

Store Separation Trajectory Predictions for Maritime Search and Rescue (SAR)

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INTRODUCTION

The Australian Maritime Safety Authority (AMSA) plans to replace Dornier 328 turboprops with Bombardier Challenger 604 special mission jets modified for search and rescue (SAR). Similarly configured CL-604 Multi-Mission Aircraft are in service with the Royal Danish Air Force.

Search and Rescue (SAR) Store Separation from Turbojet Aircraft.

There are several store separation challenges posed by replacing a turboprop aircraft with a turbojet. For the 328 the rear cargo door used for store separation is well clear of the engine, Figure 1. For the 604 it's just underneath the nacelle, Figure 2. In addition, the minimum airspeed at which the 604 can release stores is higher, but still subsonic.

Unlike military aircraft, Sea Air Rescue has not used wind tunnel testing, Computational Fluid Dynamics (CFD) nor Six Degree-of-Freedom (SDOF) trajectory simulations prior to flight testing. This might have been since the released stores were relatively light weight, the airspeeds low, and incidental contact with the aircraft unlikely to cause significant damage at low airspeeds.

This paper will describe how SDOF trajectory simulations might be used to reduce the cost and time required to safely complete a jet SAR flight test program.



Figure 1 Dornier 328 Turboprop



Figure 2 Challenger 604

DISCUSSION

Geometry

The first step in trajectory simulations is to obtain the aircraft and store geometries.

A representative 604 geometry was obtained from the internet. This geometry had to be scaled to fit the published 604 aircraft dimensions.

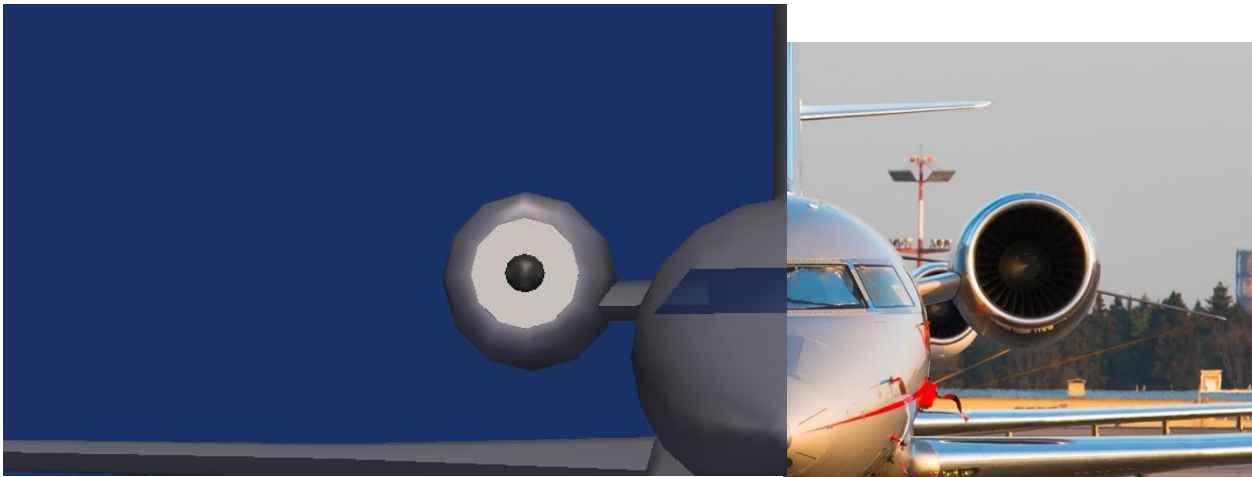


Figure 3 Comparisons of the 604 geometry model and picture of the aircraft

As may be seen in Figure 3, the 604 model, while not exact, represents the critical features of interest for the trajectory simulations. These are the relative locations of the fuselage, nacelles and wing.

Freestream

The next step is acquiring the freestream aerodynamic characteristics for the stores. These are generally obtained from wind tunnel testing.

For SAR, which uses cylindrical and rectangular shapes that tumble, limited data is available, since wind tunnel freestream data is usually taken only to 40-60 degrees. Lack of freestream data might account for no known SDOF simulations in previous SAR store release programs.

DATCOM estimates were used to generate a set of aerodynamic coefficients from 0 to 360 degrees. The most important coefficients are the normal force (CLM) and pitching moment (CLN), and not representative of what the stores might do.

This was done only to provide input to the SDOF code.

Initial Conditions

Since a SDOF code predicts a store's trajectory with time, any error in the initial conditions will be compounded as the trajectory proceeds. The usual deployment for stores for SAR involves a loadmaster, which means that the initial conditions are variable to some extent, and not repeatable. This might also account for no SDOF simulations in previous SAR store release programs

Aircraft Flowfield

Next to store freestream effects and initial conditions the most important impact on store trajectories is the aircraft flowfield. For military aircraft this is of critical importance, and has caused many cases of aircraft damage, and sometimes loss of the aircraft in the early days of store separation, when flight testing was conducted in a hit or miss fashion. The aircraft flowfield effects increase with the square of the release airspeed.

604 TRAJECTORY PREDICTIONS

Many existing SDOF trajectory simulations codes were originally based on wind tunnel Captive Trajectory System (CTS) software. This was very useful, because the pretest trajectory simulations could be checked real time with what was being measured in the wind tunnel.

Since CTS testing capability was usually limited to 50-60 degree for the store pitch (alphas) and yaw (betas) angles in the wind tunnel, most of these codes fail for store angles that exceed 90 deg.

The ASTERIX SDOF code was selected for preliminary 604 trajectory predictions because of its ease of use, excellent graphical interface, but most important its ability to function for stores that tumble.

Aircraft Store Trajectory Estimation Realized In Xcos (ASTERIX)

ASTERIX [1] is a software tool for calculating the trajectory of a weapon or other store while separating from an aircraft. The tool leverages the capabilities inherent in Scilab / Xcos for 6 dof motion simulation. The heart of the tool is a custom function block for Xcos. The function block is written in Scilab and reads a text control file containing the information for simulation. Other files in the form of multi-dimensional data tables are referenced in the control file and the data loaded into a series of data structures that describe the store mass and aerodynamic characteristics. The motion constraints of a release device such as an ejection rack, rail launcher or hook (pivot) can be simulated. New system variables can be defined in scilab equations or general data structures. This versatility enables the simulation of store configuration changes such as flip out fins. The effect of changing mass and inertia due to rocket motor burn can also be simulated. The custom Xcos block outputs body rates and has control surface deflections as inputs and so a control system such as a separation autopilot can be graphically constructed around the block in Xcos.

CSIR ARUV

ARUV is a low-order panel code with a fixed wake and an extensive array of features supporting store separation analyses. It is a further development of the USTORE code developed by the CSIR during the 1970's and 1980's. The panel code shares its underlying theoretical basis with USTORE which is described in detail in [2] and is outlined briefly here.

The panel method uses the concepts introduced in Woodward's USSAERO code [3] and is based on linear potential flow theory. The surface of the aircraft and its stores are discretised into a large number of panels. The body components have constant source distributions and as a result cannot generate lift. The panels on the lifting surfaces incorporate linearly varying vortex distributions to represent lift and linearly varying source distributions to represent the thickness distribution. Both the upper and lower wing panels lie on the mean wing plane and the boundary conditions are applied in this plane. Round leading edges are treated using a special leading edge source strength that is related to the actual leading edge radius.

Models are divided into lifting surfaces (wings, fins, etc) and non-lifting bodies which can have an arbitrary shape. There are no special restrictions on the geometry of the store. This formulation of the panel method is both a strength as panelling is simple and the code itself is very fast and a liability when modelling aircraft with integrated lifting fuselages.

Compressibility effects are taken into account using a Goethert-type rule but viscosity effects are excluded. ARUV performs well for subsonic, low angle-of-attack analyses and reasonably well for low transonic cases, depending on the configuration. ARUV has been extensively validated [2], [4].

ARUV has a wide range of features applicable to store separation analyses (it models aircraft/store dynamics, ejectors, rail launchers, boosted stores, etc.) and can either model the store as a separate panelled airframe translating within the perturbed flowfield of the parent aircraft or it can use look-up tables of the store aerodynamics derived from other sources. Multi-component look-up tables can be used to address the fact that the flowfield can change significantly along the length of the store.

The aircraft flowfield can be recalculated at every time step or a flow grid can be generated through which the store is translated. External data sources (wind-tunnels or CFD) can be used to provide the flow grid data.

ASTERIX Trajectory Simulations

1. Trajectory simulations for a squat cylinder

ASTERIX provides several modes for visualizing the trajectory simulations. Using DATCOM estimated freestream characteristics for a squat cylinder, with no 604 aircraft flowfield, and a "best guess" of what the initial conditions might be, the trajectory simulation was predicted for a cylinder, Figure 4 shows the prediction in a three view format for the first 0.80 seconds.

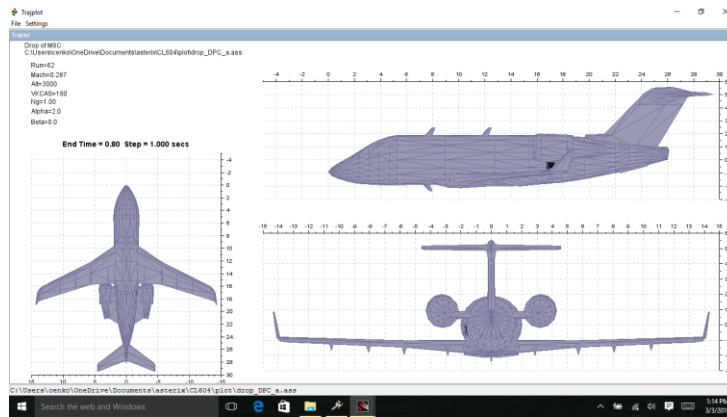


Figure 4 Trajectory Simulation of a Squat Cylinder (DPC) for the 604 aircraft

Figure 5 shows a more descriptive visualization. For the conditions selected, it appears that the DPC should separate with little difficulty. It is important to note that this simulation is not a prediction of what might actually occur, since the initial conditions, aircraft flowfield effects, store freestream are not known. It only provides a suggestion of how SDOF simulations might be used.

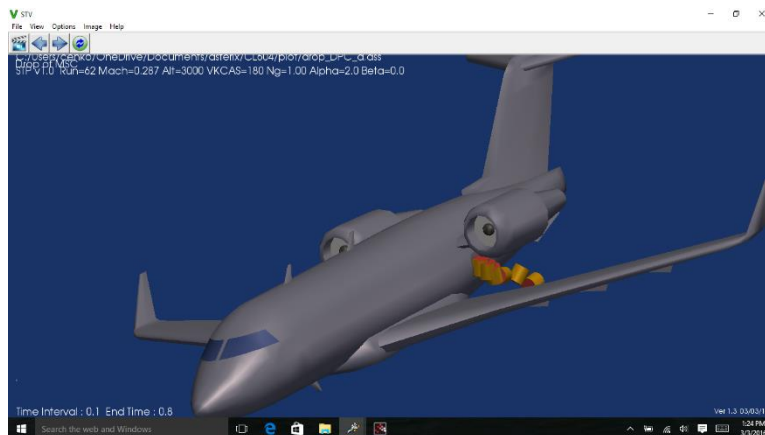


Figure 5 Three Dimensional View of the DPC from 604 Aircraft

2. Trajectory Simulation for a Rectangular Box

Using the same initial conditions and just changing the mass properties, the trajectory simulation for a rectangular box is shown in Figure 6.

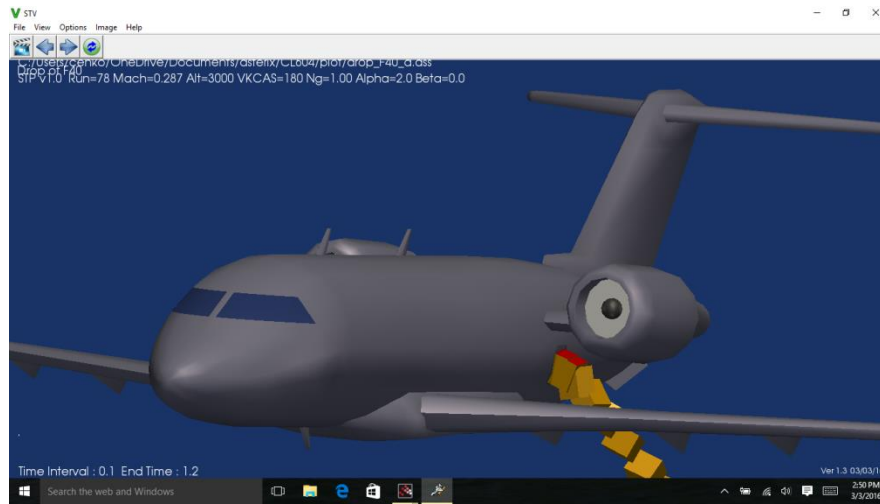


Figure 6 Three Dimensional View of Box Separating from 604 Aircraft

In this case, since the box fills the entire cargo door opening, the predicted trajectory is much more exciting, especially from a pilot's perspective.

It must be noted that both trajectories shown are speculative, since only the mass properties of the stores have been properly represented. The initial conditions are guesstimates, and the freestream aerodynamics for the stores in question are wrong. The stores are assumed to be released with no aircraft; the effects of the aircraft flowfield on the trajectories may have a significant impact.

Pan Air Predictions of Store Freestream Aerodynamics

Since three of the stores of interest were cylinders, basic mass properties and aerodynamic characteristics were developed, as shown in Figure 7.

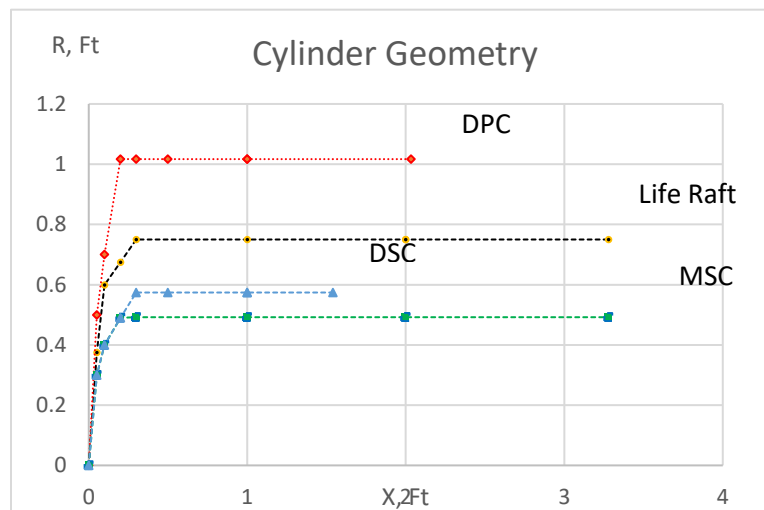


Figure 7

PanAir [5] geometries were developed for the Marine Supply Container (MSC), Deployable Stores Container (DSC), and Diesel Pump Container (DPC). As may be seen in the sketch above

(length and radius units are in feet), the noses of the stores were rounded since linear potential theory fails at sharp corners. A model for a rectangular life raft was also developed.

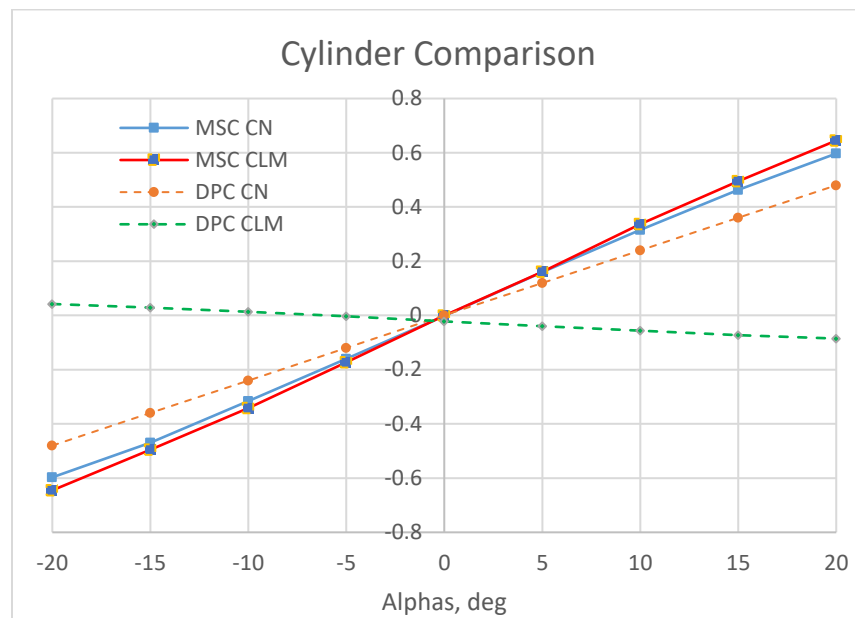


Figure 8 Aerodynamic Coefficient for Cylinders

PanAir predictions of freestream characteristics for cylinders are shown in Figure 8. Note that the normal force (CN) and pitching moment (CLN) for cylinders would be identical to the side force (CY) and Yawing moments (CLN) for the same angles. The code is based on linear theory, therefore there is no change in the moments with angle of attack. Comparisons with large scale freestream data have previously shown good agreement, Reference [6].

The major difference between the DPC and MSC containers is that the MSC container has a length to diameter (l/d) ratio of 3.33/1, while the DPC is 1/1. Figure 8 indicates that the MSC container is unstable, while the DPC container seems neutrally stable. It appears that for squat stores the tendency to rotate is significantly reduced. Since the normal is also smaller, the DPC should be easier to release. Prosser [7] showed that l/d ratio cylinders of 2 were unstable, while those of 1 were neutrally stable.

Comparison between Cylindrical and Rectangular stores

In Figure 9 the freestream predictions for the DPC container are compared to a rectangular life raft with a length to width (l/w) ratio of 2.22. The CN and CLM for the raft are like those for the MSC.

Cylinder vs Rectangular Comparisons

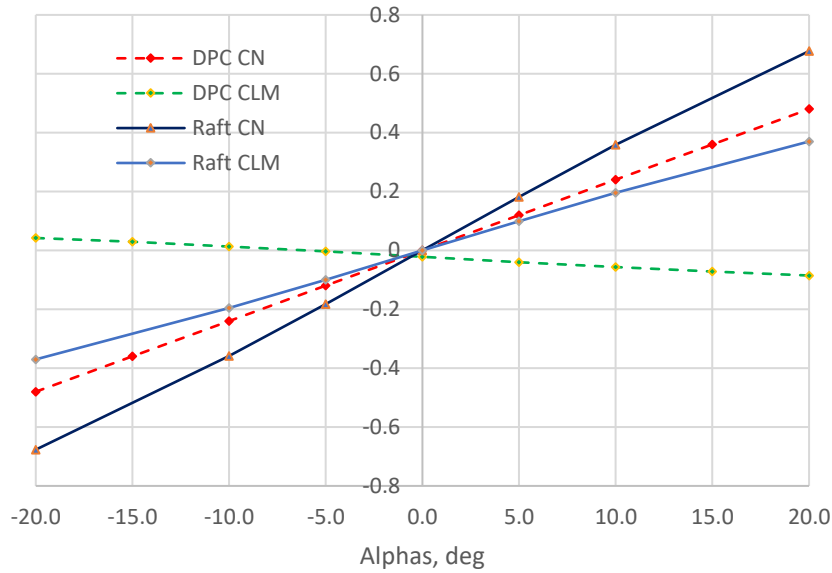


Figure 9 Aerodynamic Comparison for Cylindrical and Rectangular stores Comparison for the Mk-63 mine

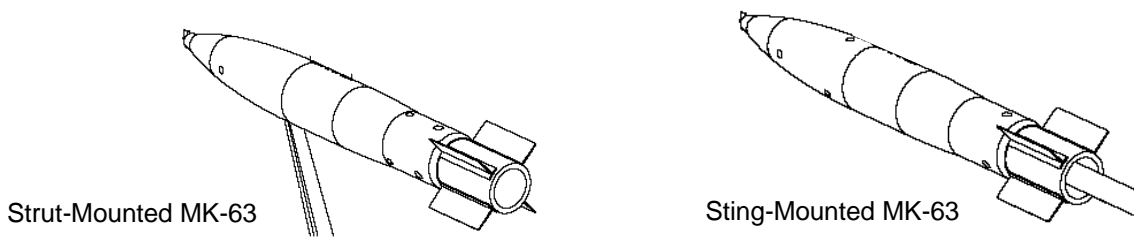


Figure 10 MK-63 wind tunnel models

Freestream test data were available [8] for the MK-63 Mine at $M = 0.85$, Figures 10, 11. Although the actual store geometry was not available, since the sting distorts the tail, an approximate PanAir model was developed using Aircraft Stores Interface Manual (ASIM), Figure 12

As may be seen in Figure 13, the CN trends are in reasonable agreement, but the MK-63 pitching moment CLM becomes non-linear at angles of attack above 4 degrees.

This was done to determine what linear theory would predict for the stability characteristics of bodies alone.



Figure 11 Solution for MK-63 in P-8A Bay

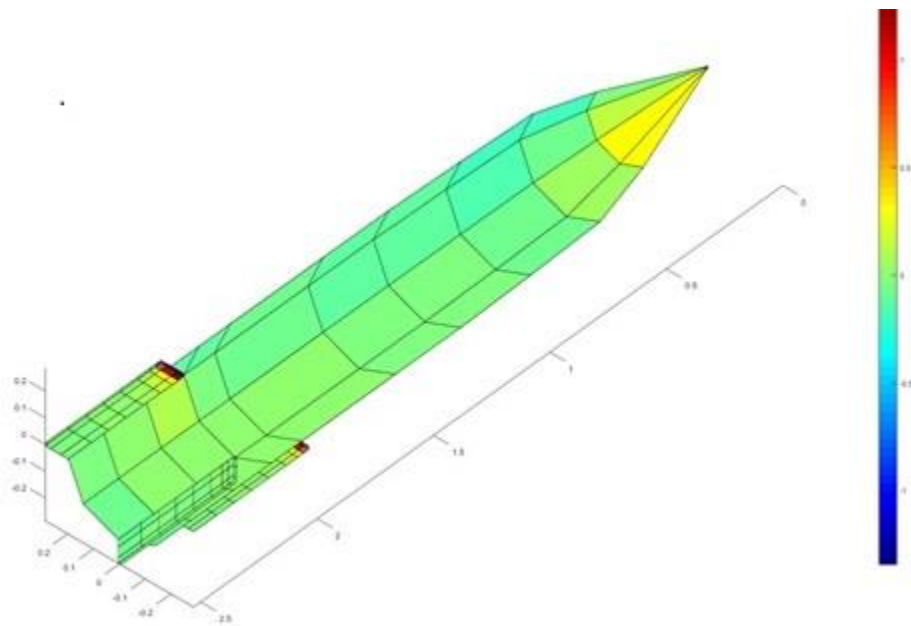


Figure 12 MK-63 Pan Air Representation

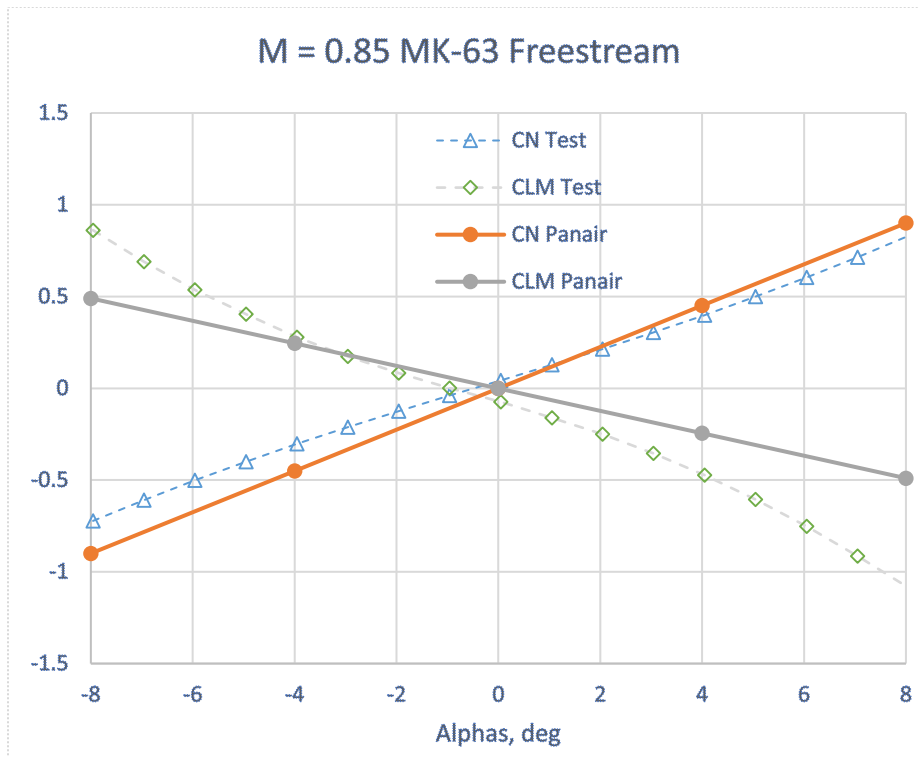


Figure 13 MK-63 comparisons

When the MK-83 tail was removed, there was a reduction in the normal force. The major difference was in the pitching moment. The store became unstable, Figure 14.

Note the similarity of the MK-63 without the tail to the predictions for the MSC in Figure 8. The MK-63 has an l/d ratio 6.3.

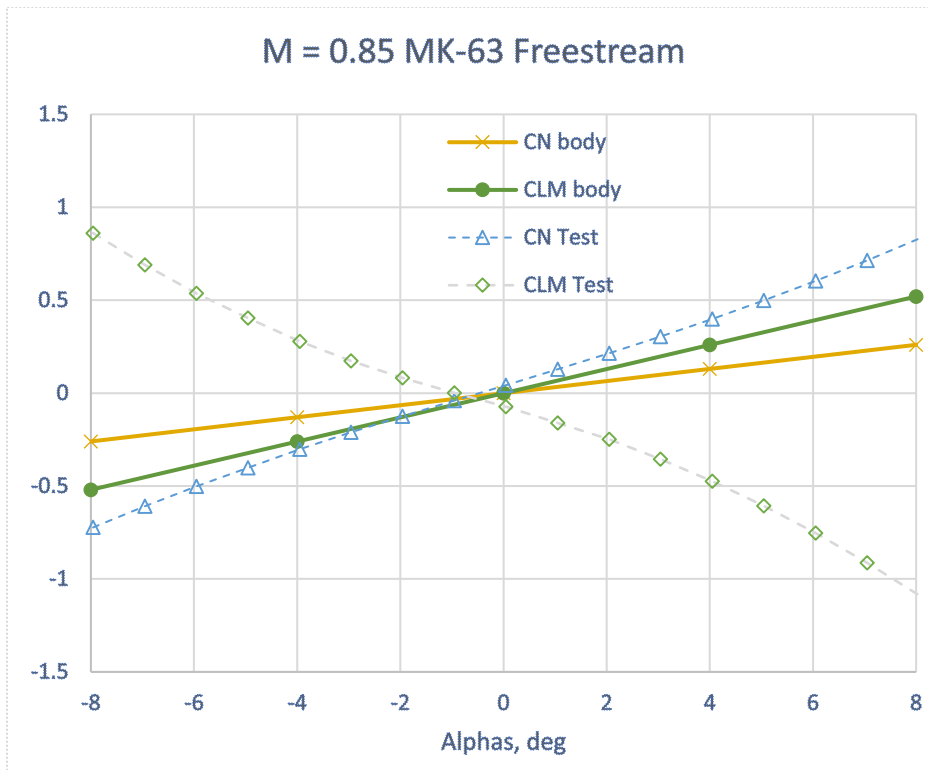


Figure 14 MK-63 Tail Effects

Comparison Between DATCOM and PanAir Freestream Predictions

The Pan Air predicted freestream for the DPC is compared with the DATCOM estimates used for the DPC in Figure 15. The CN provided by Pan Air is in reasonable agreement with that from DATCOM. The pitching moment CLM provided by DATCOM is about 20 times larger. This further illustrates the uncertainty of aerodynamic force and moment data for cylindrical stores.

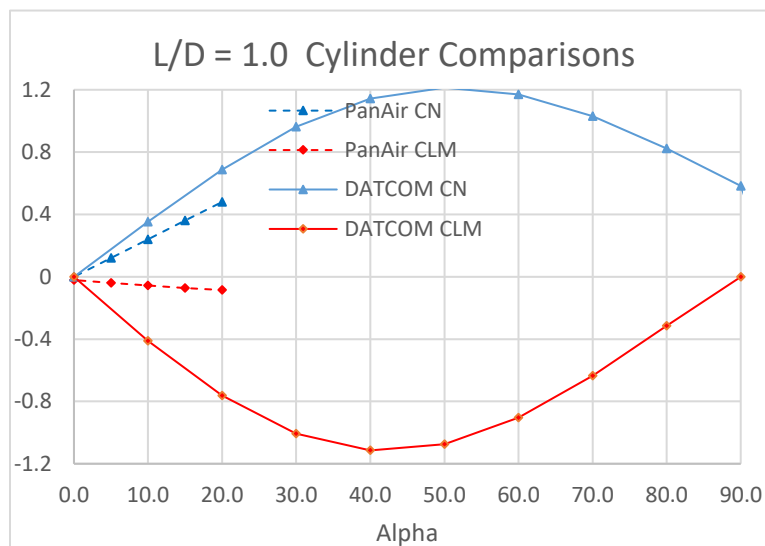


Figure 15 DPC comparisons

Trajectory Comparisons for DPC using DATCOM and PanAir Freestream

Figures 16 and 17 show the differences in trajectories using the DATCOM and PanAir freestream moments for a squat cylinder. These differences are substantial, and could be easily measured in flight testing. This would be one way that the predicted freestream aerodynamics could be validated.

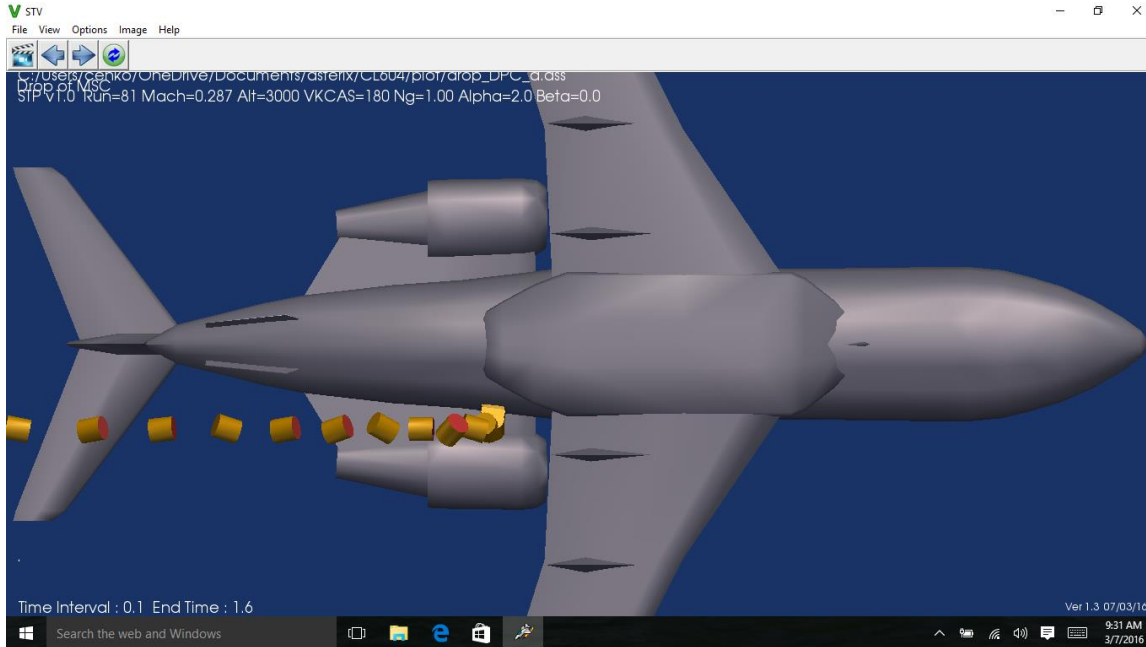


Figure 16 DATCOM CLM

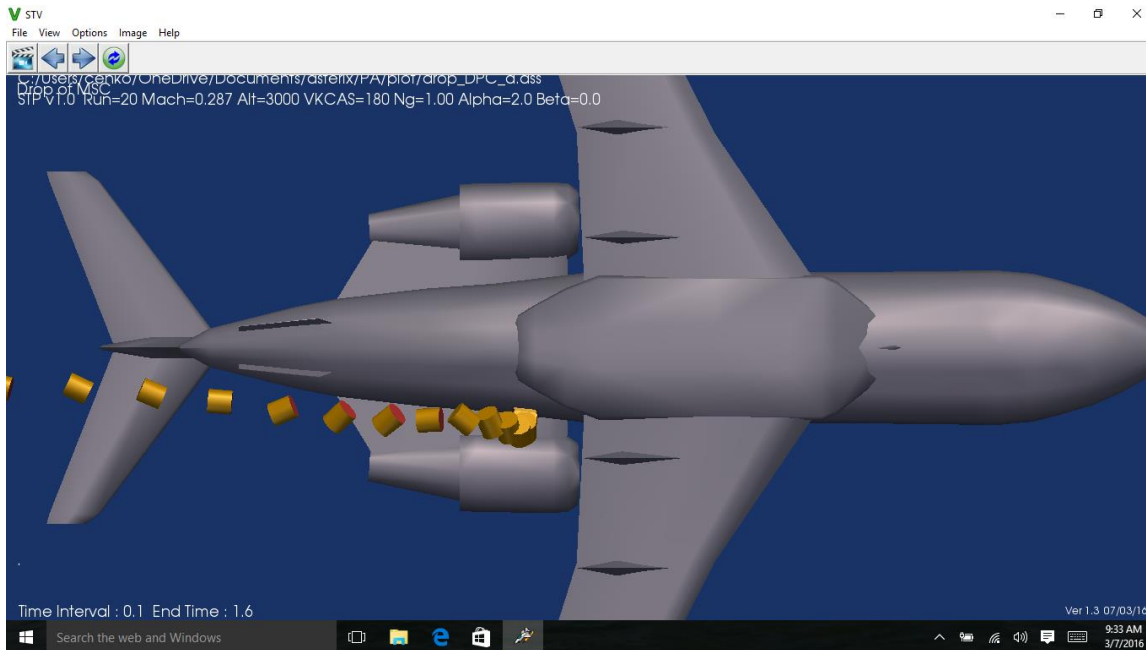


Figure 17 PanAir CLM

FURTHER WORK ON SAR TRAJECTORY PREDICTIONS

Freestream

The store geometries of interest for SAR are quite simple, and could be easily modelled in most Euler or Navier Stokes codes. A range of solutions, especially for angles of attack above 90 degrees would be preferred. In addition, a wind tunnel test for a rectangular shape and cylindrical shape for lower angles of attack in a low speed tunnel should not be too expensive, and might make for a good University class project, combined with a CFD course.

Initial Conditions

Ground testing would provide an initial estimate, which flight test photogrammetrics would confirm.

Aircraft Flowfield Effects

Since the initial conditions are unknown, time accurate trajectories would make no sense. An Euler or NS model for the 604 aircraft could be developed. However, a grid of store loads in the aircraft flowfield would require a much larger data set than used for military aircraft.

Military aircraft have well defined initial conditions, and the store trajectories follow a prescribed path largely determined by the ejectors. A grid, done either in the wind tunnel or by CFD [4] usually requires about 20 different Z locations at 2-3 pitch and yaw attitudes (around a hundred CFD calculations or wind tunnel test points) for each store at a particular Mach number and aircraft configuration.

For SAR aircraft, the trajectories are unknown. Furthermore, since the store attitudes vary from 0 to 360 degrees, the number of CFD grid points required would be in the thousands.

Panel methods have demonstrated the capabilities to estimate aircraft flowfield effects at transonic Mach numbers. Since the aircraft flowfield required is only in the effects that the upwash and sidewash have on the store at a particular location, linear theory should be adequate to predict these effects.

The usual approach for predicting aircraft flowfield effects using wind tunnel data is to subtract the small-scale store freestream data from the grid data (incremental coefficients) and use larger scale freestream data in the SDOF simulations. The geometry used in this study is adequate for linear theory calculation of store loads. The Pan Air code can be downloaded for free from PDAS.com.

SUMMARY

The goal of this paper is to determine how existing store separation tools may be applied to SAR. Several different tools will be used evaluated. Trajectories using DATCOM, panel methods, Euler and Navier Stokes for freestream aerodynamics will be compared.

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