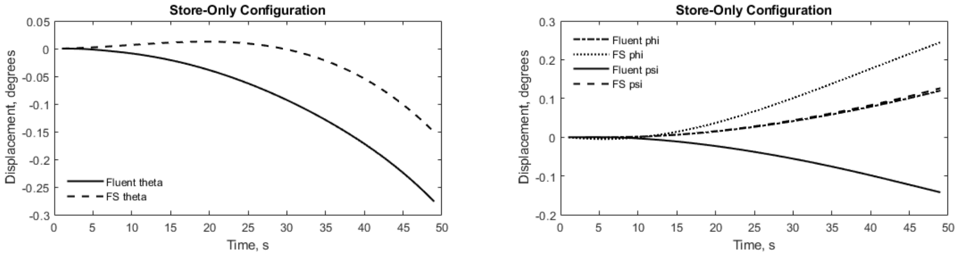
Fig. 10 Linear and angular displacements, wing-pylon-store configuration

Z displacement is captured fairly well with FlightStream. The displacement in X and Y is small for both simulations, but there is a difference in magnitude most notably in the X displacement. Change in pitch lines up well for both magnitude and trend. Change in roll and yaw angles are different in trend and magnitude.



(a) Z displacement

(b) X, Y displacement



(c) Pitch displacement

(d) Roll, Yaw displacement

Fig. 11 Linear and angular displacements, store-only configuration

For the store-only configuration, Z displacement lines up perfectly between FlightStream and Fluent. The X and Y displacements are also in fairly good agreement. X displacement is increasing faster for Fluent than FlightStream. The angular displacement in pitch is in agreement in trend but off in timing and magnitude. Angular displacement for roll is trending in the same direciton with an increasing slope for FlightStream. Yaw displacement is in disagreement in trend.

C. Forces and Moments in Carriage

Table 2 Wing-Pylon-Store Configuration

	Fx	Fy	Fz	Mx	My	Mz
Fluent	-168.5 N	-418.5 N	-1126.2 N	20.2 Nm	-937.5 Nm	-26.5 Nm
FlightStream	-229.4 N	-121.8 N	-943.1 N	-0.8 Nm	-752.6 Nm	-76.7 Nm

Table 3 Store-Only Configuration

	Fx	Fy	Fz	Mx	My	Mz
Fluent	-174.3 N	11.2 N	-16.1 N	0.8 Nm	-11.5 Nm	-13.8 Nm
FlightStream	-192.1 N	6.94 N	-2.5 N	-3.7 Nm	9.3 Nm	-4.7 Nm

Comparing the wing-pylon-store configuration to the store-only configuration, proximity flow interaction from the wing and pylon were observed to affect Fy, Fz, and My most notably. While magnitudes of forces and moments differed, trends were caught for the most part. The lateral force Fy differed in magnitude between Fluent and FlightStream, but the change in configurations is more drastic. This is true for the vertical force Fz and the pitching moment My as well.

VIII. Conclusion

It was found that FlightStream offered an acceptable prediction of quantities such as pressure coefficient profile at the intersection of store and pylon, displacement in the vertical direction, lateral direction, and in pitch. The prediction of key forces at carriage, such as lateral force, vertical force, and pitching moment was also found to be acceptable, due to the major change that was observed between configurations. The disagreements in angular displacement will be investigated in future works. Future work may include matching the wind-tunnel experiment more closely, and testing separation events at high mach numbers.

Acknowledgments

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References

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