

## **ALBAS: An Integrated Software for Carrying Out Parametric Vulnerability /Lethality PLEIADES/A Calculations**

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### **ABSTRACT**

*ALBAS<sup>1</sup> is an integrated software which enables to set, to run, to manage simulations done with the computerised endgame code PLEIADES/A<sup>2</sup> which is the DGA modular software suited for vulnerability studies of air systems (aircraft, helicopter, UAV,...) attacked by conventional weapons and anti-aircraft weapons lethality assessment.*

*Via the ALBAS Graphical Users Interface (GUI), parametric PLEIADES/A calculations can be runned. Selected parameters refer to target, threat, damage mechanisms and terminal effects and engagement geometry.*

*ALBAS engagement scenarios increase in value concern possibility to select burst points grid, burst points cloud, burst points at different miss distance and shot line. ALBAS offers possibilities to take into account uncertainties of parameters (i.e. burst point on a given shot line and miss distance) by applying a random choice of them according Monte-Carlo methods. Kill Probability (Pk values) in this probabilistic approach are done in terms of standard deviations around average values. Computing can be divided in sub-computing which are submitted each of one to one processor of the CEG ATLAS supercomputer.*

*Concerning output computing, ALBAS offers capabilities of treatment of fully results Excel tables. Statistical analysis can be conducted.*

*In conclusion, ALBAS which is based on PLEIADES/A algorithms, offers large capabilities for carrying out parametric computing using the entire CPU of the CEG supercomputer.*

### **1.0 INTRODUCTION**

As indicated above, ALBAS is based on PLEIADES/A algorithms. That's why, the first step of the paper is to remind some general remarks about PLEIADES/A : its current capabilities and its current studies conducted to improve the code. These improvements concern specifically damage mechanisms and terminal effects topics. The second step of this paper consists in a detailed presentation of ALBAS, the integrated software. Finally, bonus capabilities offered using ALBAS post processing are detailed.

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<sup>1</sup> ALBAS : Atelier Logiciel de Bombardement d'Aéronef au Sol

<sup>2</sup> PLEIADES/A : Produit Logiciel d'Etude des Infrastructures et des Aéronefs et de Détermination de l'Endommagement de leurs Systèmes/Aéronefs

## **2.0 OVERVIEW OF THE PLEIADES/A SOFTWARE ([1], [2], [3])**

The Centre d'Etudes de Gramat (CEG) is the French Defence Procurement Agency (DGA) establishment, in charge of developing and linking software devoted either to the anti-air or anti missile warfare assessment.

PLEIADES/A is a modular software suited for vulnerability studies of aircraft attacked by conventional weapons or anti-aircraft weapons lethality assessment.

### **2.1 Methodology to evaluate the vulnerability of an aircraft submitted to a conventional threat (Figures 1, 2)**

A probabilistic methodology is employed to evaluate the air vehicle vulnerability; this methodology is based on models of:

- the engagement geometry, the threat against which the vulnerability of the weapon system must be evaluated, the target and the effects of the threat on the target. With this information, influence of degradation of the functioning on component level is used to determine the functioning of the complete target by using a so-called fault tree analysis.

Threat and target basic models, vulnerability data and fault trees are obtained by using

- numerical simulations using full physics codes (namely Ouranos and/or Abaqus) to understand physical phenomena by reaching specific parameters not available through trials,
- physical experiments conducted on small-scaled targets (sample, structure model) or decommissioned target (specifically aircraft).

#### **2.1.1 Engagement geometry**

The encounter conditions describe how the warhead intercepts the target: threat location and orientation with regards to the target, target and threat speed vectors.

#### **2.1.2 Threat**

Threats taken into consideration are bullets, fragmentation warheads and KE ammunitions. Direct hit may also be achieved by taking into account missile body. Warhead models data are number of fragments, mass, ejection angle, ejection velocity, material and fragments position tables

#### **2.1.3 Targets**

Targets are fighters, transportation aircrafts, helicopters, UAV, missiles and land base radars. Target model consists of :

- a geometry including components whose damage or loss could lead to the target kill, a physical properties tables used for perforation computations (thickness, name and nature of materials,
- vulnerability data (destruction criteria tables) representing kill probability of an equipment given a threat. With the knowledge of effects of the threat on target (ie an aircraft), the influence of the degradation of the functioning on component level is used to determine the

functioning of the complete target by using the fault-tree analysis (FTA).

#### **2.1.4 Damage mechanisms and terminal effects**

Two mechanisms are taken into account :

- blast loading : depending on the warhead and fusing, the blast may be external or internal to the target (ie an aircraft),
- fragment kill mechanisms : damage inflicted on target depends on number and location of fragments impacts and on terminal effects parameters. Fragment kill mechanisms are function of target and fragments types, they are defined as follows
  - functional damage : a fragment may lead to the component function loss or degradation (ie tank leakage or control rod cut),
  - incendiary effects : vapours of kerosene are sensitive to the impact of a bullet or a fragment spray on a fuel tank ullage. An explosion of the fuel air mixture can occur, an overpressure could lead to a tank rupture, could damage surrounding structure and conduct to complete aircraft disintegration,
  - hydrodynamic Ram : HRAM is the development in a fluid, of shock waves caused by a ballistic penetrator (bullet, fragment,...).
  - synergistic effect of fragments : this effect happens when a large number of fragments impact at the same time a small area. A damage criterion  $C_S$  defined experimentally is a function of fragment kinetic energy  $E$  and the area size  $S$  that was struck.

#### **2.1.5. Fighter vulnerability assessment**

Vulnerability of an aircraft to an externally detonating warhead is usually analysed in two separate steps. One step is a determination of the aircraft structural vulnerability to the synergetic effects of blast and fragment spray and the second one examines aircraft's functional vulnerability to effects of a unitary fragments.

#### **2.2 PLEIADES/A outputs**

The PLEIADES/A modular software gives for an aircraft target, the following outputs:

- Projectile flight and path through the target (including velocity decay as a function of drag and presented area), projectile velocity and mass decay while perforating the target,
- Components of air target probability of kill from impact,
- Multiple hit synergetic effect, hydraulic ram, blast load and response of the structural parts (altitude dependant),
- Component probability of destruction from blast, probability of kill or survivability of the whole aircraft, given a hit (single hit or salvo) obtained through the fault tree and all the components or structure kill probabilities.

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### 2.3 PLEIADES/A functionalities

Via a Graphical Users Interface (GUI), PLEIADES/A calculations can be run according two modes: an interactive mode or a batch mode.

The interactive mode provides:

- Manage target and warhead database, set interaction parameters, calculate step by step since burst point date,
- Visualise partial and global results with graphical interfaces, calculate lethality grid<sup>3</sup> ([3]), create probabilities table for bay target model, record all significant operations

The batch mode provides:

- Replay recorded operations; compute multiple simulations and their post processing.

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<sup>3</sup> The software projects a Cartesian grid onto the target [3]. The probability of neutralization of the target's functions following the impact of a projectile are then calculated at each grid cell centre considering a direction of impact perpendicular to the grid. A ray tracing based calculation is then performed so that to evaluate the level of damage and, as consequence, critical components breakdown, providing finally the kill probabilities of the affected functions

## 2.4 PLEIADES/A current improving activities

As represented in the figures 1 and 2 and indicated above, physical experiments conducted on small-scaled targets (sample, structure model) or decommissioned aircraft have been conducted at CEG since the 1980's. After that, since the 1990's, numerical simulations using full physics codes (namely Ouranos and/or Abaqus) have been realised at CEG. These tests and calculations (models assessments) have permitted to analyse and evaluate effects of different types of threat on component or group of components. Functioning of the complete target (i.e. an aircraft) after possible degradation at the component level is done using the FTA analysis.

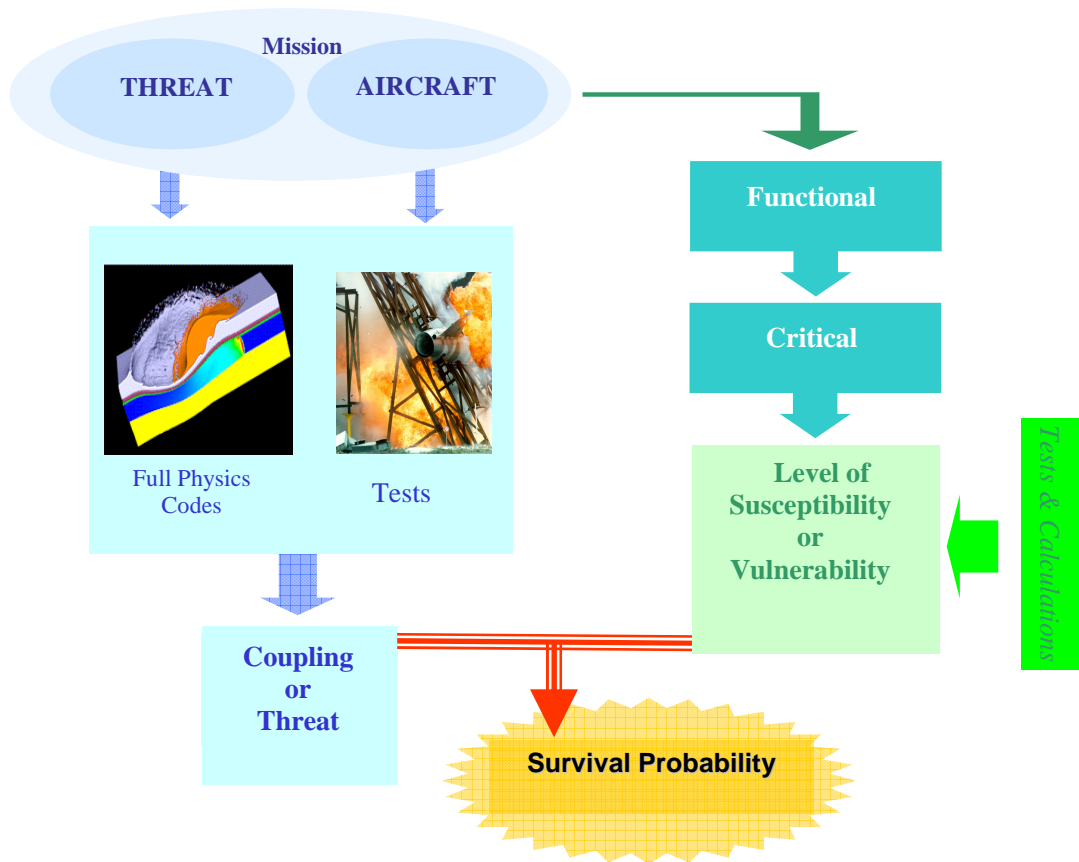


Figure 1 : Vulnerability analysis methodology

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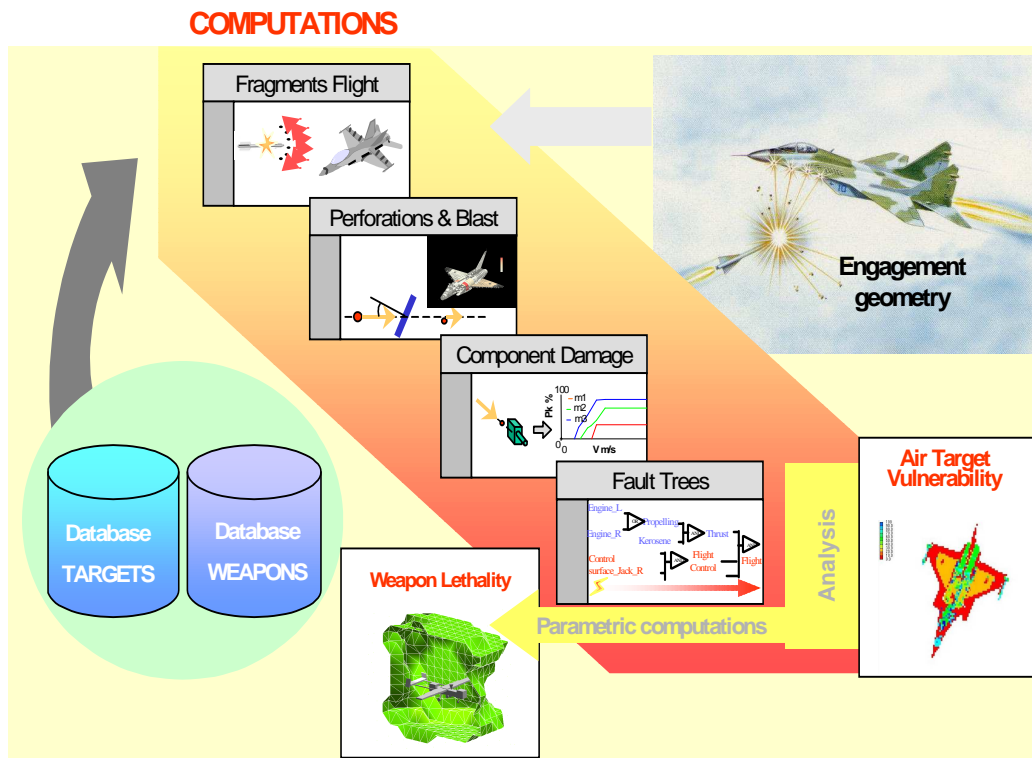


Figure 2 : Vulnerability assessment tool

Actually, two specific studies focused on the “damage mechanism” are conducted; the first one concerns incendiary effects, more precisely the effect of an explosion in an aircraft fuel tank. The second one is a study related to high velocity impact of carbon composite planes.

In addition to these studies, one work have been done and another one is still in progress

- a comparison of air and land vulnerability/lethality assessment tools used within NATO,
- a new generation of PLEIADES framework which leads to successful homogenization of lethality softwares and models in the French Defense Procurement Agency (DGA). This new generation of PLEIADES offers services in conjunction with different lethality model assemblies to perform studies on infrastructures (PLEIADES/I (infrastructures vulnerability – air to surface weapons lethality)), aircrafts (PLEIADES/A (aircraft vulnerability)), missiles (PLEIADES/TBM (Theatre Ballistic Missile Defence)) and vehicles (PLEIADES/T (vehicles))

### 2.4.1. Incendiary effects: effect of an explosion in an aircraft fuel tank ([4], [5], [6], [7], [8], [9], [10], [11])

The flammability of kerosene is commonly discussed in the context of the potential danger ignition of kerosene vapour in an aircraft fuel tanks due to the impacts of any projectile (fragment, bullet,...). This subject is investigated by the team research RES of the Laboratory PRISME which belong to the University of Orléans.

An instationary and weakly compressible combustion model based on a multi-physic code integrated

and resolved in the Comsol environment is in progress. An adapted and simplified kinetic law deduced of a specific law [5] is used. First numerical results have been compared to experimental one [6] obtained in a close cylinder (diameter 20.5 cm, high 40 cm, volume 13,2 litre).

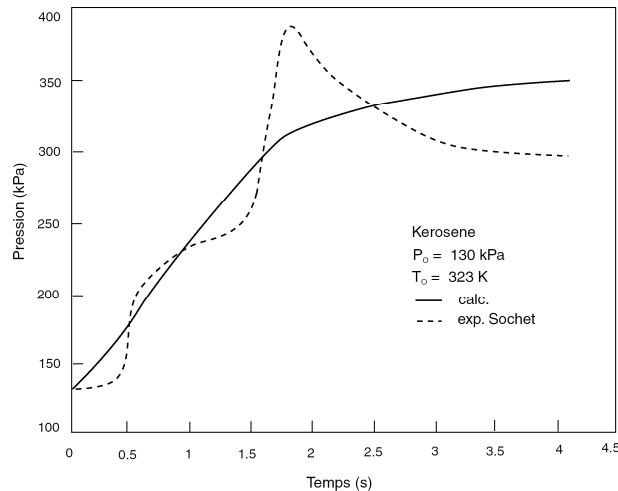


Figure 3 : Experimental and numerical pressure versus time in a vapour mixture air/kerosene close cylinder (Pressure  $1.3 \cdot 10^5$  Pa, Temperature 323°K, concentration 1.27, ignition condition a 600°K lateral wall)

Experimental (dotted line) and numerical (constant line) variations of pressure versus time inside the cylindrical tank are presented in the figure 3. Numerical ignition conditions of the air/kerosene vapour correspond to the lateral wall on which a temperature of 600°K is applied. This hypothesis reaches in term of energy, the experimental ignition condition realised by an exploded wire (around some ten joules). The temperature contour inside the cylinder after ignition of kerosene/air mixture is given in the figure 4 (ignition conditions consisting of 600 K applied on the total right lateral wall). The kerosene concentration contour at the same time is given in the figure 5. Higher temperatures are registered where the kerosene concentration is lower (top of the vessel).

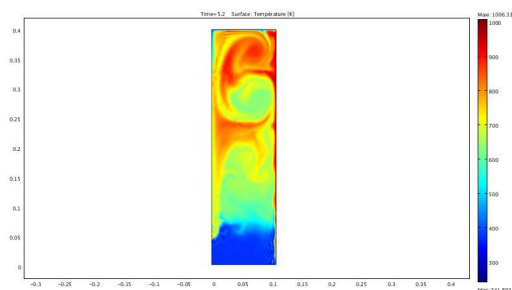
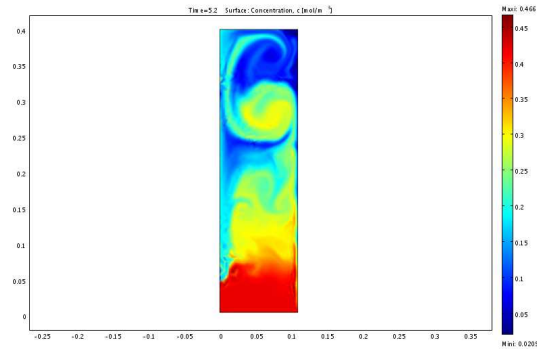


Figure 4 : Temperature repartition after ignition of kerosene/air mixture

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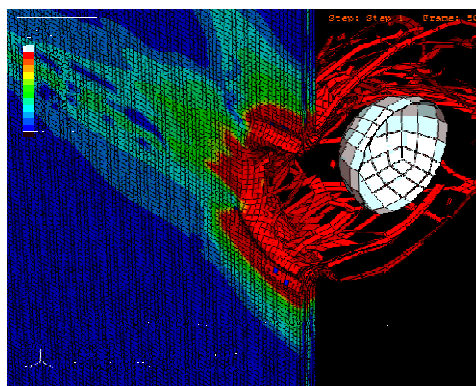
**Figure 5 : Kerosene concentration repartition after ignition of the mixture**

Capabilities of introducing in the numerical model a more realistic ignition surface are studying. In fact, the challenge is to represent the effective impact of the fragment or the bullet (size, temperature) on the wall of the tank. A simplified kinetic reaction law is tested in order to reduce the calculation times.

### 2.4.2. High velocity impact of carbon composite planes [12]

Until then, PLEIADES/A modular software has been developed for metallic structures. The objective of this numerical and experimental study is to add composite structures in the component damage data base.

A PhD's work performed by E. Jacquet [12] consisting on developing a meso mechanic model has been done. Numerical simulations of impact on carbon/epoxy laminate, based on Ladeveze [13] model and adapted to dynamic sollicitation have been conducted (Fig. 6). This meso mechanic model focus on elementary ply damage and on the interface mechanism between plies has been validated with experimental tests.



**Figure 6 : Numerical simulation of an impact of a rigid spherical projectile on carbon/epoxy laminate**

These experimental tests have been conducted in CEG's facilities (powder gun (Fig 7) or



double stage light gas gun).

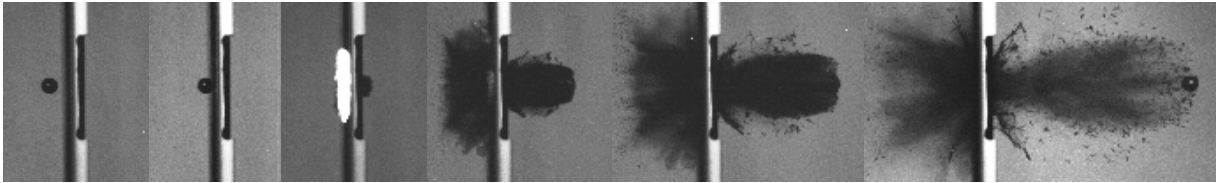


Figure 7 : Projectile : 10g and 1 000 m/s – Target : carbon/epoxy 500x400x3,4 mm<sup>3</sup>

After the validation of the meso mechanic model, the next stage is to build an analytical model with a large number of numerical simulations (application of a statistically based procedure with in fine the determination of a predictive mathematical model). Finally, this analytical model will be implemented in the composite component damage PLEIADES/A data base.

#### 2.4.3 Comparison of air and land vulnerability/lethality assessment tools used within NATO [14], [15]

Within NATO, many nations have the capability to conduct lethality assessments of weapons and vulnerability assessments of platforms including (but not limited to) aircraft, helicopters, ships, APCs, MBTs and soft skinned vehicles.

The AVT-127 collaboration (October 2004 → May 2007) involved five nations (France, Germany, Netherlands, Spain and the UK) in the comparison of results from national assessment tools to determine the performance of an anti-air warhead against a combat aircraft and an armour piercing shell against an APC (except France for this land target). Common definitions of these weapons and targets were developed and exchanged within the task group. Results from the individual assessments are presented along with a number of comparative charts demonstrating the consistency of the results to determine the likely outcome of the modelled engagements.

The air assessment used the Russian Su-47 Berkut (Fig 8 & Fig 9) fighter demonstrator as the target with the UK providing a detailed geometric description in their INTAVAL format. The threat was agreed upon as being a 20kg axi-symmetric warhead based loosely upon a weapon in the AIM-120C AMRAAM class, this too was provided by the UK.



Figure 8 : Russian SU-47 Berkut

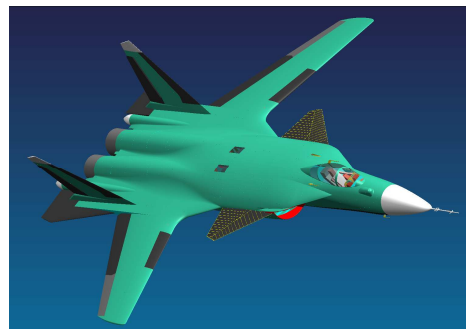


Figure 9 : SU-47 PLEIADES/A model

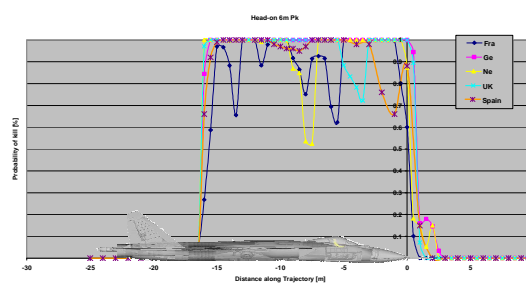
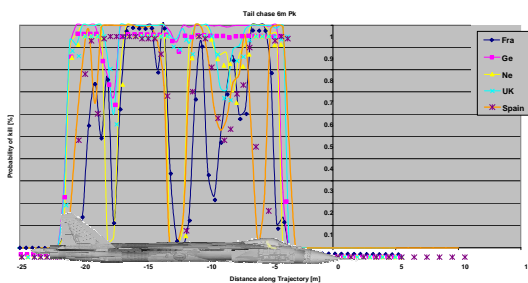
The participating organisations and the air assessment models employed are provided at Table 1.

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Nation	Establishment	Assessment Model
France	Centre d'Etudes de Gramat, CEG	Pleiades A
Germany	IABG	UniVeMo
Netherlands	TNO	TARVAC
Spain	Instituto Tecnológico de Defensa, ITM (formerly LQCA)	AVAL
UK	Defence Science & Technology Laboratory, Dstl	INTAVAL

**Table 1 : Air Environment Participants**

Two encounter situations, head-on and tail chase, with a variation of three miss distances (3,6 and 10 m) were selected to generate comparable results. The results showing the probability of kill are shown in figures 10 and 11. Each data point represents a burst point at 6 m distance to a horizontal axis running through the aircraft originating from the tip of the radome. The burst points are in incremental steps of 0.5m.



**Figure 10: Pk value for the 6 m tail chase case**

**Figure 11: Pk value for the 6 m head-on case**

The overall results show a good agreement with trends for areas of high and low Pk being consistent across all five nations. Nevertheless, there are some areas where the resulting Pk values differ. This is due to a number of reasons based upon target geometry and small variations in methodologies applied for instance: the use of perforation instead of penetration as a damage mechanism; and the interpretation and conversion of damage scoring rules.

### 2.4.4 New PLEIADES framework

This work is presented at this conference [16]. This new PLEIADES framework includes PLEIADES/A and ALBAS. This new PLEIADES framework leads to successful homogenization of lethality softwares and models in the French Defence Procurement Agency (DGA).

## 3. PRESENTATION OF THE INTEGRATED SOFTWARE “ALBAS”

ALBAS is an integrated software which enables to set, to run and to manage simulations done with the vulnerability/lethality endgame code PLEIADES/A.

ALBAS provides the following possibilities:

- parametric calculations relied on multiprocessor CEG Atlas system<sup>4</sup>,
- taking into account uncertainties of some engagement geometry parameters,
- assemblies of results, statistical treatments or analysis of results

The current ALBAS version (V2.3) configuration is the following: PLEIADES/A routine (12852 Fortran 90 source lines in 138 files), GUI (5759 TCL/TK script lines in 96 files), External 3D viewer called (OpenDX V 4.3.2, Para View V 4.2, Tecplot V 360 2008)

### 3.1 Albas capabilities

#### 3.1.1 Engagement geometry choices

By Albas GUI (Fig 12), an end user can select input data (type of charge, altitude, target and weapon speed, miss distance, coordinates, type of simulation and kill mechanism (HRAM, blast, fragment,...)).

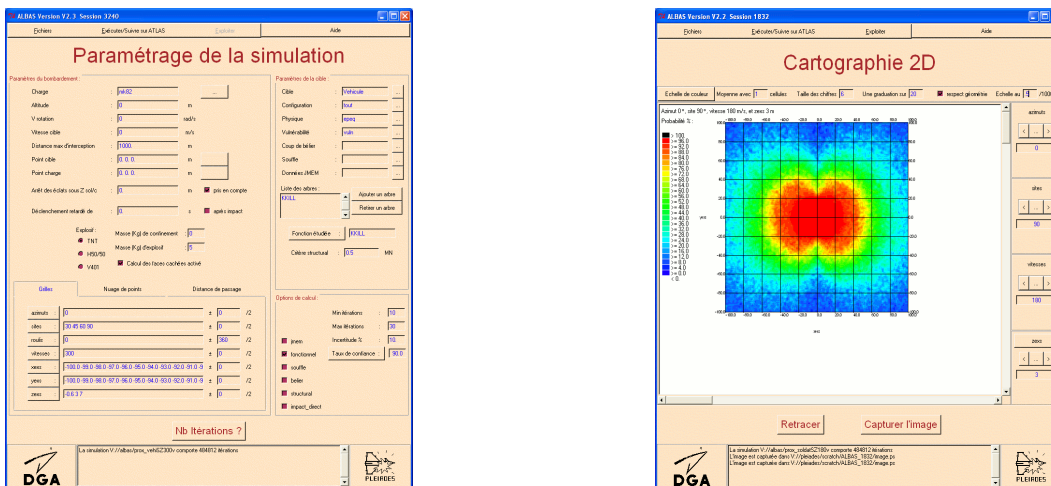


Figure 12: Possibility to run parametric calculations via Albas GUI

Albas offers the possibility to set up three types of engagement scenarios. The first one (Fig 13) is call

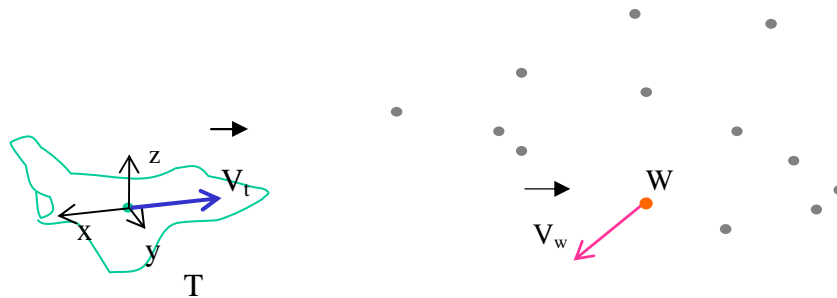
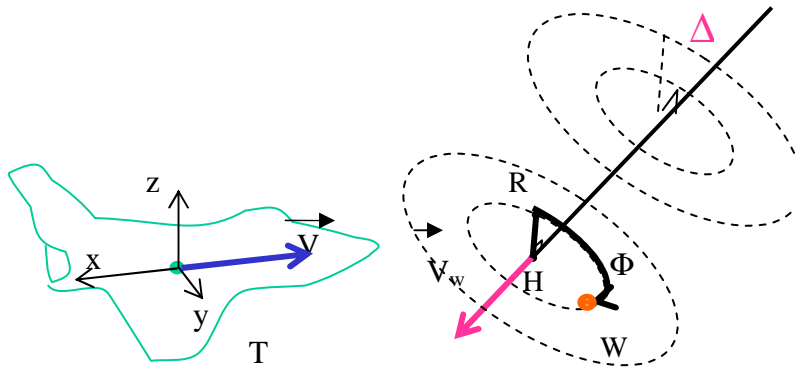


Figure 13 : “explosion cloud points” engagement

<sup>4</sup> ATLAS is a server provided by Silicon Graphics to CEG. Atlas is an Altix 3700/4700 multiprocessor system with a 3 x 64 Itanium processors of 128 GBytes and a 1 x 48 Itanium double CPU of 192 GBytes. It totalizes 576 GBytes memory with 288 nodes to deliver 1.7 Tflops power.

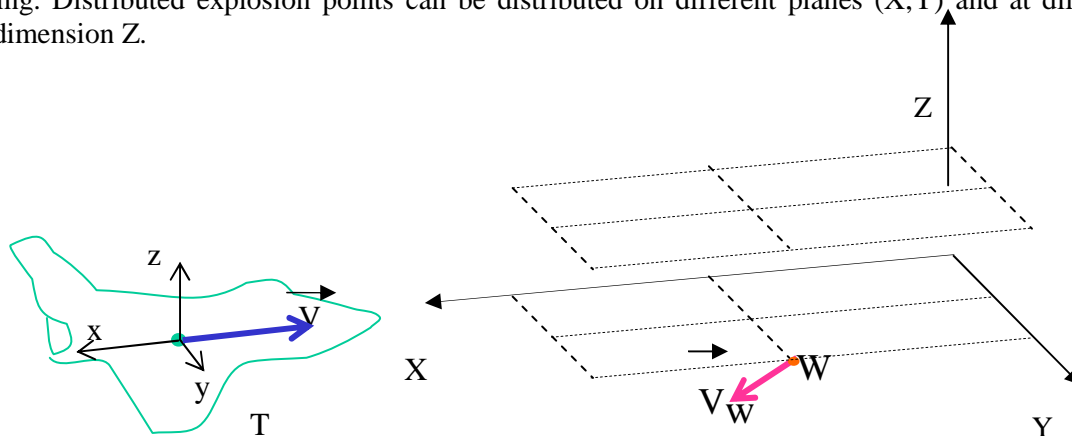
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“explosion cloud points”. This type of simulation is not a dedicate one because it’s about any engagements which don’t obey to some definite logic. Each burst point W has its own trajectory and velocity, these values are taken from a file provide by another code (i.e. delayed fusing values,...). The second one (Fig 14) is based on the miss distance concept along a weapon trajectory. It’s characterized by the following parameters:  $\Delta$  (weapon trajectory or burst line), RH (miss distance),  $\Phi$  (phase)



**Figure 14: miss distance engagement**

This type of scenario has been set to fulfil missile manufacturer needs in order to assess the lethality of their systems in terms of proximity. Explosion points can be located at different points of the  $\Delta$  weapon trajectory. Different values of miss distance and phase can also be introduced via Albas. This allows a large number of scenarios. The last scenario (Fig 15) is based on the concept of plane grids of bombing. Distributed explosion points can be distributed on different planes (X,Y) and at different third dimension Z.



**Figure 15: plane rectangular grid engagement**

Different ranges of parameters can be introduced by Albas GUI : discrete values or sequential arithmetic values.

Another possibility offered by Albas is to introduce uncertainties around burst points distributed according a constant interval along the  $\Delta$  line. The purpose of this process is to assess a Pk representative value at each of this burst point.

Figure 16 illustrates this exercise for a miss distance engagement (this exercise is also valid for a grid bombing engagement). To assess a representative Pk values at burst point  $X_4$ , up to N iterations are

calculated until a given convergence criteria is satisfied. Iteration  $i$  ( $i < N$ ) consists to evaluate Pk damage with PLEIADES/A for a random  $i$  point near  $X_4$  and calculate its average with all previous Pk. This action is called “random sampling” around each burst point. Convergence criteria are satisfied when Pk average between two consecutive iterations is lower than a given error.

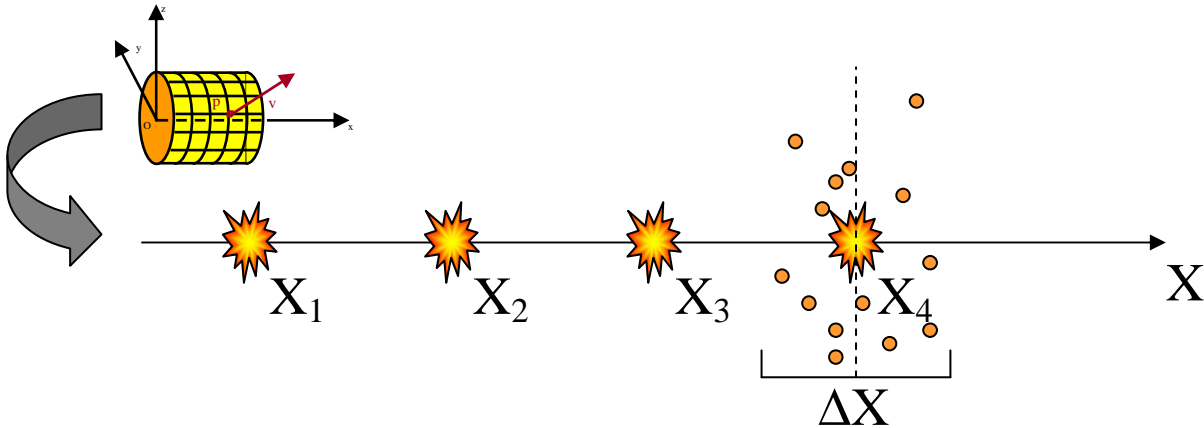


Figure 16: burst point random choice

This exercise is conducted for each burst point  $X$ . This statistical approach leads to better representativeness of Pk values deduced from more realistic engagement scenarios.

### 3.1.2 Running calculations on the Atlas system

A PLEIADES/A calculation executed from ALBAS GUI can conduct to ten thousand of iteration, especially if cases represented in the figure 16 are executed. ALBAS GUI allows the end user to distribute these iterations on several and separate Altix processors.

In practice, an end user can, by the ALBAS GUI, selected an above engagement type and families of parameters, then a number of processor to use and finally a maximum CPU time by processor.

### 3.1.3 Albas capabilities concerning PLEIADES/A post processing

External 3D viewer above mentioned combined to numerous parametric calculations which can be run with the above Albas capabilities, gives the user, a large choice of post processing.

Figures 17 and 18 represents classic Pk contours, the first one (Fig 17) in a cross circular section around the symmetrical axe  $\Delta$  (Fig 14), the second one (Fig 18) corresponds to Pk contour located in a grid rectangular engagement scenario (Fig 15).

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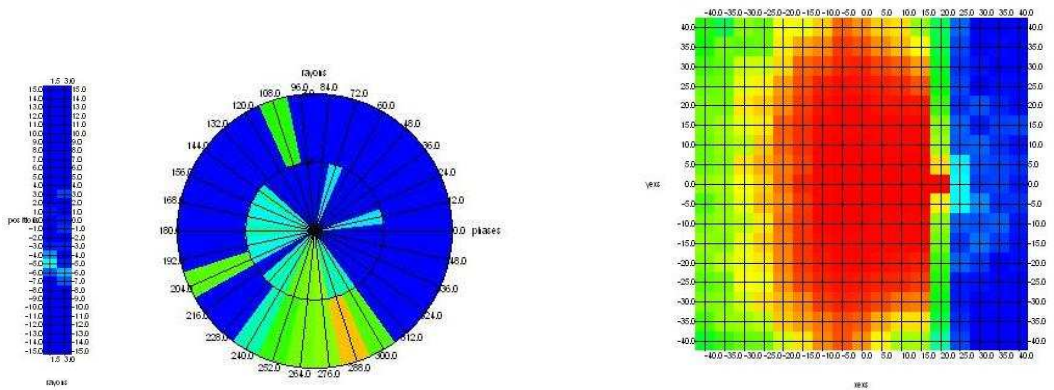


Figure 17: Pie chart Pk contour cross section H, R,  $\Phi$  F    Figure 18: Pk contour in a rectangular grid (cf. fig 15)

Figures 19 and 20 illustrate other possibilities of outputs visualisations.

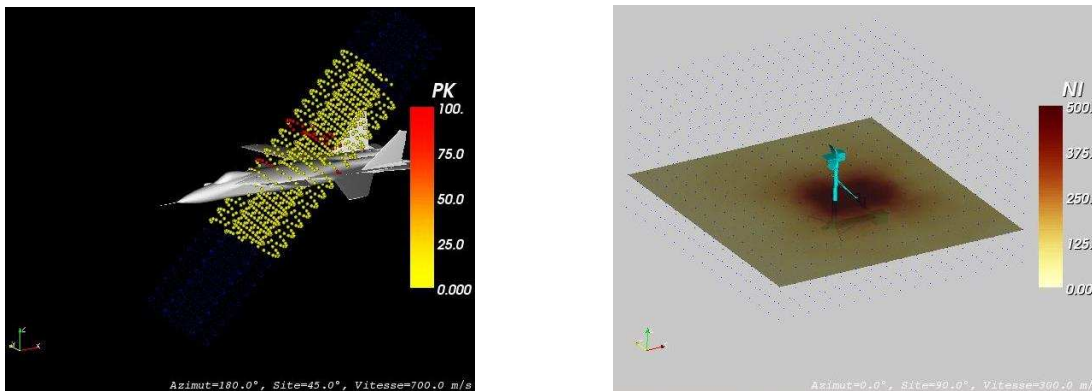


Figure 19: Pk values around a given weapon trajectory    Figure 20: Impact fragment number on a land radar base

Large number of values (i.e. Pk, hit fragment number) are delivered by PLEIADES/A. With Albas, the end user can treat this important among of data and obtain synthetic results which are useful and essential for a global or a sophisticated analysis. Albas GUI contains some statistical treatment functions.



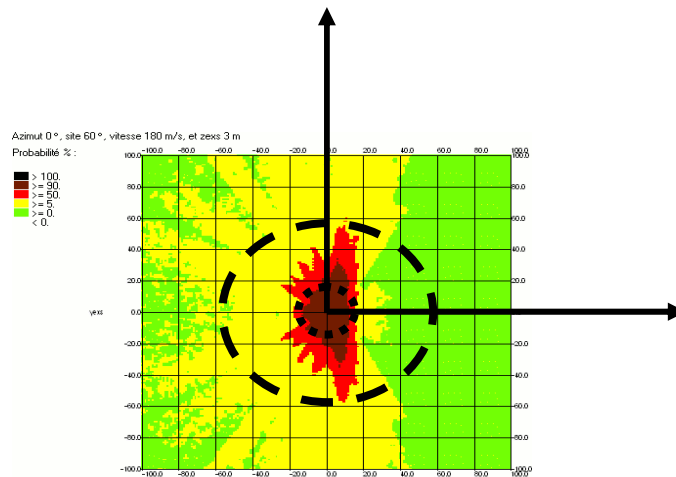


Figure 21: Lethality/vulnerability type of results

Some results can be presented in terms of lethality or vulnerability. On figure 21,  $P_k > 50\%$  are located in brown and red zones. The large dotted circle concerns vulnerability topic, in this circle, the aggressed system is vulnerable. The small dotted circle is related to lethality, if you concentrate your attack inside this circle, the  $P_k$  of the the given target is around 100%..

For plane rectangular grid engagement, some results can be presented in terms of  $P_k$  gradient uncertainties (fig 22; variation of  $P_k$  called  $\Delta P_k$  stated in a percentage)

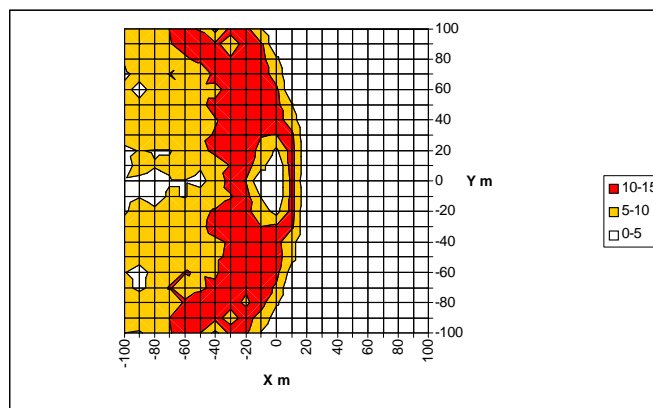
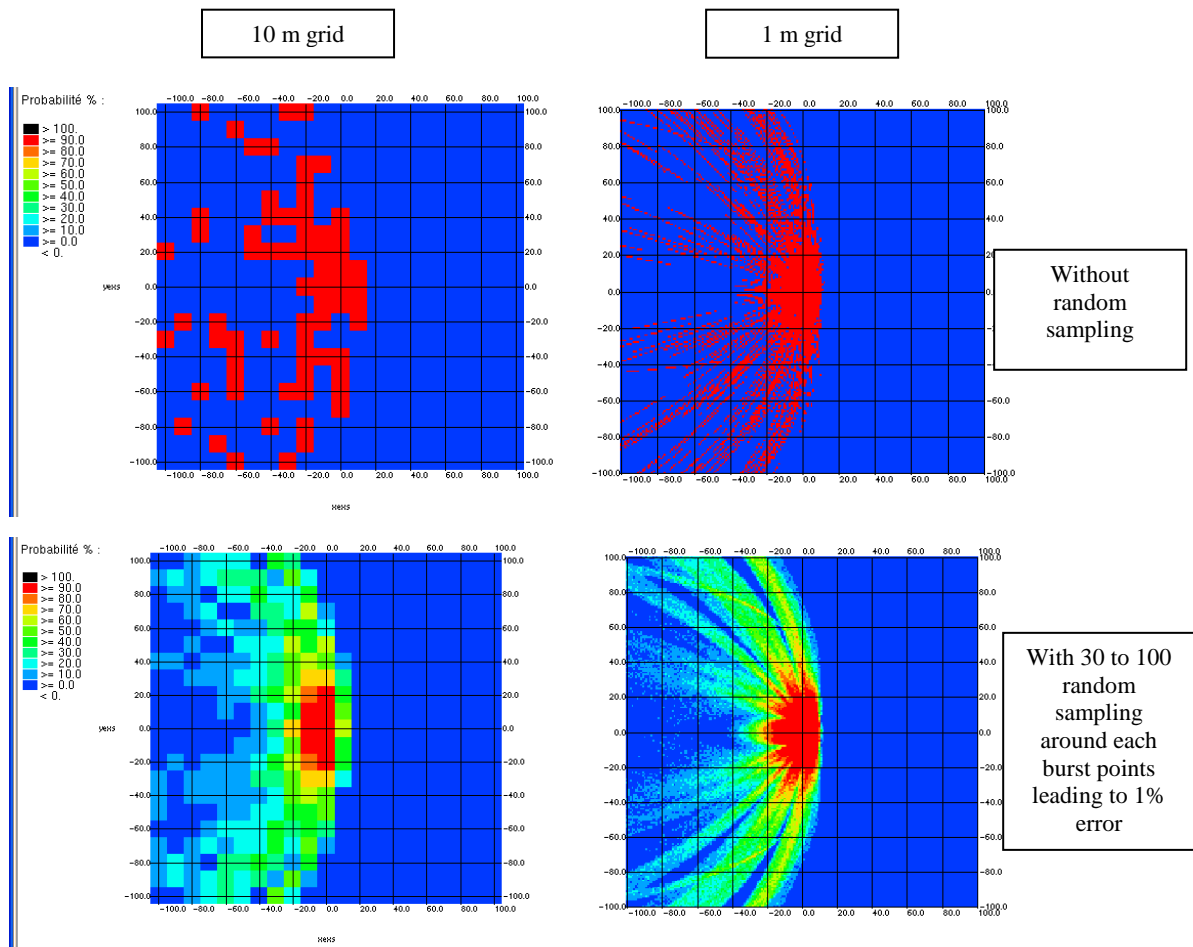


Figure 22 :  $\Delta P_k$  range contour plots

For white grids (Fig. 22), range of  $\Delta P_k$  is between 0 to 5 %, for brown grids, range of  $\Delta P_k$  is between 5 to 10% and for red grids, range of  $\Delta P_k$  is between 10 to 15%. This specific case correspond to burst point distributed each ten meters with one hundred random sampling around each burst points which leads to a 1% error (cf. fig 16).

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**Figure 23: Grid bombing engagement, effects of grid size and random sampling on the accuracy of results**

Effects of grid size and random sampling which underline the accuracy of the results are represented in the figure 23. Small burst point meshing (range of one meter) combined with a range of 30 to 100 random sampling around each one meter burst point grid leading to a 1% error give most accurate results (right and bottom Pk contour). Albas offers the possibility of running the right bottom configuration with a larger number of iteration (random sampling iteration multiplied by the number of burst points).

## CONCLUSION

Albas is a software linked to endgame PLEIADES/A code. Some works done or in progress to improve PLEIADES/A current version are conducted; they are about composite component damage and incendiary effects. The user-friendly Albas GUI offers many functionalities to set up, to test, to execute and to operate parametric PLEIADES/A calculations. Three major engagement geometries (cloud of burst points, rectangular grid burst points and miss distance burst points meshings) are available. Albas takes advantage of the multi-processor CEG ATLAS supercomputer. Statistical treatments of amount of results delivered by PLEIADES/A being effective by the large range of



capabilities of 3D viewer, lead to more representative results expressed in terms of Pk, variation of Pk ( $\Delta Pk$ ), lethality or vulnerability volume or surface.

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