# Introduction – overview of "VULCAN" FP6 Aeronautics STREP. General presentation of VULCAN objectives, consortium & work description


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# VULCAN industrial seminar agenda

| TIMETABLE | Description | |
|---|---|---|
| 11:00–11:30 | Registration - Coffee - Wellcome. TECNALIA | |
| 11:30–11:40 | Introduction – overview of “VULCAN” FP6 Aeronautics STREP. General presentation of VULCAN objectives, consortium, work description ect. | INASCO |
| 11:40–12:10 | (Numerical) Methods and tools development in VULCAN. Tools and Methods developed for blast and fire analysis of aircraft structures. | UoP – SICOMP |
| 12:10–12:40 | Aircraft structure “hardening” by Design Overview of Implicit hardening strategies for BLAST. | SENER - WUT |
| 12:40–13:10 | Developments in Material for composite and hybrid structures. Overview on material development for FIRE. | IVW – TECNALIA |
| 13:10–14:00 | Lunch – Exhibition | |
| 14:00–14:20 | Manufacturing activities for BLAST Demonstrators. Overview of component and structure manufacturing of blast demos. Design solution adopted comparison with standard practice. Lessons learned, future steps. | HAI |
| 14:20–14:40 | BLAST testing. Overview of blast tests and in the project and comparison with predictions (where possible). | TNO – RMA |
| 14:40–15:00 | Manufacturing activities for FIRE Demonstrators. Overview of component and structure manufacturing of FIRE demos. Design solution adopted comparison with standard practice. Lessons learned, future steps. | IAI |
| 15:20–16:00 | FIRE testing. Overview of FIRE tests and in the project and comparison with predictions (where possible). | HSL |
| 16:00–16:20 | SUM-UP | INASCO |
| 16:20–16:40 | Overall discussion – closure | ALL |

# VULCAN
# EC funded research project
# Framework 6 – Aeronautics & Space area

**VULNERABILITY ANALYSIS FOR NEAR FUTURE COMPOSITE/HYBRID AEROSTRUCTURES: HARDENING VIA NEW MATERIALS AND DESIGN APPROACHES AGAINST FIRE AND BLAST DUE TO ACCIDENTS OR TERRORIST ATTACKS**

**Budget: 4.9 MEURO**
**Duration: 53 months**
**Starting Date: 1st October 2006**
**Coordinator: INASCO**

# VULCAN: Background

- **Although the air traffic has increased in recent years there is no percentage increase of related life threatening accidents and incidents. However, the absolute number of fatalities due to accidents has increased in proportion. Moreover, despite the strict safety measures, terrorist acts cause the probability of an internal or external incident of fire or blast to increase. More than ever, passenger airborne safety and consumer faith require hardening strategies, which should be incorporated in aircraft design.**
- **The scope of this project encompasses the development of novel materials and design optimisation strategies aiming at strengthening composite/hybrid airborne structures and prevent catastrophic damage due to internal blast loading or fire incidents. This will be obtained via the assessment of the vulnerability of model aerostructures to blast and fire. Numerical tools will be developed and validated against experimental findings in order to develop a vulnerability map of typical substructures. Vulnerable loci will be identified and reinforced in two ways: (a) By introducing novel design approaches and (b) by using tailored novel composite and hybrid materials. Implicit and explicit measures will be considered based on reinforcing design strategies and novel materials.**
- **Finally, hardened sub aerostructures will be designed manufactured and validated aiming at a significant increase in blast and fire resistance compared to those currently used with minimum weight penalty.**

# VULCAN: Consortium

| Competency | Consortium member | Nationality | Skills |
|---|---|---|---|
| SMEs | INASCO<br>INASMET | EL<br>ES | Design integration and architecture, detail design, component manufacturing techno-logy, integration and test |
| Research Institutes | SICOMP<br>HSL<br>TNO<br>PIEP | SW<br>UK<br>NL<br>PT | Fundamental research and application of technologies, technological development, and testing |
| Universities | IVW<br>UoP<br>WUT<br>USFD<br>RMA | GER<br>EL<br>PL<br>UK<br>BE | Academic institutions, fundamental research |
| Others | PEMA | PT | Association of SME’s with complementary competences that are involved in the aerospace business |
| Industries | IAI<br>HAI<br>SENER<br>BAe<br>RR | IL<br>EL<br>ES<br>UK<br>UK | Component manufacturers, design integration, assembly technology, material suppliers, integration and testing |

**VULCAN brings together world class expertise from ten European countries and Israel. VULCAN consortium is a good balance between SME’s, Universities, Research Institutes and Industry.**

# VULCAN: Scientific Objectives

- **Development of algorithms, material models and failure criteria for high strain rate loading of composites and hybrid materials and calibration of the numerical tools against experimental results.**
- **Development of algorithms, material models and failure criteria for fire behavior; criteria for fire spread and fire burn-through.**
- **Development of numerical tools for blast and fire vulnerability analysis of composite and hybrid aeronautic structures**
- **Creation of Blast and Fire Vulnerability Map of composite and hybrid scaled fuselage substructure**
- **Implicit and explicit blast and fire hardening strategies of composite and hybrid aerostructures by design and by materials (including novel design approaches tailored to the new generation materials)**

Key Element:

The developed Methodologies are validated against Scaled and Simplified aero-structures rather than actual aircraft structure. This approach allows for use of validated models and larger scale investigations. Similar to aero elastic and noise scale models.

# VULCAN: Technical Objectives

Integration of the hardening measures, in the case of composite and hybrid aerostructures, both blast and fire in order to achieve a combined structural hardening against blast and fire

Combined loading scenarios and analysis of composite and hybrid scaled aerostructures under blast loading and fire spread conditions

Manufacturing and testing of model large aerostructures for the validation of the developed numerical tools:

Scaled fuselage substructure (blast)

Scaled attic substructure (fire spread)

Scaled curved panels (fire burn-through)

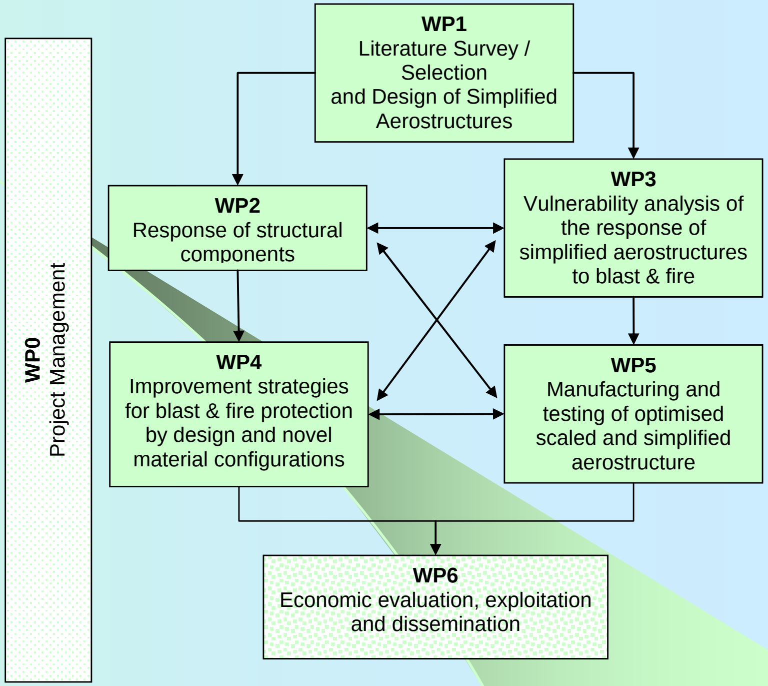
Preparation of preliminary forms of standards for:

- Fire characterization of composite and hybrid materials
- Fire spread characterization of non-structural materials
- Fire spread characterization of composite and hybrid large scale fuselage type of structures
- Fire burn-through characterization of composite and hybrid curved fuselage type panels
- High strain rate behaviour characterization of structural materials
- In-flight blast behaviour of aerostructures

# VULCAN: Project Realisation

***The main areas of VULCAN activity***

- **WP1: Literature Survey / Selection of Typical Aerostructures:** (Existing Procedures and Criteria, Materials, Civil a/c accidents-incidents and safety, selection of simplified aerostructure)
- **WP2: Response of flat structural components:** (Analysis of structural components to blast and fire incidents, experimental verifications, validation and algorithm optimisation)
- **WP3: Vulnerability analysis of the response of simplified aerostructures to blast & fire:** (Simulation of the response of simplified aerostructures to blast and fire scenario, vulnerability maps)
- **WP4: Improvement strategies for blast & fire protection by design and novel material configurations:** (Improvement strategies and combined loading simulations)
- **WP5: Manufacturing and testing of optimized scaled and simplified aerostructure:** (Manufacturing, testing, evaluation)
- **WP6: Economic evaluation, exploitation and dissemination:** (highlight cost elements and benefits, define the required efforts for the implementation of these new technologies)




| Workpackage (WP) | WP Leader |
|---|---|
| WP0: Project Management | INASCO |
| WP1: Literature Survey / Selection of Typical Aerostructures | PEMA |
| WP2: Response of flat structural components | HSL |
| WP3: Vulnerability analysis of the response of simplified aerostructures to blast & fire | UoP |
| WP4: Improvement strategies for blast & fire protection by design and novel material configurations | SENER |
| WP5: Manufacturing and testing of optimized scaled and simplified aerostructure | IAI |
| WP6: Economic evaluation, exploitation and dissemination | INASCO |

# VULCAN: Selected Results of WP1

**WP1 (Literature Survey / Selection and Design of Simplified Aerostructures) is the starting point of the project. Database-inventory created for:**

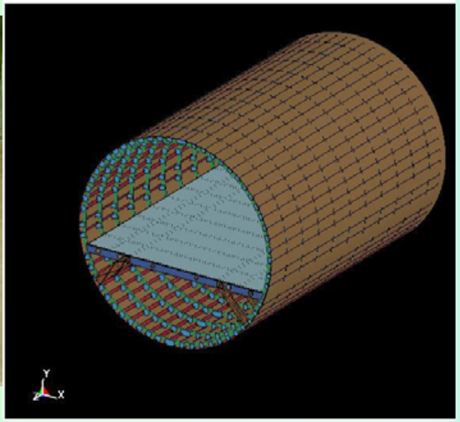
- **Standards, criteria and hardening methodologies for protecting aerostructures against blast and fire.**
- **Properties database of structural and non-structural materials for protection against blast and fire**
- **Inventory of the blast/ fire induced losses (frequency/severity/location)**

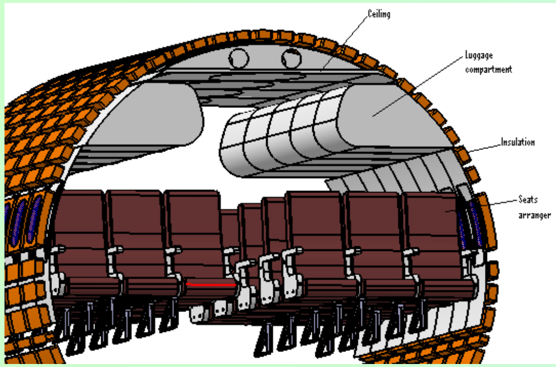
**•And provide the design basis for future work in the following WPs:**

- **Design and analysis of scaled fuselage part calculated under typical working load envelope. The scaled aerostructures (made out of full aluminium, aluminium/GLARE skin and composites) will be used for blast analysis.**
- **Design of scaled aerostructures. The scaled aerostructures (made out of full aluminium, aluminium/GLARE skin and composites) will be used for fire spread and fire burn-through analysis**

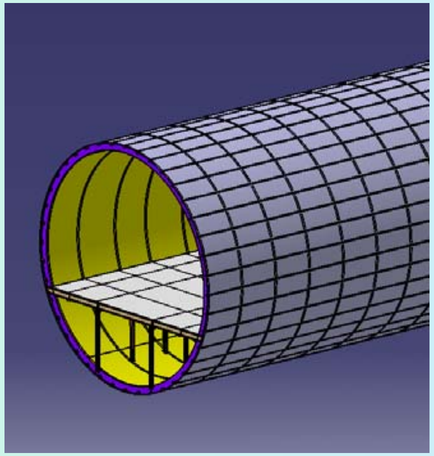
# VULCAN: Selected Results of WP1

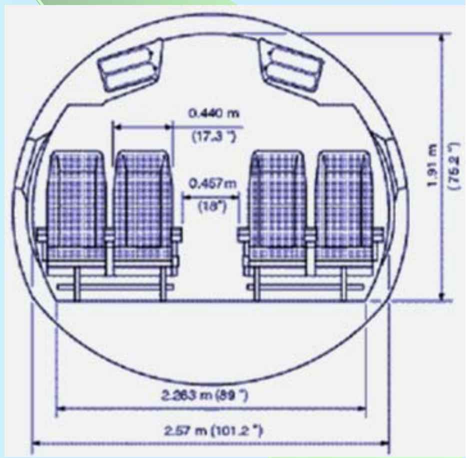
- **Target aircrafts considered so far:**
- **A319 class (Fuselage Dia. 3.95m, Max. cabin width 3.70m, Cabin length 23.78m, up to 126 passengers)**




- **Target aircrafts considered so far:**
- **Advanced Turboprop class (Fuselage Dia. 2.65m, Max. cabin width 2.50m, up to 72 passengers)**





# VULCAN: Selected Results of WP2

**WP2 (Response of structural components) is one that provides a supportive role to all other development activities and interacts with all other WPs including not only the development and up-scale of the various processes but also the validation of the multi-scales implementation / simulation. Current developments can be summarized bellow:**

- **simulation of the structural response and failure of different structural components based on progressive damage modeling**
- **solution of the fire problem based on the overall thermal / fire response of the material and appropriate degradation (material-structural) models**
- **development of accelerated methodologies for the solution of the fire problem (Surrogate Models)**
- **design and manufacturing of flat panels for small scale tests.**
- **testing in order to collect the experimental data for the calibration of the numerical models and assess new material developments**
- **fine tuning and optimization of numerical parameters based on experimental results, in order to secure convergence**

# VULCAN: Selected Results of WP2

A "building block" approach was selected that would allow gradual complexity incorporated in the models and the studies. Different approaches and numerical tools have been assessed with respect to the blast testing. Analysis involved Aluminum as well as GLARE and Carbon Fiber Reinforced panels. The assessed approaches were the CONWEP algorithm and ALE formulations for flat and curved panels. S/w codes used were LS-DYNA, ABAQUS and PAMCRASH.

### Test Matrix adopted for blast test.

**TEST MATRIX FOR BLAST TESTING**

Increasing Complexity →

| Specimen | | Purpose | Test by: | L | W | AL 1.0 | GLARE 3 | CFRP Autoclave Type 1 | CFRP LCM Type 2 |
|---|---|---|---|---|---|---|---|---|---|
| B2.0 | Coupons | Material properties, dynamic strength | TNO | 350 | 50 | 5 | 5 | 5 | |
| B2.1 | Flat sheet | Examination of crack initiation | RMA | 800 | 800 | 5 | 5 | 5 | |
| B2.3 | Prestressed sheet | Examination of crack propagation | TNO | 1600 | 800 | 5 | 5 | 5 | 0 |
| B2.4 | Skin-frame assy (bolted) | Dynamic pull through | TNO | 300 | 300 | 3 | 0 | 0 | 0 |
| B2.5[1] | Pressurised cylinder skin | Crack propagation of skin under pressure | TNO | 1500 | 1200 | 3 | 0 | 0 | 1 |

**CFRP Autoclave:**
Plain weave woven prepreg (e.g. E-765 Epoxy with T300 3K-PW woven carbon, 193 g/sq.m).
In order to have the approximate thickness of 2mm apply 10 plies in the following stacking sequence [+/-45,0/90,90/0,+/-45,0/90]s

**CFRP LCM:**
These coupons could include fire retardant agents Manuf. Materials should be equivalent with what have been used. Manuf. Route= Liquid Composite Molding. Fire retardant systems should will be considered.

### Test Matrix adopted for Fire test.

**TEST MATRIX FOR FIRE TESTING**

| Specimen | | | Test by: | L | W | AL 1 | GLARE 3 no. of specim. | CFRP (1) Topcote1 | CFRP (2) Topcote2 | CFRP (3) Topcote2 |
|---|---|---|---|---|---|---|---|---|---|---|
| F2.1 | Flat panel with acoustic insulation and liner | Assessment of fire propagation using Cone Calorimeter | RMA | 100 | 100 | 5 | 5 | 5 | 5 | 5 |
| F2.2 | Flat panel | Response to fuselage burnthrough | HSL | 1000 | 1000 | 2 | 2 | 2 | 0 | 0 |
| F2.3 | Flat panel | Response to combustor burnthrough | HSL | 400 | 400 | 2 | 2 | 2 | 0 | 0 |

**CFRP (1) :**
Autoclave. Plain weave woven prepreg (e.g. E-765 Epoxy with T300 3K-PW woven carbon, 193 g/sq.m).
In order to have the approximate thickness of 2mm apply 10 plies in the following stacking sequence [+/-45,0/90,90/0,+/-45,0/90]s

**CFRP (2) & (3):**
These coupons could include fire retardant agents Manuf. Materials should be equivalent with what have been used. Manuf. Route= Liquid Composite Molding. Two Fire retardant systems should will be considered different for (2) and (3).

### Test Matrix adopted for Fire – structure interaction test.

**TEST MATRIX FOR FIRE-STUCTURE INTERACTION TESTING**

| | Specimen | | | | Test by: | L | W | GLARE 3 | CFRP (1) Type 1 | CFRP (2) Type 2 | CFRP (3) Type 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tensile EN-ISO 527-4 | Tension | F2.0.1 | Coupons | Mechanical prop. Vs. Temp. | IVW | 250 | 25 | 5 | 5 | 5 | 5 |
| 3 point Bending EN-ISO 14125 | 3 point Bending | F2.0.2 | Coupons | Mechanical prop. Vs. Temp. | IVW | 40 | 15 | 5 | 5 | 5 | 5 |
| ILSS ISO 14130:1997 | ILSS | F2.0.3 | Coupons | Mechanical prop. Vs. Temp. | INASMET | 20 | 10 | 5 | 5 | 5 | 5 |
| Fracture Toughness ASTM D 5525 | Fracture Toughness | F2.0.4 | Coupons | Fracture Toughness | IVW | 125 | 25 | 5 | 5 | 5 | 5 |

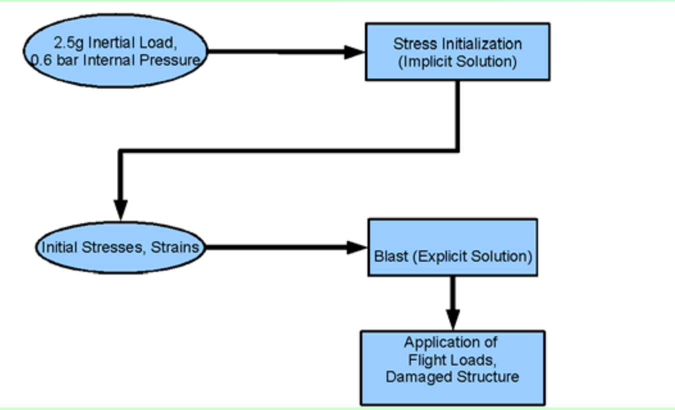
**CFRP (1) :**
Autoclave. Plain weave woven prepreg (e.g. E-765 Epoxy with T300 3K-PW woven carbon, 193 g/sq.m).
In order to have the approximate thickness of 2mm apply 10 plies in the following stacking sequence [+/-45,0/90,90/0,+/-45,0/90]s

**CFRP (2) & (3):**
These coupons could include fire retardant agents Manuf. Materials should be equivalent with what have been used. Manuf. Route= Liquid Composite Molding. Two Fire retardant systems should will be considered different for (2) and (3).

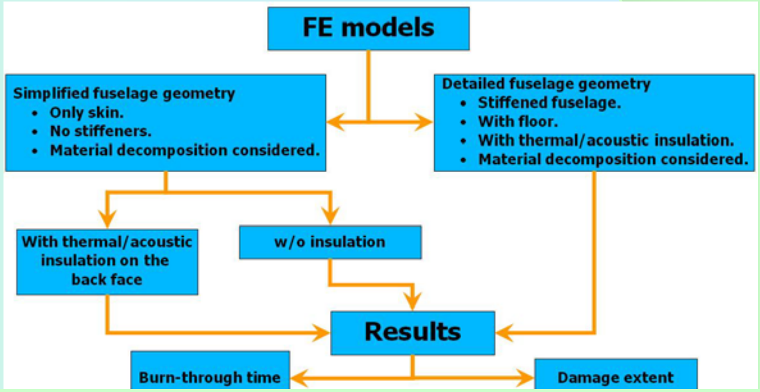
# VULCAN: Selected Results of WP3

**WP3 (Vulnerability analysis of the response of simplified aerostructures to blast & fire) The methodologies that have been developed in WP2 are utilized <u>in WP3 to simulate the behavior of more complex structures</u> (curved panels, structural details) under blast loading. The deliverables of WP3 will be <u>Vulnerability Maps</u> for various material configurations and blast and fire loadings. Various vulnerability indices are considered at the moment. Current developments can be summarized bellow:**

- **Numerical simulation results of blast loading of scaled fuselage substructures for all type of material configuration and the different charge locations**
- **Numerical simulation results of fire burnthrough for all type of material configurations curved panels**
- **Vulnerability map(s) of all the scaled fuselage substructures for blast loading**
- **Vulnerability map of all scaled curved panels for fire burnthrough**

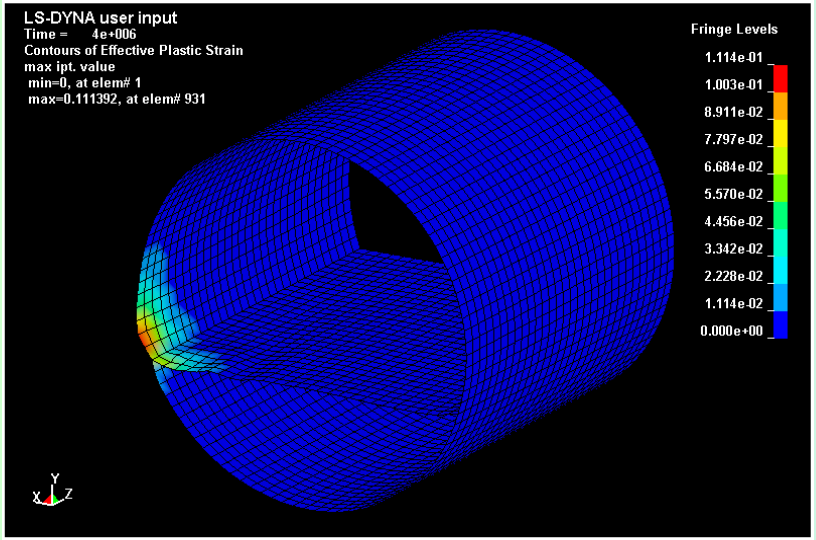


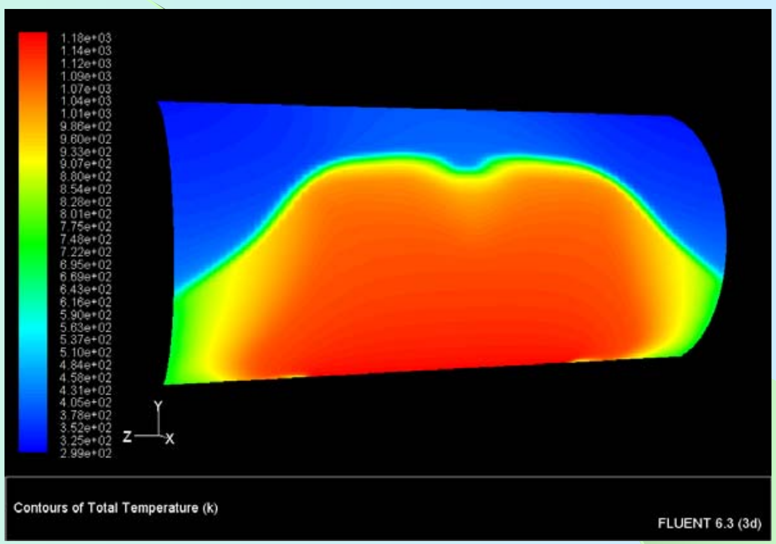

**Solution sequence of blast problem**




**FEM models for Fire burn through**

# VULCAN: Selected Results of WP3 (V-maps)




Analysis of Blast load in simplified fuselage section; Induced plastic strains that could be used to construct vulnerability map.

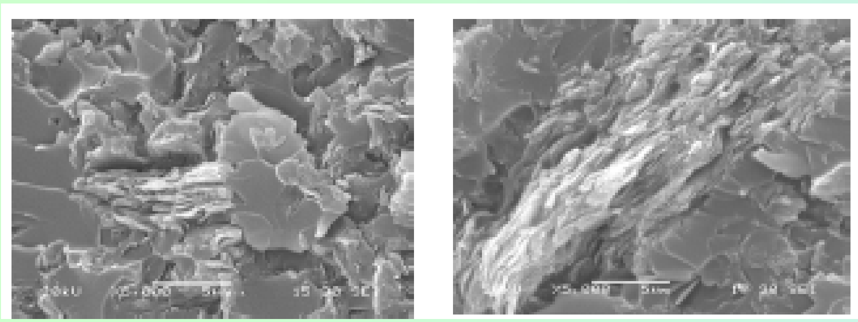
Heat affected zone due to outside fire could be used in order to construct fire vulnerability map.

# VULCAN: Selected Results of WP4

**WP4 (Improvement strategies for blast & fire protection by design and novel material configurations). After the vulnerability analysis performed in WP3, the goal of the present work is to investigate possible scenarios for the strengthening of the vulnerable elements. This would includes the investigation of:**

- **Design based hardening measures**
- **Material based hardening measures**
- **Numerical analysis and performance of hardened aerostructures against blast, fire spread and fire burn through**
- **Numerical simulation of hardened aerostructures against combined (fire+blast) scenarios**

**Work has started with the investigation of material based hardening measures (fire)**



**Morphology and fire spread studies on epoxy – nanoclays systems**

# VULCAN: Selected Results of WP5

**WP5 (Manufacturing and testing of optimized scaled and simplified aerostructure) .**

**Three (3) different groups of scaled aerostructures will be manufactured following the guidelines analyzed in WP3. Both design and materials implicit and explicit measures that have been identified as critical for enhancing structural performance against blast and fire will be implemented.**

**More precisely:**

**Two (2) cylindrical scaled fuselage type structures; CFRP and AL hybrid GLARE type materials will be manufactured for blast tests.**

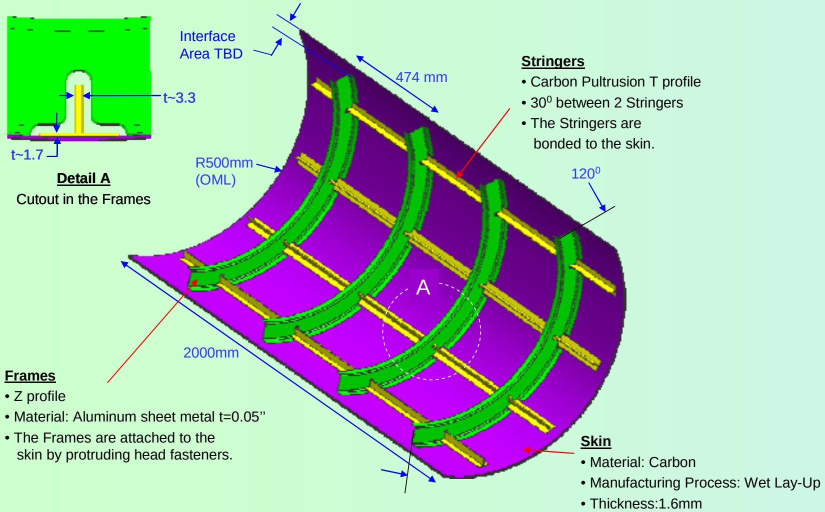
**Two (2) mock-ups of the attic area above the passengers' cabin; CFRP and AL hybrid GLARE type will be manufactured for fire spread tests.**

**Two (2) curved (cylindrical) panels representing in scale the three "layers" of a typical aircraft structure, CFRP and AL hybrid GLARE type will be manufactured for fire burn-through tests.**

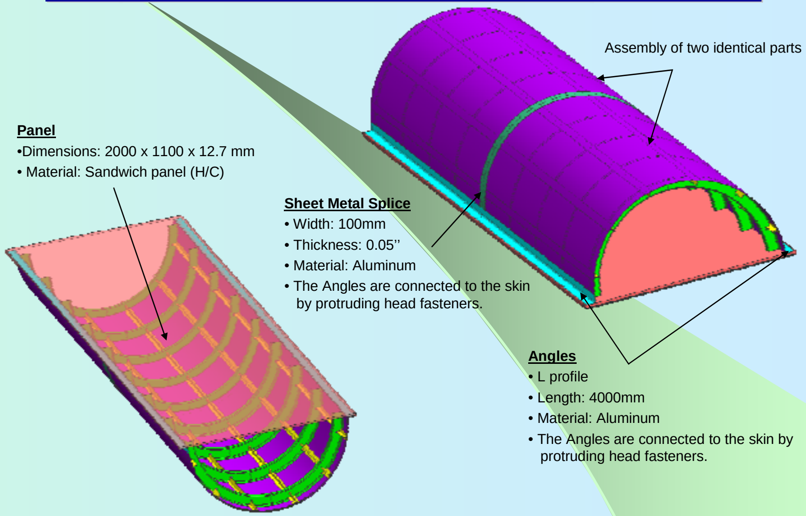
**After testing, evaluation of design and materials strengthening will be analytically made and the mitigation of the vulnerability level will be calculated.**

# VULCAN: Selected Results of WP5

## Composite Curved Panel For Fire Burn-Through Tests




## Composite Attic Structure For Fire Spread Tests




**Concept of composite curved panels for fire testing (fire spread and burn-thorough)**

# VULCAN: Selected Results of WP6

WP6 (Economical evaluation, exploitation and dissemination) will cover the economical evaluation, taking into account that the production steps and their sequence most probably have to differ from current conventional manufacturing processes to obtain full use of the advantages of nano-composites. Accordingly harmonized manufacturing scenarios under consideration of will be drawn up and evaluated, using also inputs from development work of WP2, 3, 4 and 5.

The resulting study will highlight cost elements and will define the required (financial and organizational) efforts for the implementation of these new technologies, as well as further required developments.

An additional objective of WP6 is the generation and continuous updating of an exploitation and dissemination plan.

One of the key actions of this WP6 is the exploration of steps required for certification of such technology. A certification process report will be issued outlining the procedures for future introduction of the developed technologies into production parts.

# VULCAN: Selected Results of WP6

## WP6 - Economical evaluation, exploitation & dissemination

**WP6.1 Definition of cases to be studied. Definition of common cost basis & cost calc method. Economical evaluation of reference cases.**

Definition of cases to be studied (Ongoing, Proposal:)

Reference cases: 1. Composite with VULCAN proposed technologies
2. Composite with conventional technologies

**Definition Required**

Definition of common cost basis & cost calculation metl

Calculation of cost for: CFRP Coupons (Autoclave mai

Cost elements: Raw Materials (resin, fibres, Retardants)
Hardening design solutions
Capital equipment (Autoclave)
Process cycle
Tooling cost
Labour and Overheads

AST5-CT-2006-031011: VULCA

**Economic evaluation is based on defined case studies.**

**Exploitation of results are assessed via a decision making tool.**

## WP6 - Economical evaluation, exploitation & dissemination

**Exploitation of Knowledge and Dissemination of Results through provided templates**

Company name:
Authors name:

Plan for knowledge exploitation beyond the consortium
(Part I)

| Exploitable knowledge (description) | Exploitable product(s) or measure(s) | Sector(s) of application | Timetable for commercial use (Months after project end) | Patents or other IPR protection | Owner & Other Partner(s) involved |
|---|---|---|---|---|---|
| | | | | | |

**Criteria used for the assessment of VULCAN exploitable results**

- **Short Term:** The exploitation potential is high right after project's end
- **Medium Term** The exploitation potential is high after 0-3 years of project's end
- **Long Term** The exploitation potential is high after 3 years of project's end
- **Exploitation Plan** The exploitation plan has been written in a concise way with all details and assumptions clearly described
- **Capacity** The partner(s) has the capacity to fully exploit the result(s)
- **Collaboration** Collaboration with interested parties has been foreseen or sought
- **Technology Transfer** The technology transfer potential is high
- **Direct Benefits** The direct benefits are anticipated to be over the current estimations
- **Indirect Benefits** The indirect benefits are anticipated to be well over the current estimations

Short Term
The exploitation potential is high after project's end

1. ☐ Does not meet expectations
2. ☐ Meets some, but not all expectations
3. ☐ Meets all expectations
4. ☐ Exceeds expectations

Medium Term
The exploitation potential is high after 0-3 years of project's end

1. ☐ Does not meet expectations
2. ☐ Meets some, but not all expectations
3. ☐ Meets all expectations
4. ☐ Exceeds expectations

**Will be processed to cover short medium and long term potential D6.3 M24**

Company name:
Authors name:

Plan for disseminating knowledge for VULCAN [M24]
(Part II)

Dissemination of Knowledge

| Planned/ actual dates | Type | Type of audience | Countries addressed | Size of audienc e | Partner responsible/ involved |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |

# VULCAN: Dissemination strategy

- VULCAN consortium has been very active in disseminating results through papers, conferences and workshops
- Links have been established with authorities in USA, Australia and Europe
- Interest has been created from large industrial organisations Airframe and Engine manufacturers which eventually became part of VULCAN consortium
- VULCAN is organising an industrial workshop towards the end of the project where detailed presentation of achievements and further potential will be done
- We believe that safety against blast and fire could be one of the design disciplines that should de integrated in the aircraft design and further steps should be taken towards tool and procedure harmonisation
- VULCAN consortium is open for collaboration and joint activities as this present workshop

# Thank you for your attention