Four-Powers Long Term Technology Projects:

"Airflow Influence on Airdrop" and "2nd Precision Airdrop Improvements"

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I. Abstract

The Four-Powers Air Senior National Representative (ASNRs) Long Term Technology Projects (LTTPs) related to airdrop research include both the Airflow Influence on Aircraft (AIA) Technical Group (TG) and the 2nd Precision Airdrop Improvements (PAIc) TG. The TG's are made up of Subject matter experts from France (FR), Germany (GE), The United Kingdom (UK), and the United States (US). This paper will provide an overview of each TG's objectives, work plans, results to date, and future activities. In addition, included in the PAIc activities, the paper will describe the status of a North Atlantic Treaty Organization (NATO) ad hoc Joint Precision Airdrop Capabilities Working Group (JPACWG).

II. Introduction

The Governments of the Republic of France, represented by the Minister of Defense, and the Federal Republic of Germany, represented by the Federal Minister of Defense, and the United Kingdom of Great Britain and Northern Ireland, represented by the Secretary of State for Defence and the United States of America, represented by the Secretary of the Air Force on the 28th of June 1988 entered into a Memorandum of Understanding concerning cooperative Long Term Technology Projects to be carried out under the aegis of the Four Power Air Senior National Representatives.

The overall objectives are to:

- obtain the benefits from rationalization, standardization (including common logistics) and interoperability of military equipment within NATO
- make the best use of respective research and development capacities, eliminate unnecessary duplication of work and obtain the most efficient and cost-effective results
- and collectively explore areas of cooperation using long term technologies to field technologically superior systems.

The Air SNRs constitute the Steering Committee to exercise overall responsibility for the implementation of this MOU. Reporting to the Steering Committee is a Working Group (WG) which identifies technological areas which could be the basis for future LTTPs and advises on the status of LTTPs currently in effect. For each LTTP, there is a Technical Group which cooperatively conducts research in that particular LTTP and reports to the Working Group.

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III. 4 Pwr AirSNR LTTP "Airflow Influence on Airdrop" (AIA)

The Airflow Influence on Airdrop (AIA) Technical Group is part of a Four Powers Air Senior National Representative (AirSNR) Long Term Technology Project (LTTP). The four participating countries are France, Germany, United Kingdom and the United States. The organizations for each country are as follows: France - DGA and ENSICA, Germany - BWB and IABG, United Kingdom - JATEU and AWC, and United States - Natick Soldier Center and USAF Academy. The focus of the AIA Technical Group (TG) is to develop and validate methods of predicting the airflow influence on airdrop missions. The specific objectives of the AIA TG are four fold: to identify key aspects of aircraft airflow influence on airdrop of personnel and cargo, to analyze possible aerodynamic effective aircraft extensions (e.g. flaps, spoilers, steps), to identify feasible technological solutions, and to recommend future follow-on activities that will mutually enhance airdrop capabilities. The predictive capability would then be used to determine if undesirable airdrop characteristics exist such as centerlining, deployment-bag/paratrooper contact, and paratrooper vortex interactions. Accomplishment of these specific objectives could increase safety for parachutists, loads, and aircraft, increase the landing accuracy of airdropped cargo, and increase the overall airdrop capabilities of aircraft.

The AIA effort has been broken into four major tasks. The first task was to develop and validate a detailed near-field simulation tool capable of reproducing the complex local flowfield of cargo aircraft, cargo pallets, and parachutes. The second task of the AIA is to perform detailed wind tunnel experiments of a representative cargo aircraft model (C-130H/K) in various configurations (e.g. clean, rear doors open, side doors open, and various deck angles) and compare to the CFD simulations of task one. The third task is to perform limited full scale in-flight measurements of the C-130K aircraft and compare to CFD simulations at similar flight conditions. The final task is to apply the developed simulation tools to full 3D coupled simulations of the cargo/parachute system in the near-field of the aircraft.

Accomplishment of the four tasks above will result in significant improvement of airdrop simulation capabilities. Specifically, concurrent validation of CFD and fluid-structure interaction (FSI) models against wind-tunnel test data and full scale test data. Also, comparison of various CFD simulation tools against each other. When successful, implementation, testing, and validation of full FSI capabilities/systems to include additional testing of instrumented payloads to allow for simulation and validation of personnel and cargo deployment dynamics from a C-130H/K aircraft.

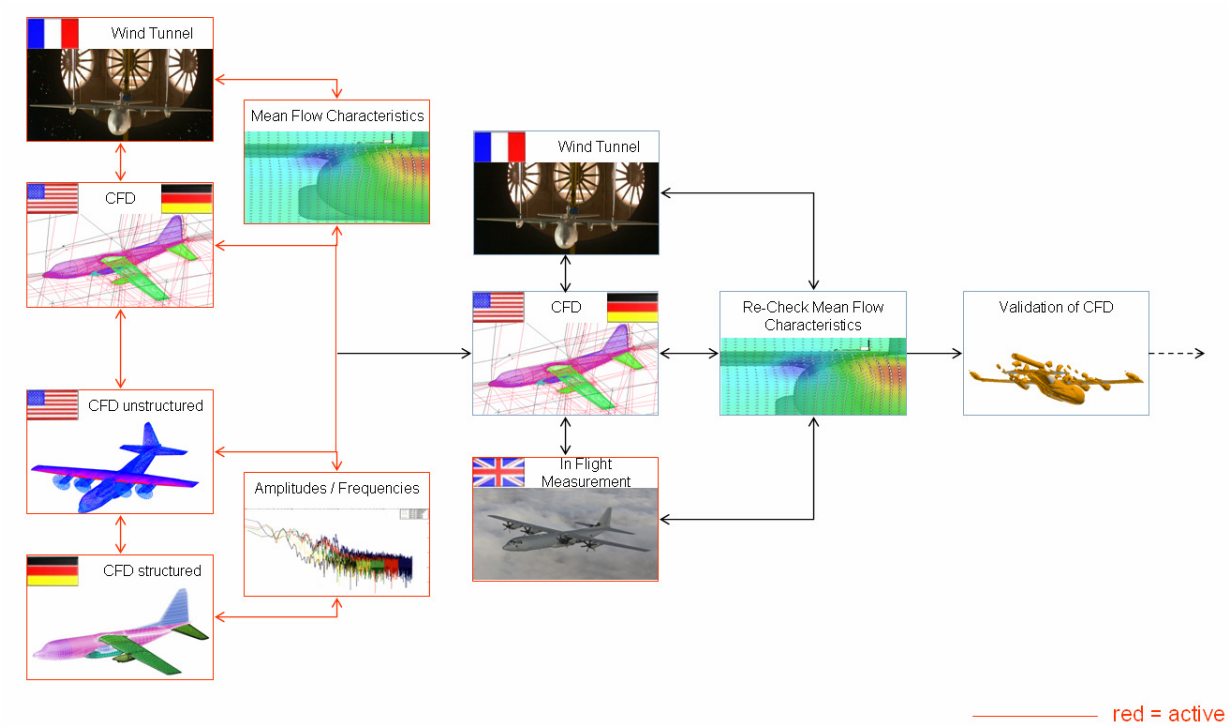

Figure 1: Airflow Influence on Airdrop CFD Validation Process.

The AIA long term technology project methodology to validate CFD simulation is depicted in Fig. 1 above. The initial tiers of the research are based on a coupled experimental-correlation approach between CFD and wind tunnel data. The comparisons comprise of both global variables such as lift, drag, and moment coefficients, as well as local variables, such as pressure and velocity profiles. The initial tiers also take into account various wind tunnel model scales by starting from a small 1/48th scale wind tunnel model/CFD correlation to obtain global variables and then increasing the model size to 1/16th scale to aid in detailed local flow field measurements of flow features such as the fuselage up-sweep vortex and the rear-door open vortices. The following discussion summarizes each tier of the research (see Fig. 1).

Initially, a study was carried out on a 1/48th scale C-130H model, referred to as Model#1 (see Fig. 2). Wind tunnel tests were achieved in the 3m by 2m open test section wind tunnel at ENSICA in France, using different measurement techniques such as weighting for global aircraft aerodynamic behaviour in different aircraft configurations (clean, side doors open, rear doors open), and 5 hole pressure probes for the characterization of the mean flow field in the near field of the closed cargo door aircraft. US and Germany performed unsteady and steady CFD simulations using unstructured and structured meshes developed from CAD and laser scans of the C-130 model using *Cobalt* and *Flower* software packages. Details of the flow field solver *Cobalt* can be found in Ref. [1] and the flow field solver *Flower* can be found in Ref. [2]. CFD simulations were compared to wind tunnel results for similar aircraft configurations, leading to a first estimation of turbulence scheme accuracy and mesh sensitivity in predicting such strongly-detached airflow in the near-field of a cargo aircraft.

Figure 2: Wind Tunnel Model #1, 1/48th scale C-130H installed in the ENSICA 3m x 2m open test section wind tunnel.

Results from the 1/48th scale C-130 model showed a need to increase the size of the model in order to improve local measurement resolution, and to be able to apply efficient unsteady measuring methods such as Particle Image Velocimetry (PIV) in the wind tunnel. As the main objective of this project is to develop efficient predictive tools of strongly detached airflow, it was decided to produce an additional wind tunnel model with a scale of 1/16th of the flight test vehicle and to simplify it to exclude wings and a detailed fuselage nose, keeping geometric properties of the so-called up-sweep zone. This new model is referred to as wind tunnel model#2 and is depicted in Fig. 3. As a consequence of this simplified shape, higher quality meshes are produced for CFD simulations. Currently, the AIA TG is producing CFD and wind tunnel results using wind tunnel model#2.

Figure 3: Wind Tunnel Model #2, 1/16th scale simplified C-130H model installed in the ENSICA 3m X 2m open test section wind tunnel. Simplifications include exclusion of wings and detailed nose shape.

Future work will include in-flight testing of the C-130H/K at airdrop flight conditions and aircraft configurations. CFD simulations will be performed at flow field conditions representative of these flight tests and qualitative comparisons made to verify the validity of the simulation approach. More detailed results of the ongoing research can be obtained in Ref [3].

IV. 4 Pwr AirSNR LTTP "2nd Precision Airdrop Improvement" (PAIc)

The Supplement to the Memorandum of Understanding (MOU) concerning 2nd PAI was established in October 2002 to continue the work of the former LTTP PAI (Ref. [4]) that had been running the previous five years.

The main topics of the 1st PAI were

- identification of error sources influencing airdrop accuracy
- quantification of error sources
- identification of the primary error sources
- suggesting methods to reduce the influence of the identified primary error sources

The former PAI Technical Group (TG) identified the following primary influences of airdrop accuracy:

- poor predictability and consistency of exit time (time the load needs to leave the aircraft)
- accuracy of wind and weather data for Calculated Air Release Point (CARP) calculations
- consistency of operational parachute systems (round chutes) and, associated with this, predictability of the rate of descent

Following this the former PAI TG ended up focussing on possible solutions to increase exit time accuracy and predictability.

The 2nd PAI TG carries out:

- national research on initiatives and development
- detailed comparison of corresponding initiatives
- detailed analysis of the key technologies
- investigations of the possibilities concerning error reduction
- comparison of selected different airdrop system configurations and scenarios
- observation of technology development in all potential areas for improvement of precision airdrop

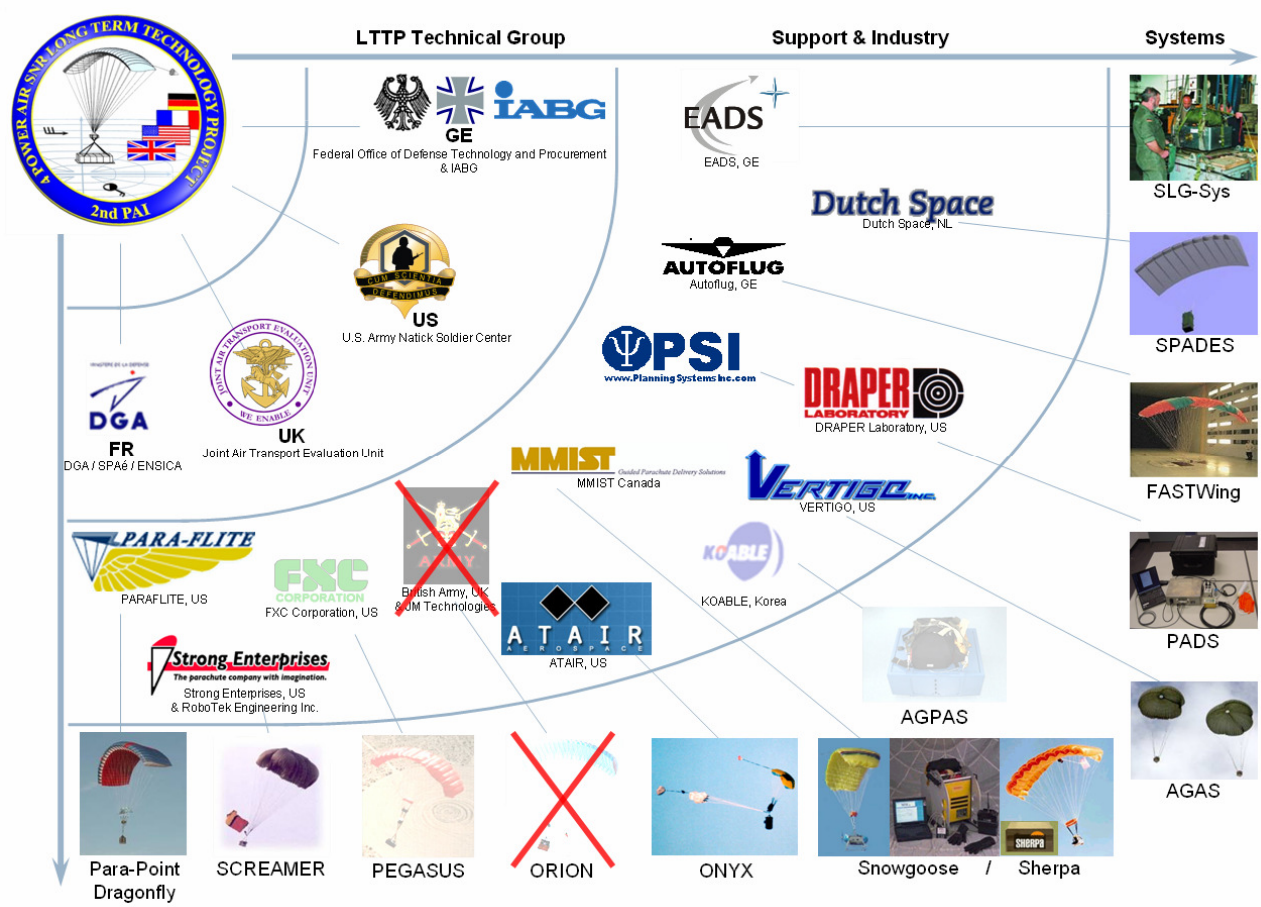

Figure 4: PAIc autonomous system overview. Pastel coloured systems are not yet observed. Red crossed systems are no longer developed.

The 2nd PAI TG is currently focusing its research efforts on:

- autonomous airdrop systems and
- wind and weather prediction and sensing

to provide to the governments of the four participating nations a wide overview of systems being available "off the shelf" or in development.

A. Autonomous Airdrop Systems

Autonomous Airdrop Systems navigate and steer to the target point self-directed. That has the benefit, that:

- delivery accuracy is less wind dependent than for unguided systems
- transport aircraft may drop the system from higher altitudes and greater offset distances from the target (landing point) which leads to increased crew and aircraft safety
- the possibility to flare some systems (i.e. parafoils) and thus reduce the system's ground impact should allow for the airdrop of delicate payloads

The 2nd PAI TG established contact with the leading contractors working on the development of autonomous airdrop systems. With consideration of industry proprietary information the PAI TG conducts interviews with industry to collect all technical data necessary to provide the best overview of current system capabilities for the governments of FR, GE, UK and US. Based on this data analysis research for the governments is carried out.

B. Wind & Weather Sensing and Prediction

Wind and weather prediction data influences the accuracy and the steering behaviour of autonomous airdrop systems. This is because of the pre-processing of the scheduled flight path which is computed by the steering and / or navigation unit of the airdrop system. Differences of the real-time weather conditions from those predicted may cause the system not to reach the pre-planned landing point as accurately as desired, which may lead to a total loss of system and payload.

In a first step, PAI TG compared measurement data from weather balloons with forecast data of the national military and civil meteorological services as well as data from drop sondes and wind measurement systems.

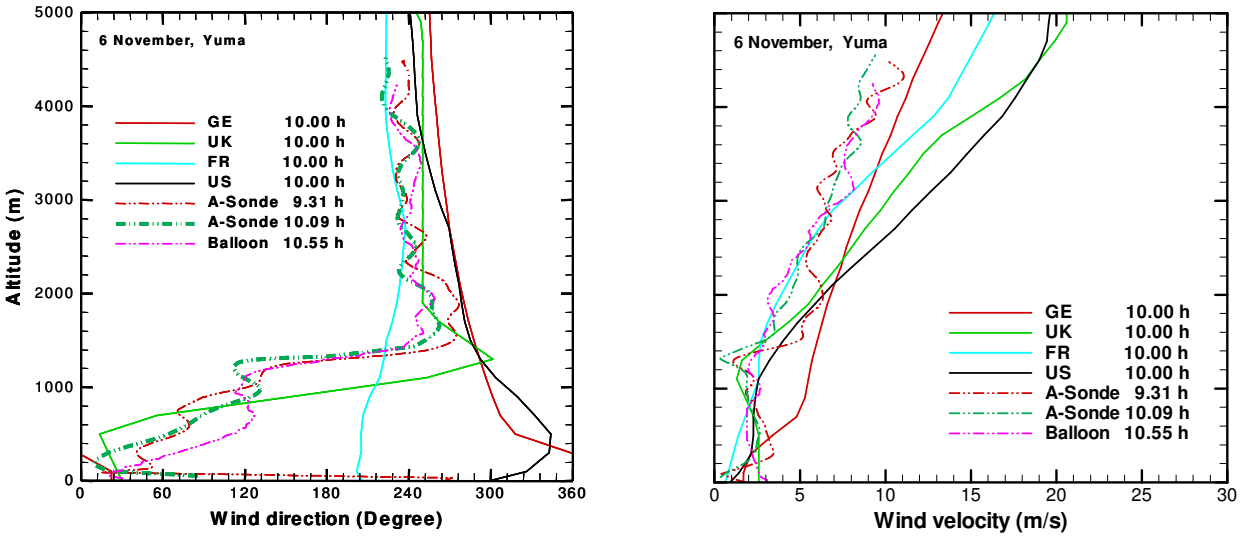

Figure 5: example from the PAIc measurement / forecast data comparison campaign 2003

Analysis of a very limited sample showed reasonable consistency of actual behaviour and a surprising variation between different nations' forecasts. All nations predicted direction accurately above 1500m but only the UK forecast was anywhere near actual low-level direction - despite the measurements being made on a US range. In contrast, all the forecasts predicted low-level speed well but under-estimated speed above 2000m.

To get a better idea of the accuracy of forecast tools, PAIc carried out a test campaign from the beginning of February 2005 until end of April 2005. In that campaign FR, GE, UK and US provided weather forecast data. Based on the data available from the latest available meteorology run, at 0600GMT each day a forecast for 0900GMT and 1200GMT was processed. At 1200UTC each day a forecast for 1500GMT and 1800GMT and a forecast for 0900GMT and 1200GTM of the following day were processed. During that period of time 3D wind measurements were performed using a ground based Doppler Radar. Comparisons are currently being made. The resulting average errors will be used to simulate the average influence of wind prediction accuracy on self guided systems and their capability to compensate. Results will be available at the end of 2005.

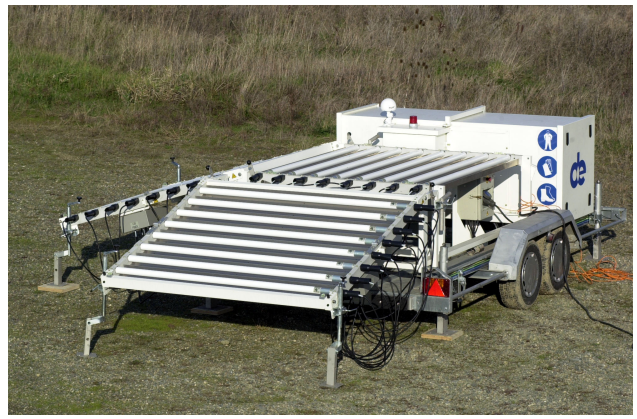

Figure 6: Ground based Doppler Radar (DGA / CEV / Toulouse).

C. NATO Joint Precision Airdrop Capabilities Working Group (JPACWG)

Precision Airdrop has recently received increased attention and prioritization within NATO. NATO requires the capability to deliver stealthily men (i.e. special forces), equipment, supplies and weapons in all types of weather conditions, at both extremely high and low altitudes, day and night and under a variety of different circumstances (Ref. [5-7]).

In addition to NATO requirements, many NATO Nations have generated their own National Precision Airdrop requirements.

The Defence Against Terrorism (DAT) prioritization was agreed to by the NATO Conference of National Armaments Directors (CNAD). The CNAD tasked the NATO Air Force Armaments Group (NAFAG) to take the lead on meeting the DAT requirements. The NAFAG assigned this work to Air Group 5 (see the organizational diagram below) which in turn established an ad-hoc Joint Precision Airdrop Capability Working Group (JPACWG) which was created in Sept 04 with a mandate expiring in June 2007

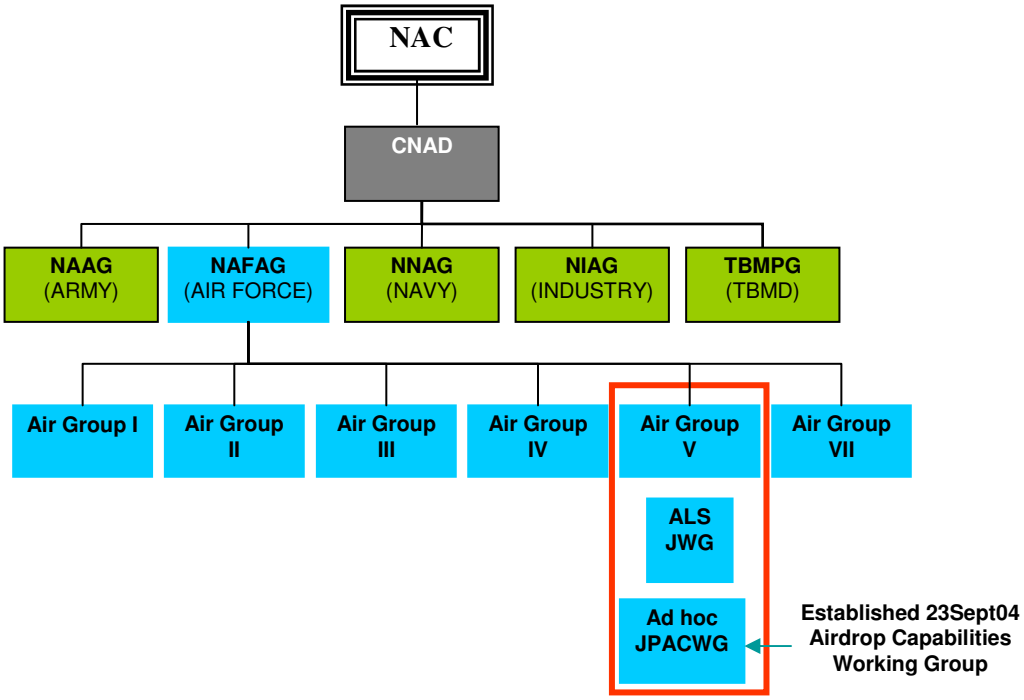

Figure 7: JPACWG related Organisational Diagram

The NATO JPACWG has established the following Precision Airdrop definition: "Precision Airdrop includes systems, which enable safe and accurate delivery of supplies, equipment, vehicles, and/or personnel from high altitudes (the definition of "high altitude" will be defined in the "Concepts of Operations" (CONOPS) and from a range of transport aircraft and helicopters. These include ballistic and/or autonomous parachute/decelerator systems (over a wide range of payload weights, offset capabilities, and accuracies), mission planning systems, weather forecasting and sensing systems, personnel navigation aids, related integrated communication systems (for use by/with Precision Airdrop systems) and there linkage and integration into the transport aircraft/ helicopters."

The JPACWG Plan of Work (see Figure 8) includes the following deliverables:

- Matrix of current National Precision Airdrop systems and the associated mission areas they support. Matrix to be developed by Nations with the support of industry and to be delivered at the end of the WG mandate
- Development of a Precision Airdrop Technology Roadmap to be developed with the support of NATO Research Technology Organization (RTO) and Industry.
- NATO Concept of Operations: CONOPS to be developed with the support of NATO organizations such as the Allied Command Transformation (ACT) and National operational experts.
- Proposed NATO Standards (STANAG) to support Alliance interoperability.

The JPACWG is actively seeking support and expects help from the following organizations:

- NATO Industry Advisory Group (NIAG) Study
- NATO Research Technology Organization Support

Demonstrations needed to prove precision Airdrop concepts/systems. The first of these will be a Precision Airdrop Technology Conference And Demonstration (PATCAD) during the week of 17-21Oct05 in the US. (Information about the previous PATCAD in 2003 can be obtained in Ref [8].)

Objectives:

- Demonstrate emerging technologies/systems capabilities in Precision Airdrop
- Expose senior NATO leaders/decision makers to emerging precision Airdrop capabilities/systems.
- Expose a larger audience from NATO to precision airdrop systems, technologies, capabilities and their military utility.
- Early look at Standardization and Interoperability considerations for precision airdrop systems.
- Foster joint NATO/coalition development on some common precision airdrop programs.
- Promote additional coalition partnering (interoperability, commonality, joint project agreements…)
- Demonstrate Capabilities for potential use by the NATO Response Force (NRF)
- Collect the maximum amount/appropriate quantity/quality test/demo data

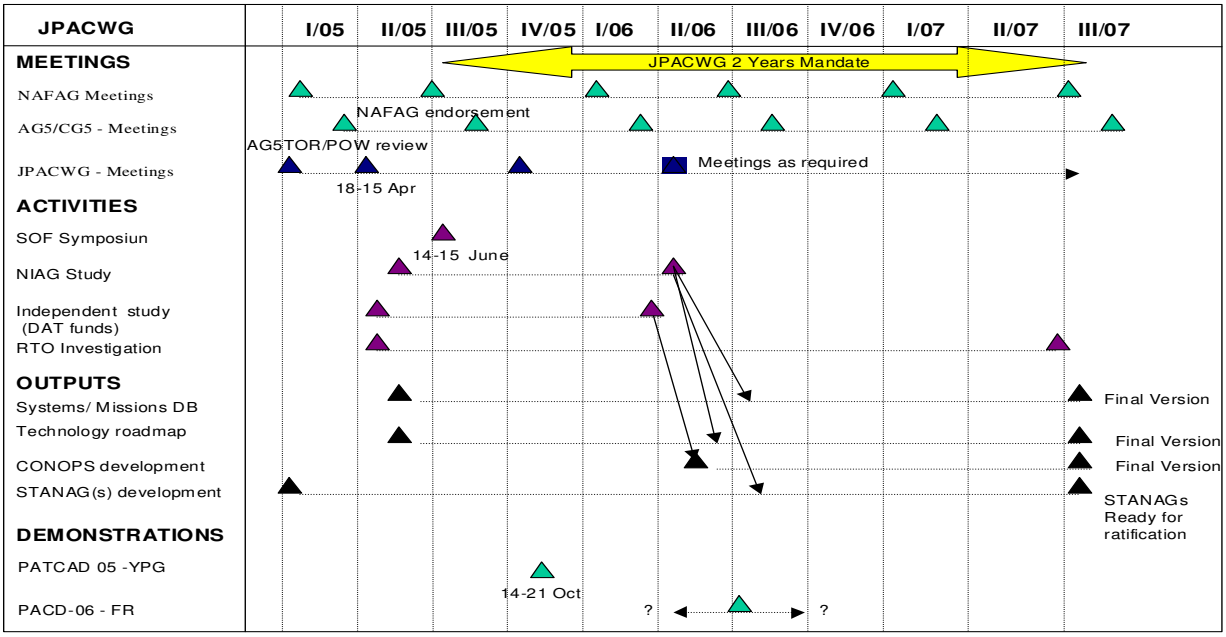

Figure 8: JPACWG Work Schedule

V. References

[1] Strang, W.Z., Tomaro, R.F., Grismer, M.J., "The Defining Methods of Cobalt: A Parallel, Implicit, Unstructured Euler/Navier-Stokes Flow Solver," AIAA 99-0786, January 1999.

[2] H. Koerner and R. Radespiel, "Some recent advances in aerodynamics of DLR", AIAA-1998-136, Aerospace Sciences Meeting and Exhibit, 36th, Reno, NV, Jan. 12-15, 1998

[3] M. Claus, S. Morton, R. Cummings, and Y. Bury "*DES Turbulence Modelling on the C-130 Comparison Between Computational and Experimental Results*", AIAA-2005-884, 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, Jan. 10-13, 2005

[4] Bagdonovich B., Desabrais K., Benney R., Seeger M., Fossat F., Vallance M., Carlsson P., "*Overview of the Precision Airdrop Improvement 4-Powers Long Term Technology Project*", AIAA paper 2003-2102 presented at the AIAA Aerodynamic Decelerator Systems Conference, May 20-23, 2003, Monterey, California, USA.

[5] NAFAG Strategic Enduring Themes: Global Operation / Distributed Operations, Ref: AC/224-N(2003)0006

[6] LTCR: Long Term Capability Requirement on "Precise delivery of equipment and supplies by air drop" (LTCR MF06-4 - AC/224-N(2004)0002)

[7] DAT Defence Against Terrorism requirement on "Precision Air Drop Technology for Special Operations Forces" (DAT-5 - Ref.: AC/259-D(2004)0023 FINAL)

[8] R. Benney, J. McHugh, J. Miletti, P. Mortaloni, "*Planning, Execution, and Results of the Precision Airdrop Technology Conference and Demonstration (2003)*", AIAA paper 2005-1668 presented at the AIAA Aerodynamic Decelerator Systems Conference, May 23-26, 2005, Munich, Germany.