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Collision Detection Modelling for Store Release Testing at AMRL

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Air Operations Division
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ABSTRACT

The Transonic Wind Tunnel and its state-of-the-art Store Model Support System, provide the Australian Defence Force with the capability to perform aerodynamic grid tests which simulate the release of stores from aircraft. A computer program called CDM, written in Java and Java 3D programming language has been developed to visualise, model, and provide collision detection, for an aerodynamic grid test. The software provides a safe, efficient and cost-effective method to analyse the grid used in an aerodynamic grid test. With its three-dimensional modelling environment, CDM can also be used as a tool for grid point design and visualisation. With a high level of flexibility in the software architecture, CDM can be easily configured for different wind tunnels, test configurations, aircraft and store models.

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Executive Summary

The recently upgraded transonic wind tunnel operated by the Australian Defence Science and Technology Organisation (DSTO) at the Aeronautical and Maritime Research Laboratory (AMRL), allows DSTO to carry out research in the areas of flight behaviour of military aircraft and missiles, and to perform aerodynamic grid tests for store carriage and release clearance investigations. Results obtained from the transonic wind tunnel are also used to validate findings from computational fluid dynamics codes.

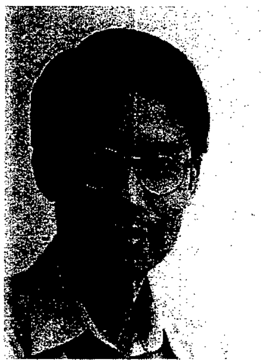
The state-of-the-art Store Model Support System, which can accurately position and orientate a store model about the aircraft model's flow field, allows accurate aerodynamic grid tests to be performed. To protect the Store Model Support System from colliding with the aircraft model and/or the test section walls during an aerodynamic grid test, a computer program called CDM (Collision Detection Modelling) has been developed.

CDM has been written using the Java and Java 3D programming languages, which allows platform-independent operation. The three-dimensional virtual environment allows CDM to simulate, model, and provide an accurate collision detection capability for an aerodynamic grid test. CDM replaces the time-consuming and cost-ineffective manual grid checking process which was carried out prior to a grid test. With its three-dimensional representation of the store model support system, CDM can also be used to visualise grid points and assist in the grid design process.

The object oriented programming architecture of CDM increases the flexibility of the software. CDM can be easily configured for different wind tunnels, test configurations, store and aircraft models used in an aerodynamic grid test.

The capability to clear new stores from existing or new ADF platforms is an essential part of the Australian defence capability. The CDM software is an essential part of the provision of timely and good quality aerodynamic data required for the store clearance process.

Authors



Sunny Yin Fat Leung
Air Operations Division

Sunny Leung completed his Bachelor of Engineering in Aerospace Engeering and Bachelor of Business in Business Administration with First Class Honours at RMIT in 1998, and joined the Aeronautical and Maritime Research Laboratory at Fishermans Bend the following year. He worked in the Flight Mechanics area of the Air Operations Division, and was involved with experimental aerodynamics and wind tunnel test techniques. He also worked extensively in the investigation of strain gauge balance calibration matrix mathematical models.

Yoel Link
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Yoel Link completed his Bachelor of Science in 1987 and his Bachelor of Engineering in Aeronautical Engineering in 1989, both at Sydney University, and he joined the Aeronautical Research Laboratory at Melbourne the following year. He completed a Master of Business Administration in Technology Management in 1995 at Monash University. He has predominantly worked in Flight Mechanics and experimental aerodynamics in the Wind Tunnels. During this period he has accumulated extensive experience in aerodynamics with the F-111, AGM-142, Jindivik, Tonic, PC-9, Mk82, Amphibious Transport (LPA) ship, and the Hydrographic Ship wind tunnel test programmes. He has also been responsible for the development of the wind tunnel data acquisition systems, and is currently responsible for the new Transonic Wind Tunnel, which was completed in March 2000.

Craig D. Edwards
Air Operations Division

Craig graduated from the University of Queensland in 1995 completing a Bachelor of Mechanical and Space Engineering with First Class Honours. The following year he obtained employment with the Aeronautical and Maritime Research Laboratory at Melbourne. Working in Flight Mechanics, he has gained considerable experience in the area of wind tunnels and experimental aerodynamics. This has included test programmes with the Hydrographic Ship and PC-9/A aircraft in the Low Speed Wind Tunnel, and contributions to the F-111/AGM-142 store clearance project in the Transonic Wind Tunnel. He has also been involved extensively in the development of wind tunnel data acquisition systems.

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Nomenclature

Symbols that are not listed here are defined and described in the corresponding section of the report.

Symbol	*Description*
ej	Ejector axis system
L_{y1}	Length of the Store Model Support's yaw arm in the x-axis direction [mm].
L_{y2}	Length of the Store Model Support's pitch arm in the x-axis direction [mm].
L_{prs}	The distance between the end of the roll drive of the Store Model Support and the geometric centre of the store model [mm].
o_{z1}	A geometric constant of the Store Model Support [mm].
r	Radial distance from pylon
T	Tunnel
VRML	Virtual Reality Modelling Language
x_o	Length of the Store Model Support's axial arm in the x-axis direction [mm].
x_{axial}	x-axis translation of the Store Model Support [mm].
x	x-axis location of the store model in the tunnel axis system [mm].
y	y-axis location of the store model in the tunnel axis system [mm].
Z_{main}	Vertical translation of the Store Model Support [mm].
Z, z	z-axis location of the store model in the tunnel axis system [mm].
ψ_{10}	Initial downstream yaw angle offset of the Store Model Support [deg].
ψ_{20}	Initial upstream yaw angle offset of the Store Model Support [deg].
θ_{act}	Pitch drive's pitch angle of the Store Model Support [deg].
θ	Pitch angle of the store model [deg].
ϕ_{act}	Roll drive's roll angle of the Store Model Support [deg].
ϕ	Roll angle of the store model [deg].
ψ_1	Downstream yaw angle of the Store Model Support [deg].
ψ_2	Upstream yaw angle of the Store Model Support [deg].
ψ	Yaw angle of the store model [deg].

1. Introduction

The Royal Australian Air Force operate aircraft which are capable of releasing stores at transonic speeds. In some cases, the flow field around the aircraft can change the trajectory of a store from that intended, and it can also affect the store to such an extent that it becomes dynamically unstable. This can result in the store inadvertently coming into contact with the release aircraft and causing structural damage.

To check whether a store can be released safely or not, aerodynamic grid testing is being carried out in the new transonic wind tunnel at the Aeronautical and Maritime Research Laboratory (AMRL). These tests provide a database of aerodynamic forces and moments for a store at various locations and orientations near the aircraft. This data is then used in a store trajectory prediction algorithm to calculate the predicted trajectory, which can then be assessed for safety or other aspects as required. The number of actual test drops needed to finally clear the store can be reduced and costs minimised by using this technique.

The new AMRL transonic wind tunnel is equipped with a Store Model Support System suitable for aerodynamic grid-type testing. The generation of the grid points covering the volume in which the model is to be tested, and the actual tests at the grid points are two separate processes. This means that a grid used in the actual aerodynamic grid test could have some grid points which might cause the store or the store support arm to collide with either the test section walls or with the aircraft model during the test. Collisions during a grid test must be avoided because they can cause serious damage to the model and to the wind tunnel.

The current method for collision avoidance requires all the grid points to be physically checked and verified to be safe inside the wind tunnel, which is very time-consuming and costly, as the test has to be effectively done twice. To avoid the time consuming manual grid checking process, a software package has been developed called 'Collision Detection Modelling' (CDM). This program simulates the store model, the aircraft model, the store support, the test section walls, and the aerodynamic grid testing process, by providing a virtual collision checking environment that allows a set of grid points to be checked quickly and easily away from the wind tunnel environment. It can also be used very effectively for grid design. A high level of flexibility has been built into the system architecture to allow CDM to be easily re-configured for different aircraft and store combinations, as well as for different wind tunnels.

The CDM software suite has been used very effectively in the development of the grids used for the F-111/AGM-142 grid tests, recently completed in the transonic wind tunnel. The software is also being used to design cranked stings for use with the F/A-18/ASRAAM grid tests.

2. The Transonic Wind Tunnel Facility

The new transonic wind tunnel was completed in March 2000, and DSTO took possession and commenced wind tunnel testing immediately. Brief details of the transonic wind tunnel and the associated model support systems are given in the following sections.

2.1 Transonic Wind Tunnel Specification

The transonic wind tunnel, as shown in Figure 1, is a closed-circuit continuous flow wind tunnel capable of achieving continuously variable Mach numbers from 0.3 to 1.2, and Mach 1.4 with a fixed nozzle. The tunnel may be pressurised to 200 kilopascals absolute or depressurised to 30 kilopascals absolute by the Plenum Evacuation System (PES). The PES is driven by a single-stage centrifugal compressor with a 2.6 MW induction motor.

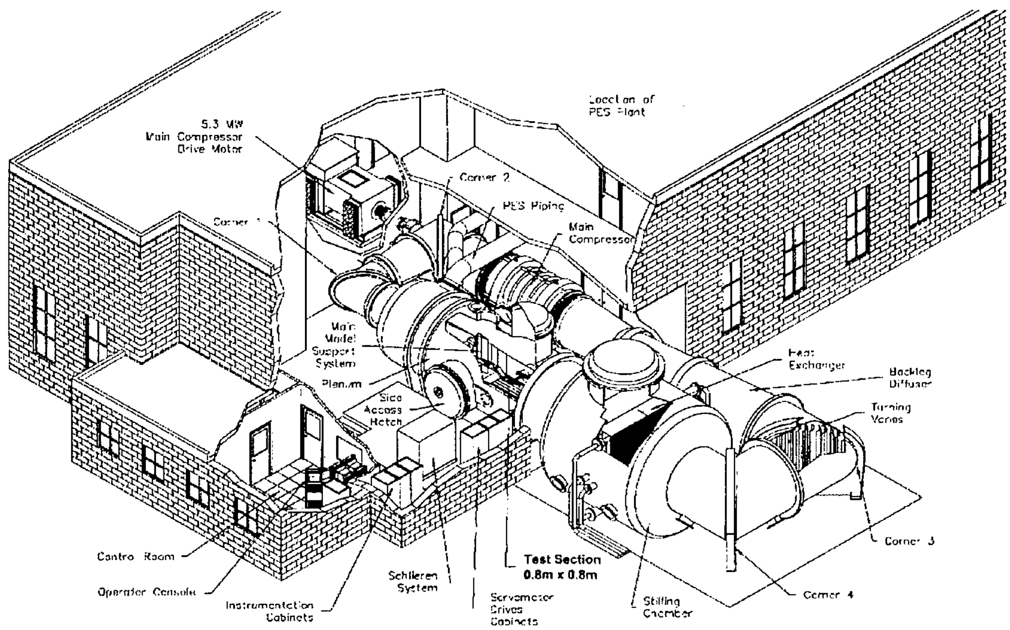


Figure 1: The new transonic tunnel at AMRL

The ability to vary the pressure inside the tunnel and the test section, increases the tunnel simulation capabilities. The transonic wind tunnel can achieve a Reynolds numbers of 27 million per metre at maximum pressure of 200 kPa absolute. The Reynolds number achievable provides test data which can be applied to full-scale aircraft with confidence.

The test section of the tunnel is located inside a cylindrical pressure chamber. The test section is 0.806 meters wide, 0.806 meters in height and 3.12 meters long, with slotted walls (6 slots/wall) and interchangeable solid sidewalls.

The tunnel is driven by a two-stage axial flow compressor powered by a 5.3 MW variable speed motor. The compressor is designed to maintain a high level of aerodynamic performance in the Mach number range from 0.6 to 1.0, with an adequate margin for all test conditions including testing aircraft models with a span of 60% of the tunnel width at up to 14° angle of attack.

A 420 mm diameter Schlieren quality window located in the plenum shell and test section sidewalls provides for flow visualisation.

2.2 Model Support System

There are three model supports for the tunnel; a main model support, a sidewall model support (a turntable in the solid sidewall), and a store model support. The model supports are remotely operated via the control and data acquisition system computer to provide accurate location and orientation of a model during a test. Full details of the model supports are given in Reference 1.

2.2.1 Main Model Support

The main model support, which has a vertical strut arrangement, supports and maintains the aircraft model centre on the tunnel centreline. It provides pitch, roll and vertical translation to the aircraft model for freestream testing.

The main model support has the following range of motion:

- Vertical: ±370 mm from the test section centreline (defined by pitch angle requirement)
- Pitch: ±15° (with model centre at test section centre)
- Roll: ±190°

2.2.2 Store Model Support System

The tunnel is equipped with a 6 degree-of-freedom support system for store release testing. Further details of the store model support are given in Section 3.

2.2.3 Sidewall Model Support System

The tunnel is equipped with a sidewall model support system, which is essential for store release testing. It is used primarily to mount half-models of aircraft, which act as the 'parent aircraft', for underwing carriage stores tests. It does not cater for centreline stores release testing which must be done using a separate centreplane strut. The sidewall model support has a 480 mm diameter motorised turntable with a pitch angle range of ±100°, a pitch rate of up to 5°/sec, and a setting accuracy of ±0.05°.

3. Store Model Support

The store model support is a six degree-of-freedom system for positioning a store model, or a probe, within the test section in the vicinity of an aircraft model (parent aircraft).

3.1 Configuration, Motion and Load Range

The system has a "double yaw" design, which includes a roll drive, a pitch drive, two yaw systems with separate drives, and an axial drive. The store model support is mounted on the port side of the vertical strut of the main model support and it utilises the vertical motion of this strut. Horizontal store motion is provided by a combination of the two yaw drives. At zero pitch and zero yaw, the store support produces just over 3.0% blockage at the test section exit. Figure 2 shows the store model support on the main model strut in the test section, and Figure 3 is a plan view layout which shows the double yaw motion.

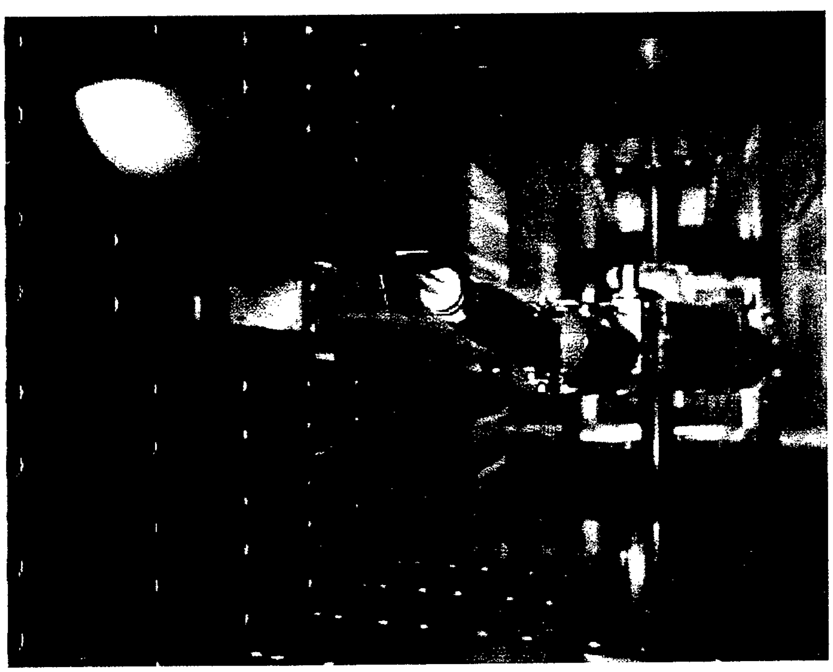


Figure 2: Store model support on the main model strut in the test section

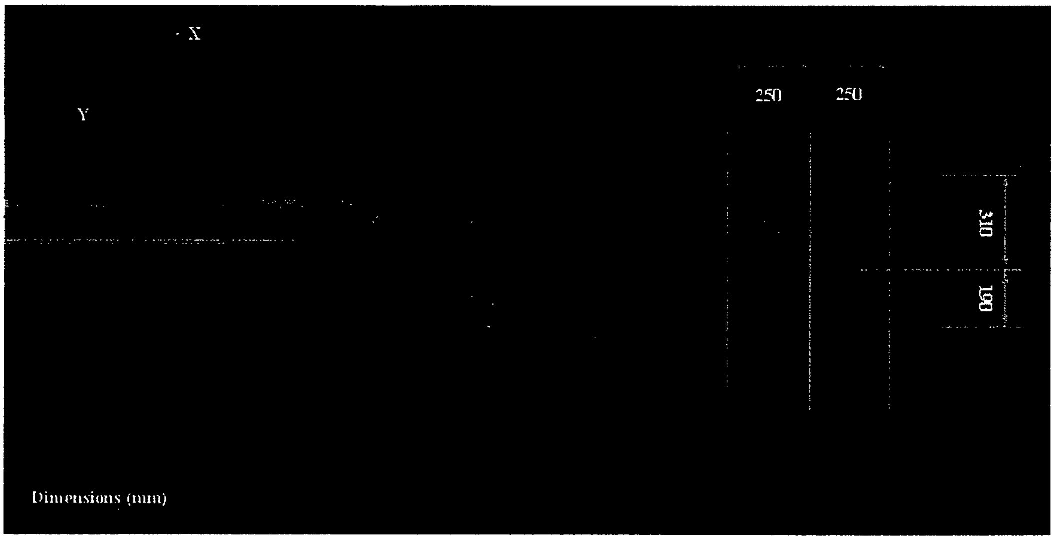


Figure 3: Plan view layout of the store model support system

The motion ranges of the support about the centre of the test section are given in Table 1. The store support system is quite rigid and it allows the model to be positioned in the test section with the accuracy and rates given in Table 1.

The design loads of the store support are as follows:

Axial force:	± 1000 N	Roll moment:	± 100 Nm
Side force:	± 2000 N	Pitching moment:	± 300 Nm
Normal force:	± 5000 N	Yaw moment:	± 150 Nm

Table 1: Store model support positioning accuracy, motion rates, motion ranges

Type of Motion	Range of Motion	Rate of Motion	Setting Accuracy	Combined Motion Setting Accuracy
Vertical Translation	500 mm	20 mm/sec	0.1 mm	0.2 mm
Horizontal Translation	500 mm	20 mm/sec	0.3 mm	0.6 mm
Axial Translation	500 mm	20 mm/sec	0.1 mm	0.3 mm
Pitch Angle	$\pm 30^\circ$	5 °/sec	0.1°	0.1°
Roll Angle	$\pm 190^\circ$	10 °/sec	0.5°	0.5°
Yaw Angle	$\pm 30^\circ$	5 °/sec	0.1°	0.1°

A cross section of the motion limits of the store model support in the vertical plane of the test section is shown in Figure 4. The store support is controlled within this envelope, in such a way that the store model support itself does not come into contact with any of the tunnel walls, or the main model vertical strut.

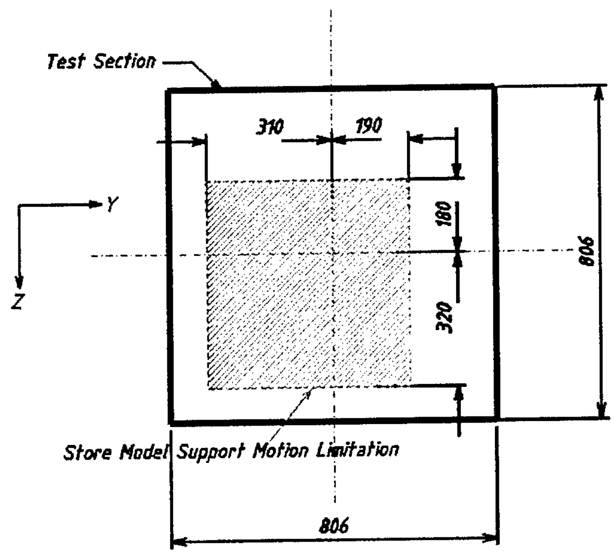


Figure 4: Store model support motion limitation (dimensions in mm)

A six component strain gauge balance is normally mounted inside the store model to measure the loads acting on the model during the wind tunnel tests. The store model support system has a very high degree of positioning accuracy, which allows the store model to be precisely placed at the desired position within the flowfield of the parent aircraft.

3.2 Control Strategy

The store model support system provides two control modes – a manual control mode and an automated control mode.

In the manual mode, the operator can enter into the control software the position coordinates of the location where the store is to be moved. This manual mode is essential for manual positioning of the store within the allowable position envelope.

In automatic mode, a number of position coordinate or grid sets (also referred to as 'model position lists' and 'angle lists') which are in a relative axis system, are entered into the control software. The store model support system will position the store according to the positions identified in each set. Each set contains a 'home position' in terms of the absolute wind tunnel axis system, as well as the set of 'store position' coordinates which are in a relative axis (coordinate) system as mentioned above. When activated, the system will translate all coordinates in the relative axis system into the activated, the system will translate all coordinates in the relative axis system into the absolute wind tunnel axis system using the store reference position as the origin, and then proceed to move the store to each location listed in the tunnel axis system coordinate set. The system will then progress to the next position coordinate set as required. The current system is capable of working with a total of 10 grid sets (model position lists), where each one contains one home position and 60 store positions.

3.3 Kinematic Equations

The store model support system uses a set of inverse kinematic equations to control its actuators in order to achieve accurate positioning of the store inside the wind tunnel test section.

Figure 5 shows the coordinates and sign conventions used to derive the kinematic equations for the store model support arm.

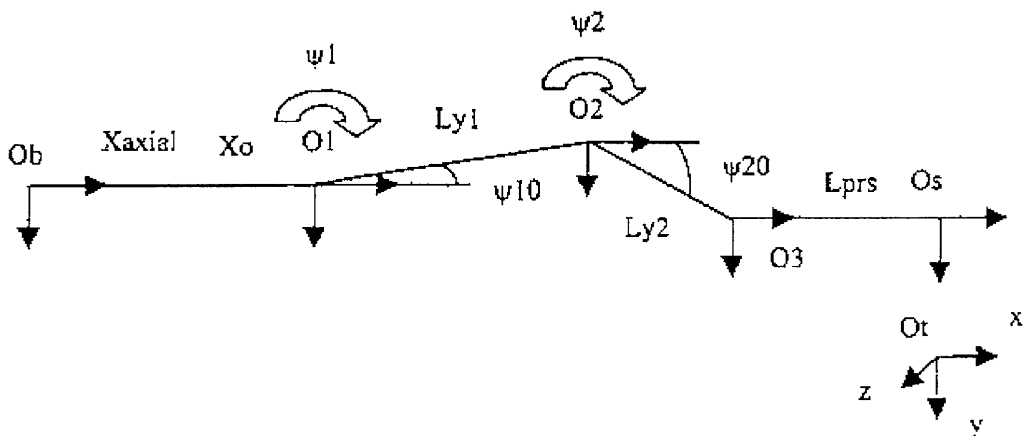


Figure 5: Store model support arm coordinate system (Plan view)

Figure 5 shows that each actuator is operated on its own individual axis system. This allows the kinematic equations to be derived in relatively simple terms, and it simplifies the operation of the store model support system.

Given a desired position $[x \quad y \quad z]^T$ and orientation $[\psi \quad \theta \quad \phi]^T$ of the store in the absolute wind tunnel coordinate system, the store model support's actuator orientation can be calculated using the following inverse kinematic equations.

Pitch actuator angle orientation:

$$\theta_{act} = \theta \qquad \textit{Equation 1}$$

Roll actuator angle orientation:

$$\phi_{act} = \phi \qquad \text{Equation 2}$$

Vertical translation:

$$Z_{main} = Z - o_{z1} + L_{prs} \sin\theta \qquad \text{Equation 3}$$

Downstream yaw actuator angle orientation:

$$\psi_1 = \sin^{-1}\left[\frac{y - o_{y1} - L_{y2}\sin(\psi + \psi_{20}) - L_{prs}\sin\psi\cos\theta}{L_{y1}}\right] + \psi_{10} \qquad \text{Equation 4}$$

Upstream yaw actuator angle orientation:

$$\psi_2 = \psi - \psi_1 \qquad \text{Equation 5}$$

Axial translation:

$$x_{axial} = x - o_{x1} - x_o - L_{y1}\cos(\psi_1 - \psi_{10}) - L_{y2}\cos(\psi + \psi_{20}) - L_{prs}\cos\psi\cos\theta \qquad \text{Equation 6}$$

The six geometric constants used in the inverse kinematic equations are:

$L_{y1} = 658.0860\, mm$

$L_{y2} = 340.4861\, mm$

$\psi_{10} = 0.015196\, rad$

$\psi_{20} = 0.052890\, rad$

$L_{prs} = 450.0\, mm$ (This constant will vary depending on the model setup.)

$x_o = 640.0\, mm$

Using Equation 1 to Equation 6, the store model support control system can activate the translation and orientation of individual actuators to achieve the required store position in the wind tunnel test section. (For a full derivation of the above inversed kinematic equations, refer to ASE documentation which is available form the Authors.)

Although the store model support has a set of motion limits for positioning the store, as shown in Figure 4, which avoids collision between the store support and the tunnel test section walls, there is no mechanism in place to prevent collision with the parent aircraft model. Hence, in order to ensure safe operation of the store model support system, it is necessary to go through all grid points in the angle lists manually to check for collisions. To avoid this time-consuming, labour-intensive and costly manual grid checking process, a software package has been developed called Collision Detection Modelling (CDM). Details of this software are given in this report.

4. Store Release Testing

When a store is released from an aircraft at high speed (Mach 0.7 - Mach 1.4), the store may become dynamically unstable due to the influence of the aerodynamic flow field surrounding the aircraft. Such behaviour could cause serious structural damage to the aircraft, if the store and aircraft collide, and/or greatly reduce the ballistic accuracy of the store.

The aim of store release testing is to ensure the safe release of a store from an aircraft, and to estimate the store's ballistic accuracy when under the influence of the aircraft's flow field in different release manoeuvres.

4.1 Grid and Captive Trajectory Testing

There are two main approaches used in store release testing. The first method, commonly referred to as 'Captive Trajectory Testing', involves measuring the aerodynamic loading on the store at a particular point, and using the forces and moments measured at this point to predict the next location of the store using a trajectory prediction algorithm. This procedure is repeated with the store at the 'next location' until the trajectory has been determined. The second approach, referred to as 'Grid Testing' is to obtain a complete database of aerodynamic loading of the store at various locations and orientations surrounding the aircraft, and using these results in a store trajectory prediction algorithm to calculate the predicted trajectory of the store.

Currently, the transonic wind tunnel can only be used to perform aerodynamic grid testings. Future upgrades may see the implementation of the trajectory prediction algorithm into the existing wind tunnel control system.

4.2 Experimental Setup

In the aerodynamic grid tests at AMRL, an aircraft half model is attached to the sidewall of the wind tunnel test section using the sidewall model support system (see Section 2.2.3), and a store model is mounted on the store model support system (see Section 3). An example of this arrangement is shown in Figure 6, with a 6% scale model of an F-111 aircraft mounted on the sidewall model support, and a 6% scale model of an AGM-142 attached to the store model support.

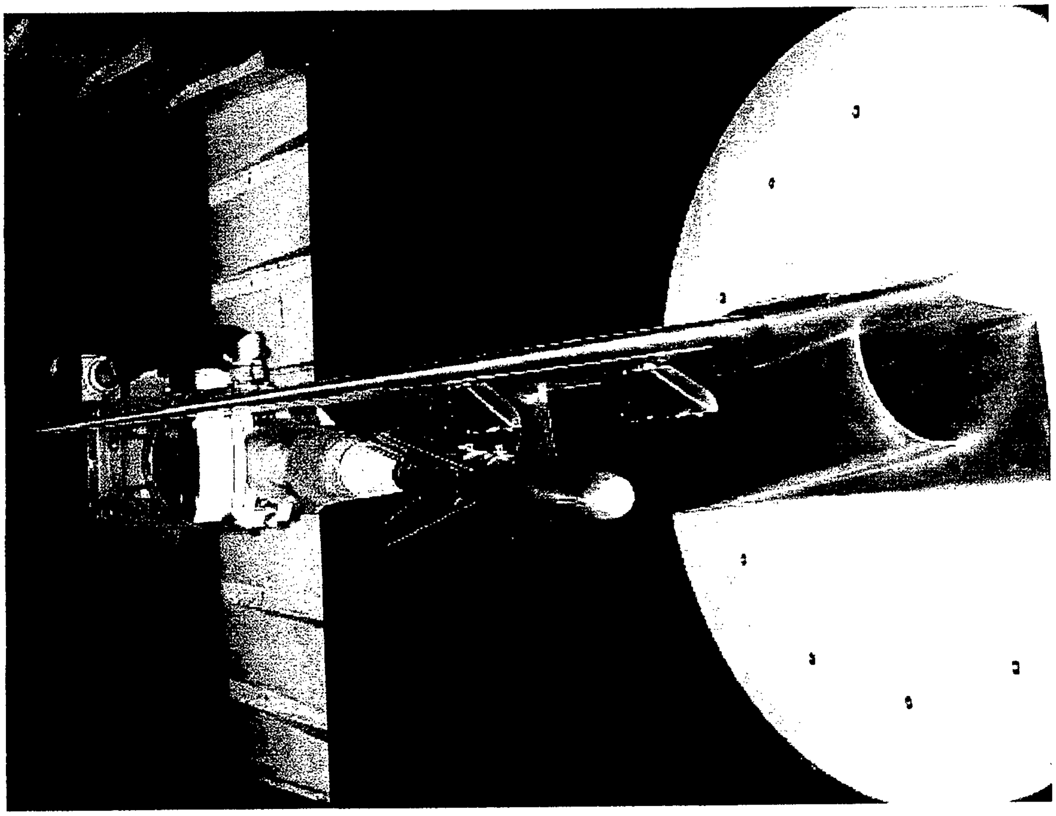


Figure 6: F-111 half model mounted on the sidewall model support with an AGM-142 model attached to the store model support

During a store clearance test, the store model support system moves the store model to specific locations and orientations (see Section 3.2). An electrical touch wire system is available and provides one level of collision avoidance. Currently, this is set up to act between the pylon of the aircraft model and the store on the store support, so that if they come into contact, electrical grounding will occur and the power to the store model support will be disconnected. To continue the test, the store must be manually moved away from the position of contact.

Although the power to the store model support system is removed immediately once a collision is detected, due to the mechanical nature of the actuators used in the store model support system, the actuators will not come to a complete stop at the instant the power is disconnected. These small movements of the actuators after a 'collision' has been detected, can cause a significant amount of damage to the strain gauge balance, the model, and the system hardware. In addition, because there is no electrical touch wire system for the store model support itself, it is possible for a collision to occur between parts of the store support arms and the parent aircraft model.

4.3 Grid Preparation

Grid points used in an aerodynamic grid test must satisfy the following requirements:

1. The grid point must be able to simulate the store separation characteristics from an aircraft; and
2. The grid point must be "collision free". In other words, the grid point can be achieved by the store model support system within the system operational envelope limits and without causing a collision.

In order to obtain a set of grid points that satisfy the above requirements, an iterative grid preparation process is adopted. Due to the complexity in calculating the locations of the store model support system inside the wind tunnel test section at different store locations and orientations, grid points are designed without consideration of the location and orientation of the store model support system. Such a design approach may lead to a grid point which could cause the store model support system to collide with the aircraft model or the tunnel test section wall.

To eliminate any potential collision scenario inside the test section, each grid point must go through a collision checking process. In general, the grid preparation process may require a number of iterations before a final grid set is ready for an aerodynamic grid test in the wind tunnel.

4.4 Grid Design

The store trajectory prediction code used to simulate the separation of the store from the actual aircraft flow field uses a polar grid $[r \quad \theta]^T$ with its origin on the pylon at the store reference attachment position, as shown in Figure 7. The grid points for assessing the release of the store are designed in this polar axis system. However, the store support system operates in the tunnel axis system $[x_{wt} \quad y_{wt} \quad z_{wt}]^T$. This obviously means that an axis transformation process is required to transform all the polar grid points into coordinates in the tunnel axis system.

The transformation of store positions and attitudes from ejector axes to wind tunnel axes is described in detail in Appendix A. Briefly, the axis transformation is accomplished in a 3-step process. First, the polar coordinates are transformed into a cartesian ejector axis system $[x_{ej} \quad y_{ej} \quad z_{ej}]^T$, shown in Figure 8, which has the same origin on the ejector as the polar axes. Second, an axis rotation is performed to align the ejector axis system parallel to the wind tunnel axis system. The rotation of the axis system is achieved by using a rotational matrix, with the order of rotation being roll and then pitch. In the third stage, a translation is made to account for any offset between the origin of the ejector axis system and the wind tunnel axis system.

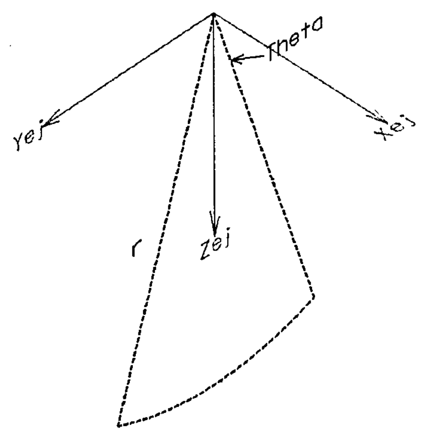


Figure 7: Ejector and polar coordinates system

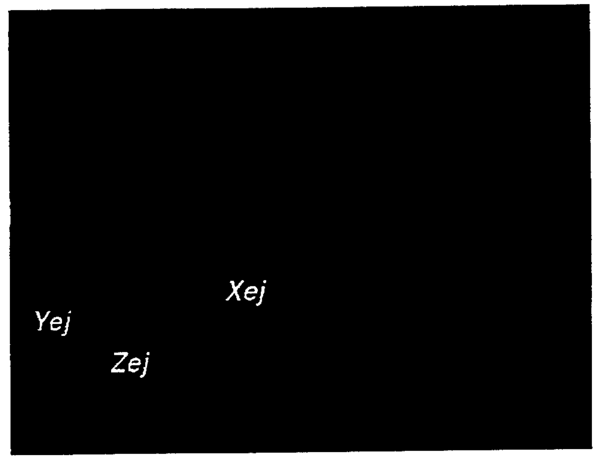


Figure 8: Ejector axis attached to the outboard pylon of an F-111 model

4.5 Grid Checking

As stated in Section 3.1, the store model support has a set of motion limits, as shown in Figure 4, for positioning the store support that should prevent it from colliding with the walls of the tunnel test section. There is also a touch wire system between the ejector and the store that shuts down the store support if a touch should occur. However, there is no mechanism in place to prevent collisions during operation between the store support and the aircraft model, or the store and the test section walls. To ensure safe operation of the store model support system, it is necessary to go through all grid points in the grid sets (angle lists) manually to check that collisions do not occur. This grid checking is an iterative process with the grid design. To avoid the time-consuming, labour-intensive, and costly manual grid checking process, a software package called 'Collision Detection Modelling' (CDM), has been developed. Comprehensive details of this program are given in the following sections of this report.

5. Collision Detection Modelling Design

The dual model support arrangement, where the store and parent aircraft are mounted on separate model supports can lead to inadvertent collisions. Although there may be a collision detection 'touch wire' system between the store and the pylon, it may not prevent the strain gauge balance, models and system hardware from being damaged if a 'touch' or 'collision' should occur. In addition, there is no mechanism in place to prevent collisions between the store support, the store and the aircraft model, or the store model and the test section walls. To eliminate the possibility of a collision during a grid test, a collision detection software system, called CDM (Collision Detection Modelling), has been developed. This system models the store and aircraft models and their mounting systems, and the wind tunnel test section. It provides an accurate and automated virtual collision detection environment that allows all grids to be checked very quickly for collisions before testing. It can also lead to more complete grids by avoiding the removal of points that might have been considered too difficult or too dangerous to obtain. Similar software, called GridGAP, has been reported in Reference 2 for stores testing in the AEDC tunnels.

5.1 Software Requirements and Execution

5.1.1 Software and Display Requirements

CDM is written in the Java programming language using the Java™ 1.2.2 API (Application Programming Interface) and Java 3D™ 1.2 Alpha1 API. CDM software is platform independent, and it can be operated on various operating systems, such as the Microsoft Window NT, UNIX and Linux operating system with the presence of the corresponding Java and Java 3D runtime systems. The CDM's executable is in the form of operating system architecture-neutral object file format, hence, CDM requires a Java complier to execute the program. To maximise the software performance, it is recommended that the Java HotSpot™ Performance Engine be used to interpret the Java bytecodes to native machine instructions. The Java 3D runtime system, and the Java HotSpot Performance Engine are freely distributed by Sun at java.sun.com.

To provide smooth rendering of the virtual world modelled by CDM, it is recommended that a graphics card, which supports OpenGL and has a minimum of 16 MB of video memory, is installed.

5.1.2 Software Execution

To execute CDM, the system must have the corresponding Java and Java 3D runtime systems installed. There are a number of ways to start the program.

1 Creation of a shortcut key (NT operating system);
2 Initiate the program through a Java interpreter (any operating systems).
    2.1 *java CDM* (execute CDM with debugging statements);
    2.2 *javaw CDM* (execute CDM without debugging statements).

Once CDM is installed onto a system, it has the directory structure as shown in Figure 9 (see Section 5.1.3 for a detailed description of the functions of each subdirectory).

Before executing CDM, the user must ensure that the system *classpath* variable points to the */bin* directory of the Java runtime system. A typical *classpath* setting is shown below:
classpath=.;C:\program files\javasoft\jre\1.2.2\bin;

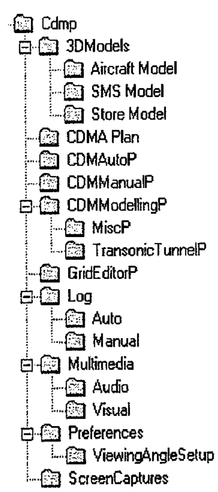


Figure 9: CDM's directory structure

Once CDM is successfully executed, a start up screen will appear on the monitor as shown in Figure 10. The start up screen provides four different options. The first two options, ***CDM-Auto*** and ***CDM-Manual,*** will launch CDM into the auto and manual mode respectively.

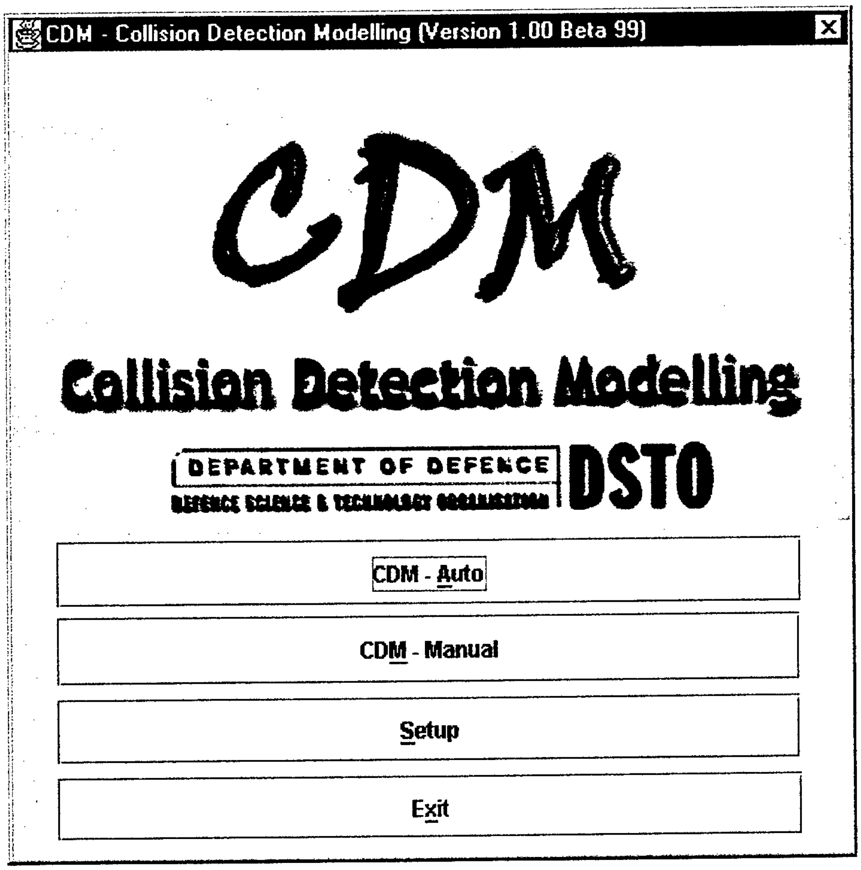


Figure 10: Start up screen of CDM

5.1.3 Software Directory Structure

CDM stores and retrieves various information to, and from, specified directories, hence, a specific directory structure must be present in order for the software to function properly. The CDM software package is stored in a *Zip* file format with subdirectory structure information embedded within the *Zip* archive file. Simply unzipping the *Zip* file will normally install the software with its directory structure to the system.

A description of each of the subdirectories for the CDM installation is given in Table 2, and a pictorial representation of the CDM directory structure is given in Figure 9.

Table 2: Description of each subdirectory for CDM installation

./3DModels/	Contains the VRML models used by CDM to model the Transonic Wind Tunnel's test section and models used in an aerodynamic grid test.
./3DModels/Aircraft Model/	Contains aircraft VRML models
./3DModels/SMS Model/	Contains the store model support arm VRML models
./3DModels/Store Model/	Contains stores' VRML models
./CDMA Plan/	Contains the test plan files (.txt) and CAP files (.cap)
./CDMAutoP/	Contains the bytecodes of the CDM-A and the Grid Editor
./CDMManualP/	Contains the bytecodes of the CDM-M, Log Manager, Screen Capturer and View Controller software
./CDMModellingP/	Contains scene graph information for the virtual world generated by CDM, it also contains the collision detection algorithm.
./CDMModelling/MiscP/	Contains bytecodes for a 3D axis system indicator.
./CDMModelling/Transonic TunnelP	Contains the bytecodes of the geometric information of the test section and model support section of the transonic wind tunnel.
./Log/	Contains log files (.log) generated by the Log Manager
./Log/Auto/	Contains log files (.log) generated by the CDM-A's Log Manager.
./Log/Manual/	Contains log files (.log) generated by the CDM-M's Log Manager.
./Multimedia/	Contains multimedia files used by CDM.
./Multimedia/Audio/	Contains audio files used by CDM. *(not used by Version 1.00)*
./Multimedia/Visual/	Contains graphic files used by CDM.
./Preferences/	Contains CDM configuration information and settings.
./Preferences/ViewingAngleSetup	Contains viewing angle setup file (.pva) generated by the View Controller.
./ScreenCaptures/	Contains graphic files (.jpg) generated by the Screen Capturer.

5.2 Software Design and Architecture

CDM uses an object oriented programming (OOP) design approach, which allows CDM to have a high degree of flexibility for future upgrades and modifications. For example, if there is an upgrade to the store model support system, the only component in CDM that requires modification is the store model support system software object. CDM can also be easily upgraded to model the AMRL low speed wind tunnel (or any other tunnel) by just introducing a new software object of the low speed wind tunnel's test section. This flexibility extends the usefulness of CDM.

The design of CDM has a strong focus on a high level of 'user friendliness'. To achieve this high level of user friendliness, CDM has a series of GUI (Graphical User Interfaces) that allow the user to operate the program effectively with minimum training. To provide an accurate representation of the store model support system, CDM models and visualises the operation of the store model support system inside the tunnel test section, and it also has the ability to simulate and visualise an aerodynamic grid test in a virtual environment. To assist the user throughout the program with the various functions on the GUI interface, an extensive set of 'tool tips' have been implemented, which contain information or descriptions of the function of its GUI interface components. An example of a tool tip is shown in Figure 11. A tool tip will appear by pointing the mouse to the GUI component and leaving it there for a few seconds.

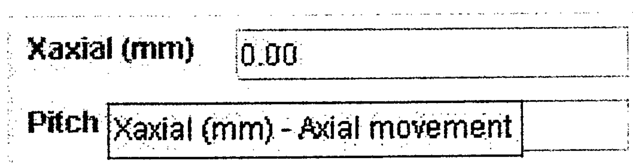


Figure 11: Tool tip information for the Xaxial (mm) cell

5.2.1 Scene Graph Design

To generate a 3D virtual environment of the transonic wind tunnel test section, CDM has adopted a scene graph-based programming model supported by the Java 3D API. This method provides a simple and flexible mechanism for representing and rendering scenes. The scene graph contains a complete description of the entire virtual universe. This includes the geometric data, the attitude information, collision detection arrangement, and the viewing information needed to render the scene from a particular point of view. Figure 12 shows a scene graph representation of the axial drive of the store model support arm.

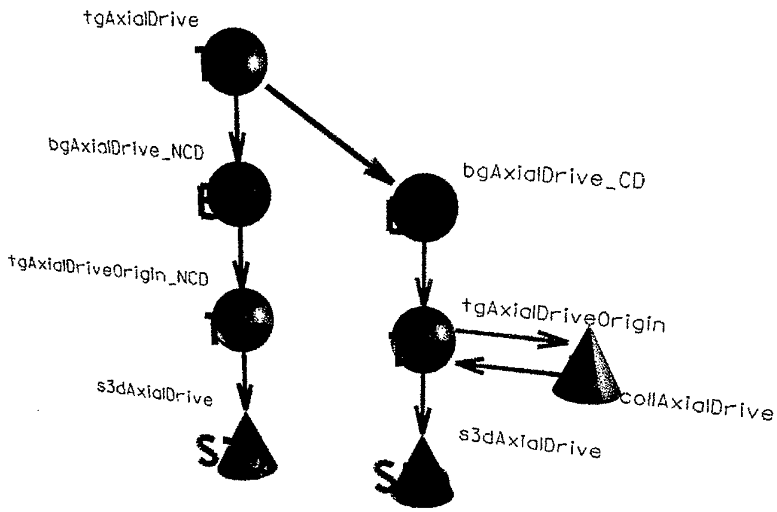


Figure 12: Store model support arm's axial drive scene graph representation

The TG (Transform Group) nodes in Figure 12 are responsible for the transformation and orientation of the axial drive model in the virtual world. The actual geometric information of the axial drive model is stored in the S3D (Shape 3D) nodes. To provide collision detection capability to the axial drive, a B (Behaviour) node is attached to the scene graph, and the collision detection algorithm is implemented inside the B node. Two separate BG (Branch Group) nodes are used for the axial drive model. One branch group only provides rendering services and the other branch group (the one with a B node attached) provides both rendering and collision detection services. This type of arrangement enables CDM to have both visualisation and collision detection modelling capabilities.

A similar scene graph structure is provided for other parts of the store model support system, for example the pitch arm, and the yaw arms. The scene graph structure is changed dynamically during runtime to simulate the motion of the store model support system during an aerodynamic grid test.

6. Collision Detection Modelling (CDM) Operations

CDM is a combination of visualisation, modelling, and collision detection mechanisms. The primary goal of CDM is to provide an active collision detection process for the aerodynamic grid tests carried out in the ARML transonic wind tunnel. The visualisation and modelling capability of CDM also make it suitable as a tool for the design and verification of grid points.

CDM consists of three primary levels of operation:

1. CDM-A, which provides automatic collision detection modelling and visualisation of the aircraft model, the store model, store support, and the test section, for an aerodynamic grid test.
2. CDM-M, which provides manual collision detection modelling and visualisation for a specific grid point in an aerodynamic grid test.
3. Grid Editor, which interprets and allows the user to modify the grid coordinate sets (angle lists) in the test plan file generated by the ASE2000[1] Test Plan Setup software (Reference 3) and to convert the output to a CAP (CDM-A Plan) file format understandable by CDM-A.

To launch CDM-A or CDM-M, simply click on the corresponding buttons in the start-up screen (see Figure 10 and Section 5.1.2).

6.1 CDM Modelling Capability and Limitation

CDM provides accurate modelling of the following key items inside the test section of the transonic wind tunnel, as illustrated in Figure 13:
- transonic wind tunnel test section's walls;
- transonic wind tunnel model support section walls (downstream of test section);
- store model support arm;
- store model;
- aircraft half model;
- main model support vertical strut.

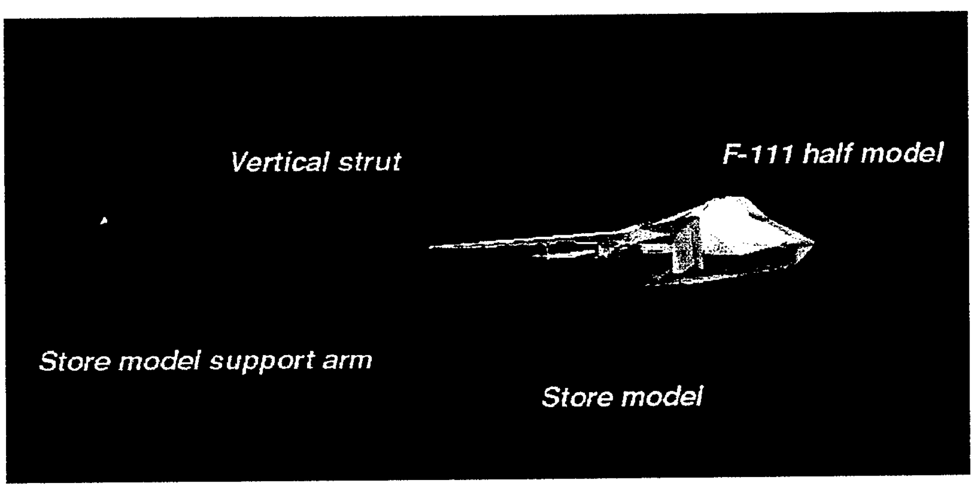


Figure 13: Items modelled by CDM

1 ASE2000 is the name of the proprietary control and data acquisition system for the Transonic Wind Tunnel.

To reduce the complexity of the scene graph and minimise the amount of computing power required for rendering and collision detection modelling, some features inside the actual test section, which are not part of the aerodynamic grid test environment, are not modelled by CDM, they are:
- the sidewall model support turntable; and
- the slots in the walls of the test section.

One of the limitations of CDM in its current state, is that it is unable to model the deflection of the store or the aircraft model caused by the aerodynamic loads, which may be significant at high Mach number. However, in most cases the lift force generated by the wing of the aircraft model, which causes an upward deflection of the wing structure, will lead to a reduction in any 'grid point collisions' that might have occurred otherwise. In addition, CDM does not model the deflection of the store support. This is because the store model support was built to be very rigid to provide accurate store positioning by minimising deflections. Therefore, it is expected that CDM will detect all of the collisions in any test grid.

6.2 CDM-A (Collision Detection Modelling - Automatic Mode)

Collision Detection Modelling - Automatic Mode (CDM-A) provides full modelling and collision detection capability for an aerodynamic grid test. It can go through multiple test plans automatically in a single analysis to check each grid point for a collision. Figure 14 shows the CDM-A interface, which consists of a menu bar, a visualisation and modelling window, and information regarding the CDM-A analysis.

The following information are displayed on the CDM-A window:

- The name of the CAP file which is selected for the CDM-A analysis.
- The starting time and the duration of the CDM-A analysis.
- Information about the current grid point.

Figure 14: CDM-A

6.2.1 Initiation of CDM-A Analysis

The following sections describe how to initiate a CDM-A type analysis.

6.2.1.1 CAP File Selection

To initiate a CDM-A analysis, a CAP file, which contains the grid point information (such as the coordinates and home position) for an aerodynamic grid test, must be selected. To load a CAP file, select the **Load CAP File(s)** command under the **Test Setup** menu, as shown in Figure 14. CDM-A can analyse multiple CAP files at the same time. To select multiple CAP files, hold down the *SHIFT* key and click on the CAP files as shown in Figure 15. A sample CAP file is included in Appendix B.

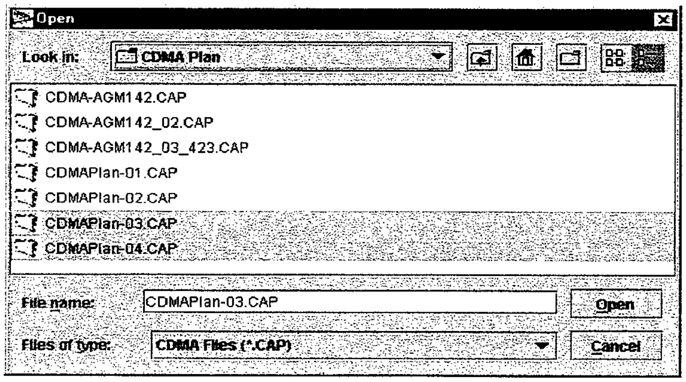


Figure 15: Multiple CAP file selection in the CAP file selection dialog box

6.2.1.2 Test Configuration

The CDM-Configuration interface allows the user to change the type of aircraft and the type of store model, and to fine tune the collision detection options for both the CDM-A and CDM-M analysis. The interface contains three separate panels:

- Aircraft Model;
- Store Model; and
- Collision Detection.

6.2.1.2.1 Aircraft Model Panel

The aircraft model panel allows the user to model different types of aircraft in the CDM analysis. The aircraft model file contains the name of the model, the model datum coordinates - as illustrated in Figure 16, the model location inside the test section, and the geometric information of the model. This information is displayed on the aircraft model panel, as shown in Figure 18.

One click on the button at the aircraft model panel will open a file selection dialog box and allow the user to select the aircraft needed from a list of 3D aircraft models currently available to the system. New aircraft models can be added to the system by placing the aircraft model files inside the */3DModels/Aircraft Model/* directory. These models are usually constructed separately in a 3D CAD form and imported into CDM. To perform a CDM analysis using the current model selected, click on the **Set Aircraft Model** button. The selected model can also be set as the default aircraft model for future CDM-A analyses by clicking on the **Set as Default Configuration** button, shown in Figure 18.

6.2.1.2.2 Store Model Panel

The store model panel allows users to change the store model in a CDM analysis. The store model file contains the name of the model, the model datum coordinates, as shown in Figure 17, the length of the store model, the value of L_{PRS} and model geometric information, as shown in Figure 19.

Clicking on the button at the store model panel will allow users to select from a list of store models available. New store models can be introduced to the system by placing the store model files inside the */3DModels/Store Model/* directory. To set the current selected model for a CDM analysis, click on the **Set Store Model** button. The current selected store model can also be set as the default model for future CDM analyses by clicking on the **Set as default configuration** button, as shown in Figure 19.

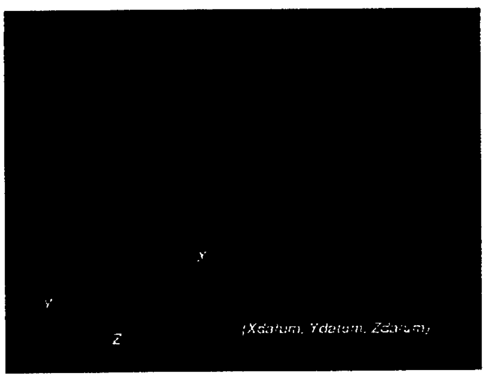


Figure 16: The F-111 3D model's datum

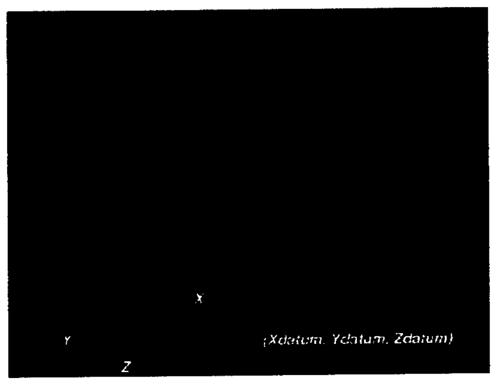


Figure 17: The AGM142 3D model's datum

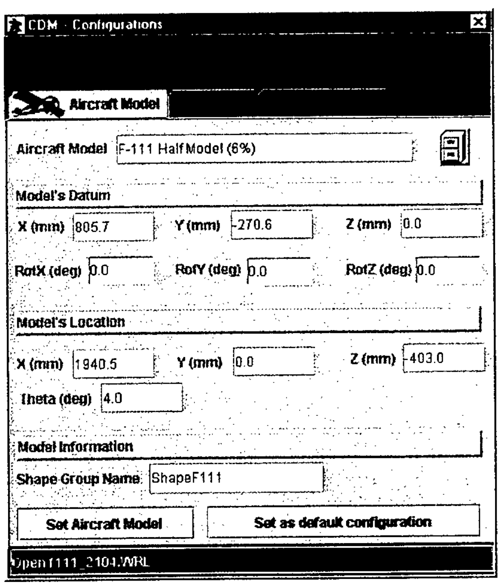


Figure 18: Aircraft model panel

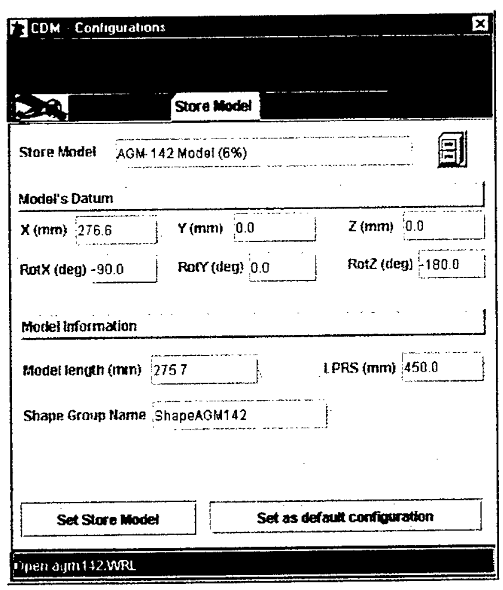


Figure 19: Store model panel

6.2.1.2.3 Collision Detection Panel

To provide maximum flexibility for collision detection, the collision detection panel shown in Figure 20, allows the user to adjust the collision detection settings between the aircraft model, the store model, and individual parts of the store model support arm, which includes the roll drive, pitch drive, yaw drive and the axial drive. CDM Version 1.00 allows five possible collision detection settings, which provide the range of combinations of models and equipment for a collision detection analysis, as shown in Table 3 and Figure 20.

Table 3: Collision detection setting options.

Setting	Aircraft Model	Store Model	Roll Drive	Pitch Drive	Yaw Drive	Axial Drive
[redacted]	✗	✗	✗	✗	✗	✗
[redacted]	✓	✓	✓	✗	✗	✗
[redacted]	✓	✓	✓	✓	✗	✗
[redacted]	✓	✓	✓	✓	✓	✗
[redacted]	✓	✓	✓	✓	✓	✓

✗ : Collision detection is turned off.
✓: Collision detection is turned on

CDM Version 1.00 also provides two different collision detection methods:

1. Collision detection using bounding boxes (**Less accurate / Fast**).
2. Collision detection using actual geometry of the models (**Accurate / Time consuming**).

The first method allocates a bounding box surrounding each 3D model, and collision detection is based on the intersection between each individual bounding box. This collision detection method is quick but it only gives an estimate of when a collision might occur.

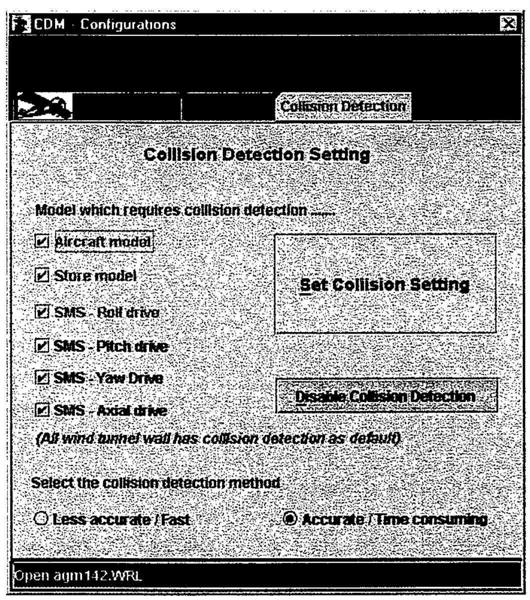


Figure 20: Collision detection panel

The second method, which uses the actual geometry of a 3D model and which checks for any intersections between points on models and the other components selected (see Table 3) is very accurate in detecting a collision, but it is more time consuming in its execution. The time required for accurate collision detection depends on the complexity of the models. For example, if a model has a large number of faces or vertices, the time required for detecting each collision iteration will increase compared with a simpler model. It is highly recommended that vertex optimisation be performed on the 3D model to minimise the number of vertices. Figure 21 to Figure 24 show a half model of an F-111 before and after a vertex optimisation process. The degree of optimisation should be carefully controlled to avoid any significant misrepresentation or modification to the 3D model, which could lead to it becoming inaccurate.

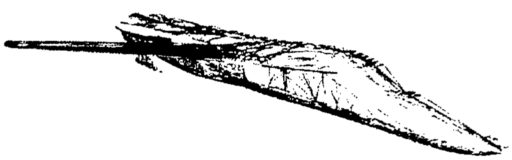


Figure 21: F-111 model with 6389 faces (Wire frame rendering)

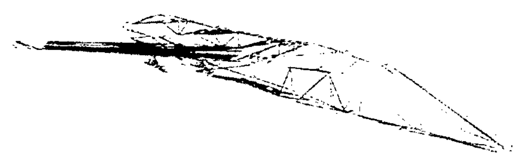


Figure 22: F-111 model with 1069 faces (Wire frame rendering)

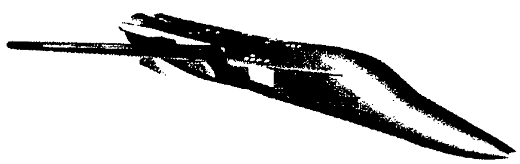


Figure 23: F-111 model with 6389 faces (Phong antialias rendering)

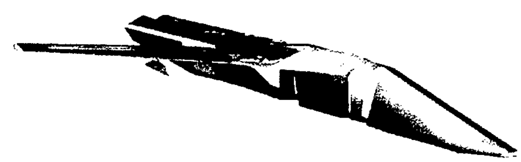


Figure 24: F-111 model with 1069 faces (Phong antialias rendering)

6.2.2 Execute a CDM-A Analysis

Once the CAP file(s) have been selected and the test configuration has been finalised, a CDM-A analysis can be started by selecting the **Run Test** command under the **Test Setup** menu, as shown in Figure 14. During a CDM-A analysis, information on the current grid point being tested will be displayed on the CDM-A interface. The progress of the analysis can be found on the status bar located at the bottom of the interface, as shown in Figure 14.

6.2.3 Visualisation of Grid Points

CDM-A provides a grid point visualisation function, which allows the user to visualise the location of grid points inside the test section with the aircraft model present. This function provides the user with an increased understanding of the grid to be used in the test.

The grid point visualisation function (located under the **View** menu) is only available after a CAP file has been selected. The user can change the colour of the grid points through a colour selection dialog box. Figure 25 shows the visualisation of a set of grid points used in an aerodynamic grid test that simulates the release of a store from the outboard pylon of an F-111 aircraft model.

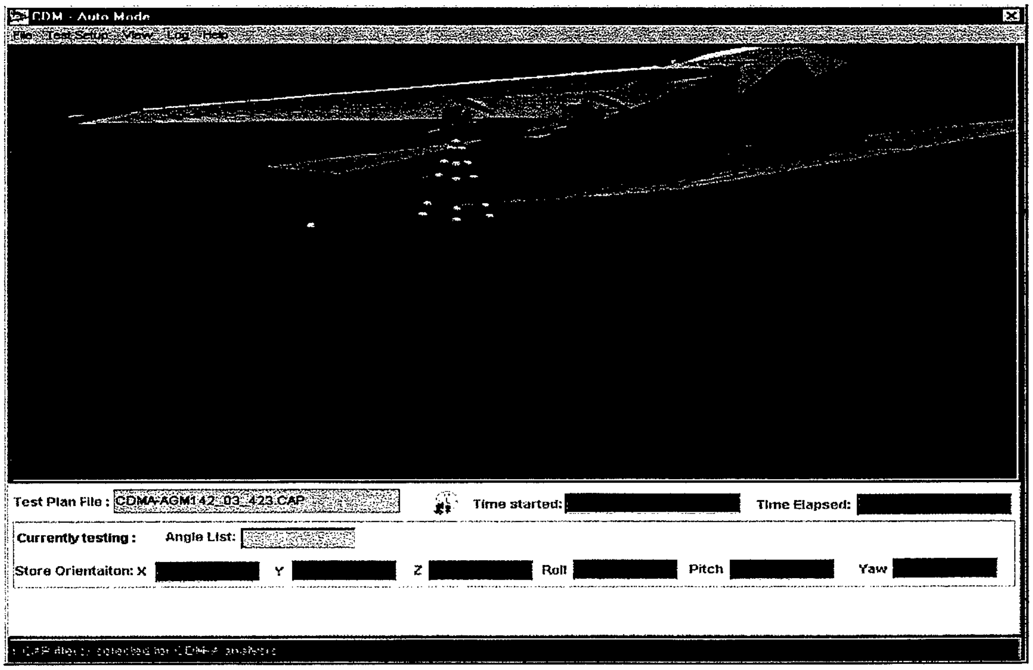


Figure 25: Visualisation of grid points of an aerodynamic grid test

6.2.4 Screen Capture and Movie Generation

CDM-A also has a screen capture function, which graphically captures the location of the store model support arm and the store orientation at each of the grid points in a CAP file. The screen capture function is located under the **Test Setup** menu. All captured image files are stored in JPEG (*jpg*) file format and located in the */ScreenCaptures* directory. Image files generated by the screen capturer have the file name, *CDM_ScreenCapture_xxx.jpg*. The *xxx* is a three digit number to identify the sequence of the files, hence the first file has *xxx* equal to 000 and the second file has *xxx* equal to 001 and so on.

A digital movie can be easily created with the sequence of image files generated by the screen capturer. This can be done with a number of software packages that are readily available, which convert a series of JPEG files into an AVI movie format.

6.2.5 View Controller

The viewing 'angle' of the virtual test section of both CDM-A and CDM-M can be changed easily by the View Controller, which is illustrated in Figure 26. The View Controller provides three different viewing 'angle' arrangements:

1. System preset viewing angles (top, bottom, upstream and downstream view of the test section and its contents).
2. Manual control viewing angle (**Virtual View**).
3. User defined preset viewing angles.

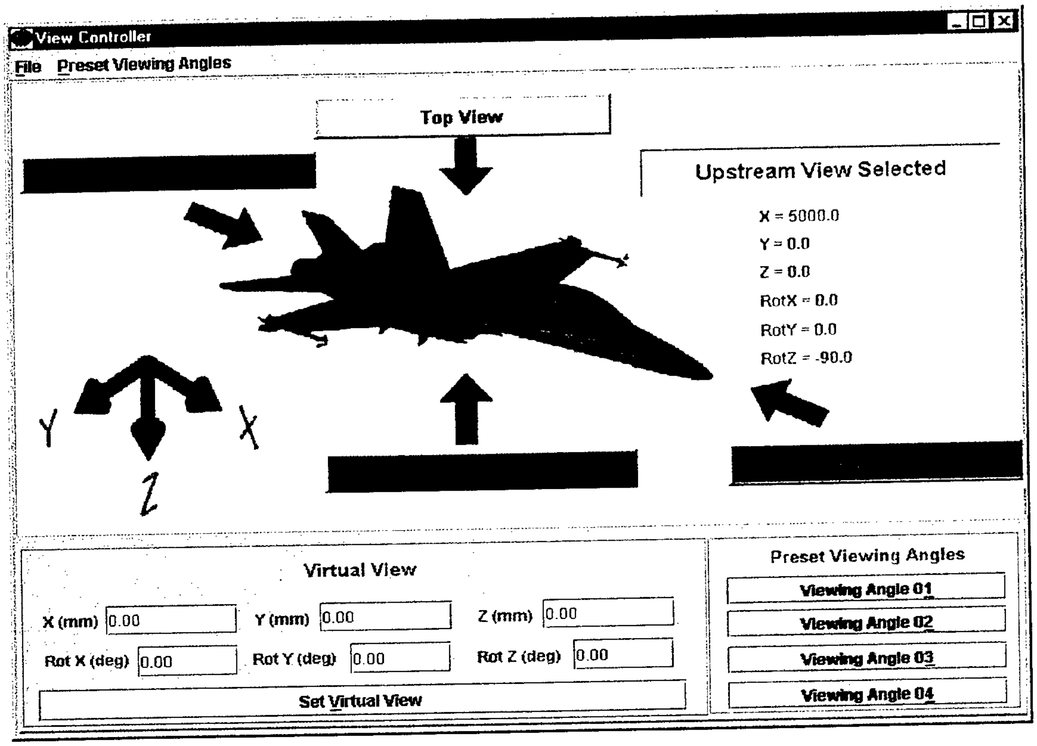


Figure 26: View Controller

6.2.5.1 System Preset Viewing Angles

To select a system preset viewing angle, simply click on the corresponding viewing angle button **Top View, Bottom View, Upstream View,** and **Downstream View**. The viewing angle in the test section will change once the button is released.

6.2.5.2 Manual Control Viewing Angle

To enable viewing from an angle apart from those defined by CDM (both automatic and manual modes), the **Virtual View** function allows the user to manually enter the location of the virtual camera inside the test section. The virtual camera always points towards the centre of the test section, so that varying the camera location will change the viewing angle. The location of the virtual camera is defined by the x_{wt}, y_{wt}, z_{wt} (tunnel axes) and the angle of rotation about those three axes, as shown in Figure 26.

6.2.5.3 *User Defined Preset Viewing Angles*

To avoid manually entering the viewing 'angle' (location) each time, the View Controller allows the user to store up to four preset viewing locations, and hence angles, to a PVA file, which is loaded at the beginning of a CDM (A and M) session. Figure 27 shows the preset viewing angle interface. The user can store an unlimited number of PVA files, each containing a distinct set of four viewing angles. PVA files are stored in the */Preferences/ViewingAngleSetup* directory.

To access a PVA file, click the **Open Viewing Angle** command under the **File** menu.

To save a PVA file, click the **Save Viewing Angle** command under the **File** menu.

To set the current selected PVA file as the default PVA file which will be loaded each time CDM is started, click the **Default PVA List** command under the **File** menu.

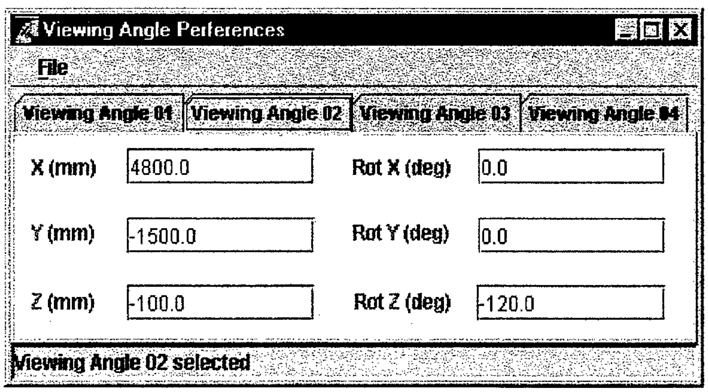


Figure 27: User preset viewing angle preferences

6.2.6 Log Manager

CDM uses the Log Manager, as shown in Figure 28, to record collision detection results for both CDM-A and CDM-M. The Log Manager generates a log file (*.log*) which contains the following information:

- The creation date and time of the log file;
- The CAP file(s) associated with the log file;
- The collision detection setting;
- Grid point information, including the orientation of the store and the store model support arm; and
- Result of the collision detection process. If a collision occurs at the grid point, it will also record the detail of the collision, stating the collision condition between different objects.

(see Appendix C.1 and C.2 for a sample CDM-A and CDM-M log file)

The CDM-A log file also contains the statistics of the collision detection results. Once a CDM-A log file has been saved, a separate log file is generated automatically which contains only the grid points where a collision has been detected. The name of the separate log file will have *_COLLIDE* attached to the end of the original log file name. For example, if the CDM-A log file is named *GridTest_01.log*, then a log file called *GridTest_01_COLLIDE.log* will also be generated automatically.

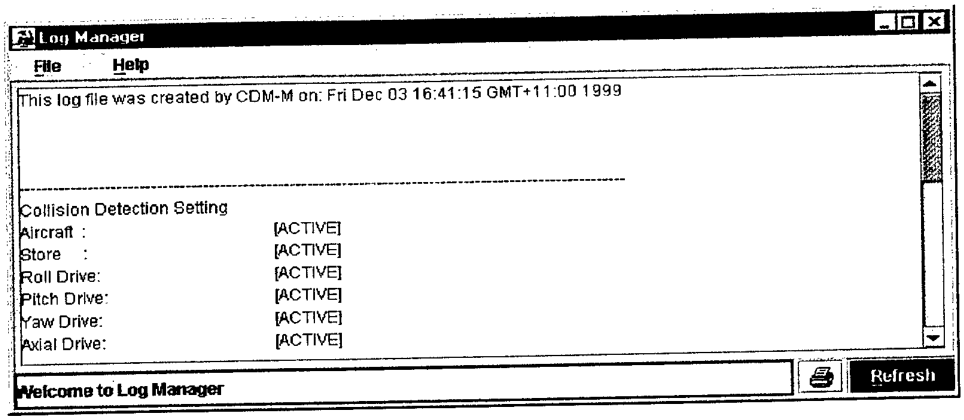


Figure 28: Log Manager

6.3 CDM-M (Collision Detection Modelling - Manual Mode)

CDM-M provides full modelling and collision detection for grid points in an aerodynamic grid test. The primary difference between CDM-M and CDM-A is that CDM-M allows the user to manually input the store model location and orientation instead of using a CAP file. This allows the user to quickly visualise the orientation of the store and the store support arm inside the test section for a particular grid point, and to check that grid point for a collision. CDM-M shares many functions with CDM-A, such as the Log Manager (Section 6.2.6), the View Controller (Section 6.2.5), the Test Configuration menu (Section 6.2.1.2) and the Screen capturer (Section 6.2.4).

To perform a CDM-M analysis, simply enter the store location (x, y, z) and orientation (ψ, θ, ϕ) in tunnel axes on the CDM-M interface, as illustrated in Figure 29. CDM-M will then perform the necessary kinematic calculations to obtain the location and orientation of the store model support arm inside the test section. The collision detection result will be displayed in the **Collision Report** panel. During the collision checking process, the will appear inside the **Collision Report** panel to indicate the system is checking for collisions.

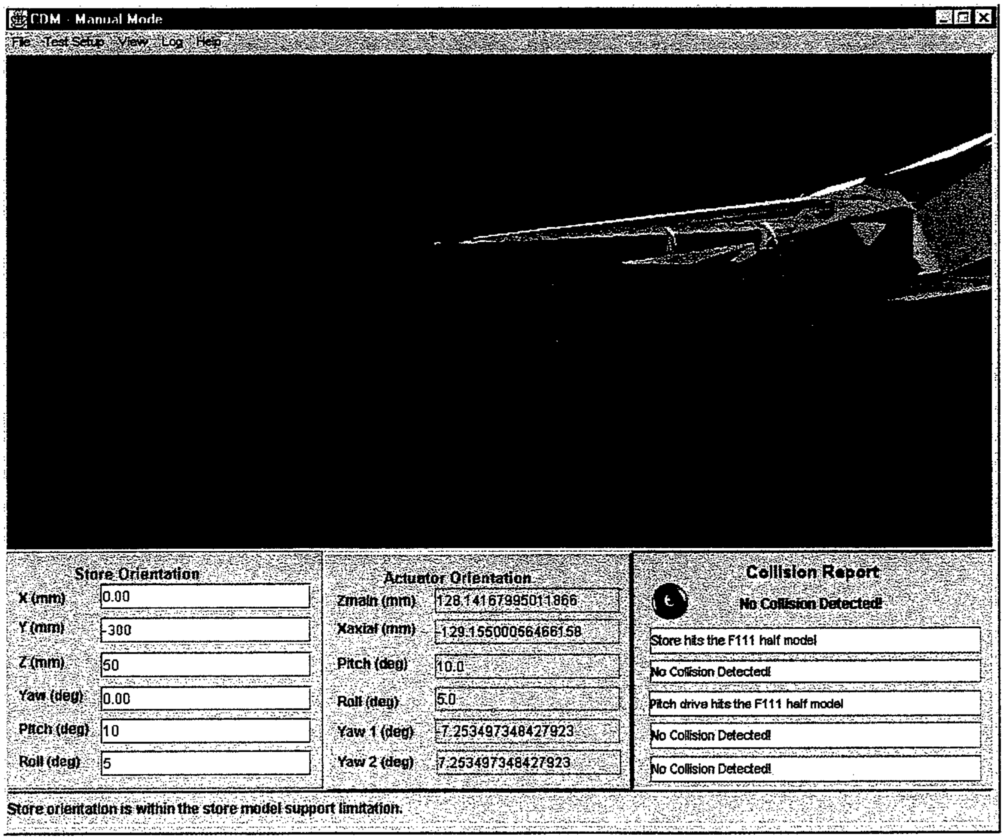


Figure 29: CDM-M interface

6.4 Grid Editor

As indicated previously, a set of grid points, containing the location and orientation of the store model, is required for a CDM-A analysis. The Grid Editor is not applicable to CDM-M analyses. Grid points for an actual aerodynamic grid test are listed as position coordinate sets (sometimes called 'angle lists'), which are stored in a test plan file generated by the ASE2000 Test Plan Setup software. The Grid Editor extracts the grid points from the test plan file and translates them into a *CAP* file format for use by the CDM-A. To launch the Grid Editor, select the **Grid Editor** command under the **Test Setup** menu at the CDM-A interface shown in Figure 14. The Grid Editor interface is shown in Figure 30.

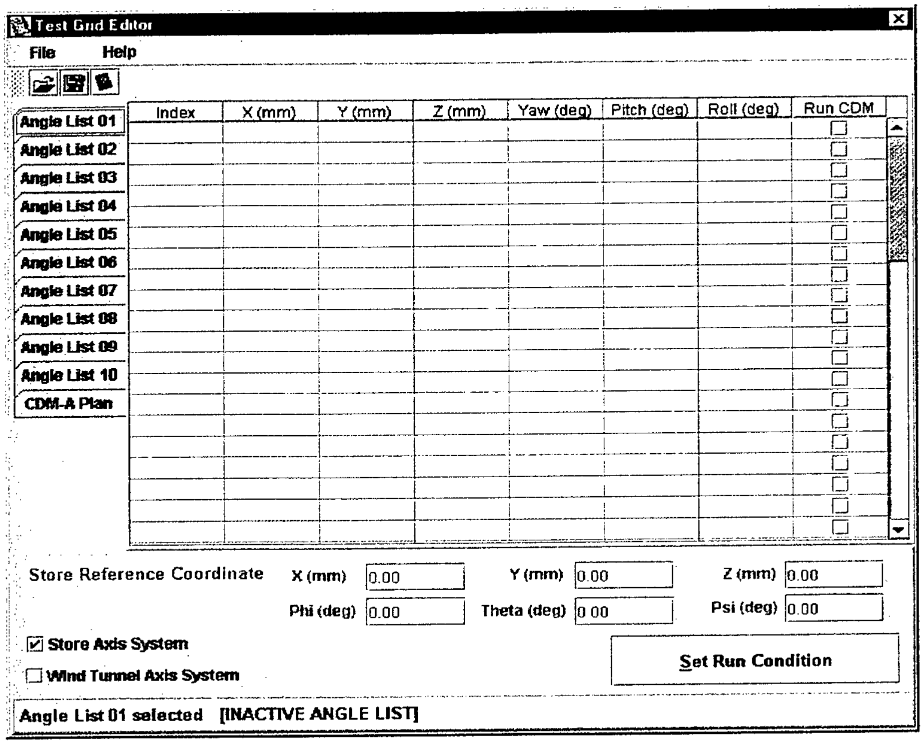


Figure 30: Grid Editor

6.4.1 Information Extracted from a Test Plan File

The test plan file generated by the ASE2000 Test Plan Setup software contains details of the 10 position sets (angle lists) (see Section 3.2) as well as other information, such as the test conditions, model settings and strain gauge balance calibration matrix, which are redundant for a CDM-A analysis. To obtain only the necessary information required for a CDM-A analysis, the Grid Editor extracts the following information from a test plan file:

- The grid points x, y, z, ψ, θ, ϕ, in tunnel axes, and information from all angle lists in relative coordinates.
- The length of the pitch arm (the distance between the pitch pivot centre and the designated store model centre of rotation). (This information is used by the store model support arm's kinematics equations.)

6.4.2 Importing Grid Points Data

There are three possible methods to use the Grid Editor to open a test plan file and extract the grid point data.

1. Click on the **Open Angle Lists** command located within the **File** menu.

2. Click on the **Open Angle Lists** button, , located at the tool bar.
3. If there is no angle list already opened by the Grid Editor, clicking on the **Set Run Condition** button will open a dialog box, shown in Figure 31, which provides the option to open the angle lists. To open the angle lists, simply click on the **Open Angle Lists** button inside the dialog box.

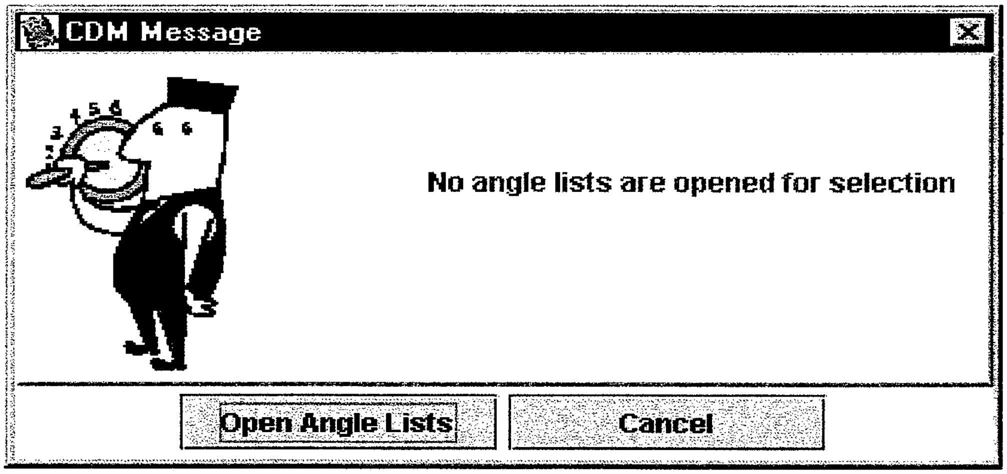
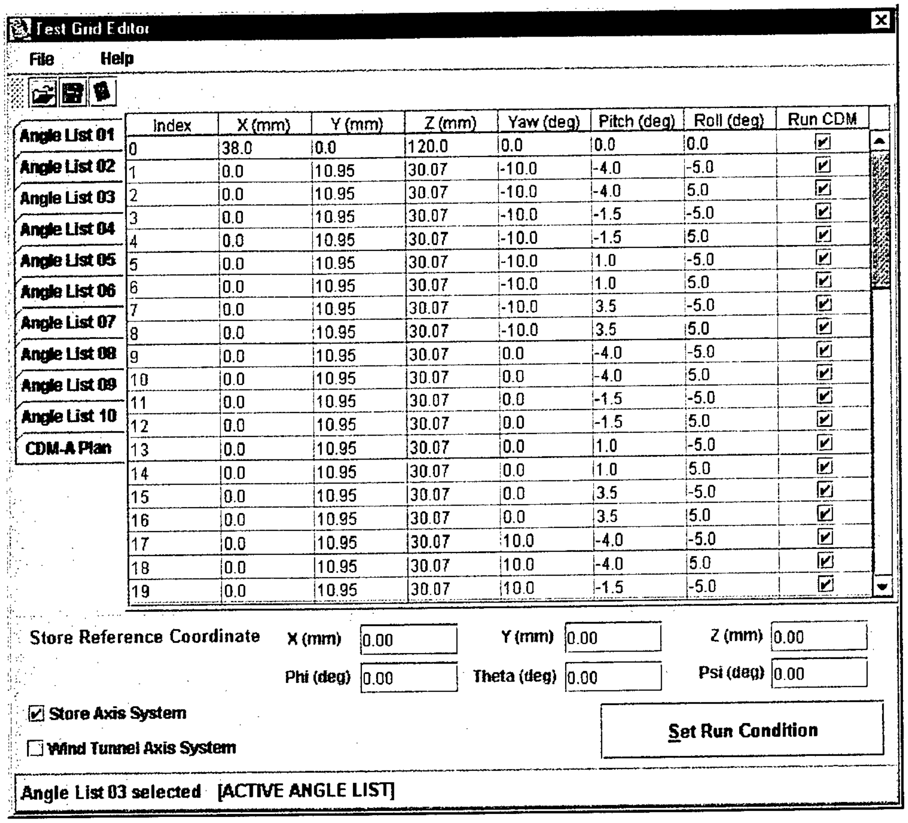


Figure 31: Dialog box, which provides an option to open angle lists

After the **Open Angle List** command has been selected, a file selection dialog box will appear, which allows the user to select a test plan file. All test plan files should be located in the *CDMA Plan* directory.

After a test plan file is selected, all grid point information will appear within the Grid Editor, and the user can access this grid point information for different angle lists by clicking on the tab located at the left hand side of the table, as shown in Figure 32.



Index	X (mm)	Y (mm)	Z (mm)	Yaw (deg)	Pitch (deg)	Roll (deg)	Run CDM
0	38.0	0.0	120.0	0.0	0.0	0.0	☑
1	0.0	10.95	30.07	-10.0	-4.0	-5.0	☑
2	0.0	10.95	30.07	-10.0	-4.0	5.0	☑
3	0.0	10.95	30.07	-10.0	-1.5	-5.0	☑
4	0.0	10.95	30.07	-10.0	-1.5	5.0	☑
5	0.0	10.95	30.07	-10.0	1.0	-5.0	☑
6	0.0	10.95	30.07	-10.0	1.0	5.0	☑
7	0.0	10.95	30.07	-10.0	3.5	-5.0	☑
8	0.0	10.95	30.07	-10.0	3.5	5.0	☑
9	0.0	10.95	30.07	0.0	-4.0	-5.0	☑
10	0.0	10.95	30.07	0.0	-4.0	5.0	☑
11	0.0	10.95	30.07	0.0	-1.5	-5.0	☑
12	0.0	10.95	30.07	0.0	-1.5	5.0	☑
13	0.0	10.95	30.07	0.0	1.0	-5.0	☑
14	0.0	10.95	30.07	0.0	1.0	5.0	☑
15	0.0	10.95	30.07	0.0	3.5	-5.0	☑
16	0.0	10.95	30.07	0.0	3.5	5.0	☑
17	0.0	10.95	30.07	10.0	-4.0	-5.0	☑
18	0.0	10.95	30.07	10.0	-4.0	5.0	☑
19	0.0	10.95	30.07	10.0	-1.5	-5.0	☑

Figure 32: Grid Editor with grid point information

Each angle list (model position list) has a "home position" (see Section 3.2) which is given in absolute wind tunnel coordinates. It is the initial location of the store model for an aerodynamic grid test. In the Grid Editor, the "home position" is displayed as the first row of data in each angle list. The actual grid points for the aerodynamic grid test are located below the "home position", from index 1 to 60. Each angle list contains 60 grid points, so that a test plan file can contain a maximum of 600 grid points and 10 "home positions", as indicated previously in Section 3.2.

Grid points 1 to 60 are represented in relative axes coordinates (see Section 4.4). For a CDM-A analysis, grid points must be represented in wind tunnel axes coordinates. To convert relative coordinates into wind tunnel coordinates, the user must enter into the Grid Editor the store reference coordinates in the wind tunnel axes system (see Figure 32). Selecting the **Wind Tunnel Axis System** check box will change all grid points into wind tunnel coordinates based on the store reference coordinates' information.

6.4.3 Exporting Grid Points to CDM-A

After a test plan file is loaded into the Grid Editor, the grid points data can be saved as a CAP file, which is required for a CDM-A analysis. By default, all grid points in the test plan file are saved as a CAP file. To save the grid points information to a CAP file, simply click on the **Set Run Condition** button and give the CAP file a filename. All CAP files generated by the Grid Editor are stored in the *CDMA Plan* directory.

The user may also omit some grid points by checking 'off' the check box at the **Run CDM** column at the Grid Editor (see Figure 32). This allows a few 'critical' grid points, for example close to the aircraft, to be checked quickly by CDM-A. It has some similarities with a manual grid point step-through mode.

6.4.4 To View a CAP File

There are two ways to view an existing CAP file.

1. Click on the **Open CDM-A Plan** command located within the **File** menu.
2. If there is no CAP file already opened by the Grid Editor, clicking on the **CDM-A Plan** tab will open a dialog box, as shown in Figure 33, which provides the option to open a CAP file. Then, to open a CAP file, simply click on the **Open CAP File** button inside the dialog box.

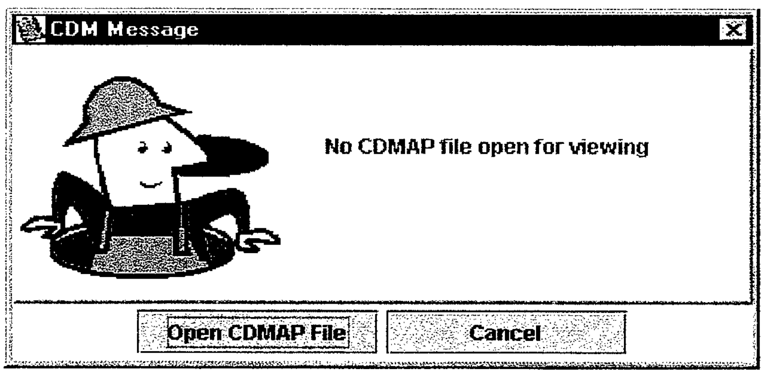


Figure 33: Dialog box, which provides an option to open a CAP file

7. Conclusion

A software package called CDM has been developed for store aerodynamic grid tests in the Transonic Wind Tunnel at AMRL. CDM simulates, models, visualises, and provides a collision detection capability for an aerodynamic grid test. CDM replaces the time consuming and labour intensive physical collision checking process with an accurate and automated simulation procedure. A high level of user friendliness has been implemented into the system, so that it requires minimal training and is easy to use effectively. The object oriented programming architecture also provides a high degree of flexibility, which allows CDM to be easily upgraded to model an aerodynamic grid test in a different test section with different store and aircraft model configurations.

CDM has two operating modes, an automated mode (CDM-A) and a manual mode (CDM-M). CDM-A enables an aerodynamic grid test to be fully simulated and a large set of grid points to be automatically and accurately checked for collisions in a very time effective manner. CDM-A uses the grid information for a test grid that has been generated previously by the wind tunnel Test Plan Setup software (ASE2000). A separate software package called the 'Grid Editor' has been developed which extracts this grid information, such as the store model location and orientation inside the test section, from the test plan file and converts it into a format suitable for CDM-A.

CDM-M provides similar functions as CDM-A, except it requires the user to enter the store model location and orientation manually. CDM-M can be used to visualise and manually check a particular grid for collisions.

In addition to providing collision detection for store grid development, the three dimensional virtual environment also allows CDM to be used as a tool for grid design and visualisation.

8. References

1. Matheson, N., Link, Y. Y. and Lam, S. S. "Construction of the Transonic Wind Tunnel at AMRL in Melbourne", Paper presented at the 90th Supersonic Tunnel Association International meeting, hosted by the Institute for Aerospace Research, Ottawa, Canada, 4 - 6 October, 1998.

2. Lawrence, F. C. "Grid Graphical Analysis Package (GridGAP) For Store Separation Testing at AEDC", Paper presented at the 83rd Supersonic Tunnel Association meeting, hosted by the Naval Surface Warfare Center, Dahlgren Division, White Oak, Silver Springs, Maryland, USA, 2 - 4 April 1995.

3. Celsius, 1999, "Operator's Guide, Transonic Wind Tunnel - AMRL", ASE/704303TP01, Aero Systems Engineering, St Paul, USA.

Appendix A Transformation of Store Positions and Attitudes from Ejector Axes to Wind Tunnel Axes

A.1. Introduction

The Excel spreadsheet titled "Transformation of Store to Tunnel Axes" can be used to construct grids of store positions and attitudes in wind tunnel axes to assist in setting up a test plan in the Transonic Wind Tunnel. It enables a user to generate large grids of store positions and attitudes for a range of ejector orientations and aircraft angles of attack. These grid points can then be transformed to obtain the positions and attitudes of the store relative to wind tunnel axes.

A.2. Generation of Store Grid Positions

Each store grid position is defined by several parameters (refer to Figure A.1 for axes system definitions):

1. Point - number to identify each grid point and its sequence in the wind tunnel test.
2. Store Grid r -defines the location of the store relative to ejector axes as a radial distance from the store release point in the Y_EZ_E-plane.
3. Store Grid θ_r - defines the location of the store relative to ejector axes as an angle away from Z_E in the Y_EZ_E-plane.
4. Store ψ_S - defines the store yaw (psi) relative to ejector axes (rotation about Z_E).
5. Store θ_S - defines the store pitch (theta) relative to ejector axes (rotation about Y_E).
6. Store ϕ_S - defines the store roll (phi) relative to ejector axes (rotation about X_E).
7. Ejector ψ_E - defines the ejector yaw (psi) relative to aircraft axes (rotation about Z_A).
8. Ejector θ_E - defines ejector pitch (theta) relative to aircraft axes (rotation about X_A).
9. Ejector ϕ_E - defines the ejector roll (phi) relative to aircraft axes (rotation about Y_A).
10. Aircraft θ_A - defines the aircraft pitch (theta) relative to wind tunnel axes.

NOTE: For each set of angles the sequence of rotations are defined as (ψ, θ, ϕ) and are defined to be positive using the right hand rule about the appropriate axes (Z, Y, X).

The user can construct a grid of store positions and attitudes in two different ways, by manual entry or automatic generation.

A.2.1 Manual Entry

The user selects the "View Store Grid Positions" button from the main menu and manually enters (or copies and pastes from other Excel files) individual grid points for each ejector orientation and aircraft angle of attack to be tested.

A.2.2 Automatic Generation

The user selects the "Generate Grid Positions Automatically" button from the main menu. For each parameter in the table, the user must enter the values that will comprise the grid points planned for testing. Each parameter is also assigned an "Order of Variance" number ranging from 1 to 9. This determines the order in which the parameters in the grid will be generated. The parameter with the highest number is varied first in the grid sequence. Once this table is complete, the "Generate Grid Positions" button is activated and the store grid will be automatically generated and displayed to the user. The user may then edit or add any individual points to further refine the grid.

A.3. Grid Transformation and Transformation Calculations

Once the store grid is constructed through the means shown in Section A.2, the "Transform to Wind Tunnel Axes" button is activated to begin the transformation process of all points contained in the store grid. Once the transformation is complete, the user is shown the grid of transformed positions and attitudes.

The following sections detail the calculations involved in the grid transformation.

The general transformation matrix to rotate frame F_B to F_V using Euler angles with order of rotations ($-\phi$, $-\theta$, $-\psi$) is:

$$L_{VB} = L_3(-\psi).L_2(-\theta).L_1(-\phi) = L_{BV}^T$$

$$= \begin{bmatrix} \cos\theta\cos\psi & \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi \\ \cos\theta\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi \\ -\sin\theta & \sin\phi\cos\theta & \cos\phi\cos\theta \end{bmatrix} \quad (1)$$

$$= \begin{bmatrix} \text{Element } 1.1 & \text{Element } 1.2 & \text{Element } 1.3 \\ \text{Element } 1.4 & \text{Element } 1.5 & \text{Element } 1.6 \\ \text{Element } 1.7 & \text{Element } 1.8 & \text{Element } 1.9 \end{bmatrix}$$

Reference: Etkin, B., Dynamics of Atmospheric Flight, 1972.
(Note that in this reference the transformation is performed in the opposite direction using the opposite order of rotations.)

To transform from store axes to wind tunnel axes, three transformations of this form are required:
L_{ES} = Transformation from store axes to ejector axes - order of rotations (ϕ_S, θ_S, ψ_S)
L_{AE} = Transformation from ejector axes to aircraft axes - order of rotations (ϕ_E, θ_E, ψ_E)
L_{TA} = Transformation from aircraft axes to tunnel axes - order of rotations (ϕ_A, θ_A, ψ_A)

The above three transformation matrices can be determined by substituting the appropriate angles into equation (1).

The final transformation matrices used to determine the store's position and attitude in wind tunnel axes are:

L_{TE} = Transformation from ejector axes to tunnel axes = $L_{TA} * L_{AE}$ (2)

L_{TS} = Transformation from store axes to tunnel axes = $L_{TA} * L_{AE} * L_{ES} = L_{TE} * L_{ES}$ (3)

A.3.1 Store Position Transformation

To transform a store grid position (r, θ_r) located in the yz-plane of the ejector axes system to wind tunnel axes (x, y, z) equations (2) and (4) are used. As the grid is constructed in terms of (r, θ_r) from the store release point on the carriage, the final transformed store position in wind tunnel axes (x, y, z) is referenced to the store release location.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = L_{TE} \begin{pmatrix} 0 \\ r\sin\theta_r \\ r\cos\theta_r \end{pmatrix} \tag{4}$$

A.3.2 Store Attitude Transformation

To transform a store's attitude into wind tunnel axes equation (3) is used. The L_{TS} transformation matrix can be regarded as having the form of equation (1). Therefore, the actual orientation of the store in wind tunnel axes (ψ, θ, ϕ) can be calculated using specific elements of this matrix.

1. θ can be calculated from element 1.7 to give a value ranging between $-\pi/2$ and $\pi/2$.
2. ϕ can be calculated from element 1.9 to give a value ranging between $-\pi/2$ and $\pi/2$.
3. ψ can be calculated from element 1.1 to give a value ranging between $-\pi/2$ and $\pi/2$.

These solutions are only valid if the rotations are kept reasonably small so that the final angles are within the $\pm\pi/2$ range.

A.4. Concluding Remarks

When the transformation procedure is complete the Excel worksheets, "Grid" and "Output", should be copied and renamed to allow the user to construct and transform further grids.

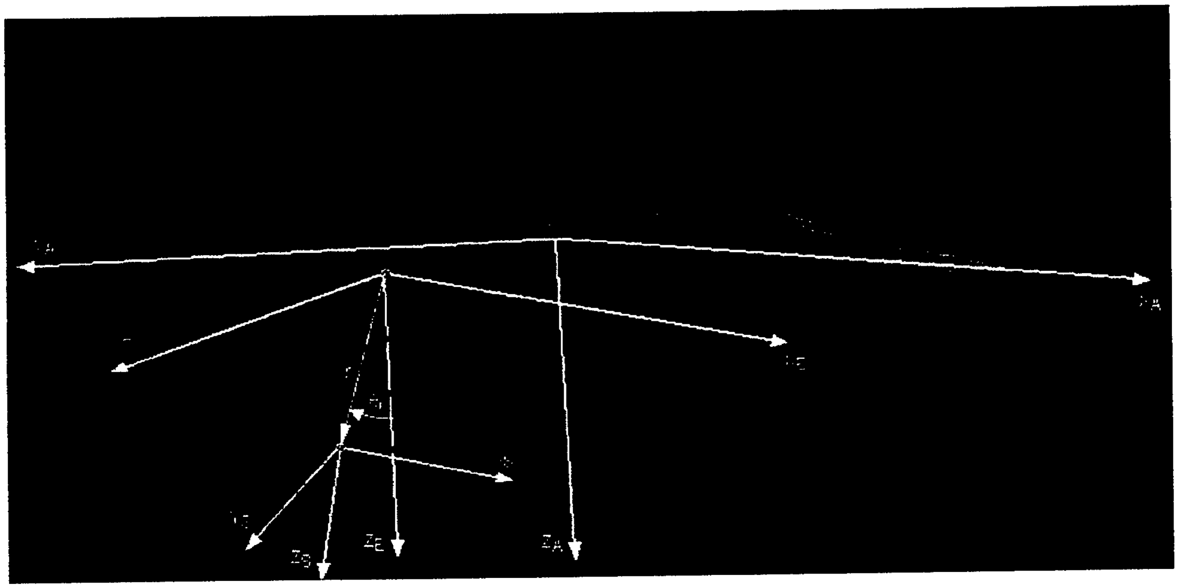


Figure A.1 Store, Ejector and Aircraft Axes Definition

Appendix B CAP File Sample

```
425 38.0 -128.0 18.5 0.0 0.0 0.0
# ------------------------------------------------------------------------------------
# CAP file: C:\JBuilder3\myprojects\TWTSMS\CDMP\CDMA Plan\CDMA-AGM142_03_423.CAP
# This CAP file was generated by GridEditor on Wed Nov 10 18:39:53 GMT+11:00 1999
#
# Reference test plan file: C:\JBuilder3\myprojects\TWTSMS\CDMP\CDMA Plan\TPLAN142_1199.TXT
#
# Total number of grid points in the CAP file for CDM-A analysis: 424
#
# Store reference position (WT axis system): X     = 38.0mm
#                                            Y     = -128.0mm
#                                            Z     = 18.5mm
#                                            Psi   = 0.0deg
#                                            Theta = 0.0deg
#                                            Phi   = 0.0deg
#
# !! All coordinate are in absolute wind tunnel axis system !!
# ------------------------------------------------------------------------------------------------------------
# AL    x(mm)     y(mm)      z(mm)     Psi(deg)   Theta(deg)   Phi(deg)
# ------------------------------------------------------------------------------------------------------------
1.0     38.0      0.0        120.0     0.0        0.0          0.0
1.0     38.0      -128.0     26.5      -10.0      -1.5         -5.0
1.0     38.0      -128.0     26.5      -10.0      -1.5         5.0
1.0     38.0      -128.0     26.5      -10.0      1.0          -5.0
1.0     38.0      -128.0     26.5      -10.0      1.0          5.0
1.0     38.0      -128.0     26.5      -10.0      3.5          -5.0
1.0     38.0      -128.0     26.5      -10.0      3.5          5.0
1.0     38.0      -128.0     26.5      0.0        -1.5         -5.0
1.0     38.0      -128.0     26.5      0.0        -1.5         5.0
1.0     38.0      -128.0     26.5      0.0        1.0          -5.0
1.0     38.0      -128.0     26.5      0.0        1.0          5.0
1.0     38.0      -128.0     26.5      0.0        3.5          -5.0
1.0     38.0      -128.0     26.5      0.0        3.5          5.0
1.0     38.0      -128.0     26.5      10.0       -1.5         -5.0
1.0     38.0      -128.0     26.5      10.0       -1.5         5.0
1.0     38.0      -128.0     26.5      10.0       1.0          -5.0
1.0     38.0      -128.0     26.5      10.0       1.0          5.0
1.0     38.0      -128.0     26.5      10.0       3.5          -5.0
1.0     38.0      -128.0     26.5      10.0       3.5          5.0
2.0     38.0      0.0        120.0     0.0        0.0          0.0
2.0     38.0      -122.53    33.54     -10.0      -1.5         -5.0
2.0     38.0      -122.53    33.54     -10.0      -1.5         5.0
2.0     38.0      -122.53    33.54     -10.0      1.0          -5.0
2.0     38.0      -122.53    33.54     -10.0      1.0          5.0
2.0     38.0      -122.53    33.54     -10.0      3.5          -5.0
2.0     38.0      -122.53    33.54     -10.0      3.5          5.0
2.0     38.0      -122.53    33.54     0.0        -1.5         -5.0
2.0     38.0      -122.53    33.54     0.0        -1.5         5.0
2.0     38.0      -122.53    33.54     0.0        1.0          -5.0
2.0     38.0      -122.53    33.54     0.0        1.0          5.0
2.0     38.0      -122.53    33.54     0.0        3.5          -5.0
2.0     38.0      -122.53    33.54     0.0        3.5          5.0
2.0     38.0      -122.53    33.54     10.0       -1.5         -5.0
2.0     38.0      -122.53    33.54     10.0       -1.5         5.0
2.0     38.0      -122.53    33.54     10.0       1.0          -5.0
2.0     38.0      -122.53    33.54     10.0       1.0          5.0
2.0     38.0      -122.53    33.54     10.0       3.5          -5.0
2.0     38.0      -122.53    33.54     10.0       3.5          5.0
2.0     38.0      -128.0     34.5      -10.0      -1.5         -5.0
2.0     38.0      -128.0     34.5      -10.0      -1.5         5.0
2.0     38.0      -128.0     34.5      -10.0      1.0          -5.0
```

Appendix C Log Manager Outputs

C.1. CDM-A Log File Sample

```
This log file was created by CDM-A on: Fri Dec 03 10:36:05 GMT+11:00 1999
CAP File(s) associated with this CDM-A analysis: CDMA-AGM142_03_423.CAP

Collision Detection Setting
Aircraft:        [ACTIVE]
Store:           [ACTIVE]
Roll Drive:      [ACTIVE]
Pitch Drive:               [ACTIVE]
Yaw Drive:       [ACTIVE]
Axial Drive:               [ACTIVE]


--------------------------------------------------------------------------------

Store's orientation:
X = 38.0 mm
Y = 0.0 mm
Z = 120.0 mm
Psi = 0.0 deg
Theta = 0.0 deg
Phi = 0.0deg

Store Support Arm's orientation:
X-axial = -71.19244737972315 mm
Z-main = 120.0 mm
Psi1 = 19.204239380661253 deg
Psi2 = -19.204239380661253 deg
Theta = 0.0 deg
Phi = 0.0deg

No Collision Detected


--------------------------------------------------------------------------------

Store's orientation:
X = 38.0 mm
Y = -128.0 mm
Z = 26.5 mm
Psi = -10.0 deg
Theta = -1.5 deg
Phi = -5.0deg

Store Support Arm's orientation:
X-axial = -58.95986184952022 mm
Z-main = 14.720373261457082 mm
Psi1 = 20.071409187407053 deg
Psi2 = -30.071409187407053 deg
Theta = -1.5 deg
Phi = -5.0deg

COLLISION DETECTED
Store:        Store hits the F111 half model
Roll Drive:   NO COLLISION DETECTED
Pitch Drive:  Pitch drive hits the F111 half model
Yaw Drive:    NO COLLISION DETECTED
Axial Drive:  NO COLLISION DETECTED

--------------------------------------------------------------------------------
```

C.2. CDM-M Log File Sample

```
This log file was created by CDM-M on: Fri Dec 17 13:56:01 GMT+11:00 1999

----------------------------------------------------------------------------------------
Collision Detection Setting
Aircraft :              [ACTIVE]
Store    :              [ACTIVE]
Roll Drive:             [ACTIVE]
Pitch Drive:                    [ACTIVE]
Yaw Drive:              [ACTIVE]
Axial Drive:                    [ACTIVE]

Aircraft model:         F-111 Half Model (6%)
Aircraft pitch angle:   4.0 deg

Store model:            AGM-142 Model (6%)
LPRS:     450.0 mm

Store's orientation:
X = 0.0 mm              Y = 300.0 mm                Z = 0 0 mm
Phi = 0.0 deg                   Theta = 0.0 deg             Psi = 0.0

Store Support Arm's orientation:
X-axial = 95.9329001518447 mm
Z-main = 0.0 mm
Phi = 0.0 deg
Theta = 0.0 deg
Psi1 = 0.8946896401015175 deg
Psi2 = -0.8946896401015175 deg

NO COLLISION DETECTED

----------------------------------------------------------------------------------------
Collision Detection Setting
Aircraft :              [ACTIVE]
Store    :              [ACTIVE]
Roll Drive:             [ACTIVE]
Pitch Drive:                    [ACTIVE]
Yaw Drive:              [ACTIVE]
Axial Drive:                    [ACTIVE]

Aircraft model:         F-111 Half Model (6%)
Aircraft pitch angle:   4.0 deg

Store model:            AGM-142 Model (6%)
LPRS:     450.0 mm

Store's orientation:
X = 0.0 mm              Y = 300.0 mm                Z = 400.0 mm
Phi = 0.0 deg                   Theta = 0.0 deg             Psi = 0.0

Store Support Arm's orientation:
X-axial = 95.9329001518447 mm
Z-main = 400.0 mm
Phi = 0.0 deg
Theta = 0.0 deg
Psi1 = 0.8946896401015175 deg
Psi2 = -0.8946896401015175 deg

COLLISION DETECTED
Store:                  Store hits the test section wall [+Z]
Roll Drive:             Roll drive hits the test section wall [+Z]
Pitch Drive:                    Pitch drive hits the test section wall [+Z]
Yaw Drive:              Yaw drive hits the test section wall [+Z]
Axial Drive:                    Axial drive hits model support section wall [Section 1, +Z]
```

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wind tunnels, Transonic wind tunnels, JAVA (Computer program language), computational fluid dynamics, store separation, collision detection, computer modelling

19. ABSTRACT

The Transonic Wind Tunnel and its state-of-the-art Store Model Support System, provide the Australian Defence Force with the capability to perform aerodynamic grid tests which simulate the release of stores from aircraft. A computer program called CDM, written in Java and Java 3D programming language has been developed to visualise, model, and provide collision detection, for an aerodynamic grid test. The software provides a safe, efficient and cost-effective method to analyse the grid used in an aerodynamic grid test. With its three-dimensional modelling environment, CDM can also be used as a tool for grid point design and visualisation. With a high level of flexibility in the software architecture, CDM can be easily configured for different wind tunnels, test configurations, aircraft and store models.