Technical Evaluation Report

Functional and Mechanical Integration of Weapons with Land and Air Vehicles

Session Air Vehicles

Williamsburg VA, USA
7 – 11 June 2004

SUMMARY:

All objectives of this RTO Symposium were met. All key issues were covered with partly innovative and partly state-of-the-art presentations describing not only a broad spectrum of applications, but also providing deep enough signals and impulses for future work. Hereby novel methodologies were highlighted as well as possibilities how to achieve improvements in accuracy and efficiency.

A wide field of recommendations covered novel solutions for equipment hardware, hybrid coupling strategies and high fidelity methods for complex investigations in subsonics, transonics and supersonic speeds.

A revival of this RTO Symposium is therefore strongly recommended. Reflecting to the characteristical development cycles of computing power, an interval of 4 up to 5 years will be enough to ensure the availability of a broad variety of new applications for this future event.

INTRODUCTION:

The key objective of the symposium was to increase the awareness and understanding of the problems and solutions connected to the functional and physical weapon system integration through in-depth presentations and discussions among researchers, academians and engineers, promoting and fortifying at the same time the international network between them.

The main topics addressed were groupped into six sessions:

- Carriage and Release Systems
- Weapon Integration Tests
- Structures and Aeroelasticity
- Safe Separation Models
- Computational Fluid Dynamics
- Weapon Bays

A total of 32 contributions were selected whereby 25 have been presented at the Symposium in Williamsburg. Three of the cancelled presentations were made available as draft papers. Four papers were completely withdrawn.

The 32 selected contributions originated from 11 different nations, most of them coming from industry and national or government agencies followed by few from research laboratories and universities.

At the peak , 60 observers were counted in the audience of the most frequented sessions. This number mirrored a considerably high interest on the addressed topics.

In addition to the formal evaluation , this TER contains also a glossary derived from the specific papers, with a cross-reference to the origines.

In a third part, the live discussions are documented in the session editing pages.

EVALUATION

Session 1 Carriage and Release Systems

From 4 papers planned, 3 papers were presented to an audience of 40 observers in this session. Paper No 2 was withdrawn.

Paper 1 : Interoperability & aircraft stores certification – an Australian perspective on where to from here

The paper represented a very good introduction to all the themes of the symposium and must be seen as a supplement to the keynotes addresses presented after the opening ceremony.

It gave us an extensive and a most complete overview of the functional & physical weapon integration world. The two parts of the presentation contained guidelines for the complete Weapon Integration Process impact on certification and interoperability of multinational airforces.

Highlighting the background of Weapon System Integration M.Tutty gave us a comprehensive view on the past, today's and future challenges raising from the three levels of Interoperability identified in commonality, interchange-ability and compatibility. His paper addressed also use and benefits of Aircraft Stores Clearances Methods , Modeling and Simulation and Validation in order to provide airworthiness and certification also in the view of full functionality.

The paper contains also implications of certification aspects for future Network Enabled Warfare .

Paper 3 : Pneumatic Triple Store Rack for the Rafale Combat Aircraft

The main purpose of the paper was to demonstrate how efficiently cold gas pneumatic ejector systems can be integrated into a modern fighter triple ejector rack. This informative paper highlights also the innovative capability of designing an in-flight adjustable ejection performance for end of stroke velocity and pitch rate.

Paper 4 : Use of Cold Gas Energy for Tactical Missile In-Flight Release

The paper justified the use of cold gas systems in contrast with pyrotechnics. In a promotive presentation the speaker highlighted performance improvements controllability and tune-ability as well as operational advantages against traditional systems.

Session 2 - Weapon Integration Tests

With only 2 papers on the programme this was the shortest session. Both papers were presented to an audience of 35 observers.

Paper 5 : Experience Report of Integration and Test of the PARS3-LR-System on Helicopter

This presentation comprehensively described a stepwise approach to weapon system integration , highlighting all test-cycles on a helicopter with some recommendations for improvements derived from lessons learned.

Paper 6 : F/A-18/AIM-132 ASRAAM Integration and Test Program

In absence of the author D.Pierens, M.Tutty presented an instructive report on the F/A-18 ASRAAM integration program with a most complete survey of the integration process. Highlights were set on:

- Store Separation Clearance Process and Integration concept
- Fit and Function
- Flutter and Aeroelastics
- EM Compatibility / Interference and HERO
- Jettison Missile +Twin-Launcher
- High G and High Alpha Rail-Launch-Gouging
- End to End Functional Testing

Session 3 - Structures and Aeroelastics

Despite the fact that only 4 papers of the 5 selected contributions were presented in this session, 60 observers in the audience attended the presentations with high interest.

Paper 7 : Deck Landing Load Specifications on the Rafale External Stores using Finite Element Models Computations

Jean-Philippe Planas, Bertrand Courmont from Dassault Aviation provided a straight forward show on a state of the art engineering approach for structural clearances associated to deck landing shocks impacting on a modern fighter aircraft with complex external store configurations. Items highlighted were:

- Deck landing loads and shock impact sequence
- Modeling of high energy shock
- Load specification and shock response spectra (low and high frequencies)
- How to improve integration

Paper 8 : A Bending Beam Approach for Capturing Ejection Shocks on Missiles

We saw here an academic and innovative description of an extended bending beam formulation capturing structural response effects induced by ejection shocks on a missile body. A.Eberle described how the

captured structural response effects on store separation provided considerable difference between rigid and elastic body acceleration profiles. A key issue in his presentation dealt with tuning the estimated material constants by matching the telemetry records.

Paper 9 : LCO Analysis of a Rectangular Wing with Stores

This paper reports on academic and scientific investigations for limit cycle oscillation phenomena on a generic wing carrying stores in the transonic mach number range. It highlights an attempt to apply Transonic Small Perturbation Theory for LCO and gave a trade off view between TSP-Euler-NS for LCO predictions .

Paper 11 : Multibody Simulation of Low Frequency Aeroelastic Wing Loads

This one is a prospective contribution on multi disciplinary simulation for coupled structural finite element with computational fluid dynamic codes and their reciprocal interaction with flight mechanics and dynamics. Special focus is put on:

- Steady , quasi steady and unsteady low frequency aeroelastics
- Multi Body Systems and Simulation
- Time coupling techniques
- Spatial coupling

Session 4 - Safe Separation Models

In presence of 50 observers in the audience , 7 out of 8 planned papers were presented in this session.

Paper 12 : Store Release from ASTOVL Aircraft with Vectoring Jets

Dr.Raj Nangia outlined separation problems to be expected on VSTOL platforms and associated with jet exhaust effects. Trajectories are predicted by using experimentally derived data to represent jet effects on the store. Store emergency jettison during the transit post hover phase and effects of jet exhaust positioning on the separation behavior were highlighted.

Paper 13 : Use of Statistical Tools to Improve Modelling and Simulation of Store Separation.

This paper demonstrated how trouble shooting for mismatches of separation flight test results can improve roll and yaw motion predictions for a separating store by using empirical fits . Main issues highlighted were:

- use of telemetry
- post flight matching process
- complexity of salvos from multiple rack systems
- cost reduction by more efficient trials

Paper 14 : Method of Simulation of Fuel Sloshing Effects on External Fuel Tank Separation

This paper provided an innovative and promising mathematical modeling for physics and dynamics of liquids enclosed in moving reservoirs. Based on the novel an unique limit surface approach , it was demonstrated how

liquid spring forces and fuel damping forces can be derived and applied to the dynamics of fuel slosh effects on fuel tank trajectories.

Paper 15 : CFD Aspects of the Store Clearance Process

This paper delivered an informative as well as prospective report on the development and application of high fidelity CFD methods such as Euler and RANS finite volume formulations for structured and unstructured meshes in trajectory predictions. Emphasis is put on:

- automation, accuracy and efficiency of trajectory prediction
- store transpiration terms
- inviscid / viscous store separation
- shallow cavity trajectory analysis

Paper 17 : Weapon Separation Analysis Tools Using Matlab

This contribution provided an instructive report on the benefits of using commercial software systems such as MATLAB & SIMULINK, in order to develop a store separation code including trajectory prediction, visualization, animation and test analysis from movies. Main topics covered here were:

- Code design and development efficiency
- Toolbox versatility for solving store separation problems
- Code validation

Paper 18 : Prediction of Tank Fuel Sloshing during Jettison

Similarly oriented as Paper 14, we also find herein a novel but more scientific approach for the analytical description of the physical properties of fast moving encaged liquids, now based on molecular dynamics coupled with a pragmatic cook book solution featuring fuel slosh effects in separating fuel tanks. Highlights are here:

- intermolecular forces
- quasi particle clouds and clusters
- fuel slosh
- partially filled fuel tank trajectories

Paper 19 : Evaluation and Experimental Validation of Low Costs CFD Based Mathematics Model Describing External Stores Separation.

This paper dealt with an overview on a low cost CFD based approach to store separation clearances built on a nonlinear, unsteady panel method for aerodynamics and using a state of the art flight mechanics module from full aircraft simulation for trajectory predictions. Here we find highlights on:

- drag corrections
- Validation by WT-drop tests of Uranium made models
- Flight test validation by movie and telemetry records

Session 5- Computational Fluid Dynamic Methods

From 7 papers planned, 6 papers were presented to an audience of 45 observers in this session. Paper No 25 was withdrawn. Paper 23 was swapped into Session 6 but has been reallocated to Session 5 in this TER.

Paper 20 : Improvements of Automation for Mesh Generation of a Canadian Capability for Store Release Predictions

Francois Fortin provided a descriptive and prospective presentation on a trajectory prediction code using time discrete loose coupling of a quasi steady Euler Solver for an unstructured mesh motion module attached to a 6 DOF trajectory module. Accents were clearly placed on:

- automation and fool proofing of global mesh generation and remeshing
- customizing commercial CFD modules
- design of an efficient graphical user interface (GUI)
- extension to object hierarchy control

Paper 21 : External Store Separation from Fighter Aircraft

In this contribution a detailed confrontation of the capabilities of two well known store separation prediction tools: Inviscid FASTRAN including grid overlapping and unsteady USAERO with boundary layer representation was projected . Based on the well known Eglin Test case and other F-16 derived configurations, following topics were highlighted:

- chimera grid topologies
- trajectory loads
- fuselage interference effects
- modeling efficiency and range of application

Paper 22: RANS and DES Turblence Model Predictions on Two Rectangular Cavities at M=0.85

The authors provided results of a prospective and scientific research study on the ability of different turbulence models to capture narrow and broadband Rossiter mode acoustics for deep cavity flows at transonic speeds. A justification for the preference of DES models against the URANS approach is underline by an extended experimental cavity flow-acoustic database.

Paper 23: Studies of Transonic Cavity Flows Relevant to Aircraft Stores Carriage and Release

This paper dealt with highly informative experimental/analytical investigations for the classification of complex cavity flows at transonic Mach numbers. It contains highlights on:

- Flow visualization by particle image velocimetry (PIV)
- URANS CFD solutions
- Classification for open and closed cavities
- Improvements for PIV cavity flow assessments

Paper 24: Advances in Modelling and Simulation Capabilities for Predicting Store Trajectories – Past Success and Future Challenges

Alex Cenko gave again an informative survey on 20 years experience in store separation work, providing prospective recommendation on how to efficiently improve the clearance process based on lessons learned in the pass.The key recommendations outlined in his presentation were:

- The use of WT for installed load measurements
- CTS Rigs for load/flow grid measurements
- CFD applications for incremental sensitivities analysis
- More cost efficient flight testing by both side testing

Paper 26: An Adaptive Unstructured Mesh Approach for Aircraft/Store Compatibility Asessments

This promotive demonstration for a high fidelity CFD application to trajectory prediction deals with refinements of the representation of numerical aerothermodynamic effects . After justifying the efforts to be invested into adaptive meshes and global remeshing, highlights are put on the 3D NS-Supersolver for unstructured mixed element meshes in motion, which also provides turbulence and chemistry modeling. It is coupled to an universal adaptive multi-element mesh reconditioning and re-modeling module. Examples selected for this high fidelity demonstration were:

- missile rail launch with plume representation
- cavity eject launch application

Session 6- Weapon Bays

6 papers were selected for the last Session 6 however only three papers came up to the podium for presentation. Nevertheless this session was with 61 observers in the audience the most frequented one , a fact proving the high interest behind the topics concerning internal weapon carriage.

Paper 27: Relaxed Fidelity CFD Methods Applied to Store Separation Problems

Simplifications of high fidelity approaches have always been an attractive tool to conserve the quality of modeling by reducing complexity and extension of the flow volume under consideration. This prospective report on relaxed fidelity CFD methods demonstrated how to still maintain a good level of accuracy , even at a low CFD complexity level, in order to provide a higher productivity for store trajectory predictions. Highlighted here:

- minimized domain CFD
- sensitivity analysis methods
- internal store separation

Paper 29: Experimental Techniques for External and Internal Stores Integration and Release at the Aircraft Research Association (ARA)

This paper deals with a retrospective and promotive presentation of the rig/ test techniques and facilities in evolution at the ARA within the last 14 years. Focal issues reported here were:

- improvements of accuracy and efficiency of the TSR facility
- cavity research studies for :
- internal store installation and release mechanism
- weapon bay loads and acoustics

Paper 30: Active Flow Control for High Speed Weapon Release from a Bay

This innovative contribution gave some guidelines about the efficiency of active flow control techniques in order to support noise suppression , shock manipulation and weapon release disturbance at supersonic speeds. Highlights here were set on:

- powered resonance tubes for shear layer control
- jetscreens and supersonic microjets for shock and shear layer control
- light scaled cavity ejection at supersonic speeds in WTT

SESSION SUMMARY

Out of all of the above contributions, key topics can be selected and ordered according to the magnitude of the frequency of their occurrence in the different papers. Picking up the essential objectives of our Symposium with some add-ons following picture can be derived:

- G Rail Launch Gouging **(1)**
- Fuel Slosh **(2)**
- Movie Analysis **(3)**
- UAV and UCAV **(3)**
- Aeroelastics **(3)**
- Turbulence models**(3)**
- Viscous flows**(4)**
- Structural Responses **(5)**
- Cavity Flows**(6)**
- Weapon Bay Release **(7)**
- Weapon System and Store Integration Process **(8)**
- Prediction of Store Separation **(16)**
- Computational Fluid Dynamics **(17)**

The numbers in the parentheses indicate the frequency of each of the above topics. Nominations greater than seven indicate a grown maturity and readiness of the appropriate technology for military application. Values between 4 and 7 are representing topics which are well addressed in actual research enterprises, whereas values below these are stressing the necessity for more dense and future efforts.

CONCLUSIONS

The Air Session revealed distinct links to the keynotes given in the contributions following the Opening Ceremony of the Symposium. The weapon integration process is an effort not only attached to premiere air vehicle design or development cycles but remain a continuous life time companion of the flying weapon system with numerous upgrade cycles.

Quick win potentials require multifunctional and operational superiority, survivability and kill accuracy. These requirements call for an universal compatibility, interchangeability up to a potential to plug and fly, connectivity by network enabled design and a profound understanding for systems engineering and safety. These are the core challenges of the Functional and Mechanical Integration of Weapons on future combat air vehicles. From them we can derive the requirements for fast, accurate and cost efficient integration processes as well as the requirement for technology readiness and maturity.

The Air Session provided some contributions to match these challenges. As far as methodologies were concerned, the maturity of CFD applications for Store Trajectory Predictions has been more than clearly underlined. Efficient solutions were demonstrated for structural dynamics and for aero acoustics interference problems within the integration process. The furtherance of knowledge also benefited from innovative contributions on molecular dynamics of encaged fluids as well as high fidelity approaches with respect to multiphase flow solvers and grid generation.

Also potentials for refinements of the process were outlined in several fields. It is evident that the predictive accuracy is improved by viscous formulations and the use of appropriate turbulence models. Considerable improvements are also achievable by the application of multiphase solutions and by time accurate coupling in multidisciplinary formulations.

Simulation is now well installed as a standard tool of the weapon integration process. The completeness of the used mathematical modeling is no more seen in some missing technology links or imperfections of the tooling but in the available computing power which remains the key driver for all the above.

RECOMMENDATIONS

A wide field of recommendations are offered in the above.

Cold gas systems provide novel and efficient solutions for carriage equipment not only for external but especially for internal stores integration.

Physical completeness of the models used in simulation must be carefully and continouusly grown in suitable proportion to the availability of computing power without the lost of productivity and cost efficiency.

Weapon integration cannot be uniquely solved by providing highly sophisticated solutions. CFD is one part of the full story. Structural response and interactions as well as functional properties and tolerances such as autopilots provide also significant influences.

Engineering skill will never be replaced by automation or by improving producivity neither in simulations nor in windtunnel testing. Here some limits of experimental tools such as CTS have been outlined which should be better used as support to adjacent simulations and full scale testing instead as unique source for trajectory predictions especially as in the case of internal carriage systems.

Potentials for future development gaps and needs, could be identified from disciplines,which appeared with a low frequency in the technical contributions

Also missing items such as the analysis of missile plume ingestion compatibility and the modeling of post collision store to store trajectories in order to assess the criticality of such events should not be forgotten here.

Defensive aids systems and their implications were only mentioned in the keynotes but also remain a field of great interest for military applications.

Last but not least, some essentials as for instance lessons learned shall always be kept in mind. Some of these can be found in Paper 1 and I would like to pick up the one I considered as most important one as a closing remark under these recommendations:

All models are wrong, some are useful.

Dr.Marie Ronald Deslandes

GLOSSARY :

Topics covered	Paper No	Author
active flow control	30	Kibens,Bower,Schwartz
Adaptive Mesh	26	Cavallo,Sinha
aeroelastic coupling	11	Krueger, Spieck
Aeroelastics	6	D.Pierens
Autopilot/Matlab Simulink	17	G.Akroyd
Bending Beam	8	Eberle/Deslandes
Boosted non guided	6	D.Pierens
Both side testing	24	Cenko,Piranian
Captive Trajectory	29	Corby,Hill
Catapult Launch	7	Courmont,Planas
Cavity acoustics	22	Allen,Mendonca,Kirkham
Cavity Flow Measurements	23	Knowles,Lawson,Bray,Ritchie,Geraldson
Cavity loads	29	Corby,Hill
Cavity release mechanism	29	Corby,Hill
Cavity research	29	Corby,Hill
cavity separation	27	Johnson, Davis, Finley
Center of gravity bubble	14	Eronn,Lindberg,Ljungberg
Certification	1	M.Tutty
Chemistry Modelling	26	Cavallo,Sinha
Chimera methods	26	Cavallo,Sinha
close coupling	11	Krueger, Spieck
Closed Cavity	23	Knowles,Lawson,Bray,Ritchie,Geraldson
Cold Gas Ejection	3	S.Cocault

Cold Gas Ejector	4	Guitaut
Cold Gas Generator	3	S.Cocault
Commonality	1	M.Tutty
Compatibility	1	M.Tutty
Coulomb friction	8	Eberle/Deslandes
Damping force of fuel slosh	14	Eronn,Lindberg,Ljungberg
Deck Landing Impacts	7	Courmont,Planas
Deck Landing Loads	7	Courmont,Planas
Deformation	8	Eberle/Deslandes
DES(detached Eddy Simulation)	22	Allen,Mendonca,Kirkham
Divergent Flutter	9	Khot,Scott,Snyder,Beran
DSE - Dynamic Super Element	7	Courmont,Planas
Dynamic damping	8	Eberle/Deslandes
Ejection Characteristics	4	Guitaut
Ejection Release unit	4	Guitaut
Ejection Shocks	8	Eberle/Deslandes
Elastic body acceleration	8	Eberle/Deslandes
EMC Compatibility	6	D.Pierens
Exhaust plume modelling of missiles	26	Cavallo,Sinha
External fuel tank separation	14	Eronn,Lindberg,Ljungberg
Fit and Function	6	D.Pierens
Flight Testing	24	Cenko,Piranian
fluid structure coupling	11	Krueger, Spieck
Flutter	6	D.Pierens
Fuel sloshing effects	18	Baeten/Gleissl
Fuel sloshing effects	14	Eronn,Lindberg,Ljungberg

General requirement for trajectory predictors	15	Stokes
Global mesh generation	20	Fortin,Zoric, Benmeddour
Graphical User Interface	20	Fortin,Zoric, Benmeddour
Gyroscopic moment of rotating engine mass	19	Buler,Loroch et al.
High G Rail Launch	6	D.Pierens
High speed supersonic weapon bay release	30	Kibens,Bower,Schwartz
improvement of predictions	13	Cenko,Piranian,Rupert
Influence function method	27	Johnson, Davis, Finley
Integrated Approach to Store Separation	24	Cenko,Piranian
Interchangeability	1	M.Tutty
Intermolecular forces	18	Baeten/Gleissl
Interoperability	1	M.Tutty
Jet induced effects on trajectories	12	R.Nangia
jet screen actuator	30	Kibens,Bower,Schwartz
Jettison Missile+Twin-Launcher	6	D.Pierens
K-e Turbulence Model	26	Cavallo,Sinha
LES(Large eddy simulation)	22	Allen,Mendonca,Kirkham
light scale drop testing from weapon bays	30	Kibens,Bower,Schwartz
Limit Cycle Oscillations LCO	9	Khot,Scott,Snyder,Beran
Liquid physical properties	18	Baeten/Gleissl
Long Range Strike Weaponization (LRS.)	30	Kibens,Bower,Schwartz
loose coupling	11	Krueger, Spieck
Low frequency aeroelastics	11	Krueger, Spieck
Mass point motion	14	Eronn,Lindberg,Ljungberg
mesh refinements	15	Stokes
Missile Gouging	6	D.Pierens

Modeling	1	M.Tutty
Movie Analysis	17	G.Akroyd
Network Centric Warfare	1	M.Tutty
Numerical modeling	8	Eberle/Deslandes
NURBS(non uniform Bi-splines)	20	Fortin,Zoric, Benmeddour
Octree Technique	20	Fortin,Zoric, Benmeddour
Open Cavity	23	Knowles,Lawson,Bray,Ritchie,Geraldson
Panel Methods	21	Demir, Alemdaroglu, Özveren
Partially filled fuel compartments in Tanks	18	Baeten/Gleissl
Particle cluster	18	Baeten/Gleissl
PIV Particle Image Velocimetry	23	Knowles,Lawson,Bray,Ritchie,Geraldson
Pneumatic Ejector Systems	3	S.Cocault
Postprocessing Trajectory	17	G.Akroyd
powered resonance tube	30	Kibens,Bower,Schwartz
Quasi-Particle Approach	18	Baeten/Gleissl
Relaxed Fidelity CFD	27	Johnson, Davis, Finley
Reverberation Chamber	6	D.Pierens
Rigid Body acceleration	8	Eberle/Deslandes
Risk Management	1	M.Tutty
safe separation	27	Johnson, Davis, Finley
Sensitivity analysis	27	Johnson, Davis, Finley
Skin friction	19	Buler,Loroch et al.
Spring force of fuel slosh	14	Eronn,Lindberg,Ljungberg
statistical tools	13	Cenko,Piranian,Rupert
Store Release predictions	20	Fortin,Zoric, Benmeddour
Store Separation	21	Demir, Alemdaroglu, Özveren

Store Separation Clearance Process	6	D.Pierens
Store Separation Clearances	1	M.Tutty
Store Separation Modeling	19	Buler,Loroch et al.
Store Separation Prediction	26	Cavallo,Sinha
Store Separation Process	18	Baeten/Gleissl
Store separation prediction tools	15	Stokes
store transpiration terms	15	Stokes
Structural Response	8	Eberle/Deslandes
supersonic microjets	30	Kibens,Bower,Schwartz
System Engineering Processes	6	D.Pierens
System integration	5	Hoerl,Hengst
tandem microjet	30	Kibens,Bower,Schwartz
Tank jettison	18	Baeten/Gleissl
telemetry	13	Cenko,Piranian,Rupert
Telemetry	24	Cenko,Piranian
Telemetry results	8	Eberle/Deslandes
time discrete coupling	11	Krueger, Spieck
time discrete coupling of CFD Module	20	Fortin,Zoric, Benmeddour
Trajectory Computation	17	G.Akroyd
Transonic Small Perturbation Theory	9	Khot,Scott,Snyder,Beran
Triple Ejector Rack	3	S.Cocault
Twin Sting Rig	29	Corby,Hill
Unsteady Reynolds Average Nav Stokes	22	Allen,Mendonca,Kirkham
Unsteady Panel method	19	Buler,Loroch et al.
Unstructured Mesh	26	Cavallo,Sinha
Validation	1	M.Tutty

Vectoring jets	12	R.Nangia
viscous inviscid trajectories	15	Stokes
Weapon Integration	1	M.Tutty
Weapon Integration on a Helicopter	5	Hoerl,Hengst
Wind Tunnel Test Techniques	29	Corby,Hill
Windtunnel Testing	24	Cenko,Piranian