Capabilities of Deployment Tests at DNW-NWB

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ABSTRACT

Ground based simulations of deployment tests with rigid objects (cubes) jettisoned from the open ramp of a military transport aircraft are described. The tests have been performed in the open test section of the low speed wind tunnel NWB, which is operated by the foundation "German – Dutch Wind Tunnels" (DNW).

The specific technical equipment makes the test set-up unique and the essential two components, the 6 DOF Model Positioning System MPM as well as the 6 DOF optical tracking system, will be reviewed in detail. Thereafter examples of typical trajectories of the jettisoned objects are given.

The tests have been performed in collaboration with the DLR Institute of Aerodynamics and Flow Technology.

1 INTRODUCTION.

Motivation

The motivation for the store separation tests in the NWB was the prediction of store separation characteristics, especially for the generation of a data base for CFD validation. This data base will include

- Data of the flow field in close vicinity to the open ramp
- Surface pressure measurements
- Force measurements
- Measurement of the trajectories and orientation of the deployed objects.

Time plan

The data base is intended to be generated in the following steps:

First, the determination of trajectories of rigid objects, deployed from a static (non-moving) wind tunnel model together with force measurements; followed by drop tests with the wind tunnel model performing the same motions during and after the deployment as the full scale aircraft. The model motion will be achieved with NWB's Model Positioning Mechanism MPM. This second step will include surface pressure measure measurements as well as PIV measurements. In the final step the solid objects will be replaced with parachute models.

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This paper describes the set-up and first results

2 NOTATIONS AND ABBREVIATIONS

Symbol	dimension	name
CG		centre of gravity
g	m/s^2	acceleration due to gravity
Fr	1	Froude number
l_μ	m	reference chord
s	m	wing span
V	m/s	free stream velocity
α	°	angle of attack
β	°	angle of sideslip
ρ	kg/m^3	density

Subscripts

exit	object departure
FS	Full scale
WT	Wind tunnel

3 TECHNICAL ENVIRONMENT

The facility NWB-NWB

The low speed wind tunnel NWB (Niedergeschwindigkeits-Windkanal Braunschweig) is operated by the foundation German-Dutch Wind Tunnels (DNW) and is located at the site of the German Aerospace Center DLR at the Braunschweig airport. The NWB is an atmospheric wind tunnel with a closed return circuit and can be operated optionally with a closed, slotted or open test section. The test section has a size of $3.25 \cdot 2.80\ m^2$ and a length of 8.0 m.

For the tests described in this paper the open test section has been used because of the better optical access, accepting the reduction in flow quality compared to the closed test section. A net has been installed below the test section and in front of the collection ring to collect the deployed objects without damage. With a power consumption of the electric motor of 1.6 MW a maximum flow velocity of 75 m/s can be achieved in the open test section. Further information about the NWB is available in [1].

The Model Positioning Mechanism MPM

NWB’s unique model positioning mechanism MPM can be described as a 6-DOF parallel kinematic incorporating six constant length struts, whose joints at the wind tunnel fixed side connect to six electric linear motors. These electric linear motors traverse along two rails, which are located above the test section, so that the MPM can be used not only for dynamic measurements, but also for ground effect simulation.

The major characteristic of this test rig is its high dynamic capability combined with high and nearly constant stiffness over the whole workspace. To meet the demands of large amplitude and high-rate arbitrary motion the MPM parallel kinematic mechanism was developed with the following advantages compared to a conventional serial axes arrangement:

- higher dynamics despite identical input power because lower weights are being moved,
- higher accuracy because errors in parallel kinematics exert less effect,
- lower costs due to simpler construction and identical components for each axis,
- lower demands on tolerances for production and assembly because geometric transformation takes the place of axial alignment.

For control of the MPM an NC milling machine hardware, Sinumerik 840D, in combination with an adapted software is used. To avoid a conventional ballscrew drive with its elasticity in the drive chain the axes are brought into motion by application of the linear direct drive technology. Altogether six Simodrive 1FN3 linear motors are used, allowing acceleration up to 2.5g. The accuracy of the system in pivoting angles is better than 0.005°. The first Eigenfrequency at the top of the sting is above 20Hz. The test rig allows a payload of up to 500 kgs. The MPM is depicted in **Figure 1**.

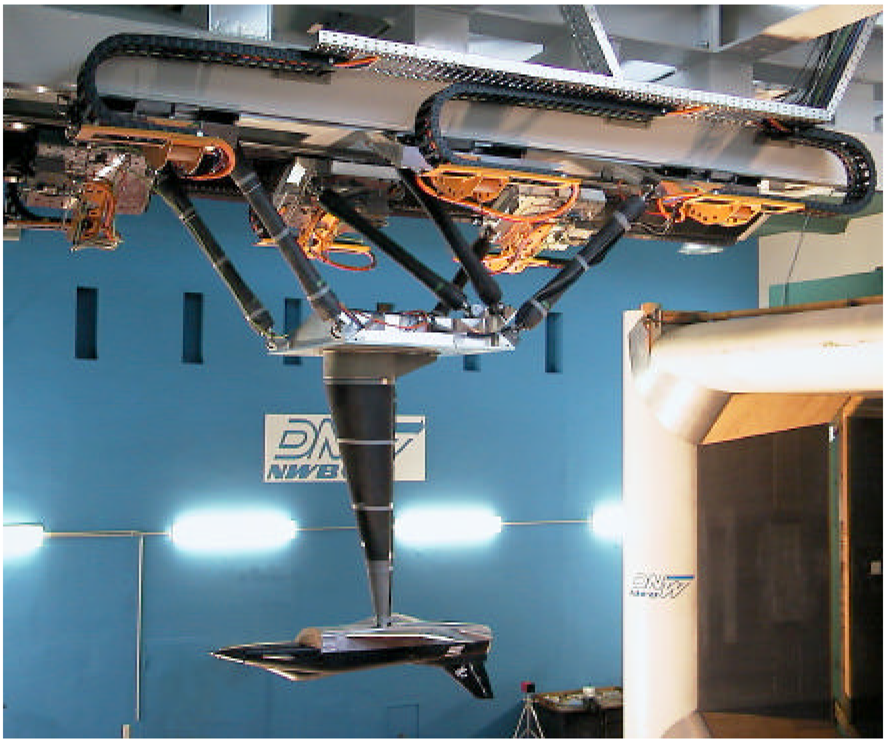

Figure 1: A X31 wind tunnel model on the MPM in the DNW-NWB

Currently the scope of the MPM includes ground effect simulation, manoeuvre simulation and forced oscillation tests in addition to the standard static tests, see [3] and [4].

The wind tunnel model with ejection mechanism

The wind tunnel model used is the model of a generic military transport aircraft. It is shown in figure 2. It is equipped with an open cargo ramp and has a wing span of s = 2 m. It is made from carbon fibre composite. The model is instrumented with an internal 6-component strain gauge balance, 64 pressure taps arranged in 4 sections x = const and an inclinometer.

The model is attached to the MPM by a dorsal sting, as can be seen in **Figure 2**, to keep the sensitive flow past the rear fuselage bottom undisturbed.

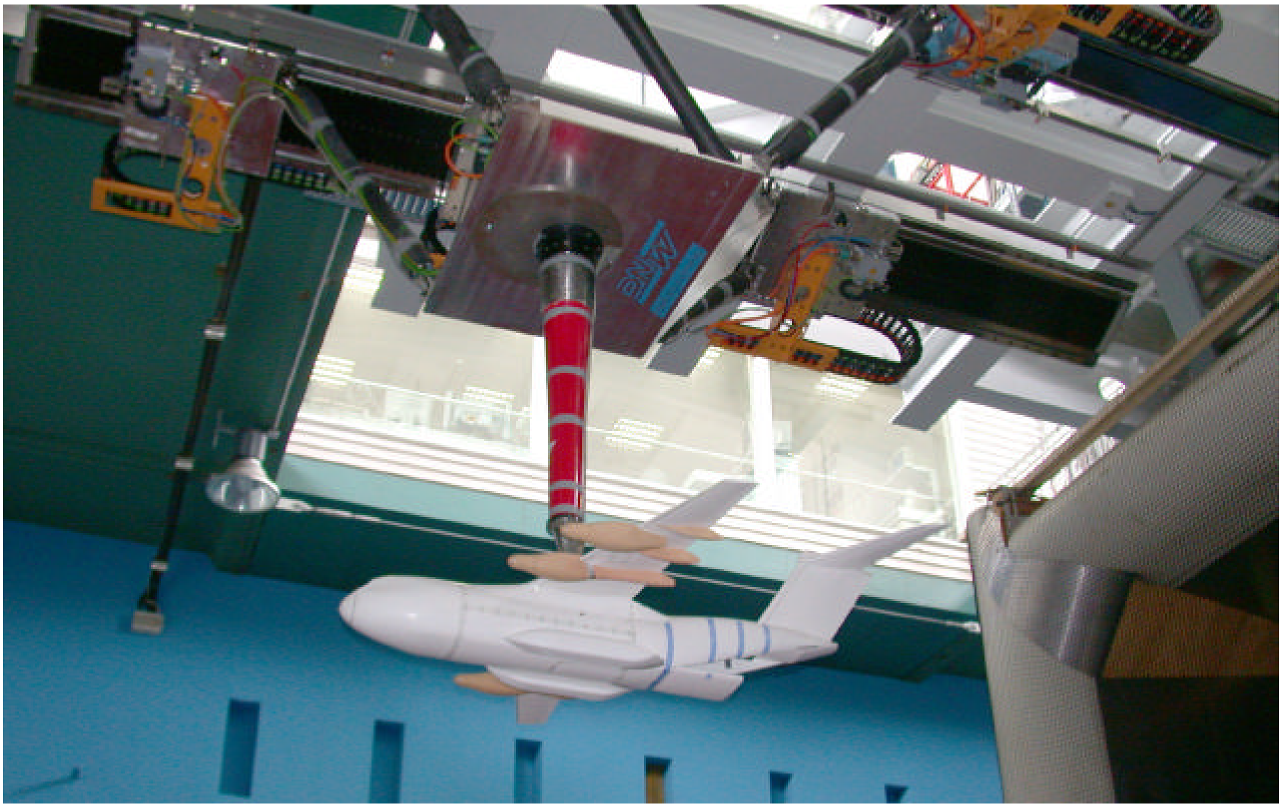

Figure 2: Military transport aircraft on the MPM in the open test section of DNW-NWB

A remotely controlled spindle drive is installed in the model's cargo bay. An aluminium carriage, in which the cuboids are placed, is moved by the spindle drive. The cuboids are secured in the carriage with springs of adjustable tension. After accelerating to a selectable speed, the carriage stops abruptly at the end of the cargo floor and the cuboid leaves the cargo bay with the selected speed. The ejection mechanism is shown in **figure 3**.

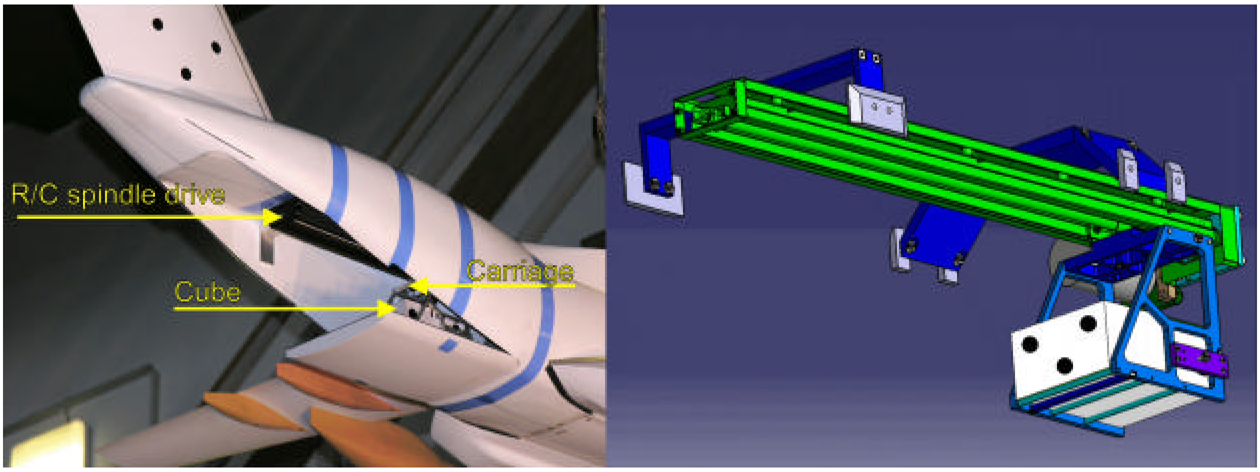

Figure 3: Detail of the wind tunnel model with the ejection mechanism and a cuboid in starting position shown

The optical tracking system

The trajectories of the deployed cuboids are recorded by NWB's 3D video tracking system. It's main components are two Mikrotron MC 1310 CMOS video cameras with a maximum resolution of 1280 x 1024 pixels and a maximum frame rate of 500 images per second at this resolution. Because of data transfer band width reasons a frame rate of 300 images per seconds has been used. The two cameras are connected to a single personal computer with two frame grabber cards, which is used for camera control as well as for image storage and image processing. The cameras are equipped with standard SLR camera C-Mount lenses of the suitable focal length.

For the definition of the co-ordinate system and for camera calibration the recorded pixel co-ordinates from a set of at least six known reference points are necessary. The camera positions don't have to be determined because they are calculated by the system from the reference points.

As reference points the locations of the spiral wound filaments of 16 small electric light bulbs are taken. The bulbs are arranged evenly spaced in the volume to be observed (approximately 2.5 m by 1.5 m by 1.0 m). Their position was determined by using the Universal Precision Measurement System UPM 400 from Trimble Co [2]. Two elecro-optical precision tachymeters are pointed at each of the light bulbs in succession and the corresponding software delivers the co-ordinates of interest. Depending on the observation distance the UPM 400 has an spatial accuracy from 10 µm to 100 µm. At NWB an accuracy of 50 µm has been achieved with the set-up depicted in **figure 4**. The UPM 400 system itself is calibrated in situ with a reference scale.

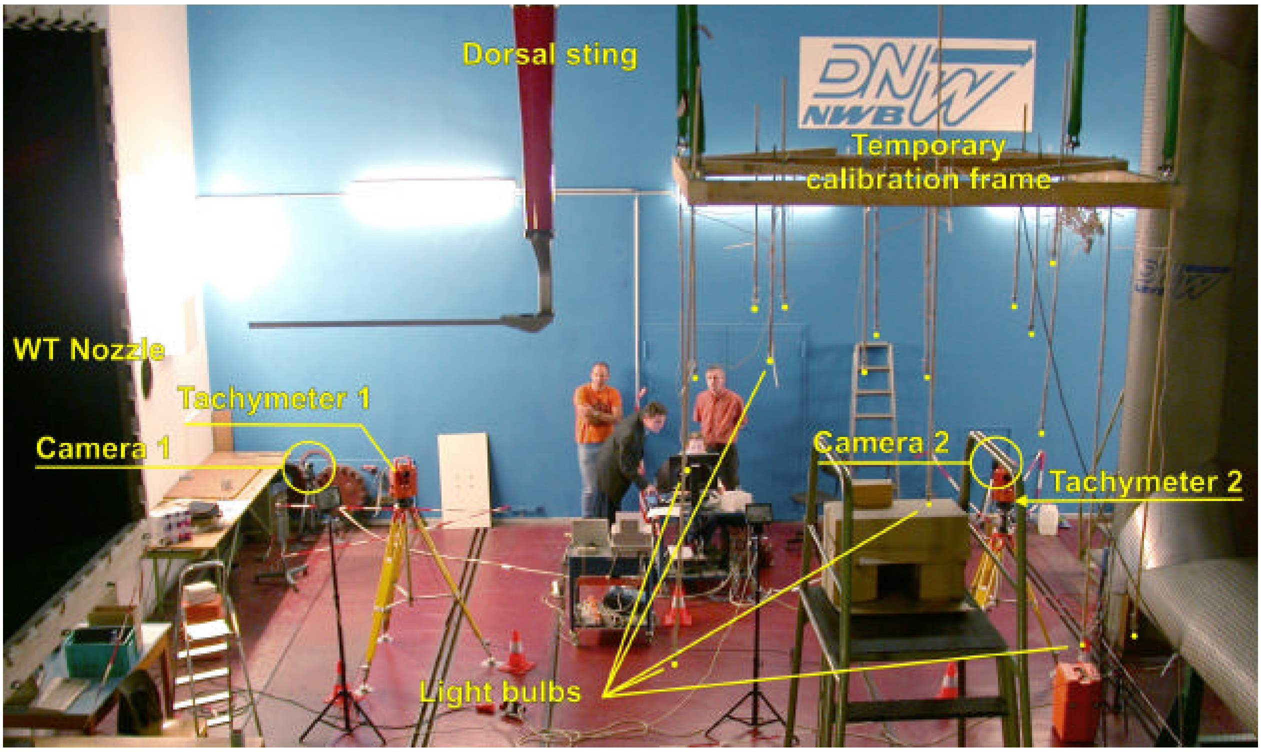

Figure 4: Calibration of the optical tracking system

Position and attitude of the cuboids along their trajectories are calculated from the pixel co-ordinates of (at least) three circular markers, which have to be visible for both cameras simultaneously. As the pixel co-ordinates of the centre of each marker are calculated, the position of the markers can be given with sub-pixel accuracy. Assuming a marker diameter of 10 pixels, an accuracy of 1/10th pixel can be achieved. The overall spatial accuracy of the test set-up is better than 0.3 mm. For the camera control as well as for image processing and analysis the software PicColor from F.I.B.U.S. is used.

Data acquisition and evaluation

For the acquisition of the balance data NWB uses a Hottinger-Baldwin MGC+ DAQ system. As mentioned in the previous section, the images from the two cameras are stored in the control PC and are evaluated after the measurement. The image processing works semi-automatically, meaning that the program evaluates the marker co-ordinates of consecutive image pairs as long as the markers remain clearly detectable for the program.

EXPERIMENTAL RESULTS AND DISCUSSION

Tests performed

The first test campaign has been performed in May 2006 using the set-up described above. The deployed objects were cuboids with a length of 110 mm (˜ 4.3 ”), a width of 90 mm (˜ 3.5 ”) and a height of 50 mm (˜ 2 ”). Three different materials with different densities ρ have been used: balsa wood, basswood and PUR plastic. The cuboids weighed 60 grams ($\rho = 120$ kg/m^3), 290 grams ($\rho = 580$ kg/m^3) and 500 grams ($\rho = 1000$ kg/m^3).

The free stream velocity during the tests has been chosen so that the Froude number, $Fr = V^2/(l \cdot g)$ of the wind tunnel set-up comes close to the typical full scale Froude number. So the wind tunnel free stream velocity has to be $V_{WT} = V_{FS} \cdot (l_{\mu,WT} / l_{\mu,FS})^{0.5} = 0.22 \cdot V_{FS.}$

Three circular markers have been applied to each side of the cuboids. In addition, a unique symbol has been printed on each side, so that the sides can be distinguished during the analysis of the video images. The wind tunnel fixed co-ordinate system has it’s origin in the fuselage nose (at $\alpha = \beta = 0°$).

The speed, with which the cuboids leave the cargo bay has been $U_{exit} = 1$ m/s for all tests. The free stream velocity has been set to values between $V = 14$ m/s and $V = 20$ m/s. The angle of attack has been varied between $\alpha = 0°$ and $\alpha = 6°$. Values between $\beta = 0°$ and $\beta = 6°$ have been used for the angle of sideslip. **Figures 5 and 6** illustrate the typical trajectories of the cuboids with the different densities ρ but otherwise identical test conditions ($\alpha = \beta = 0°$, $V = 20$ m/s).

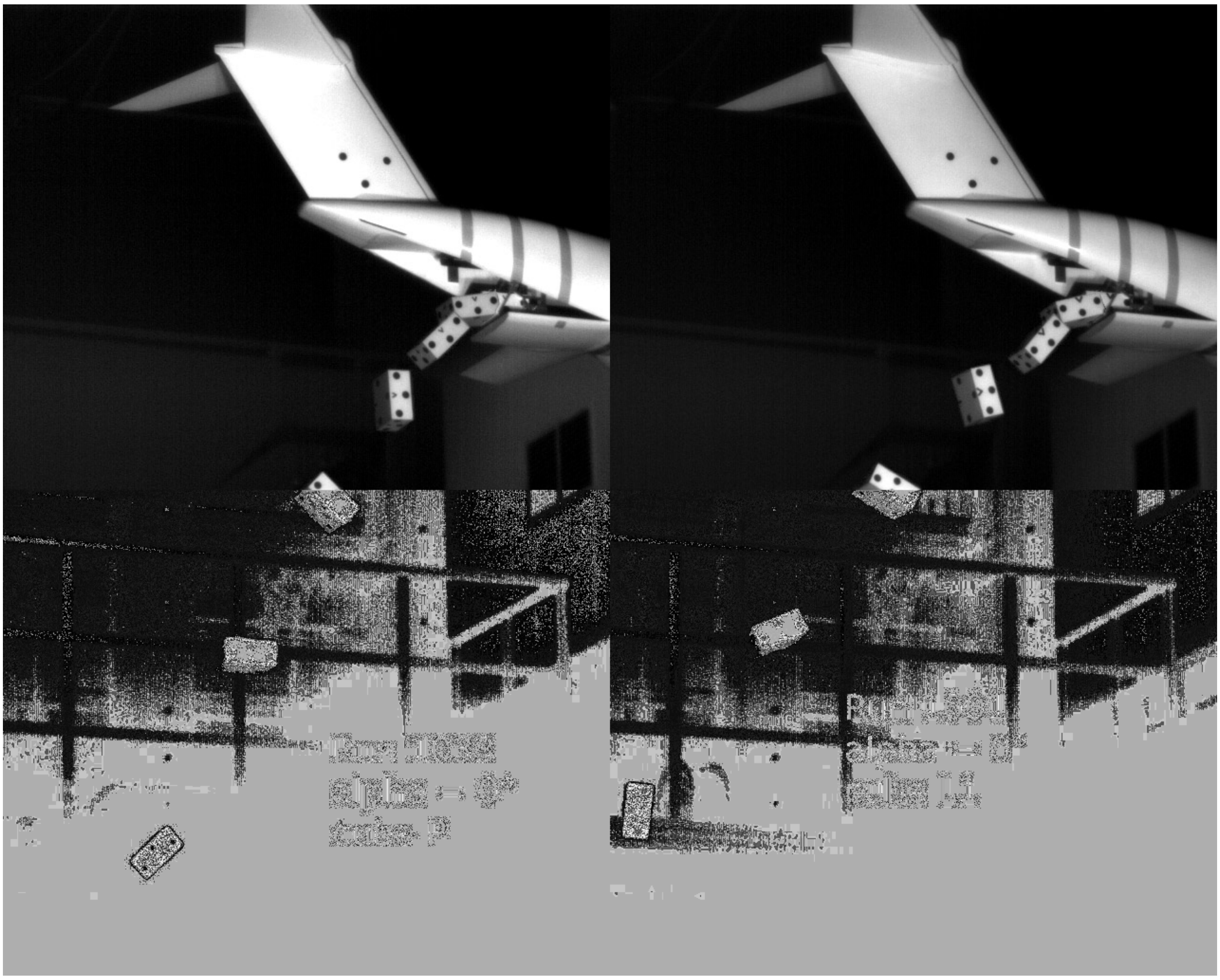

Figure 5: trajectories of high density (left) and medium density (right) cuboids, time interval of 100 ms shown

While the trajectories of the medium density and high density blocks indicate that the blocks leave the vicinity of the rear fuselage immediately and without rotation about the blocks’ longitudinal axes, the low density block is strongly influenced by the low static pressure region and the vortex dominated flow past the lower side of the rear fuselage. The low density block moves upwards initially and rotates around all three body axes.

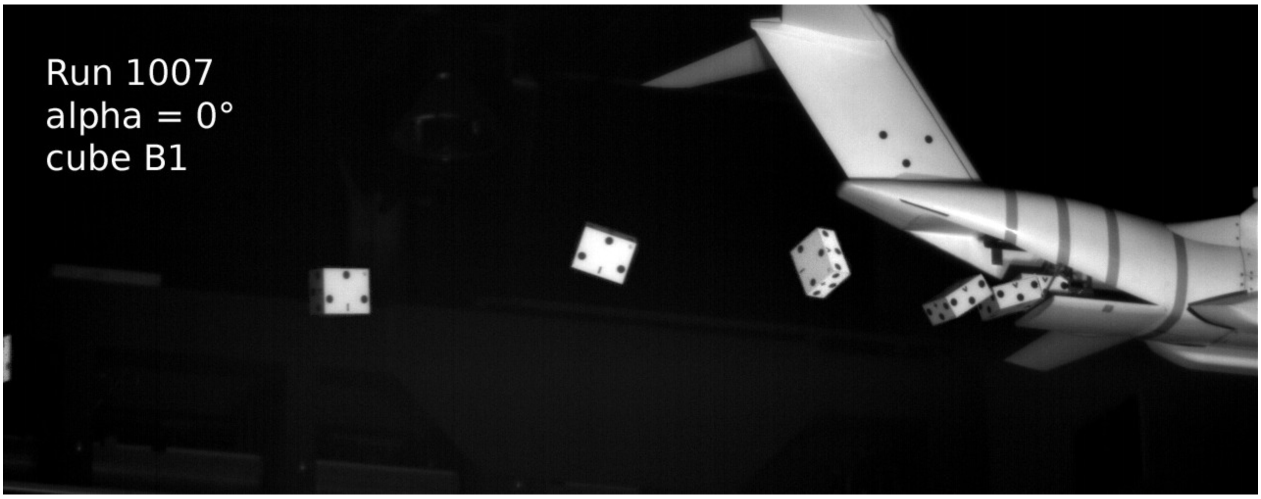

Figure 6: trajectory of low density cuboid, , time interval of 100 ms shown

The **figures 7 to 9** contain quantitative results of the deployment tests in NWB. The three co-ordinates of the centre of gravity of the cuboid are given as function of time. In figures 7 to 9 the small symbols along the lines mark every other image taken by the optical system. In figure 7 four repetitions of the trajectory of the medium density block are shown. While the x co-ordinate and the z co-ordinate of the four repetitions show great similarity, the y co-ordinate, which should be constant in an ideal deployment, varies considerably. This results from the unsteadyness of the flow past the lower rear fuselage.

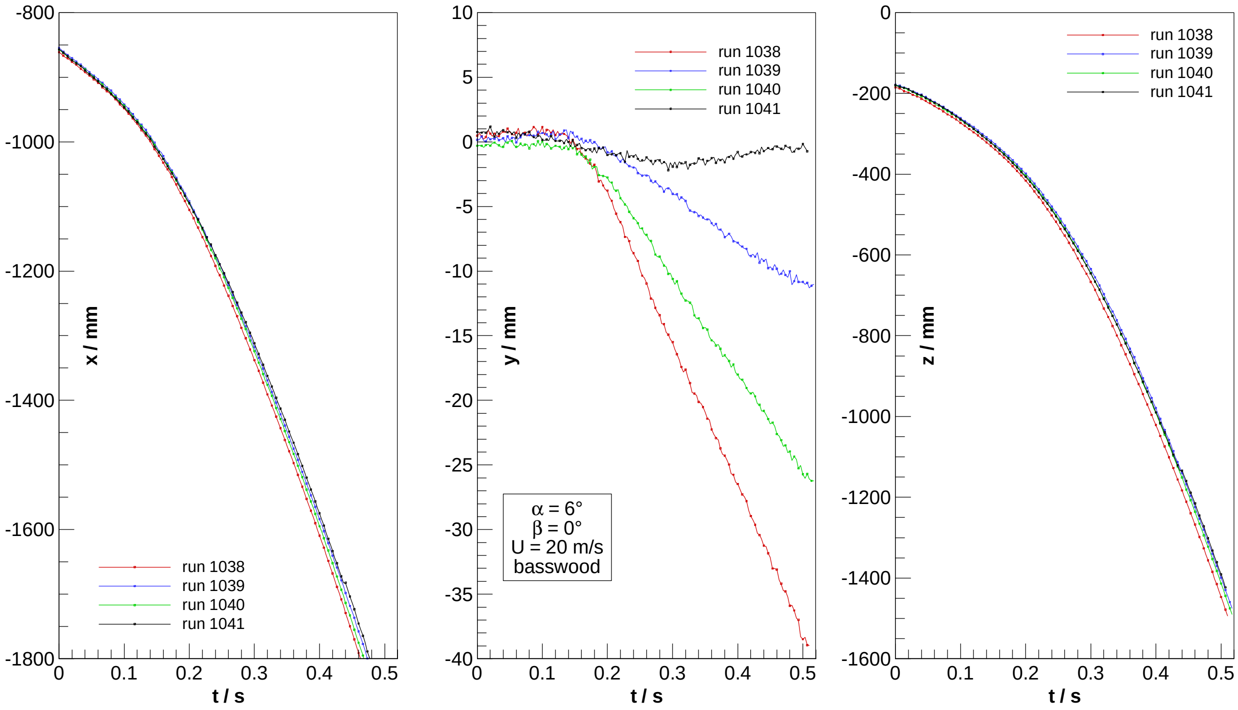

Figure 7: Trajectory repeatability of a medium density cuboid. CG co-ordinates x(t), y(t) and z(t)

Figure 8 depicts the effect of the wind tunnel model’s angle of attack α on the trajectories. The different values of the x and the z co-ordinates for the four different angles of attack at t = 0 result from the (mainly vertical) displacement of the rear fuselage relative to the wind tunnel fixed co-ordinate system with it's origin near the fuselage nose (at $\alpha = \beta = 0°$) due to the angle of attack. The effect of α on the x and the z co-ordinates appears to be rather small. The ostensible dependency of the y co-ordinate is only of the same magnitude as the variation of y during the repetitive tests shown in figure 7.

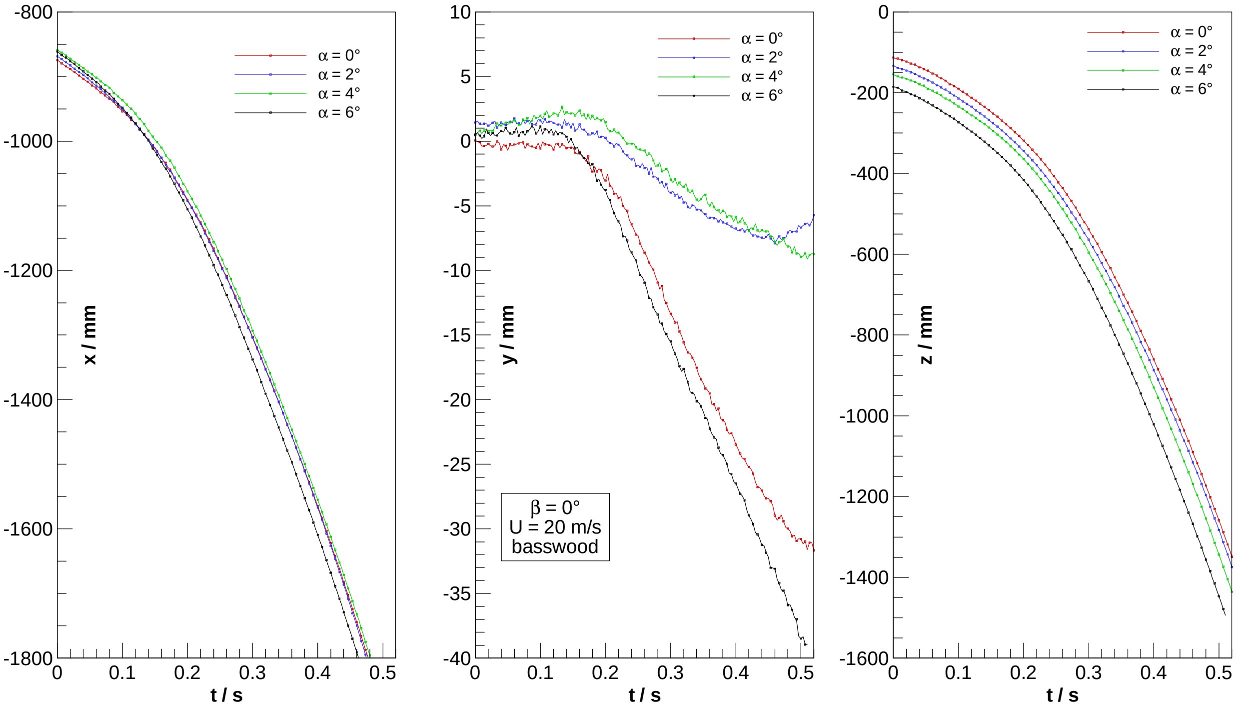

Figure 8: Trajectories of a medium density cuboid deployed at different angles of attack. CG co-ordinates x(t), y(t) and z(t)

Finally, figure 9 shows the effect of three different free stream velocities on the trajectories of the high density cuboid. The x co-ordinates show the expected result that the cuboids are displaced downstream to a smaller extent when the free stream velocity is low. The z co-ordinate indicates that the vertical displacement of the cuboids becomes smaller, when the free stream velocity is increased. The y co-ordinate seems to indicate a small dependency but the differences of the y co-ordinate shown in figure 9 are significantly less than the differences encountered during the repetitive tests (figure 7). Obviously the high density cuboid is less affected by the unsteady vortex dominated flow field with respect to the lateral displacement than the medium (and low) density cuboids.

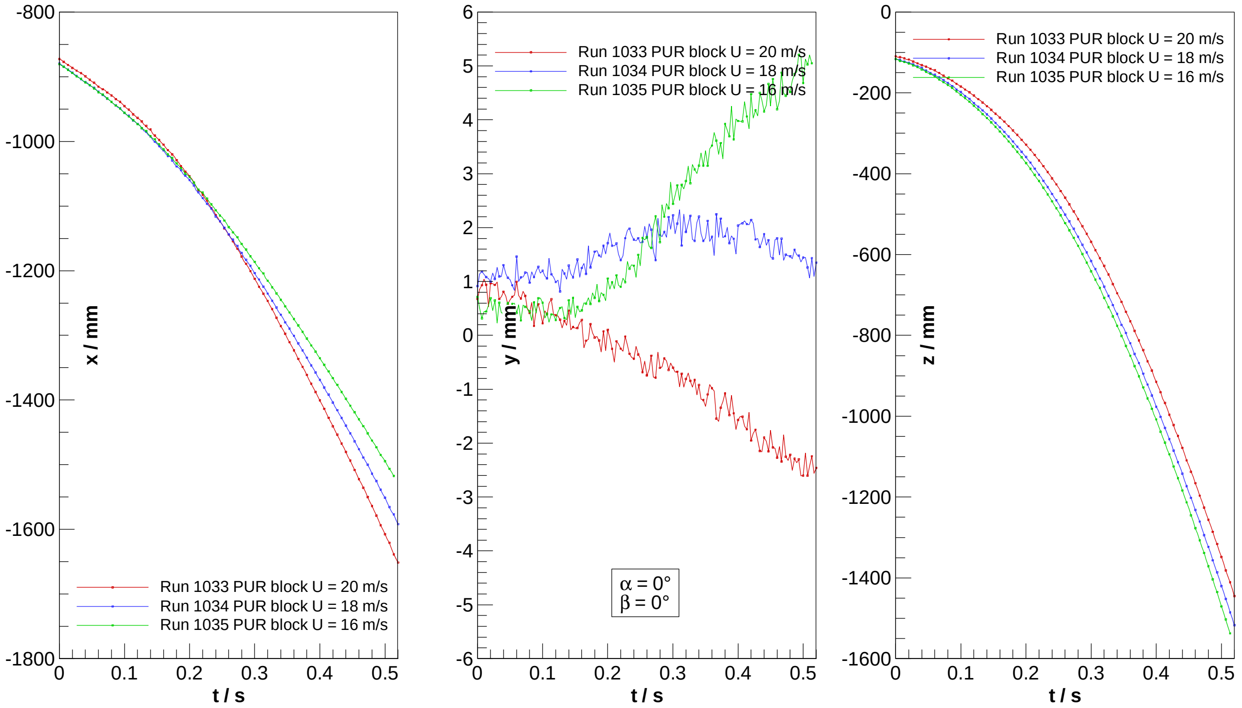

Figure 9: Trajectories of a high density cuboid deployed at different free stream velocities. CG co-ordinates x(t), y(t) and z(t)

CONCLUSIONS AND OUTLOOK

A ground based method for determination of deployment trajectories of rigid bodies using a 6 DOF optical tracing system has been successfully developed and tested. The tests have been performed in the low speed facility DNW-NWB using a generic military transport aircraft with realistic open ramp geometry. The objective is to establish a reliable data base for CFD validation.

The described tests are the first part within a major ground based test programme, which will also include measurement of the flow field in the vicinity of an open ramp, trajectories of deployed parachutes and unsteady deployment tests incorporating a moving wind tunnel model.

In this paper results are given from the very first test, which show that the vortex dominated flow field in the vicinity of the open ramp significantly influences the repeatability with respect to the lateral displacement. This inherent unsteadiness will have to be addressed in future tests.

ACKNOWLEDGEMENTS

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SYMPOSIA DISCUSSION – PAPER NO: 10

Author's Name: T. Loeser

Discussor's Name: S. Donauer

Question:
Is the development mechanism able to prevent the sub from an initial yaw motion leading to lateral displacements?

Author's Response:
An initial yawing motion can be securely excluded. An initial yaw example, if present, would be extremely small. Its value will be measured in future.

Discussor's Name: D. Hummel

Question:
What is known about the flow field in the wake of the fuselage with open door? If this flow field is unsteady, there should be different trajectories for different drops.

Author's Response:
In a future test (2007) it is planned to investigate the flow field in the vicinity of the open ramp with unsteady PIV.

Discussor's Name: Luis Ruiz Calavera

Question:
Would it be possible to perform test without the presence of the aircraft model to separate the influence of aircraft interfering flow field and store own aerodynamics?

Author's Response:
It would be possible, one would only have to build a fairing for the ejection mechanism.

Discussor's Name: Richard Benney

Question:
What are the planned follow on tests for this effort? I would welcome more details….

Author's Response:
Yes, efforts will continue.