Project no. AST3-CT-2003-502884

ECOSHAPE

Economic Advanced Shaping Processes for Integral Structures

Instrument: Specific Targeted Research Project

Thematic Priority: Aeronautics and Space

Publishable Final Activity Report

Period covered: from 01.02.2006 to 31.01.2007

Date of preparation: 30.04.2007

Start date of project: 01.02.2004

Duration: 36 months

Project coordinator name: Achim Schoberth
Project coordinator organisation name: EADS Deutschland GmbH
Internal reference: E.45009

Revision: issue 1

Content

1 Project execution

1.1 Original project data

1.1.1 Title: “Economic Advanced Shaping Processes for Integral Structures”

1.1.2 Short title and number: “ECOSHAPE”, Nr. AST3-CT-2003-502884

1.1.3 Abstract

A **future need** for aircraft structures is the development towards an increased degree of integration to save weight and **to reduce manufacturing costs**. An actual target is the reduction of assembly cost (riveting process) by laser welding (e. g. fuselage) or integral machining (e. g. wing structures). For such new concepts the current manufacturing chain has to be altered, **unifying the forming steps and shifting it further towards the end**. This **enables more processing** (e. g. machining, pocketing, welding) **in a flat condition to achieve the full cost reduction** potential.
With this **approach**, **laser based forming** processes offer huge economic potentials due to high automation possibilities and avoidance of heavy, large and costly forming tools, required for each of the numerous differently shaped parts of current cold and hot forming processes.
The **main project target** is the **development of** such **laser forming processes for integral fuselage and wing structures**. Thus relevant laser parameters with respect to minimum material degradation on one side and maximum formable sheet thickness on the other side are evaluated. A simulation tool for the forming process is built up and integrated into a control system. Key to the control of the process is the development of a predictive model to provide scan strategies based on a required geometry. This system includes online 3D shape measurement to enable straight-line laser forming to the required final geometry.
The **main innovation** of the project is the **combination of the simulation, the control system and the online 3D shape measurement to** a tool offering a self correcting, reliable, quick, **robust and** thus **economic laser forming process** for Al based structures.

1.1.4 Objectives

Following measurable **objectives** are envisaged:
1. Forming stiffened structures to **single curvature** of 1250 to 3000 mm radii along stiffeners
2. Forming **bi-axially curved structures** with additional 10000 mm radius across stiffeners
3. Verification of estimated shell **manufacturing cost reduction** of 10 % by more processing in a flat condition and a further 10 % by avoidance of heavy and complex tooling
4. **Shell weight reduction** of 10 % with new alloys, less useful with conventional forming

1.1.5 Partners

The **consortium** reflects the strong industrial interest due to the participation of 4 aerospace companies, supported by 3 industrial research organisations, 1 SME and 2 Universities from 4 member states, all those well experienced in aerospace processing.

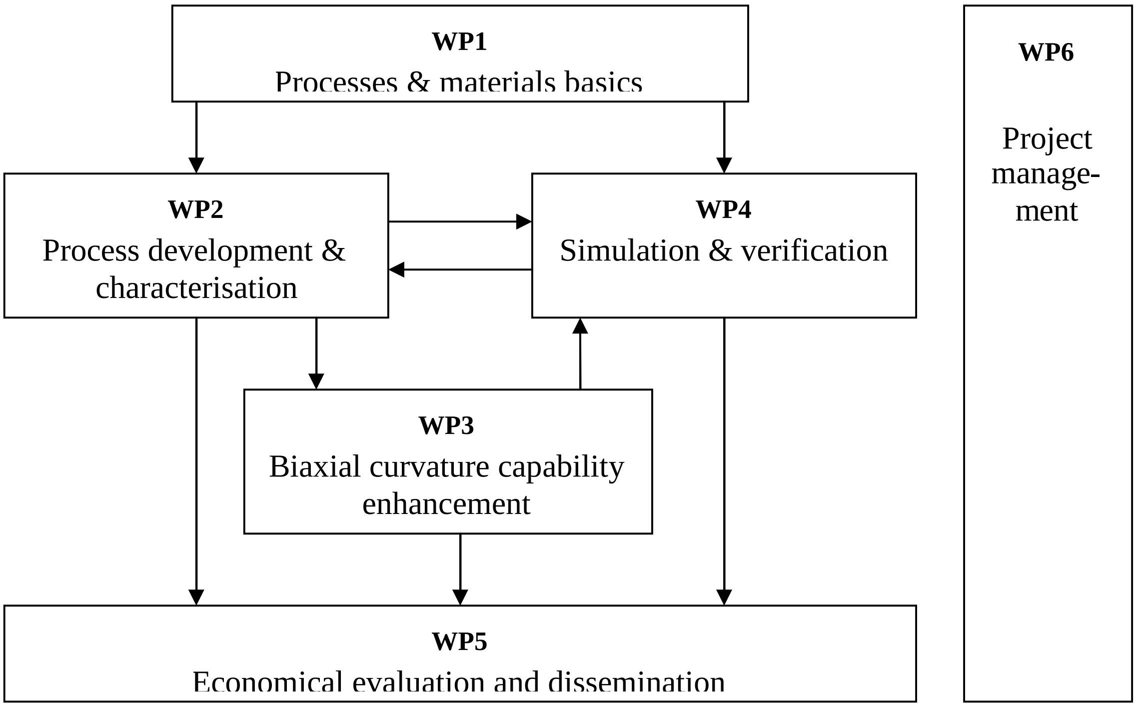
Participant Role*	**Participant no.**	**Participant name**	**Particip. short name**	**Country**	**Date enter project****	**Date exit project****
CO	1	EADS Deutschland GmbH	EAG	Germany	Month 1	Month 36
CR	2	Airbus Deutschland GmbH	AID	Germany	Month 1	Month 36
CR	3	Airbus France	AIF	France	Month 1	Month 36
CR	4	Alenia Aeronautica S.p.A.	ALA	Italy	Month 1	Month 36
CR	5	DASSAULT AVIATION	DAS	France	Month 1	Month 36
CR	6	EADS CCR	EAF	France	Month 1	Month 36
CR	7	INASCO Hellas	INA	Greece	Month 1	Month 36
CR	8	ISTRAM	IST	Greece	Month 1	Month 36
CR	9	iwb – TU München	IWB	Germany	Month 1	Month 36
CR	10	RTM S.p.A.	RTM	Italy	Month 1	Month 36

* CO = Coordinator
CR = Contractor

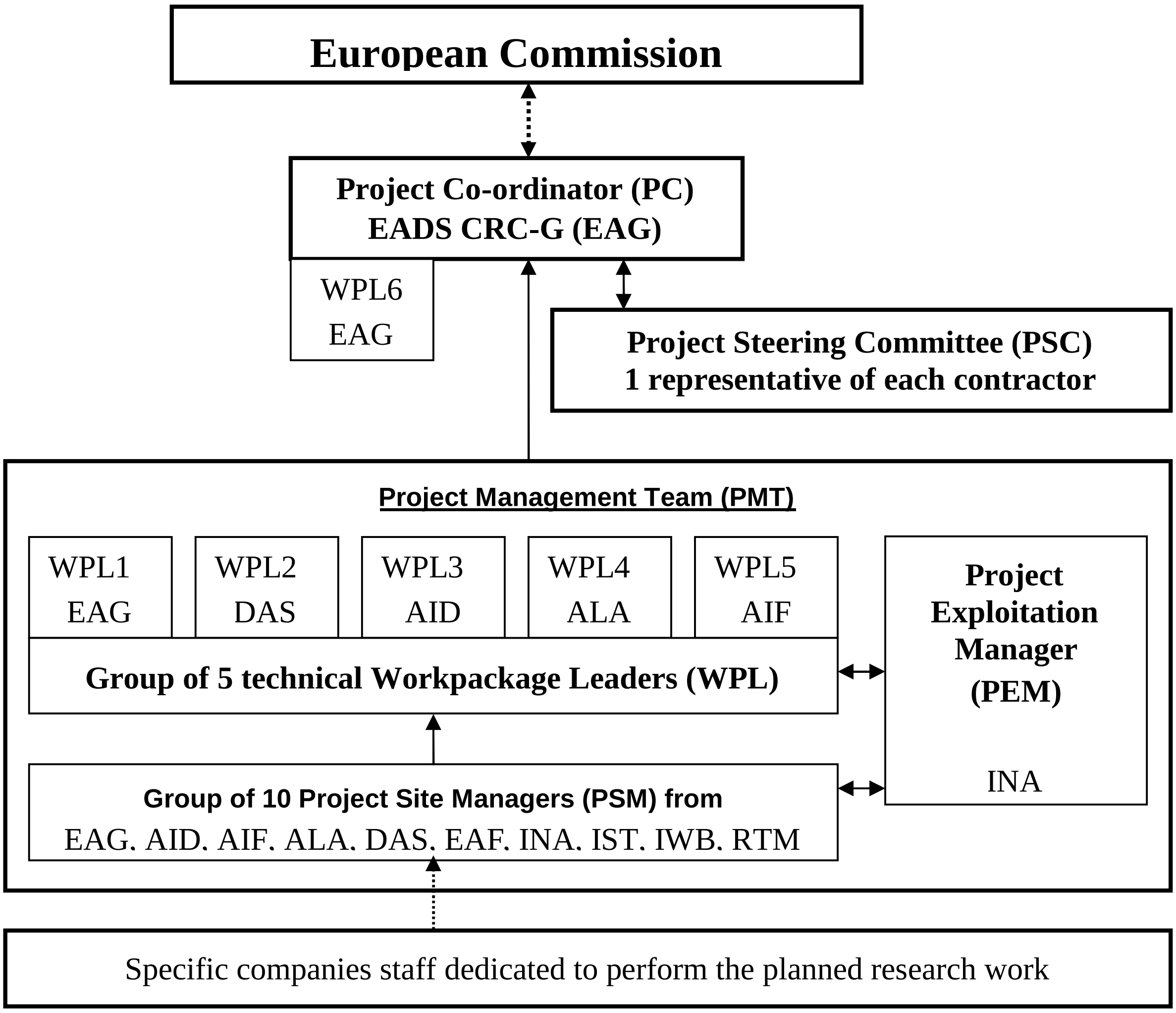
** Normally insert "month 1 (start of project)" and "month n (end of project)"
These columns are needed for possible later contract revisions caused by joining/leaving participants

1.1.6 *Duration:* 01.02.04-31.01.07

1.1.7 *Project Workpackage interdependence*



1.1.8 *Project organisation structure*



1.1.9 *Project information and logo*

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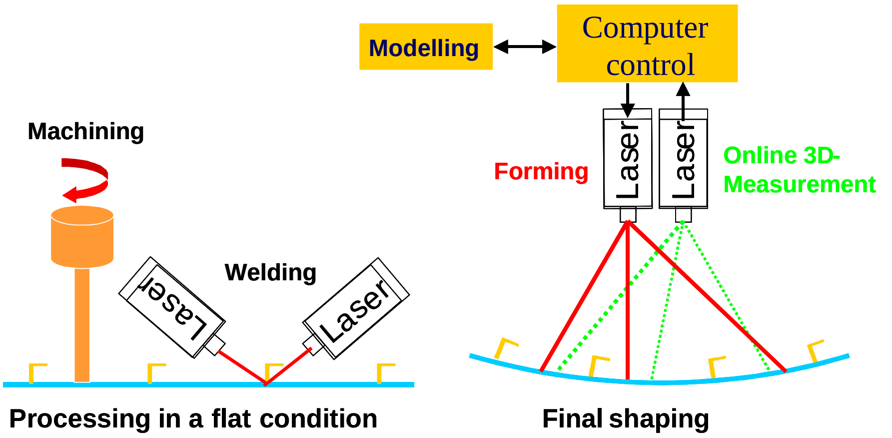
Project logo:

Project website address:

www.ecoshape.info
The project website will be kept online beyond the end of the project, dated 31.01.07.

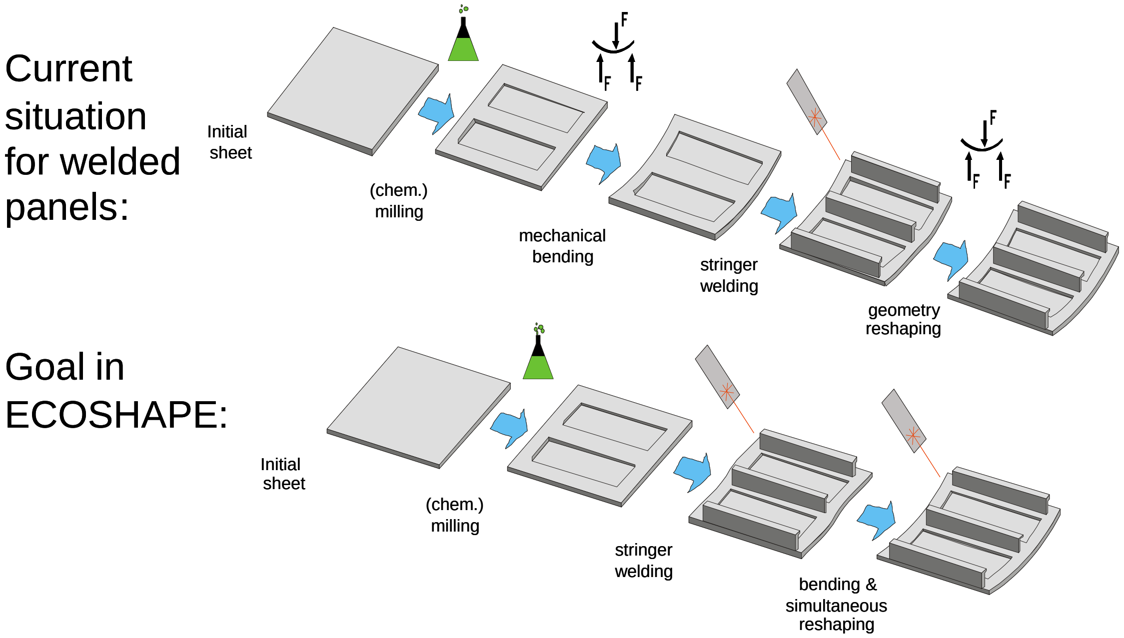
1.1.10 *Main advantage of Laser Beam Forming (LBF) process*

Main processing (machining, welding) in flat condition



1.1.11 *Main project motivation*

Reduction of process steps and cost



1.2 Work performed and end results

The summary of performed work on Laser Beam Forming (LBF) development and gained results during the whole project duration follows the Work Package (WP) and Task structure, defined at project start and described in the Work Programme (Annex I), which was updated during project duration from issue a to d with the agreement of the EC Scientific Officer.

Before starting this description and in order to ease understanding, an explanation of the LBF process is helpful:
The LBF process uses the power provided by a laser beam to inject heat within a sheet. The heat flows into the sheet and modifies the temperature distribution (Figure 1.2.1). The temperature has two effects in the hot areas:

- an expansion,
- a decrease of the mechanical properties (and in particular of the yield stress).

Because of the temperature gradient in sheet thickness, mechanical incompatibilities develop themselves and create compressive stresses in the hottest and tensile stresses in the coldest layers (Figure 1.2.2). Since the yield stress in the hottest layers is lower, a compressive plastic strain field is created, which modifies the dimensions of the concerned layers. Cooled down to room temperature, the resolution of these incompatibilities leads to a residual stress field and distortions. Considering the motion of the laser, the summation of the distortions creates a line of bending, which can be described with a bending angle.

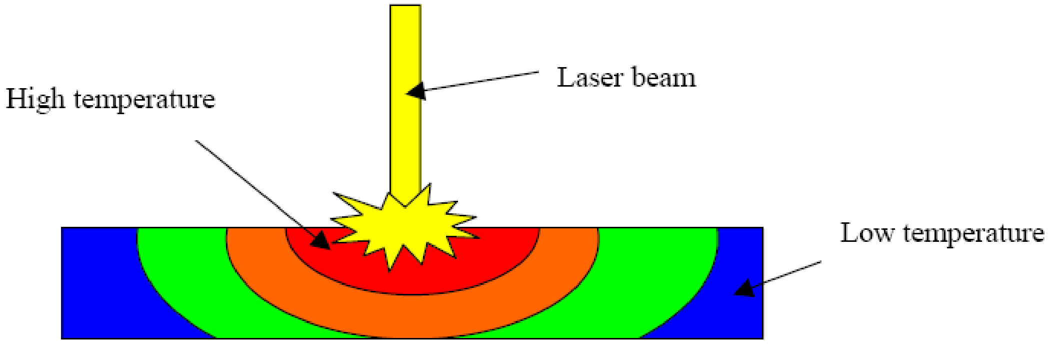


Figure 1.2.1: Temperature distribution within the sheet

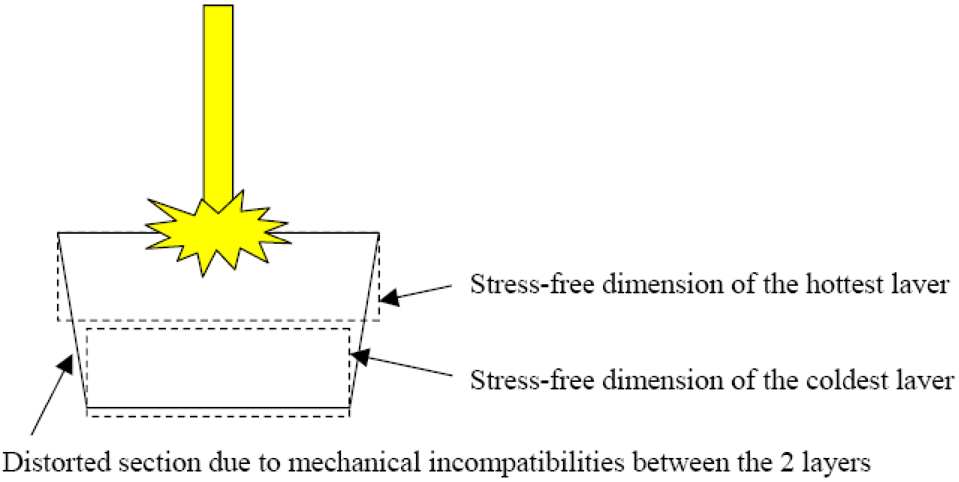


Figure 1.2.2: Mechanical incompatibilities developed during laser impact

1.2.1 WP1: Processes & materials basics

WP1 consisted of 3 Tasks with the objective to analyse basic laser forming influence for all selected materials on a specimen level. It was successfully completed, including the 3 planned Deliverable reports D1.1, D1.2 and D1.3, but with about 6 months delay compared to the original planning and the set Milestones in Annex I, issue a (see Tables 1.2.1.1 and 1.2.1.2).

Table 1.2.1.1: Deliverables list

Del. no	Deliverable name	Task no.	Date due, month	Delivery, month	Lead con-tractor
D1.1a	Set of basic simulation input data for 6013, 6056	1.1	06	12	EAG
D1.1b	Set of basic simulation input data for IS237, 1424	1.1	18	24	EAG
D1.2a	Set of basic properties of 6013, 6056 with NdYAG used in WP2	1.2	12	12	EAG
D1.2b	Set of basic properties of 6013, IS237 with CO2, IS237, 1424 with NdYAG, IS237 with LPF used in WP2	1.2	18	24	EAG
D1.3	Description of basic forming behavior	1.3	18	24	EAG

Table 1.2.1.2: Milestones list

MS no.	Milestone name	Task no.	Date due, month	Delivery, month	Lead con-tractor
M1.1a	Input data 6013, 6056 for WP4 (simulation) available	1.1	6	12	EAG
M1.1b	Input data IS237, 1424 for WP4 (simulation) available	1.1	18	24	EAG
M1.2a	Basic input data 6013, 6056 with NdYAG for WP2 (processing) available	1.2	12	12	EAG
M1.2b	Basic input data for WP2 6013, IS237 with CO2, IS237, 1424 with NdYAG, IS237 with LPF (processing) available	1.2	18	24	EAG
M1.3	Basic laser forming analysis finished	1.3	18	24	EAG

More details about work content and the results, reached, are summarized in the following Task descriptions.

Task 1.1: Basic properties of all selected alloys for simulation in WP4

In Task 1.1, basic properties with NdYAG, CO2 and HPD (High Power Diode) lasers were investigated for the selected Aluminum alloys 6013, 6056, 1424 and 2022 (the old IS237). Suitable ranges of LBF parameters like laser power, feed and focal diameter have been determined with respect to different material parameters like alloy type, sheet thickness, sheet width and surface condition. As a measure, the resulting bending angle was used.
The data were used as input for simulation in WP4 und thus delivered to partner IST.

For all alloys a useful parameter window has been developed showing that 2022 alloy has a better suitability (= higher bending angle for same line energy input) for LBF compared to the 6XXX alloys, caused by the lower heat conductivity of the AlCuMg alloy system. The alloy 1424 parameter showed similar results.
The influence of material thickness was as expected. Due to increasing stiffness, an increasing thickness leads to lower bending angles while keeping the forming parameters constant. The upper thickness limit for effective processing was found to be 5 mm.
The influence of sheet width was unexpectedly non linear, showing a minimum bending angle at intermediate width.
The specific surface condition was found to be the major influencing parameter. The laser absorption difference between grinded and black surface was more than a factor of 5. Black coating was found to be necessary for successful LBF process using CO2 laser.
Residual stress analysis using X-ray-diffractometry identified the temperature gradient mechanism as the dominating bending mechanism by typical tensile loads in the laser path in and also perpendicular to forming path direction.

Task 1.2: Basic properties of all selected alloys for processing in WP2

In Task 1.2, basic properties of all selected alloys selected Aluminum alloys 6013, 6056, 1424 and 2024 (due to bad availability of 2022) were investigated as prerequisite for basic process development in WP2. This consisted mainly in the measurement of mechanical properties (hardness, static strength, fatigue strength) as well as metallographic investigations. All this work was finally performed to check the 10 % strength degradation limit, which was defined by the Consortium to be an acceptable value for industrial application.

As a result, alloys 6013, 6056, 2022 and 2024 can be formed without any hardness and thus strength degradation, see for example Figure 1.2.1.1 but the 1424 alloy in final heat temper showed loss of hardness higher than 10 %, see Figure 1.2.1.2. As a consequence, 1424 alloy has no potential for LBF because of its high susceptibility against heat impacts after installation of the final heat temper.

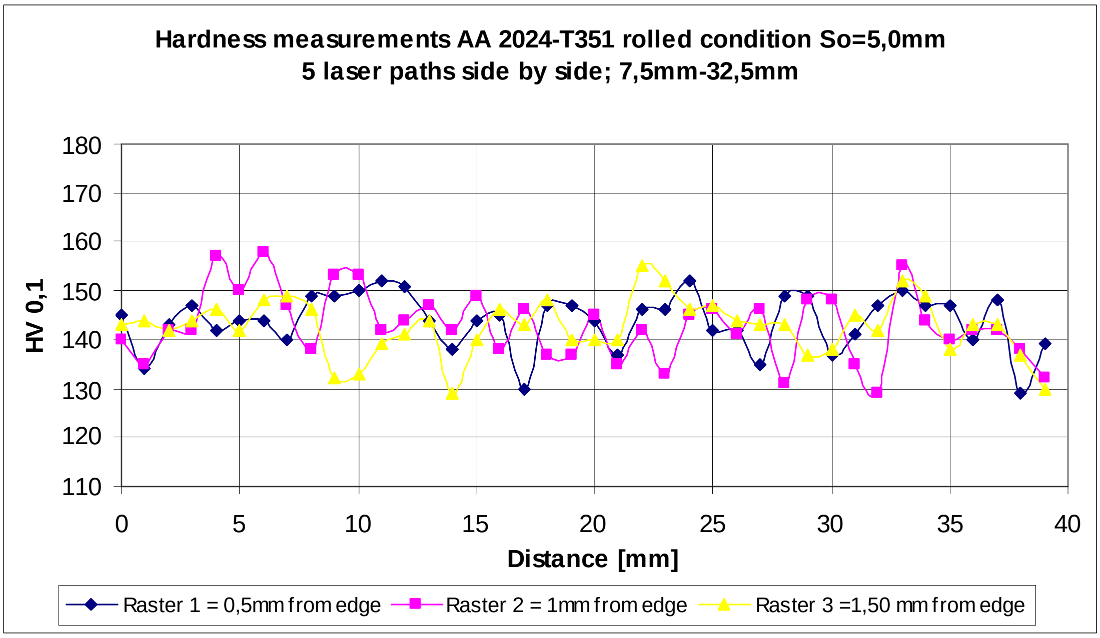


Figure 1.2.1.1: No hardness drop of 2024 after LBF (NdYAG)

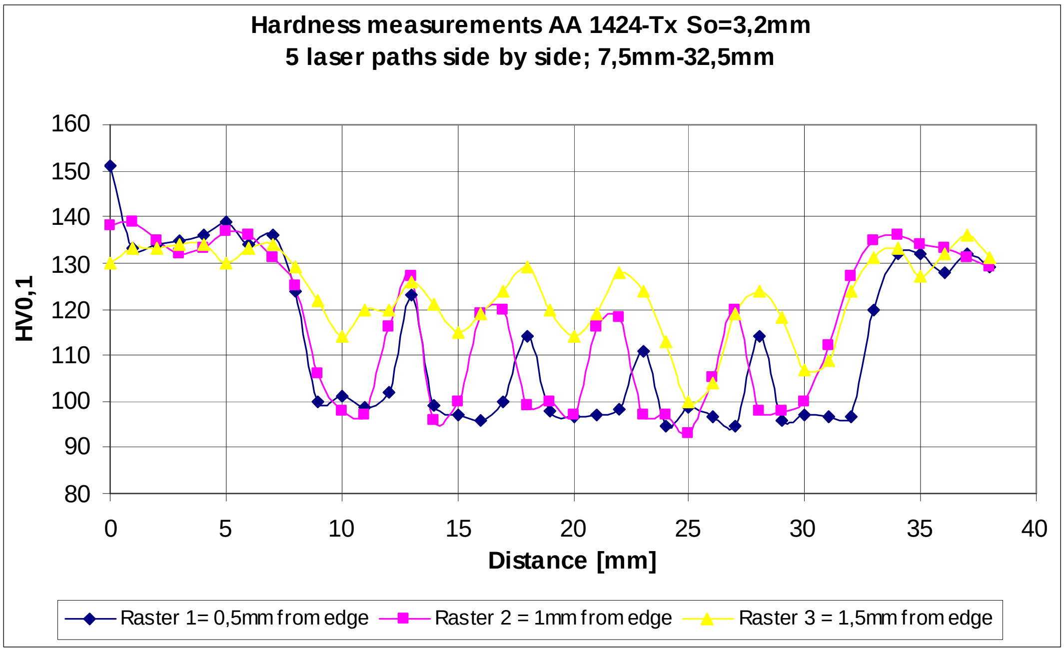


Figure 1.2.1.2: Not acceptable hardness drop of 1424 after LBF (NdYAG)

Fatigue tests on specimen after LBF where performed using alloy 6013-T6. As a result, the generated Woehler curve is slightly lower than the base material curve, but is still in the scatter range of the base material fatigue curve. For that reason it can be stated that LBF has no influence on the fatigue behaviour when suitable parameters have been used.

A fall back technology within the project was Laser Peen Forming (LPF). Unstiffened coupons made of 2022 alloy of 5 and 10 mm skin thickness have been formed successfully using LPF process. With this potential the LPF process is recommended for thick sheets and plates, on which the LBF process is not or nearly not able to generate forming effects.

Task 1.3: Enhanced properties of all selected alloys for process up-scale in WP2

In Task 1.3, enhanced properties, like corrosion, fatigue crack propagation and the effect of multiple path lines have been analysed on large unstiffened sheets as a prerequisite for process scale up in WP2.
Crack propagation testing on 6056-T78 specimen after LBF has shown a slight difference in the crack initiation and propagation but the trend is that crack propagation rate is decreasing after LBF. Possible reason is that the slight softening of the material near surface has a positive influence on ductility of the material and therefore decelerates crack propagation. LBF formed 6013-T6 shows same curve as the reference material without laser penetration, see Figure 1.2.1.3.

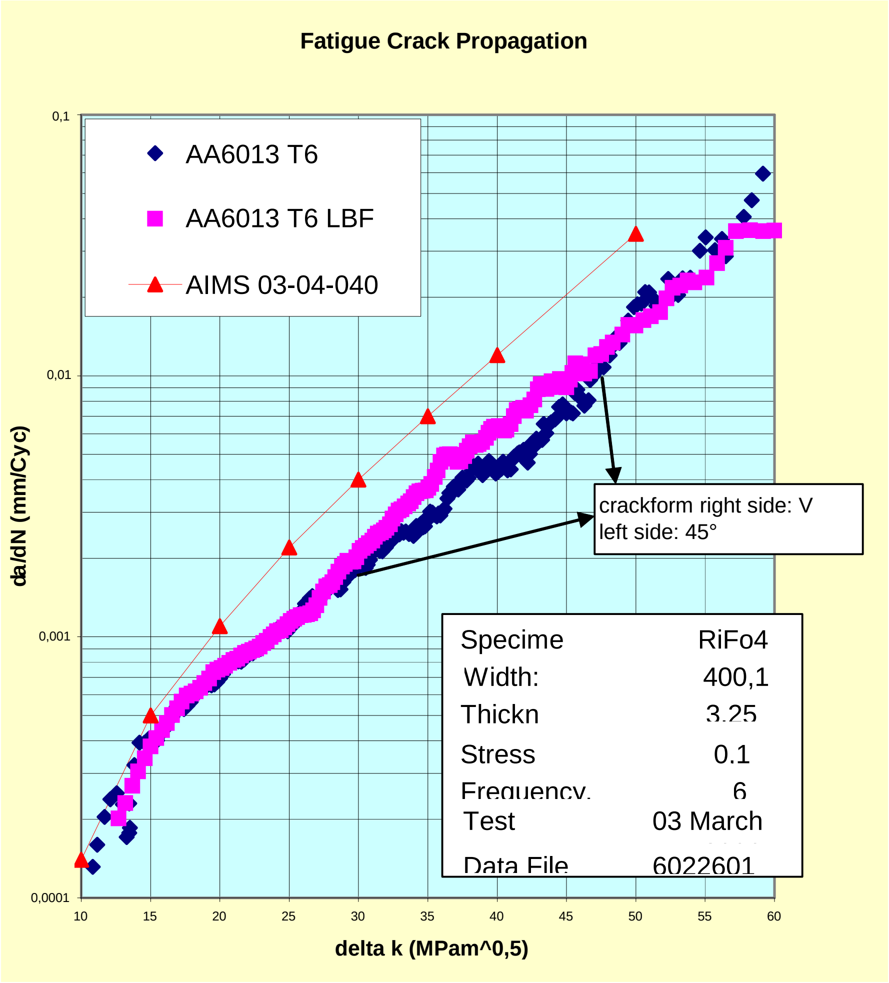


Figure 1.2.1.3: Crack propagation of 6013-T6 after LBF and unformed

The corrosion behaviour of 6013-T6 and 6056-T78 specimen after LBF has been assessed using 3 different tests: salt spray, inter-granular corrosion and exfoliation corrosion. All tests where successfully. In the cases where corrosion artefacts were detected, they were under the limit penetration depth of 0,2 mm. Thus it can be concluded that the LBF process does not affect corrosion resistance of the investigated materials.

The analysis of multiple path lines showed that it is important to keep the local temperature condition constant during LBF in order to create similar temperature gradients for each path.

1.2.2 WP2: Process development & characterisation

WP2 consisted of 4 Tasks with the objective to develop and up-scale the laser forming process for single curvature (2D) using laser geometry analysis, simulation and self learning path generation. It was successfully completed, including the 4 planned Deliverables D2.1, D2.2, D2.3 and D2.4, but with up to 6 months delay compared to the original planning and the set Milestones in Annex I, issue a (see Tables 1.2.2.1 and 1.2.2.2).

Table 1.2.2.1: Deliverables list

Del. no	Deliverable name	Task no.	Date due, month	Delivery, month	Lead con-tractor
D2.1	Prototype laser beam forming process	2.1	18	24	INA
D2.2	Up-scaled laser forming system	2.2	30	33	EAG
D2.3	Test report on curved coupon material properties	2.3	33	36	EAF
D2.4	Process chain prototype (+ simulation & self learning)	2.4	36	36	IWB

Table 1.2.2.2: Milestones list

MS no.	Milestone name	WP no.	Date due, month	Delivery, month	Lead con-tractor
M2.1	Basic process development successful	2	18	24	INA
M2.2	Process up-scale successful	2	30	30	EAG
M2.3	Process up-scale successful	2	33	36	EAF
M2.4	Coupon characterization finished	2	36	36	IWB

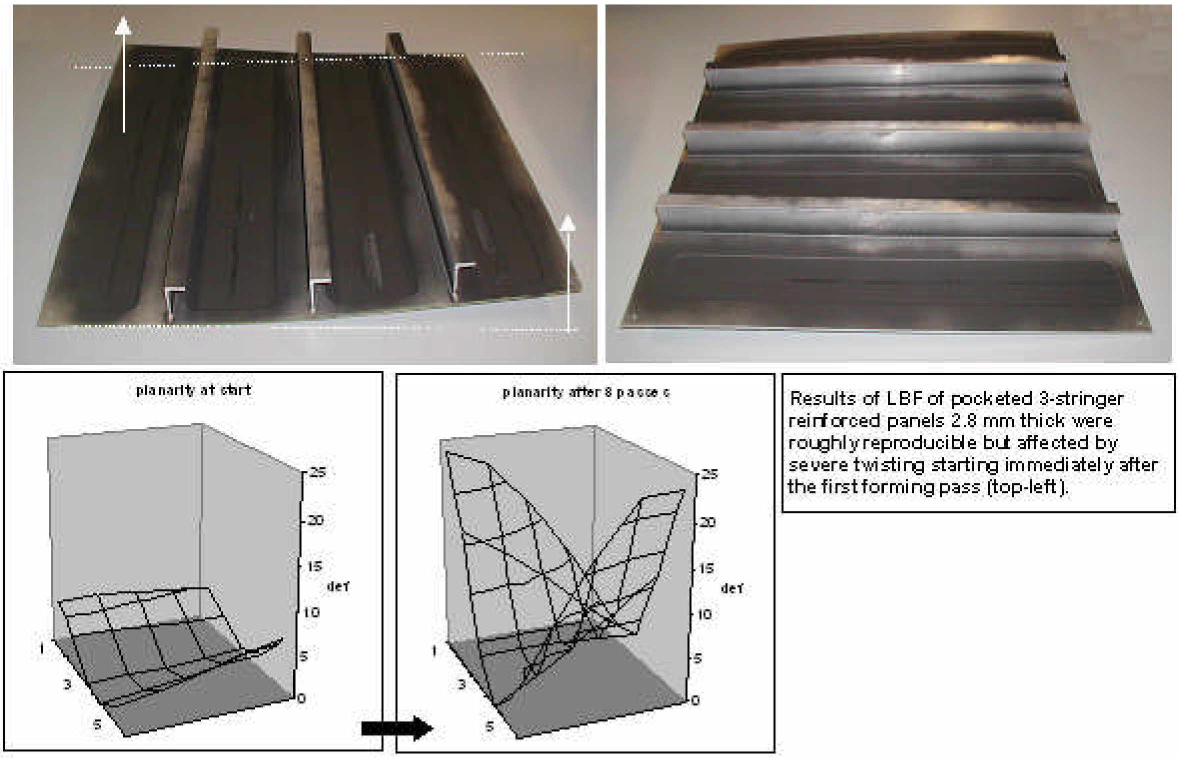
More details about work content and the results, reached, are summarized in the following Task descriptions.

Task 2.1: Basic process development

Work was focused on the basic LBF process development to realize a prototype of a self learning LBF control system as output deliverable of Task 2.1. This was done using large but unstiffened sheets. After the definition of required features, the integration of the system has been launched by IWB based on Nd-YAG laser as forming equipment. For temperature control, an integrated optical system was developed based on a pyrometric temperature measurement unit. For the measurement of geometry, a triangulation sensor was installed and linked to the robot control unit. In parallel, the software to pilot the laser system was developed by partner INA after definition of overall strategy and selected calculation method. Protocol for data transfer has been defined. The envisaged prototype LBF system has been successfully realized after month 24 (6 month delay) to be validated and improved in Task 2.2 by forming experiments on unstiffened and stiffened panels and to validate the strategy software (process parameters, paths, ….).

Task 2.2: Process up-scale

In Task 2.2 (Process upscale), different stiffened coupons, representative of fuselage panels were defined by ALA together with RTM (500x500 mm, up to 4 pockets and 3 stringers, 6013, CO2-LBF), EAG in relation with AID (685x1000 mm, different pocketing depth, 4 stringers, 6013/6056, NdYAG-LBF), EAF together with AIF (500x500 mm, 3 stringers, 6056, NdYAG-LBF) and DAS (475x475 mm, 7 stringers, 2022-T351, LPF). Various of those panels have been manufactured. After laser beam forming to single curvature, geometry defects on integrated panels appeared during the LBF process (with both, NdYAG laser and CO2 laser), being secondary 3D bending and twisting. Each partner involved in the LBF process joined the common effort to understand the twisting effect (see Figure 1.2.2.1). As a result, such twisting was avoided only in the case of bonded stringers instead of welded ones.



Results of LBF of pocketed 3-stringer reinforced panels 2.8 mm thick were roughly reproducible but affected by severe twisting starting immediately after the first forming pass (top-left).

Figure 1.2.2.1: Twisting after LBF (e. g. with CO2 laser) on panels having pockets and welded stiffeners (RTM forming of ALA fabricated integral panels)

To compensate the twisting effects, found in Task 2.2 for welded structures, a fundamental investigation of a “hot forming” operation as additional forming step was performed, consisting of heating to desired temperatures for specific times. Using this additional step allows to pre-form the panel by LBF and to use hot-forming for calibration of the shape. This forming step is being performed during the tempering thermal treatment of the panel in a respective mould.

As an advantage, the mould can be machined the real shape of part to be formed (no elastic spring back) and the residual stresses are at low level, compared with conventional forming processes such as roll forming and successive bending.

Major drawback of this technology is the requirement for extra material length in order to clamp the panel periphery (see Figure 1.2.2.2). An appropriate clamping of the panel borders is necessary in order to avoid elastic spring back after hot forming.

Basic results were promising, but the up-scale of such process combination was beyond the project scope.

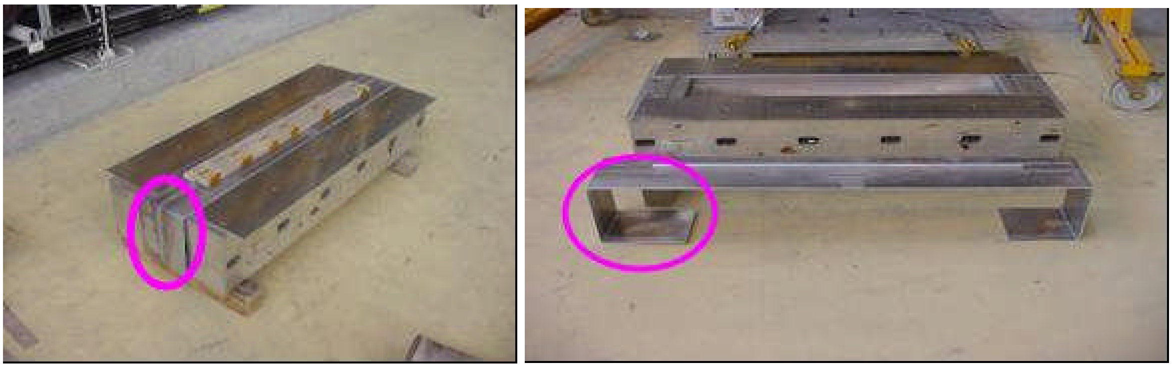


Figure 1.2.2.2.: Example of extra length on coupon test

In parallel and as fall back solution to LBF for higher thickness, investigations on Laser Peen Forming (LPF) on thick walled integrally stiffened panels was successful, but shows a typical pattern at the surface (Figure 1.2.2.3).

Figure 1.2.2.3: Thick walled stiffened panel after successful LPF processing

Task 2.3: Coupon characterisation

Task 2.3 has been reduced for increased Task 2.2 activities. The results of remaining 4 point bending fatigue, tensile and tearing tests as well as metallographic analysis showed no negative impact of the LBF and LPF process.

As an example, the lifetime in 4 point bending fatigue after laser peen forming is not penalised by the geometry and the position on the loading tool (see Figure 1.2.2.4). The results confirm that the laser peen forming is not prejudicial for the fatigue crack initiation of the tested specimens.

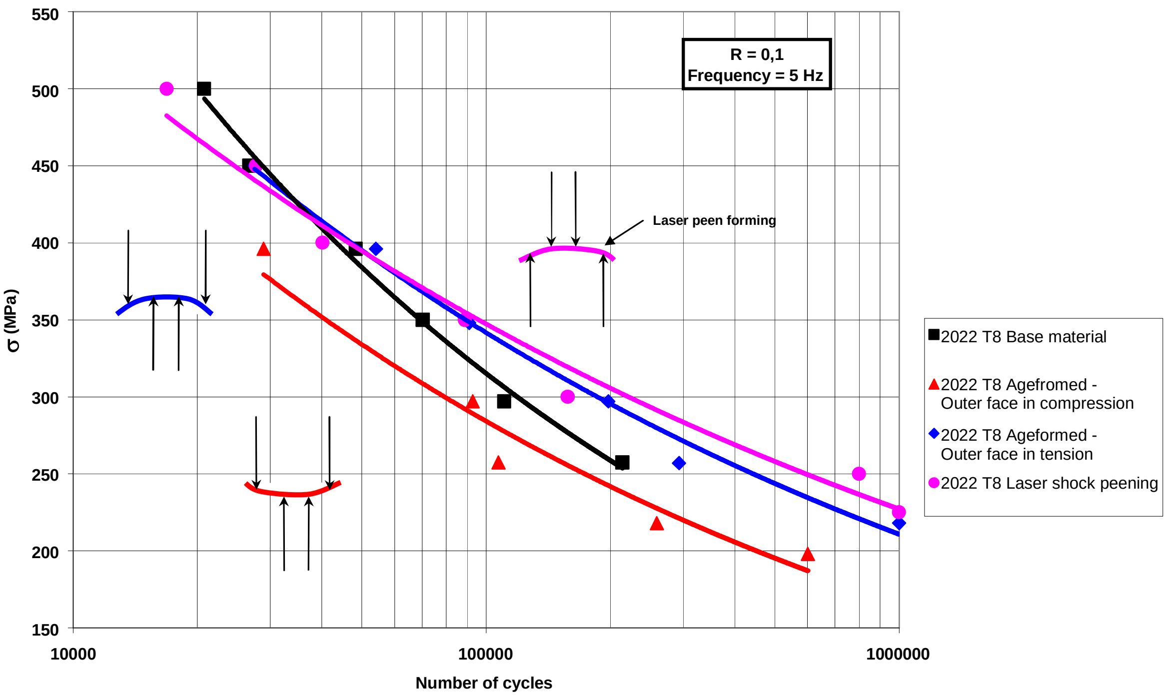


Figure 1.2.2.4: 4 point bending fatigue results on different 10 mm thick 2022 specimen

Task 2.4: Integration of process and simulation

In Task 2.4, integration of LBF process, optical geometry measurement, in-line quality control by pyrometric surface temperature measurement and self learning LBF system was driven by partners IWB and INA on large scale complex components. As main achievement, the system performance was successfully demonstrated, using an iterative approach, but forming to desired shape was only possible with bonded stringers. Further work and numerous real components would be necessary to adapt the system to the distortions effects, described in Task 2.2, which is beyond the scope of this project. Figure 1.2.2.5 shows the prototype LBF forming unit, indicating also the effort involved to reduce specific tooling. As visible in the right picture of Figure 1.2.2.5, the panel is hanging in a vertical position in a simple frame and is only slightly constrained to secure on the one side an exact positioning of the panel but to allow on the other side a free deformation due to the LBF process.

Figure 1.2.2.6 shows the optical system (CCD camera) for geometry measurement by triangulation, which integrates also the in-line quality control, realised by a coaxial coupling of a pyrometric system to measure the component surface near to the laser beam. This enables at specific boundary conditions the temperature control of the heated surface.

Figure 1.2.2.5: Completed prototype of LBF forming unit

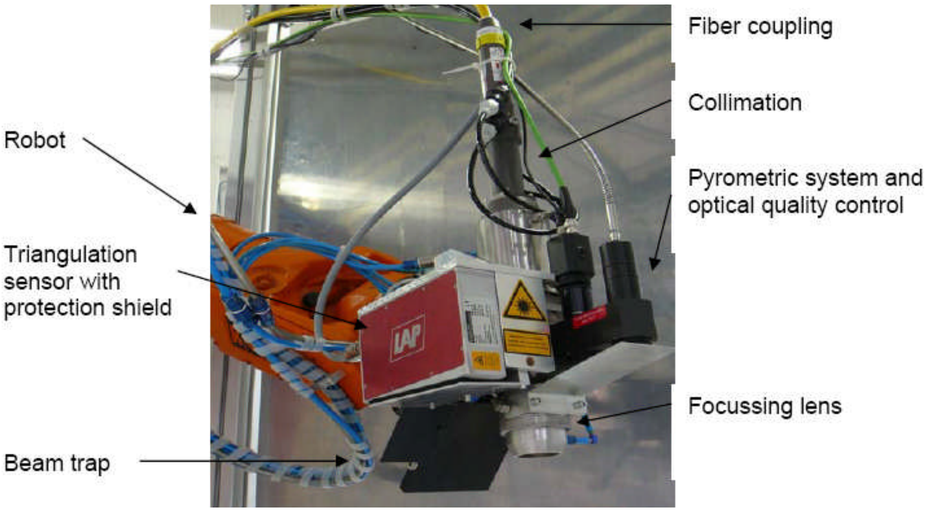


Figure 1.2.2.6: Optical geometry measurement system and in-line quality control

1.2.3 WP3: Process development & characterisation

WP3 had the objective to develop further and enhance the forming process to cope with stiffened, biaxial (3D) curved generic shapes. It was completely skipped in agreement with the EC Scientific Officer, including the planned Deliverable reports D3.1 and D3.2. This was done to support the additional work in WP2, necessary in understand the 3D distortion effects during single curvature (2D) forming.

1.2.4 WP4: Simulation & verification

WP4 consisted originally of 4 Tasks with the objective to develop a thermo-mechanical and a benchmark model to simulate the laser beam forming, using a local-global approach. It was successfully completed, including 3 of the 4 planned Deliverable reports D4.1, D4.2 and D4.3, but with up to 6 months delay compared to the original planning and the set Milestones in Annex I, issue a (see Tables 1.2.4.1 and 1.2.4.2). Task 4.4 was completely skipped in agreement with the EC Scientific Officer, including the planned Deliverable D4.4. This was done to support the additional work in WP2 and WP4, necessary in understand the 3D distortion effects during single curvature (2D) forming.

Table 1.2.4. 1: Deliverables list

Del. no	**Deliverable name**	**Task no.**	**Date due, month**	**Delivery, month**	**Lead con-tractor**
D4.1	3D thermo-mech. simulation report of local behavior	4	27	33	IST
D4.2a	Benchmark model: methodology report & data	4	30	36	ALA
D4.2b	Fuzzy logic: feasibility for benchmark model	4	30	36	ALA
D4.3	Methodology report for the global model	4	27	27	EAF
~~D4.4~~	~~Shop floor level software in- & outputs defined~~	~~4~~	~~30~~	~~30~~	~~AIF~~

Table 1.2.4.2: Milestones list

MS no.	**Milestone name**	**Task no.**	**Date due, month**	**Delivery, month**	**Lead con-tractor**
M4.1	Local simulation validated	4.1	27	33	IST
M4.2	High speed benchmark simulation available	4.2	30	36	ALA
M4.3	Global simulation validated	4.3	36	36	EAF
~~M4.4~~	~~Interface to production plant completed~~	~~4.4~~	~~36~~	~~36~~	~~AIF~~

More details about work content and the results, reached, are summarized in the following Task descriptions.

Task 4.1: 3D simulation of the local behaviour

Based on a detailed determination of requirements, a specification of the form of data needed for exchange of results between different models (local-global), a collection of material properties needed for the numerical simulation and a literature review concerning laser forming aspects of aluminium alloys, the numerical methodology for the simulation of the laser forming process was defined and flow chart was created. Partner IST has then developed and validated a parametric three-dimensional finite element model for the simulation of the laser beam forming process. This has been originally utilized for both, the thermal and structural analysis, in order to properly simulate the thermal and structural response of the material to the laser beam heat flux. Afterwards, numerical simulations of laser formed coupons of WP1 have been performed. The developed model has then been applied for the prediction of the bending angle of small-size specimens, in order to provide data to Task 4.2 and finally, the local model was connected to the global model of Task 4.3 by data exchange.

In addition to these originally planned activities, partner IST supported the WP2 investigations in the unexpected distortion and twisting problem by application of the 3-D local model to medium or large scale structures with and without stiffeners. This has led to extremely high computing times, making the simulation process impractical. In order to overcome these difficulties, an improvement has been performed in the simulation methodology by adopting a combination of a 3-D thermal with a 2-D mechanical approach (see Figure 1.2.4.1). For the validation of the proposed 3-D/2-D methodology, the obtained data were compared to the full 3-D analysis data. As a result, the accuracy concerning the bending angle has not been seriously affected and the computational time has been reduced by 50 % to 80 %.

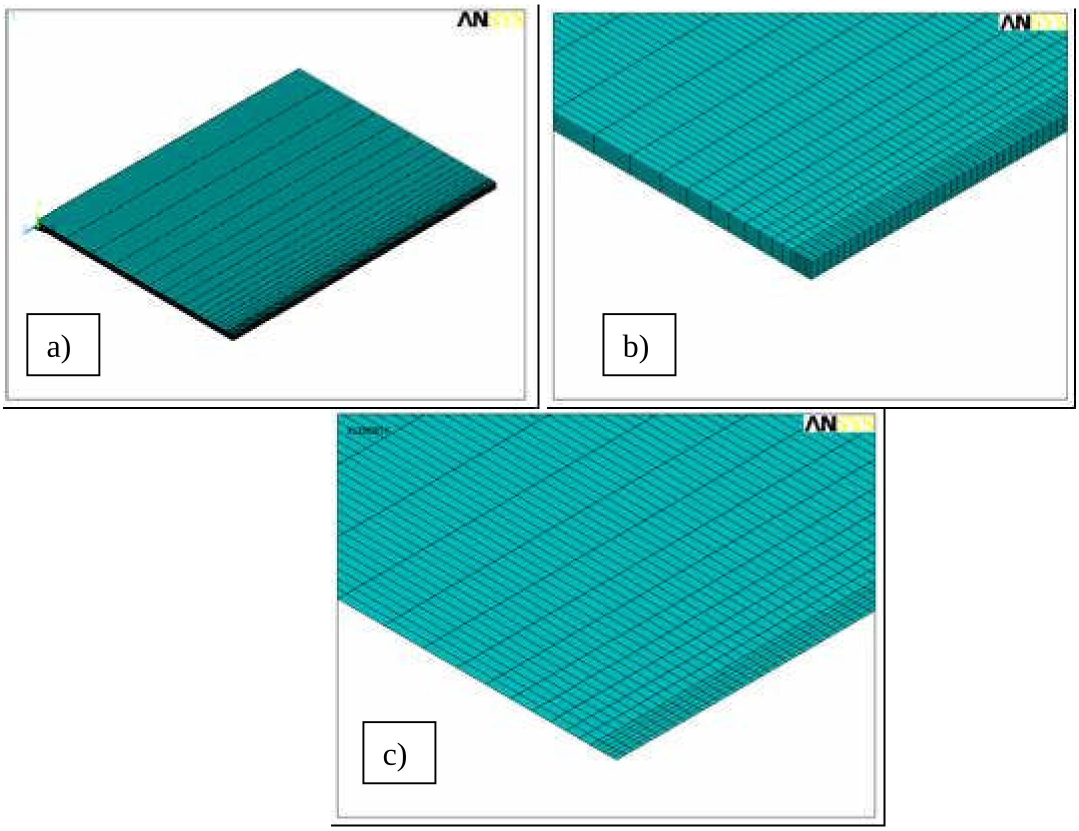


Figure 1.2.4.1: (a) 3-D thermal model, (b) detail of a) at the laser pass line and (c) corresponding 2-D mechanical model detail

With this optimized hybrid 3D/2D model, partner IST has performed a parametric analysis, in order to evaluate the effect of panel length and width as well as of stringer addition of various types to the resulting bending angle and the component geometry.

Analysis of the ‘size effect’ has indicated a negative effect of length on the calculated bending angle. On the other hand, it has been observed that the increase of panel width leads to an increase of the bending angle. Furthermore, there is an edge effect, i.e. in the last heating steps (laser run-out), the temperature is increased with respect to the rest of the path (where it is almost constant). In contrast, the effect of addition of 1 stringers of different thickness on the bending angles transverse to the stringers has no serious effect. On the other hand, bending angles is severely affected in the case of addition of different stringers and is also a function of the number of laser passes. This makes the prediction of complex structures very difficult.

In order to explain the lack of ‘flatness’ (or un-evenness of bending and twisting), the laser forming process of large stiffened panels has been simulated using the developed numerical methodology for cases of real stiffened panels provided by Partner IWB (see Figure 1.2.4.2).

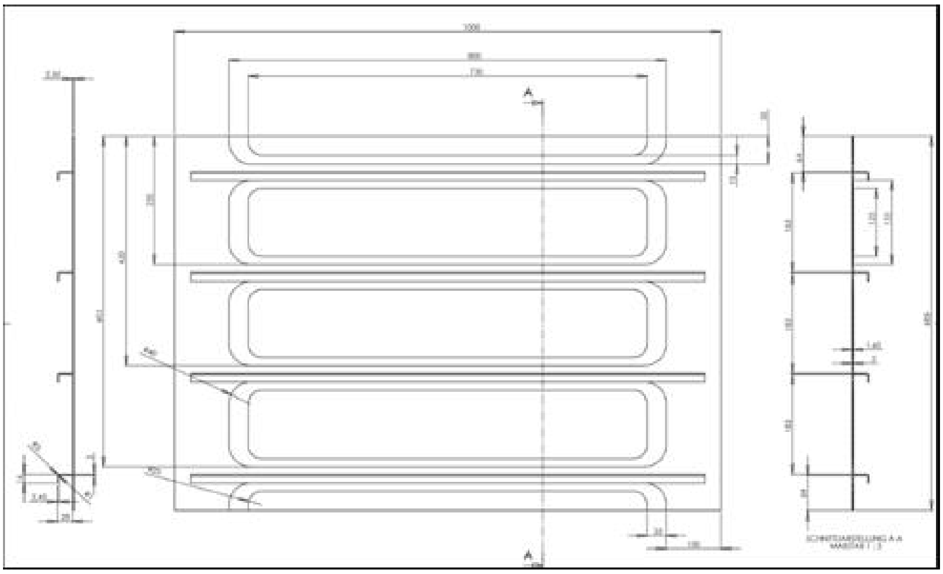


Figure 1.2.4.2: Geometry of the large stiffened panel.

The purpose of these simulations was to investigate the effect of stiffeners, panel size and laser beam path on the response of the structures during the laser forming process, as well as to clarify, if the twisting effect is caused by previously existing residual stresses in the plate (e.g. due to laser beam welding of stiffeners). Different combinations of geometries and laser beam routes have been used during the study and various plots have been produced. From these results, the following remarks and conclusions may be drawn:

- The final shape of the panel seems not to be “stable”. This is concluded by the observation that the bending direction of the stiffeners, that primary effects the secondary bending of the panel, is not constant, but “sudden” reversals appear during the forming process.
- At the final state of forming, stiffeners exhibit significant twisting, which is one additional reason for the “unstable” condition of the formed panel.
- The secondary bending of the panel is of the same order (and potentially larger) compared to the primary bending due to the laser beam.

- The secondary bending is not uniform and it seems, that it depends on the symmetry of the stiffeners with respect to the laser beam line.
- The stiffeners cross-section lack of symmetry (with respect to the stiffener axis) does not seem to substantially affect their twisting and consequently the secondary bending of the panel.
- It is very possible, that twisting and non-uniform bending is not necessarily caused by previously existing residual stresses in the plate (e.g. due to laser beam welding of stiffeners), as all previously presented analysis did not include any pre-existing residual stresses.

Finally, a full set of 30 cases determined by partner ALA have been simulated and the results including bending angles, temperature and plastic strain distributions along the laser root and vertical to it at various depths of the plate, as shown in Figure 2.4.2.2, have been delivered to ALA for evaluation of the global model, based on fuzzy approach.

Task 4.2: Fast benchmark simulation

Task 4.2 is guided by ALA and the developing of the activities are performed in concurrence with the University of Salerno (UNISA) that have a big experience in mathematical methodologies development. They have identified the flow chart solving the steps needed for the developing of the so called Fuzzy Fast FEM, a mathematical method that is able to forecast the forming behaviour starting from the input that are needed for the forming itself.

A discrepancy verified between numerical and experimental data relating to large structures has produced a leakage of input data. Thus, the Fuzzy system was built from simulation results of laser formed coupons (0.15 * 0.10 m and material 6013-chemically milled) provided by partner IST. On the basis of individuated membership functions and of chosen level of detail, rules for different conditions, related to known results, were defined. Membership function, rules and elaboration algorithm are written in MatLab, using Fuzzy toolbox of Simulink. This Software, during its running, ask to user the value for laser power, for absorption coefficient, for laser speed and for sheet thickness, and elaborate the result by Centroid method application.

Task 4.3: Detailed simulation of the global behaviour

The objectives of the WP4.3 are to perform Laser Beam Forming (LBF) simulations of large structures. Such simulations are called “global modelling”, in contrast to “local modelling”, performed by partner IST within Task 4.1.
Local Modelling is usually dedicated to the simulation of the thermo-mechanical behaviour of small samples. The relevant result is the bending angle as a function of sample geometry, material and LBF parameters.
Global modelling aims at describing the behaviour of large LBF samples and structures. It is based on the exploitation of the results of local modelling. The relevant global result is a description of the final global geometry. The influence of specific geometrical features such as stringers and pocketing, which are not represented at the local scale, should be taken into account. The model has to represent potential large scale effects such as buckling.

For the development of a detailed 2D global Finite Element model, EAF tools have been used, dedicated to welding simulations as a basis, and developments have been made to add the capability to use 100 % shell models (best suitable elements for large structures). Two heat sources have been developed: an imposed-temperature source and an imposed flux one.
To perform the development of the global modelling methodology, it has been necessary to test various implementation schemes. This required the building of different finite element models (local non linear models, local super-element models, global super-element models) and the development of several utility routines in order to facilitate the definition, use and post-processing of the global model. As an example, modelling of deformation of a 3-stringer panel as a function of laser paths is shown in Figure 1.2.4.3.

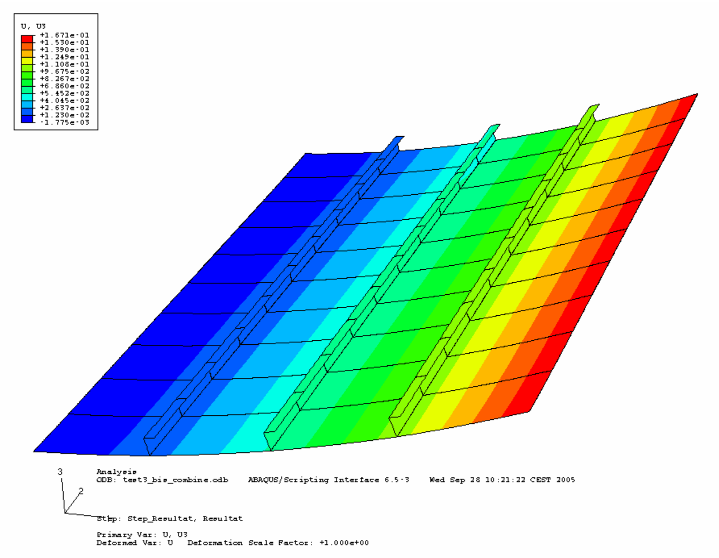


Figure 1.2.4.3: Global modelling of 3 stringers-panel. – Vertical displacement after 68 paths.

Due to the unexpected distortions experienced in WP2, detailed simulation of the global behaviour was used to support understanding of this effects. To do so, partner EAF has developed a simulation chain for forming of large panels with the following steps:

- local thermal simulation,
- local mechanical simulation,
- global mechanical simulation using a field transfer approach.

This method has been applied on a 1 m long stiffened panel and a 4 m long stiffened panel. In a first step, a 1 m wide and 10 cm long panel with 3 stringers has been simulated. The forming parameters (power, spot diameter and position of the paths) have been defined by partner IWB.
The thermal model uses a heat source, which is moved along the forming paths.
After the thermal simulation, the local mechanical simulation is performed, using the same mesh. The Figure 1.2.4.4 presents the displacement and stress field during forming. The positions of the forming paths are clearly visible. Then a procedure is used to transfer the plastic strains from the local model onto the 1 m long panel (Figure 1.2.4.5). This procedure is based on an elastic procedure, using thermal expansion as described in deliverable D4.3. The results were in global agreement with the experiments performed by IWB.

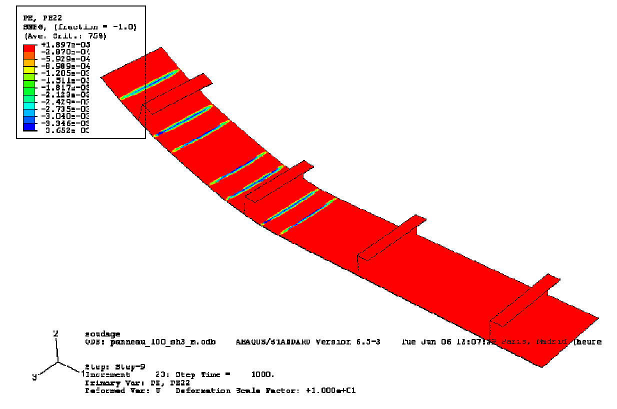


Figure 1.2.4.4 Local mechanical simulation Displacement x 10

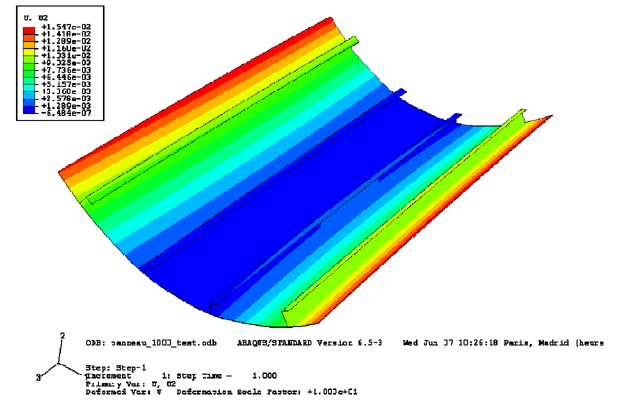


Figure 1.2.4.5 Distortion of a 1 m long panel Displacement x10

In order to evaluate the usability of the process for industrial components, a simulation has been performed for a 4 m long panel (which is representative of a medium-size panel). The same method than for the 1 m long panel has been used. The results are presented on Figure 1.2.4.6.

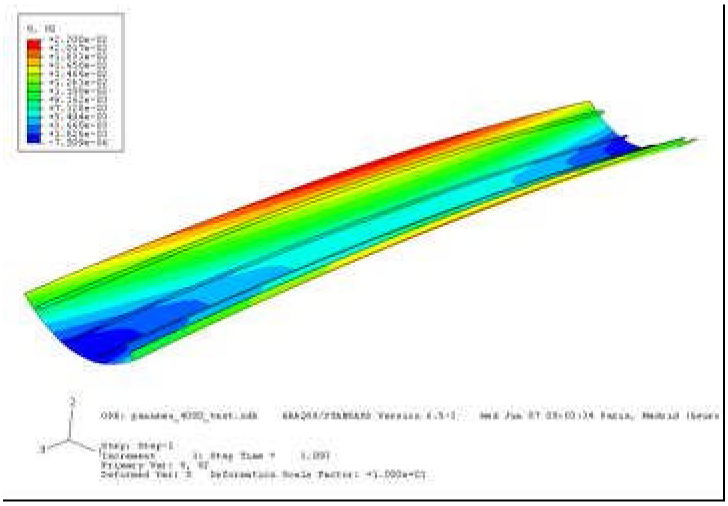


Figure 1.2.4.6: Distortion of a 4 m long panel – Displacement x 10

In terms of longitudinal distortions, the deflections induced by the forming are 15 mm for the 1 m long panel and 22 mm for the 4 m panel. These values are not negligible and have to be compared to the industrial production tolerances in order to check their acceptability.

In order to explain the twisting, being observed experimentally, a numerical analysis has been performed. Since a qualitative explanation was needed, simplified models have been used. The principle of the simulation was to introduce a thermal strain within the finite element model in order to recreate the shrinkage induced by the real process. No heat source was used. The following assumptions have been made:

- welding is taken into account and is introduced as a shrinkage within seams
- seams are created in one step (shrinkage is introduced at the same time for the whole length)
- all the seams are created at the same time
- the forming paths are created one after another,
- each forming path is created in 3 steps (1/3 of the length, then another 1/3, then the last 1/3).

As a result, no twisting was observed. To overcome the incapacity of the simulation to reproduce the twisting, different solutions have been tested:

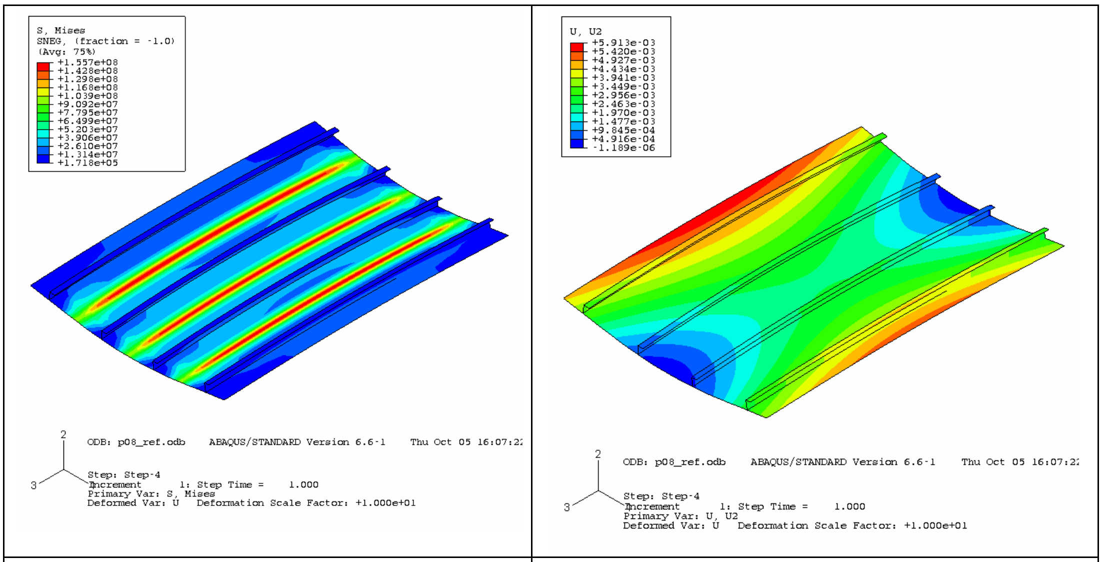
- use of other solvers (RIKS and EXPLICIT solvers),
- introduction of geometric imperfections into the structure.

The first attempt was driven by the fact, that the instability was possibly not caught by the NEWTON-RAPHSON solver. The RIKS method allows handling snap-through problems and the explicit solver takes the inertia into account. However, both solvers led to the same results than before.

The introduction of geometric imperfections aimed at triggering the instability by breaking the symmetry. The following procedure has been used:

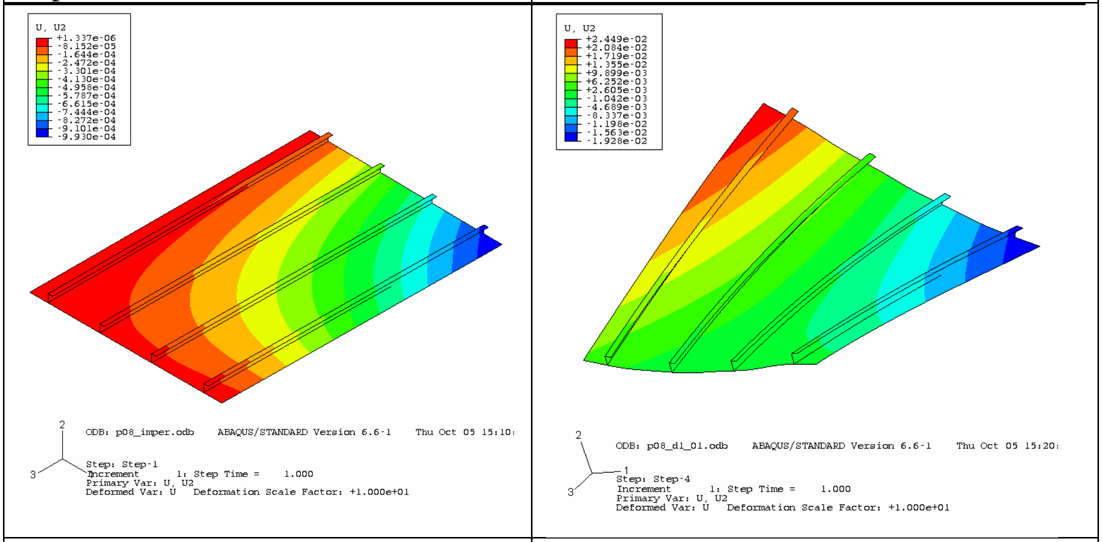
- small geometric imperfections are introduced within the mesh,
- the mesh is modified but no initial stress is introduced.

Figure 1.2.4.7 clearly shows, that the twisting is related to geometric imperfections. A small amount of imperfection triggers a high amount of twisting (20 mm).



a) Reference case: no geometric imperfection

b) Reference case: Final shape



c) Initial geometric imperfection: one corner is 1 mm below the others

d) Final shape: Twisting (20 mm)

Figure 1.2.4.7: Impact of geometric imperfection on twisting

An analysis has then been carried out in order to check the sensitivity of the twisting to the distribution of the geometric imperfection and the amount of geometric imperfection. The conclusions are the following:

- the twisting pattern and value does not seem to be sensitive to the imperfection patterns: two imperfection distribution have been used, leading to the same twisting,
- the amount of imperfection has no influence on the twisting value. Below a value, no twisting is observed. Beyond a certain value, twisting is triggered, with the same value.

Further analysis was to correct the final shape after forming. The idea was to evaluate the necessary forces to correct the shape and check if they are small enough to be acceptable. As a result, to correct the shape, it is necessary to use many fixture points and very high forces.

As a conclusion, and according to these simulations, the process does not seem suitable to the manufacturing of large panels without unwanted distorsion.

1.2.5 WP5: Economical evaluation, exploitation & dissemination

WP5 consisted originally of 3 Tasks with the objective to prepare an economical evaluation of laser based forming processes developed during the project to create an exploitation and dissemination plan based on all partners inputs. It was successfully completed, including 3 planned Deliverable reports D5.1, D5.2 and D5.3, but with up to 6 months delay compared to the original planning and the set Milestones in Annex I, issue a (see Tables 1.2.5.1, 1.2.5.2).

Table 1.2.5.1: Deliverables list

Del. no	**Deliverable name**	**Task no.**	**Date due, month**	**Delivery, month**	**Lead con-tractor**
D5.1	Economical evaluation report of reference cases	5	24	30	AIF
D5.2	Economical evaluation report considering the whole manufacturing chain	5	33	36	EAF
D5.3a	First exploitation and dissemination plans	5	12	12	all
D5.3b	Final exploitation and dissemination plans	5	36	36	all
D5.3c	Summary exploitation & economical evaluation report	5	36	36	INA

Table 1.2.5.2: Milestones list

MS no.	**Milestone name**	**Task no.**	**Date due month**	**Delivery, month**	**Lead con-tractor**
M5.1	Economical evaluation report on selected reference cases available	4	24	30	AIF
M5.2	Economical evaluation report of new process performed	4	33	36	EAF
M5.3	Exploitation plan and economical evaluation report available	4	36	36	INA

More details about work content and the results, reached, are summarized in the following Task descriptions.

Task 5.1: Definition of a common base line

It was agreed to define 3 case studies, one for each industrial partner, involved in this Task (AIF, AID, DAS), according to the most likely process, since the impact of the cost of laser forming will depend also on the savings in the previous or further manufacturing operations. The assumption of possible manufacturing scenarios was based on the process know-how generated in WP's 1 and 2, including specific parameters like

- type of laser beam source, influencing investment cost,
- need for coating (absorption of surface), influencing process duration and cost,
- applicable feed, influencing process duration,
- achievable bending angle, influencing number of laser lines (process duration).

Based on that, the following cases have been selected:

1.) A complex integrally machined single curved thin panel currently formed by successive bending (AIF)
2.) A single curved panel with laser beam welded stringers (AID)
3.) A complex integrally machined thick panel for assessment of laser peen forming (DAS)

It has been further defined to avoid costs disclosure. Thus only relative values were calculated by evaluation of savings on a case to case basis, based on a comparative study.
In addition, recurring costs are agreed to be calculated by each partner using its own basis.
For non recurring costs, investments are to be considered like dedicated laser beam machine tool, tooling, measuring device, simulation equipment and programming tools.

As an output of this Task, the manufacturing sequences of the 3 specific cases, using the conventional processes and laser beam or peen forming, have been defined.

Task 5.2: Economical evaluation

After basic definitions in Task 5.1, the economical evaluation of laser forming and combined processes was performed. As different scenarios have been selected by the different end user partners AIF, AID and DAS, the resulting economical evaluations differ and are therefore described separately.

For AIF, the main influencing factors for the evaluation were specified (see Table 1.2.5.3). A detailed evaluation has then been performed, taken into account all cost factors and process steps. As a conclusion, LBF is competitive for the shape calibration operations of the selected 2D complex panel, but not for the forming operation. Process time can be reduced from 20 h (calibration done by hand) to 2,5 h (LBF including self learning process), which is a factor of 8. However, this application is a niche (only 4 relevant panels per aircraft). Payback is too long if an investment is to be done (12 years), but is applicable with existing machine tool (pay back estimated to 4 years).

Table 1.2.5.3: Specification of influencing factors for AIF evaluation

Main influences to be considered during the evaluation	**WP5 definitions by AIF**
Oversizes of semifinished products	For 2D panels: Same for conventional and LBF (thus not taken into account).
Production steps and their sequence	According to flow diagrams for conventional process and new process incorporating LBF for welded panels
Structural area to be evaluated	The evaluation is focused on a single panel.
Definition of baseline(s)	Complex 2D panel, 7175 skin alloy, machined stringers (LR Aircraft): 2D machined panel + bending forming

For AID, the main influencing factors for the evaluation were specified (see Table 1.2.5.4).

Table 1.2.5.4: Specification of influencing factors for AID evaluation

Main influences to be considered during the evaluation	**WP5 definitions by AID**
Oversizes of semifinished products	For 2D panels: Same for roll forming and LBF (thus not taken into account).
Production steps and their sequence	According to flow diagrams for conventional process and new process incorporating LBF for welded panels
Structural area to be evaluated	The evaluation is focused on a single panel.
Definition of baseline(s)	2D panel, 6013 skin alloy, laser beam welded stringers (as in section 14 of A340-600 HGW). • 2D welded panel roll formed • 2D welded panel roll formed + reshaped
Definition of the number and types of variants to be investigated	• Scenario 1: 2D panel LBF with NdYAG-laser • Scenario 2: 2D panel LBF, CO2-laser, “grey” surface • Scenario 3: 2D panel LBF, CO2-laser, “black” surface

A detailed evaluation has then been performed, taken into account all cost factors and process steps. Based on that, the following conclusions have been found:

- Due to the focus on 2D-panels, LBF cannot compete with the conventional simple roll forming process.
- Taking into account the effort for the reshaping process, required for welded panels, the LBF process becomes cost competitive.
- LBF scenario 1 (NdYAG) reduces the process time by a factor of 2,3
- LBF scenario 2 (CO2, grey surface) reduces the process time by a factor of 3,8. However, a modification of the pickling bath is required.
- LBF scenario 3 (CO2, black surface) has the shortest pure LBF process time. However, additional time required for painting and subsequent removal of the black surface layer results in a total time equal to the roll forming/reshaping process.

For DAS, specific cost evaluation was very difficult due to the focus on the LPF process because of the limitations of LBF to low thicknesses. Although technical feasibility of LPF has been demonstrated, gathered data of relevant economical parameters was not sufficient to perform a real cost evaluation at this basic stage of LPF development. Thus, only a rough estimation of the potential of the LPF was possible. One approach is seen in Figure 1.2.5.1, showing the cost distribution of conventional (manual) forming (using press and skill working) between forming effort, 3 axes milling and material consumption. In this case, the machining is done in flat as for LPF, but then formed by press and manual working. The new approach is to replace conventional forming by LPF. Thus, the material and milling costs are equal in both cases. The forming cost has the highest importance and consequently, LPF has the potential to effectively contribute to cost reduction in an industrial production process.

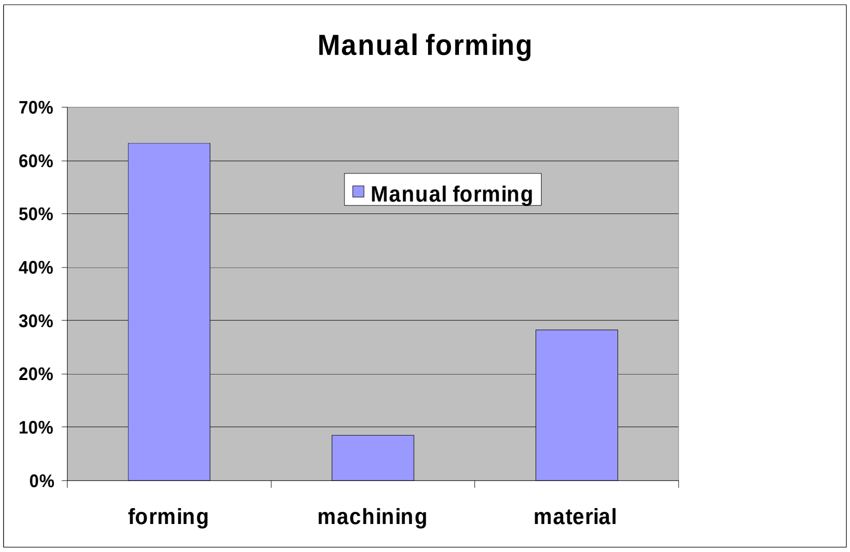


Figure 1.2.5.1: Cost distribution of conventional manual forming of selected DAS component

The major conclusion of this economical study is that competitiveness is linked with manual operation avoidance. This is not specific to LBF but more generally provided by a better control of a forming process, being incremental in nature, which allows combination of forming and measurement.

An appropriate economical evaluation would require a comparison of LBF or LPF with a process of the same nature. However, today such processes are more or less at the same level of development as LBF or LPF.

Task 5.3: Exploitation and dissemination

This Task was pushed and well organized by the Project Exploitation Manager (partner INA). A special template was created to continuously collect all partners exploitation input and a special software (freeware) was used to evaluate this input. In addition, inputs were collected from all partners to create and update the “Plan for using and disseminating the knowledge”, which was added as Appendix 1 in the annual reporting to the EC. A “Final plan for using and disseminating the knowledge” was prepared to be annexed to the final reporting documents. The publishable results of that document are summarized in chapter 2.

1.3 Degree to which the objectives were reached

The following measurable major objectives were originally envisaged in the project:
1. Forming stiffened structures to **single curvature** of 1250 to 3000 mm radii along stiffeners
2. Forming **bi-axially curved structures** with additional 10000 mm radius across stiffeners
3. Verification of estimated shell **manufacturing cost reduction** of 10 % by more processing in a flat condition and a further 10 % by avoidance of heavy and complex tooling
4. **Shell weight reduction** of 10 % with new alloys, less useful with conventional forming

1.3.1 Forming stiffened structures to single curvature along stiffeners

This first major objective has been fully reached, when Laser Beam Forming (LBF) is applied to stiffened structures with bonded stringers. In this case, no unwanted distortion, twisting or kinking is found. Consequently, the effort to reach the desired geometry should be low, even without using the developed self learning system, but applying only the large experience gathered during the project.

Even in the case of welded stringers, is seems to be realistic to reach that objective. In this case, more effort is necessary to form a larger set of identical structures and to consequently apply the developed self learning system in order to include the distortion effects in the laser path strategy to be applied. The learning curve would speed up very quickly, allowing the forming of specific component geometries, and the integrated optical temperature measurement system can act as in-line quality control system for industrial manufacturing.

Finally, the basic evaluation of Laser Peen Forming (LPF) as back-up process for structures with higher wall thickness was successful enough to forecast the ability to fulfill this objective for single curvature forming and thin-walled structures , although it has been applied for more complex 3D forming. Nevertheless a lot of additional work will be necessary to prove this.

1.3.2 Forming bi-axially curved structures across stiffeners

Although the respective WP3 was finally skipped with the latest Annex I, issue d, the project results showed that forming across the stiffeners is possible with the LBF process. The only problem was to control such deformations and to introduce them into the laser path strategy to reach the desired geometry. As already mentioned in chapter 1.3.1, the consequent application of the developed self learning system to a specific number of identical stiffened structures will solve that problem. It is expected, that a first specific geometry needs a high number of trials and thus identical structures to be prepared and formed, but with increasing “experience” of the system, the learning curve should speed up dramatically, requiring only limited numbers of parts to realize new types of bi-axially curved structures with new geometries.

In addition, the basic evaluation of the LPF process was performed on such a 3D structure, but with high wall thickness. The results showed the principle ability of such a process to create even smaller radii than the envisaged 10000 mm across the stiffeners. Nevertheless, a lot of additional work is necessary to show the overall performance of that process also for reduced wall thickness and different Aluminum alloys.

1.3.3 Verification of estimated shell manufacturing cost reduction

This objective has been split into cost reduction of 10 % by more processing in a flat condition and a further 10 % by avoidance of heavy and complex tooling. Although cost evaluation results in WP5 are described by avoiding absolute cost disclosure for competition reasons, this objective is nevertheless reached due to the following reasons:

1.) The cost evaluation has identified specific cases, where LBF can compete with the current process chain and others, where this is not the case. This shows, that the applied evaluation procedure was selective enough.
2.) The reduction of process time by a factor of 2.3 (AID scenario 1), 3,8 (AID scenario 2) and 8 (AIF scenario) is not a marginal improvement but should be sufficiently high to create cost reductions that are higher than 10 %.
3.) The LBF process applied to large complex structures was developed in a way to have them hanging in a quite simple frame with slight fixtures to allow free motion during forming but secure positioning for geometry and temperature measurement. This tool is absolutely flexible and low cost compared to heavy steel dies, necessary for each types of panels. Thus it is obvious to create a cost reduction, which is not neglectable and which can easily reach 10 % of the total processing cost of the component.

As pointed out, these arguments cannot be applied for LPF to perform a good cost evaluation due to insufficient economical parameters available at this basic stage of LPF development. In any case, there is a need for a specific forming tool, able to constrain the structure during the process, which needs sufficient weight and stiffness and thus does not save costs compared to conventional dies. The residual effect of flat processing should assure some cost savings due to reduced thickness of semifinished plate and thus reduced machining effort, if full machining without subsequent conventional forming is applied. However, the major cost item is the forming, which requires specific time and experienced staff. This parameter is moving for LPF due to the continuous improvement of laser sources in terms of power, treatable surface with one shot and pulse frequency.

1.3.4 Shell weight reduction of 10 % with new alloys

This objective has been addressed by investigations on the AlLi alloy 1424, which has a reduced density due to the Lithium content, is laser weldable and was available in the desired sheet form. Unfortunately this specific alloy did not pass the set value of 10 % drop of mechanical properties during LBF processing due to its high susceptibility against heat impacts after installation of the final heat temper. Other AlLi alloys exist, like AA2098, which are envisaged to be applied in future metallic fuselage concepts. Unfortunately they were not available during the project duration and thus it was not possible to check their suitability. On the other hand, such alloys (including 11424) should be suitable for the LPF process, because of the neglectable thermal impact during this procedure.

1.4 Achievements of the project related to the state of the art

1.4.1 State of the art before project start

In the aircraft industry, laser based technologies such as laser cutting of parts and chemical milling masks, laser drilling and laser beam welding are used to an increasing extent for the manufacturing of aircraft structures. The utilisation of laser energy for forming tasks is a logical step forward towards an innovative and highly flexible manufacturing scenario.

Before project start, activities on shaping by laser have been carried out only outside the aerospace industry and mainly regarding small electro-optical-mechanical precision components such as fibre couplings for telecommunication industry, complex optical lens systems (photocopiers, wafer steppers), computer peripherals (disk, CD drives, DVD), recording heads (digital audio/video), modern display systems (cathode ray electron gun, opto-electronics), illumination systems (automotive lamps), micro-electro-mechanical systems (MEMS) as well as electrical contacts and switches.

Pulsed NdYAG, Excimer, Diode and CO_2 lasers for high precision bending has been demonstrated on Ni alloys, Stainless Steel, Be-Cu and nanocrystalline structures, but not yet on Al alloys. Laser beam forming of large sheet metal structures has been applied on steel, but again there is still little knowledge with Al as favourite material for aerospace applications.

Until project start, laser forming has been performed using empirically gained results. Thus the results were only applicable for the specific cases investigated in these publications. To overcome these shortcomings, several efforts have been made to simulate the process. A number of finite element models have been developed, but most of them were proposed for a single laser beam pass of the work piece only. Only one more generic model has been developed for the simulation of more complex shapes such as the sine shape, but this was dedicated to steel sheet. Analytical models have been developed as well. Again, most of them were case specific, whereas one more common model was done for steel sheets.

1.4.2 Achievements of the project

The achievements are a major step beyond the state of the art and summarized as following:

- **Influence on material properties**
  Determination of material properties and influences (static and fatigue strength, crack propagation, corrosion properties) as a function of process parameters
- **Interactions of process parameters, different materials and forming strategy**
  Influence of the intensity of the heat source, exposure time and material on the process results. Timing and locality of material heat exposure for increased process predictability.**Process development**
  Development & validation of an on-line measurement and control system for laser beam forming of Al structures by iterative and analytic development and combination of
  - optimised laser beam path strategy
  - geometry measurements
  - computer control based on stored strategies with self-learning correction functions
  - control algorithms for a robot based laser forming application

- **Simulation**
  Development & validation of an on-line measurement and control system for laser beam forming of Aluminium structures by iterative and analytic development and combination.
- **Spin-off**
  While laser beam forming is attractive for the manufacturing of thin panels, it is of limited suitability for thicker structures. Indeed, the necessary amount of plastic strain for bending presumably requires a through-thickness temperature gradient that may lead to important micro-structural material alterations. For this type of components, the laser peen forming has been evaluated to be a very promising alternative.

2 Dissemination and use

In WP5, the plan for using and dissemination the knowledge was prepared by the Project Exploitation Manager (INA) and continuously updated with all partners inputs. A “Final plan for using and disseminating the knowledge” was prepared to be annexed to the final reporting documents. The publishable results of that document are summarized in the following.

2.1 Exploitable Knowledge and its Use

The project aimed to address significant challenges related to the following user groups:

- the aerospace metallic material producers
- the manufacturers of sheet metal process equipment and systems
- the measurement and testing equipment producers
- the developers and users of Laser Beam Forming process monitoring sensors
- the research laboratories and process development sites

The first analysis of exploitation potential of the project results was available at the end of Year 1. Results and planned dissemination activities form the Appendix 1 of the yearly reports. Since then and in the form of a “living document” this appendix was updated yearly or when a new result was available. It is noted that the present exploitable results are defined as knowledge having a considerable potential for one or more of the following:

(i) industrial or commercial application in research activities
(ii) developing, creating or marketing a product or process
(iii) creating or providing a service.

Table 2.1.1 in the following pages lists the exploitable results referring to knowledge generated within this project, their type, the application range and the partners owning the result or the partner leading the exploitation activities. The partners involved in each exploitable knowledge item are shown at the last column of the Table. Where more than one partner appears, then it is understood that these partners share the ownership of the result.

Table 2.1.1: Overview on exploitable results and related information

Exploitable knowledge (description)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use (after project end)	Patents or other IPR protection	Owner & Other Partner(s) involved
Know how on the laser beam forming process for the manufacturing of fuselage structures	Scenarios for opt. manufacturing processes, process qualification plan	Aircraft production	1 year	None	Consortium
Introduction of an optimised manufacturing process chain for aircraft (fuselage) structures	Process qualification	Aircraft production	2 years	None	Airbus and key partners
Definition of a general methodology for solving processes problems	Software Tools	Engineering	2 years	None	ALA
Static tests on formed IS237/6013 specimens	Exp. Results	Sheet forming	3 years	None	ALA

Static, fatigue, corrosion, and methallographic investigation on specimen cut of formed, thin walled IS237and 6013 coupons	Exp. Results	Sheet forming	4 years	None	ALA
Task 4.2 benchmark model for control unit input	Exp. Results	Sheet forming	5 years	None	ALA
Mechanical characterisation on laser peen formed specimens	Reports	Aeronautics	N/A	None	DAS/EAF
Global expertise in processing LBF	Aircraft fuselage panels	Sheet forming	> 5 years	None	AIF, AID, EAF, IWB, RTM, DAS
Materials behaviour during LBF	Aircraft fuselage panels	Materials characterization	Before project end	None	AIF, AID, EAF, IWB, RTM, DAS
Forming behaviour of complex parts	Aircraft fuselage panels	Panel manufacturing	> 5 years	None	EAG, IWB
Corrosion behaviour of LBFormed Al-sheets	Aircraft fuselage panels	Characterisation	> 1 year	None	EAG
Knowledge of the relevant laser parameters to laser beam form an Al panel	Reports	Aeronautics, car industry	5 – 10 years	None	EAF
Proven methodology to simulate laser beam forming of Al sheets	Reports	Aeronautics, car industry	5 – 10 years	None	EAF
Know-how on laser path strategies for AL alloys	Software tools	Material processing	4 years	None	INA
Development of numerical methods for prediction of temperature and residual strains distribution in Al laser beam formed structures	Methodology	Material processing	4 years	None	IST
Suitable forming parameters for 6013 and 6056 alloys	Aircraft fuselage panels	Sheet forming	> 5 years	None	AIF, AID, EAF, EAG, RTM, DAS
Suitable path and measurement strategy	Aircraft fuselage panels	Sheet forming	> 5 years	None	AIF, AID, EAF, EAG, RTM, DAS
Integration of simulation to create a self teaching process	Aircraft fuselage panels	Sheet forming	> 5 years	None	AIF, AID, EAF, EAG, RTM, DAS
Laser Beam Forming Technology on Aluminium alloys	Workshop activity of LB forming for third parties on demand	Wide radii of curvature in industrial production	Immediately	None	RTM

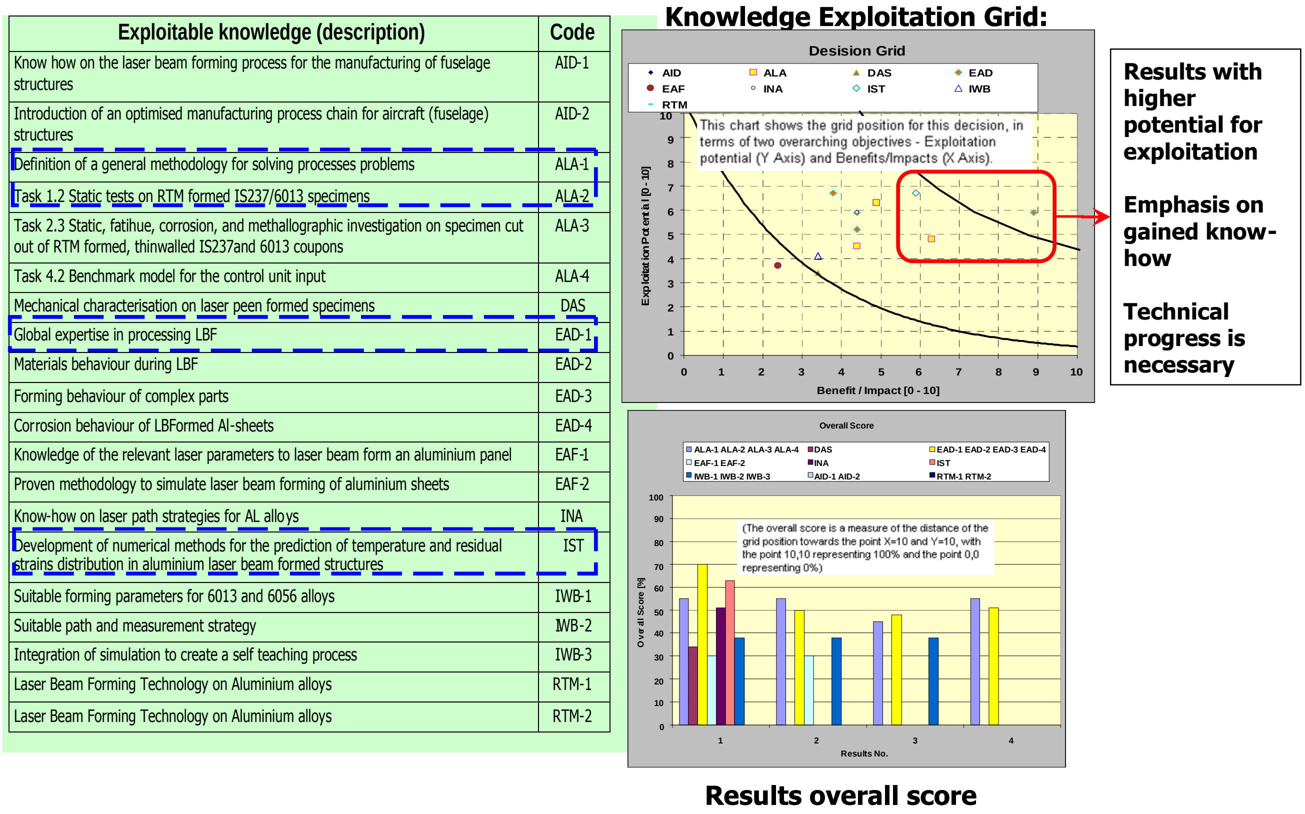
Regarding IPR issues, there is no provision for issuing patents for any of the obtained results. Where more than one partner owns a result this is shared among them on equal basis.

In order to have a better insight of the ECOSHAPE exploitable results and to identify their potential, an additional study was performed based on questionnaires filled by experts of each of the consortium members. A dedicated software tool (ProGrid) was used for the analysis and decision support phase. The analysis of results was possible for the cases where appropriate information was available. For each result, various criteria were assessed, investigating short and long term potential. The criteria that were addressed are described in Figure 2.1.1 and a depictive view of ECOSHAPE exploitable results analysis is given in Figure 2.1.2. More detailed but consortium confidential evaluation for each partner is presented in the project internal Deliverable report D5.3c, which is the "Final plan for using and disseminating the knowledge". Details concerning the evaluation method can be asked from the Project Exploitation Manager (partner INA).

Besides other common conclusions, analysis reveals that results with higher potential for short term exploitation regard mainly acquired knowledge (experimental data) on the processes and methods development (FEM analysis). In addition, it was highlighted that further development is necessary before Laser Beam Forming process can be adopted at industrial scale. It was also noted that further development activities should include actors from other industrial sectors for example the automotive industry.

• **Short Term:** The exploitation potential is high 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 5 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	 Name of Decision Maker: Exploitation Manager File Reference: Exploitation Template - ECOSHAPE Technology Transfer The technology transfer potential is high ○ A) Does not meet expectations ○ B) Meets some, but not all expectations ProGrid-Advisor Demo Name of Decision Maker: Exploitation Manager File Reference: Exploitation Template - ECOSHAPE Summary or Decision Statement: Examine the exploitation potential of ECOSHAPE results Chart 2 - Decision Profile This chart shows the ratings for each of the decision criteria as determined by the Decision Maker. This chart is very useful in identifying the strengths (tall bars) and weaknesses (short bars) of the proposed decision.
Criteria used for the assessment of ECOSHAPE exploitable results	Example of assessment of the potential of each result by means of score in each of the criteria

Figure 2.1.1: Overview on assessment of ECOSHAPE exploitable results



Exploitable knowledge (description)	Code
Know how on the laser beam forming process for the manufacturing of fuselage structures	AID-1
Introduction of an optimised manufacturing process chain for aircraft (fuselage) structures	AID-2
Definition of a general methodology for solving processes problems	ALA-1
Task 1.2 Static tests on RTM formed IS237/6013 specimens	ALA-2
Task 2.3 Static, fatihue, corrosion, and methallographic investigation on specimen cut out of RTM formed, thinwalled IS237and 6013 coupons	ALA-3
Task 4.2 Benchmark model for the control unit input	ALA-4
Mechanical characterisation on laser peen formed specimens	DAS
Global expertise in processing LBF	EAD-1
Materials behaviour during LBF	EAD-2
Forming behaviour of complex parts	EAD-3
Corrosion behaviour of LBFormed Al-sheets	EAD-4
Knowledge of the relevant laser parameters to laser beam form an aluminium panel	EAF-1
Proven methodology to simulate laser beam forming of aluminium sheets	EAF-2
Know-how on laser path strategies for AL alloys	INA
Development of numerical methods for the prediction of temperature and residual strains distribution in aluminium laser beam formed structures	IST
Suitable forming parameters for 6013 and 6056 alloys	IWB-1
Suitable path and measurement strategy	IWB-2
Integration of simulation to create a self teaching process	IWB-3
Laser Beam Forming Technology on Aluminium alloys	RTM-1
Laser Beam Forming Technology on Aluminium alloys	RTM-2

Knowledge Exploitation Grid:

This chart shows the grid position for this decision, in terms of two overarching objectives - Exploitation potential (Y Axis) and Benefits/Impacts (X Axis).

Results with higher potential for exploitation

Emphasis on gained know-how

Technical progress is necessary

(The overall score is a measure of the distance of the grid position towards the point X=10 and Y=10, with the point 10,10 representing 100% and the point 0,0 representing 0%)

Results overall score

Figure 2.1.2: Depictive view of ECOSHAPE exploitable results analysis

2.2 Dissemination of Knowledge

The Dissemination Table 2.2.1 presents the dissemination activities performed during and after the span of the project. The Dissemination Table was updated with the partners' activities and plans at each Consortium meeting.

Table 2.2.1: Dissemination activities performed by the consortium

Planned/ actual dates	Type	Type of audience	Countries addressed	Size of audi-ence	Partner responsible / involved
Okt. 2004	Newsletter	Research and industr.	Germany	500	IWB
April 2005	Conference presentation	Forming specialists audience	International	100	IWB
June 2005	Presentation/ Trade fair	Laser specialists audience	International	200	IWB
Feb. 2006	ECOSHAPE Homepage	Internet	International	>500	Consortium
June 2006	European Aeron. Days	Research and industrial	International	>500	IWB
June 2007	Publication	Research	International	>500	IST
June 2007	Conference	Research and industr.	International	150	UNISA
Sept. 2007	Conference	Research and industr.	International	200	IWB

2.3 Publishable results

The publishable results are summarized in chapter 1 of this Publishable Final Activity Report and were published in somewhat more detail during the dissemination activities summarized in Table 2.2.1.