

This project has received funding from the European Union Horizon 2020 Programme for research, technological development and demonstration

**IODA Consortium Meeting**

**8.45 am October 24th 2017**

CFMS, Bristol

Room 1

**AGENDA**

 **Apologies:** Cecil Armstrong**,** Andrea Walther, Susan Barker

 Welcome by Jens-Dominik Mueller

1. **Upcoming project deliverables**
2. **Periodic Review**

 Deviations from Annex 1 – D2.1, D2.5, D3.2,

 D4.10 Paraview API

 Milestones, Publications, Impact and Dissemination

ESRs finishing in 3 months need to update publications, outreach and impact on website and write final report.

1. **Future training events & finance**

**Training 10:** High Performance Computing 5-7 February UPB

 **Final Conference: Date and Venue**

1. **ESR Presentations starting with ESR15**
2. **Any Other Business**
3. **Date of next Consortium Meeting M36**

 **8th February 2018 UPB**

**Table of Deliverables**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **WP No** | **Del** | **Del****Rel No** | **Title** | **Lead** | **DissemLvl** | **Est. Del. Date (annex I)** | **Reason for delay** |
| WP4 | 29 | 4.10 | NURBS kernel with trimmed patches | QMUL | CO | 01/09/16 | Delayed due to late start of ESR1 |
| WP5 | 35 | 5.5 | Feature shape optimisation | OPENCASCADE | CO | 01/01/17 | Target Sept 2017 |
| WP5 | 52 | 5.8 | Constraints for NURBS parametrisation | QMUL | CO | 01/05/17 | ESR1 8m delay |
|  |  |  | Deliverables due in next 6 months |  |  |  |  |
| WP5 | 66 | 5.13 | TN-based SQP for constraint handling | NTUA | PU | 01/11/17 |  |
| WP6 | 67 | 6.8 | Multi-objective adjoint solvers | QMUL | CO | 01/11/17 |  |
| WP1 | 69 | 1.5 | Final version of optimisation loop | VW | CO | 01/12/17 |  |
| WP3 | 71 | 3.5 | Differentiated version of mesh to CAD algorithm | UPB | CO | 01/01/18 | 4.12 instead |
| WP5 | 72 | 5.14 | Automated re-meshing | ENGYS | CO | 01/01/18 |  |
| WP6 | 74 | 6.10 | Integration of AD-ed CAD into workflows | UPB | CO | 01/01/18 |  |
| WP6 | 75 | 6.11 | Optimisation workflow for multi-objective and multi-point adjoint | ENGYS | CO | 01/01/18 |  |
| WP6 | 76 | 6.12 | User features in OCCT | OPENCASCADE | CO | 01/01/18 |  |
| WP6 | 77 | 6.13 | RRD process chain demonstration | RRD | CO | 01/01/18 |  |
| WP6 | 73 | 6.9 | Integration of node-based parametrisation | QMUL | CO | 01/01/18 |  |
| WP7 | 79 | 7.10 | Training 10: High Performance Computing | UPB | PU | 01/01/18 | 5,6,7/2/18 |
| WP9 | 78 | 9.10 | M36 Consortium Meeting | QMUL | CO | 01/01/18 | 8/2/18 |
| WP6 | 80 | 6.14 | Workflows with adaptively inserted CAD feature | QUB | CO | 01/05/18 |  |
| WP6 | 81 | 6.15 | Differentiated OCCT into workflow | UPB | PU | 01/05/18 |  |
| WP6 | 82 | 6.16 | Integration of constraint methodology into workflows | NTUA | CO | 01/05/18 |  |
| WP1 | 83 | 1.6 | Report on industrial test cases | ENGYS |  | 01/07/18 |  |
| WP6 | 84 | 6.17 | Integration of HC into workflows | ENGYS | CO | 01/07/18 |  |
| WP6 | 85 | 6.18 | Also empty | QMUL | - | 01/07/18 |  |
| WP6 | 86 | 6.19 | Application of CAD-based turbomachinery optimisation | IVKDF | CO | 01/07/18 |  |
| WP6 | 87 | 6.20 | Demonstration of mechanical constraint methodology | IVKDF | CO | 01/07/18 |  |
| WP6 | 88 | 6.21 | Automotive applications of shape-topology optimisation | NTUA | CO | 01/07/18 |  |
| WP8 | 89 | 8.3 | Final conference | QMUL | PU | 01/01/19 |  |
| WP9 | 90 | 9.11 | M48 Consortium Meeting | QMUL | CO | 01/01/19 |  |

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| **ESR 1: REJISH JESUDASAN** DoB 30.3.91 Start Date: 2.11.15 End Date: 1.11.18 |
| **Project Title: CONSTRAINED OPTIMIZATION WITH CAD FREE AND CAD BASED PARAMETRIZATION** |
| **PhD Registration Host** QMUL **Supervisor:** Dr.Jens-Dominik Mueller**Expected Progress, Project plan:*** **M1-M6:** Familiarisation with existing in-house 3D primal and adjoint solver and implementation of surface smoothing methodologies to perform CAD free optimisation.
* **M6-M12**: Familiarisation with the in-house CAD parametrisation tool (Nspcc) and implementation to impose geometric constrains for CAD free and CAD based parametrizations.
* **M12-M20**: Extension of the QMUL CAD kernel (NURBS only) to support trimmed and intersected patches, adaptive refinement of patches.
* **M20-M28**: Development of methodology and implementation to evaluate the cost of constrains and fitness of parametrizations integration into workflows to adjust the parametrizations
* **M28-M36**: Integration with in-house solver for demonstration and evaluation, linking as a plugin into Paraview using the IODA API
 |
| **Current status and achieved progress, changes to plan:*** Performed CAD-based optimisation using adaptive control point enrichment to refine the design space in areas of high sensitivity.
* Implemented the intersection algorithm suitable for handling intersection of parametric surfaces.
* Differentiated the intersection algorithm in forward mode to calculate the CAD sensitivities for CAD based shape parametrisation.
* Tested the effectiveness of the intersection algorithm and surface mesh morphing method using DLR F6 wing-body configuration.

**Status of Publications, Presentations,Conference and Journal:*** *Publication (on-going) Adjoint Optimisation of internal cooling channel using NURBS based automatic and adaptive parametrisation method. ASME GT-2017.*
* ***Publication(on-going): Surface mesh morphing method for handling wing-fuselage intersection. EUROGEN-2017***
 |
| **Interaction with other project partners*** (M20-M28) Secondment to Kitware. 3-Nov-17 to 10-Nov-17. And 4 Jan 2018 to 5 Feb 2018
* (M28-M36) Secondment to RR to apply developed methodologies to the industrial cases.(August -September 2018)
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| **Next steps:*** Differentiate the CAD kernel in Reverse mode to calculate CAD sensitivities including differentiation of intersection.
* Perform CAD-based optimisation with including moving intersection using DLR-F6 wing-body configuration.
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| **ESR 2: Orest Mykhaskiv** DoB 18.3.90 Start Date: 22.6.15 End Date: 21.6.18 |
| **Project Title: CAD-based optimisation loops with automatically differentiated CAD systems** |
| **PhD Registration Host and Supervisor:** QMUL, Dr. Jens-Dominik Mueller |
| **Overview:** The derivatives of the parametrisation are required to fully integrate the parametrisation into gradient-based optimisation workflows, but for typical CAD systems these derivatives are not available. In this project the open-source CAD kernel Open Cascade is differentiated using the Automatic Differentiation software tool ADOL-C from the University of Paderborn. The focus for the project is to integrate the differentiated code into the optimisation workflow and apply it to industrial testcases. |
| **Expected Progress, Project plan:*** **M1-M12**: Familiarisation with OCCT (secondment to [OCC](http://ioda.sems.qmul.ac.uk/people/partners/occ)), definition of a reduced kernel for differentiation, familiarisation with ADOL-C AD tool (secondment to [UPB](http://ioda.sems.qmul.ac.uk/people/partners/upb)), application of AD to the reduced kernel, demonstration on small testcase, Publication. (WP4).
* **M12-M18**: Extension of the methodology to industrially relevant kernel, demonstration on industrial testcase, Publication. (WP4).
* **M18-M26**: Development of an effective methodology for constraint definition. Extraction/definition of constraints from/with CAD/ParaView GUI (WP5).
* **M26-M36**: Encapsulation, linking as a plugin into ParaView using the IODA API, Integration with in-house solver and  OPENFOAM solver for demonstration/evaluation, (secondment to [VW](http://ioda.sems.qmul.ac.uk/people/partners/vw)) (WP6).
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| **Current status, achieved progress, changes to plan:*** OCCT was successfully differentiated (Publication)
* Differentiated OCCT extended for optimisation of both Parametric CAD-models and NURBS (Publication)
* Efficient constraints definition technique for NURBS-based optimisation is developed with support of trimmed patches; Constraints are stored in a standard CAD format and hence could be easily inspected by user; Optimisation is driven with projected gradient method
* Differentiated OCCT was used for the optimisation of wing-fuselage intersection. This type of optimisation uses derivatives of OCCT in important Boolean operations modules
* Differentiated OCCT applied to the industrial testcases. Re-parametrisation techniques to create suitable NURBS design spaces are developed.
 |
| **Interaction with other project partners and work packages and secondment arrangements*** Secondment to Open Cascade(done Oct-Nov 15)
* Secondment to VW (done Sept-Oct 17)
* Application of differentiated OCCT TUB-stator testcase (ESRs 9, 11, 12)
* NURBS-based optimisation and application for trimmed patches (NASA CRM) (ESR 1)
* Improvement of differentiated OCCT for reverse mode
* Application of differentiated OCCT to VW testcases (ESR 15)
* **Outreach:** Big Bang London. Showcased basic principles of aerodynamics on prepared drone-like rotor. (ESR 1,3; done July 17)
 |
| **Publications to date:*** S. Auriemma, M. Banovic, O. Mykhaskiv, H. Legrand, J.-D. Mueller, T. Verstraete, A. Walther.Optimisation of a U-bend using a CAD-based adjoint method with differentiated CAD kernel, ECCOMAS Congress 2016.
* S. Xu, S. Timme, O. Mykhaskiv, J. D. Müller. Wing-body junction optimisation with CAD-based parametrisation including a moving intersection. Aerospace Science and Tech. 2017.
* O. Mykhaskiv, P. Mohanamuraly, J. D. Müller, S. Xu, S. Timme. CAD-based shape optimisation of the NASA CRM wing-body intersection using differentiated CAD-kernel. AIAA Aviation Forum, 2017.
* O. Mykhaskiv, J. D. Mueller, M. Banovic, S. Auriemma, P. Mohanamuraly, A. Walther, H. Legrand. NURBS-based and Parametric-based Shape Optimisation with differentiated CAD Kernel. Computer Aided Design & Applications, 2017
 |
| **ESR3 : PAVANAKUMAR MOHANAMURALY**Date of Birth: 5.4.1984 |  Start Date: 14.6.15 End Date: 13.6.18 Queen Mary University of London |
| **Project Title:** Robust CAD-free and CAD-based optimisation |
| **PhD Registration Host and Supervisor :** QMUL, Jens-Dominik Mueller |
| **Overview:**Uncertainty quantification is an integral part of robust design optimisation. The application to CAD/CAD-free shape problems for industrial problems requires careful selection of robust algorithms and efficient numerical models. |
| **Expected Progress, Project plan:*** M1-M12: Completed implementation of robust mesh deformation and optimised mesh smoothing framework for large deformations
* M12-M24: Complete parallelisation of in-house code and implement multi-objective adjoint solvers for robust optimisation using IMC
* M24-M36: Running Industrial test cases, integration to workflows, and thesis writeup
 |
| **Current status, achieved progress, changes to plan:*** Completed robust mesh deformation and optimised mesh smoothing framework and integrated with in-house CFD code
* Implementing vector adjoints in in-house solver for multi-objective adjoint optimisation
* Implementing uncertainty quantification tools in in-house code for robust design
 |
| **Interaction with other project partners and work packages and secondment arrangements*** Completed second to RR on mesh deformation
* Completed secondment to Kitware on parallel mesh and solution visualisation using paraview
* Currently on secondment to ESI, working on uncertantiy quantification and consistent mesh morphing and adjoint
* Planned secondment to RR January 7-20 2018.
 |
| **Publications to date:*** Mykhaskiv O., Banovic M., Auriemma S., Mohanamuraly P., Walther A., Legrand H., Müller J., “NURBS-based and Parametric-based Shape Optimisation with differentiated CAD Kernel”, Computer-Aided Design and Applications, 2017.
* Mykhaskiv O., Mohanamuraly P., Müller J., Xu S., Timme S., “CAD-based shape optimisation of the NASA CRM wing-body intersection using differentiated CAD-kernel”, 35th AIAA Applied Aero. Conf., 2017.
* Mohanamuraly P., Mykhaskiv O., Mueller J., “Some assumptions and their implications on correctness of MPI adjoints”, 4th Conference on Optimization Methods and Software, Dec 2017. (submitted)
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| **Training needs**:  |

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| **ESR: 4 NAME: Alexias Pavlos** | Date started on project: 01/06/2016 (M6) |
| **Project Title:**  Automated CAD-free adjoint shape optimisation based on harmonic coordinates |
| **PhD Registration Host: Prof. Kyriakos Giannakoglou (NTUA)****Supervisor: Dr. Eugene De Villiers** |
| **Overview:** The objective is to create a fast, reliable and accurate CAD free morphing framework that can be utilised effectively in industrial adjoint optimisation applications. The method should respect user defined constraints and be formulated to require minimal operator input. The main challenges of the work are to find effective morphing and constraint application strategies. The main avenue of investigation for morphing – harmonic coordinates – does not naturally support simplistic constraints. Alternative morphing methods and hybrid formulations will be explored and equivalency sought in the harmonic space to overcome this issue. A strong contribution is expected in the missing option of considering constrains into the optimisation procedure/loop, which is one of the overall aims of IODA project, seeking also efficient ways to extract constrains specified in a CAD model and apply them to the CAD-free morphing tool. |
| **Expected Progress, Project plan:****M30-M36**: Advanced constraints methods. Curvature Constraints. Automated remeshing solution  |
| **Current status, achieved progress, changes to plan:*** Current Status:
	+ Curvature constraints inside shape optimisation framework
* Achieved Progress:
	+ Verification, adjoint coupling and testing for harmonic coordinate based shape optimisation engine.
	+ Development of a mesh optimization tool.
	+ Development of implicit solver for smoothing the adjoint sensitivities.
	+ Development of a node-based morphing framework based on mesh optimization techniques coupled with the adjoint tool.
	+ Smooth transition keeping desired continuity (C0, C1, or C2) between constraint and deformable patches during shape optimization.
	+ Mesh regularization methods to maintain surface mesh quality during shape deformation
 |
| **Interaction with other project partners** * **Secondment** **to VW** **(8.9.16- 7.10.16)** Testing of the node-based morphing framework on large scale industrial cases, understand in depth the industry workflow and what requirements incur in order to have a robust morphing framework (contribution to WP6).
* **Secondment to NTUA (19.4.17-19.5.17)** Advanced mesh morphing techniques and CAD-free model constraints (contribution to WP5).
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| **Publications to date:** |
| **Training needs**: |
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| **ESR 5: MARIOS DAMIGOS** | Started in M6 |
| **Intuitive interfaces for optimisation parameterisation, constraint definition and automated mesh-to-CAD conversion** |
| **PhD Registration Host: Prof. Kyriakos Giannakoglou, Supervisor: Dr. Eugene de Villiers** |
| **Overview:** Optimization starts by supplying the optimization software with a CAD file. Therefore, it is logical that it delivers the optimized product in a CAD-compatible format. The target of this project is to make this possible firstly by providing the user with a methodology and its interface for constraint definition, as well as by completing the cycle with a robust mesh-to-CAD technique. |
| **Expected Progress, Project plan:*** **M9-M18:** Basic implementation of NURBS Symbolic Regression with discontinuity detection and filtering/smoothing of input data. Secondment to NTUA (WP3)
* **M18-M24:** CAD GUI interface based on VTK/OCCT/HELYX, Secondment to OCC (WP5).
* **M24-M30:** Interactive CAD manipulation, constraint and parameter selection, Secondment to OCC (WP5).
* **M30-M36:** Workflow integration: level-set surface extraction, multi-objective/constraint control algorithm, (WP6).
* **M36-M42:** Industrial application (WP1).
 |
| **Current status, achieved progress, changes to plan:*** Started in M06.
* Completed the feasibility study for the mesh to CAD conversion.
* Currently in M34 (28th).
* Mesh to CAD transition tools deliverable delayed (D3.2) due to outcome of D3,1.
* CAD to mesh tool developed .
* Geometric morpher finished
* Currently: Implemented geometric constraints (volume & curvature), undergoing tests
* Next steps: Attempting multi – objective optimization (including constraints)
 |
| **Interaction with other project partners and work packages and secondment arrangements*** Secondment to NTUA: Completed in November – December 2016
* Secondment to OCC: Completed in May-June 2017
* Secondment to Kitware: Completed in September-October 2017
* Outreach arranged for December 2017 in collaboration with ESR 6
 |
| **Publications to date:*** ECCOMAS 2016: CAD based parameterization and constraints for Adjoint optimization
* OFW11 Book: CAD Based Parameterization for Adjoint Optimization
* Eurogen 2017: Adjoint Shape Optimisation using model Boundary Representation

**Training Needs: None** |

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| **ESR 6: Athanasios G. Liatsikouras** Start Date: 1.5.15 End Date: 30.4.18Date of Birth: 10.9.92 ESI |
| **Project Title:** Automated CAD-free & CAD-based shape optimisation with immersive visualisation**PhD Registration Host**: National Technical University of Athens **Supervisor**: K. Giannakoglou |
| **Overview:**The new version of the existing mesh morpher has been developed, tested and demonstrated in Eurogen 2017 in Spain. It is a non-linear problem to be solved. Efficiency of the method (final mesh quality) has been proved. Recently, I started extending this aforementioned mesh morpher as a mesh optimization tool. Simple 2D cases have been successfully performed. Problems occur in 3D case that need to be solved. Moreover, a collaboration has been started with ESR 3 to perform full optimization by using the CAD. Most of the cases deal with turbomachinery components. |
| **Expected progress, project plan:*** Start at M1
* M1-12: Implementation of a CAD-free surface parameterisation based on smooth constraints & integration in in-house mesh morpher. Adaptive selection of control points based on local geometrical features (typically curvature). Handling of simple geometrical constraints (box). Integration in the ESI i-adjoint morpher. Validation & evaluation.
* M12-20: Immersive visualisation of adjoint results within IC.IDO including sensitivity maps & adjoint states. Possibility of visualising shape deformation as recommended by the adjoint solver in real-time will be investigated.
* M20-36: FD-based CAD gradient from surface node sensitivity using the approach based on discrete harmonic mapping to a reference patch. Development of the harmonic and inverse harmonic mapping within ESI adjoint kernel.
 |
| **Current status, achieved progress, changes to plan:*** (Start at M5)
* Non-Linear version of the Rigid Motion Mesh Morpher has been implemented, tested and presented in Eurogen 2017 in Spain.
* Started collaborating with ESR 3 towards CAD-based optimization.
* Outreach activity will take place on a school in Greece on December 2017.
* Started extending the Non-Linear version of the morpher as a mesh optimization tool.
 |
| **Interaction with other project partners*** 1M secondment to VW (mid January)
* 1M secondment to NTUA (6.11.2017 – 6.12.2017)
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| **Next steps:*** Perform CAD-based optimization in collaboration with ESR 3.
* Test the mesh optimization tool in many cases.
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| **ESR 7 : Flavio Gagliardi** | Date started on project: M4. Current date: M33 |
| **Project Title: Shape parametrisation and integrated constrained optimisation loops for turbomachinery applications** |
| **PhD Registration Host and Supervisor:** NTUA – Prof. K. Giannakoglou |
| **Overview:** The project aims to develop a robust tool for optimization of turbomachineries based on adjoint. The existing in-house 3D blade parameterization software (s/w) is differentiated to support the adjoint-based optimization process. Cases are tested with both the in-house GPU code and OpenFoam code. Mesh displacements and constraints handling features are also implemented. |
| **Expected Progress, Project plan:*** M4-M8: Familiarization with existing tools. Integration of the in-house parametrisation tool for turbomachinery applications into the adjoint-based optimisation loop. Link with both the in-house GPU-enabled CFD code (compressible) & OPENFOAM (incompressible) and their (continuous) adjoints. (WP4)
* M8-M18: Differentiation of the parametrisation procedure. Secondment to VKI (WP4)
* M14-M28: Handling geometrical constraints in the parametrisation. Integration. (WP5)
* M24-M34: Mesh movement techniques. Cost reduction. Integration in workflow. (WP6)
* M12-M40: Turbomachinery applications. Secondment to RRD (WP1)
 |
| **Current status, achieved progress, changes to plan:*** M04-M09 – Familiarization and features addition (i.e. IGES support) to the in-house blade parameterization software. Implementation of a re-parameterization procedure to import existing blade and casing geometries (WP4 - Deliverable 4.5). Mesh conversion tools (WP6).
* M08-M10 – Differentiation, through finite differences, of the parameterization procedure to support the adjoint-based optimization process. (WP4 – Deliverable 4.11)
* M10-M22 – Complete integration of a mesh deformation s/w module for arbitrary grids based on Radial Basis Functions (RBFs) interpolation. The module updates a mesh according to an updated shape of the domain boundary (new design) generated by the in-house 3D blade parameterization software. Cost reduction techniques based on multilevel solvers, the sparse approximate inverse preconditioning and the Fast Multipole Method (FMM) are implemented. Anticipated from M24-M34. (WP6)
* M15-M20 – Implementation of algorithms for non-linear programming for constrained and unconstrained optimization to solve problems with one or more objectives, in serial or parallel. Work carried out on the Method of Moving Asymptotes (MMA) and Sequential Quadratic Programming (SQP). (WP5)
* M09-M32 – Application of programmed s/w to turbomachinery optimization test cases, including the IODA TUB stator benchmark test case. (WP6)
* M32-M33 Parameterization software based on RBF to include generic CAD models into the optimization loop, with focus on turbomachinery optimization. The parameterization procedure will be differentiated. (Extension of the in-house blade parameterization for arbitrary geometric features) (WP4-WP5)
 |
| **Interaction with other project partners:** 1.5M to VKI in M22 to exchange ideas about turbomachinery parametrisation and comparing different approaches for its differentiation. 0.75M to RRD in M27 on which s/w was tested on industrial cases. 0.5M will be spent to RRD in M36 to continue the work undertaken in the first period. |
| **Publications to date:*** Shape optimization of turbomachinery rows using a parametric blade modeller and the continuous adjoint method running on GPUs, *ECCOMAS Congress 2016, Crete, Greece,* 2016
* A Two–Step Mesh Adaptation Tool Based on RBF applied to Turbomachinery Optimization Loops, *Eurogen 2017, Madrid, Spain, 2017*
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| **Training needs:** None**.** |

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| **ESR 8: James Robert Lee Koch** | **Started: 02/06/15** |
| **Project Title: Combined Shape-Topology Optimization with Constraints for Automotive****Applications** |
| **PhD Registration Host: National Technical University of Athens (NTUA) Supervisor: K. Giannakoglou** |
| **Overview:**Continuation, development and coupling of continuous adjoint topology and shape optimization software regarding automotive-related application. Coupling of the shape and topology methods will be employed in a sequential manner, resulting in a software capable of handling industrial geometrical constraints and producing optimized results compatible with major CAD formatting softwares. |
| **Expected progress, project plan:*** **M6-M18**: Development and validation of shape and level set-based topology optimization software, accounting for input/output data's compatibility requirement with CAD software. Upon completion of the topology software tools, initial development of tools for the transition between the developed topology and shape optimization will begin. [**WP2**]
* **M16-M26**: Continued development of interfacing software. Fitting of topological level-set surfaces, followed by their automated reconstruction, via methods such as Field Matching (see publication below). A shape optimization problem is from this constructed CAD mesh to generate a final, optimized CAD model for export, resulting in an integrated/automated kernel. Continued development of the topology and shape optimization softwares as required. [**WP3,6**]
* **M24-M34**: Constraints regarding flow and geometry introduced into the topology optimization process. Constraints forcing shape to respect the original topological domain and prevent selfintersection during fitting of topology solution and shape optimization will be developed. Methods to handle such constraints will be considered and explored. [**WP5**]
* **M30-M38**: Hierarchical topology, CAD and shape optimization interface kernel will be linked with the HCM and RBF-based morphing tools developed by ESR7 when finished. **\*\*\*** [**WP3,4**]
* **M12-M42**: Application of developed software to test cases. Upon validation of software performance, application will progress to cases related to the automotive industry. [**WP1**]
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| **Current status, achieved progress, changes to plan:*** Gained deep knowledge of in-house topology OpenFOAM software and the adjoint method.  Developed level set-based topology software in 2D and 3D with volume and curvature constraints. Provides target solution and auxiliary information for the topology-to-shape transition process (dubbed the 'TtoST' process: (see publication below)).
* Currently: expansion of the TtoST transition process to 3D nearly complete; development of constraints to force shape-optimization to respect the limits of the original topological domain pending; improving efficiency and convergence of all aforementioned processes.  Anticipated end date: **M42**.
 |
| **Interaction with other project partners, work packages, secondment arrangements:*** **1.5M** secondment to ENGYS to exchange ideas about level-set based topology optimization and familiarization with industrial software **(15/09/16-31/10/16)**. [**M12-42**]
* **1.5M** secondment to VW to apply the developed methodology to industrial cases. [**M6-18**]
* Collaboration with ESR7 **(01/11/17-15/12/17)**: **see '\*\*\*' above**. [**M30-38**]
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| **Publications to date:**• J.R.L. Koch et al., “Transition from adjoint level set topology to shape optimization for 2D fluid mechanics*”*, *Computers & Fluids,* Vol. 150, 2017, pp. 123–138. |
| **Training Needs:** None. |

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| **ESR 9: Salvatore Auriemma Start Date: 9.9.15 Opencascade**Date of Birth: 8.10.87 **End Date: 8.9.18** |
| **Project Title: Integration of CAD systems into the design loop** **PhD Host**: Queen Mary University of London **Supervisor**: Jens-Dominik Mueller |
| **Overview:**This project aims to integrate the CAD open source Kernel Open Cascade into the Design loop for a Adjoint CFD Simulation. In particular the derivatives of the parametrisation are required to fully integrate the parametrisation into gradient-based optimisation workflows, but for typical CAD systems these derivatives are not available. In this project the open-source CAD kernel OpenCASCADE (OCC) is differentiated using the Automatic Differentiation (AD) software tool ADOL-C from UPB. The focus for this project is to support the application of AD to the OCC software and to apply AD to the parametric layer in OCC. |
| **Expected progress, project plan:*** **M1-M12**: Integration of AD algorithm into OCCT. Secondment to UPB, (WP4).
* **M12-M18**: Integration of algorithm in the parametric system. Secondment to QMUL (WP4).
* **M18-M24**: Implementation of the design loop using parametric features.
* **M24-M36**: parametric CAD based optimisation corresponding RRD use cases. Implementation of a back to CAD algorithm using OCCT differentiated applied to VW industrial test cases. Secondments to VW, RRD. (WP6).
 |
| **Current status, achieved progress, changes to plan:*** Currently at the month number 25 of the project.
* Done low fidelity TU Berlin test case optimisation. Currently working on the high fidelity optimisation.
* Parametric engine under development for its involvement in the design loop.
* Waiting for the last review of the paper for “Optimisation methods and Software Journal”.
* Developed back to CAD algorithm for VW industrial test cases.
* Done Secondment at VW (16th of Sept. 2017 - 14th of Oct. 2017).
* Presented paper at the CAD Exhibition Conference 2017, Okayama, Japan.
 |
| **Interaction with other project partners:*** Close cooperation with ESR 2 – Orest Mykhaskiv (QMUL) and ESR 12 – Mladen Banovic (UPB) for he publication of the scientific article and optimisation of new test cases.
* Close collaboration with ESR at VW (number 15) during and after the secondment.
 |
| **Next steps:*** High fidelity Optimization of the TU Berlin stator test case.
* Development of the parametric engine to involve it in the design loop.
* Paper submission about the work carried out at VW.
* Optimisation of RRD industrial test cases using the parametrisation developed for the blades and by using OCCT differentiated.
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| **Any training needs not covered:** |

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| **ESR 10: Dheeraj Agarwal** |  **Project Start Date:** 29 June 2015 |
| **Project Title:** CAD based optimization with adaptive feature Insertion |
| **Project plan:*** **M4-M6**: Investigating strategies for linking the CAD tools used in WP1 with existing QUB research prototypes. (WP4). **(completed)**
* **M7-M18**: Investigating methodologies for adaptively inserting new features to a CAD model to improve the ability of the CAD models to create the optimum design. **(completed)**
* **M18-M26**: Investigating the use of adjacent components in a CAD model assembly as constraints on design space. **(ongoing)**
* **M26-M32**: Investigating the use of parametric effectiveness as a means to improve the efficiency of CAD based optimisation, secondment to VW. **(completed)**
* **M32-M40**: Demonstration and evaluation of the IODA developments (WP6).
 |
| **Progress Update:*** An automated process for the insertion of new CAD features into a CATIA V5 model has been developed and tested for cantilever beam model and S-Bend.
* Incorporation of geometrical constraints including parameter bounds, constant volume, thickness constraint and constraints due to assembly components is in progress.
* Generation of a parametric CAD model for DrivAer mirror in CATIA V5 is completed. Using parametric effectiveness for DrivAer optimization completed and presented in EUROGEN 2017.
* In collaboration with VW, an inverse design methodology is formulated to use parametric CAD model to reach the optimized design obtained using CAD-free method.
* An optimization framework has been formulated, which runs primal/adjoint analysis using Abaqus, HELYX, SU2 and linked with CAD software (CATIA & NX) to directly update the CAD parameters.
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| **Secondments:*** To RRD completed during Feb 1 – Feb 21, 2017.
* To VW completed during March 13 - April 7, 2017.
* To be planned in Feb-March 2018.
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| **Publications to date:*** **Agarwal D.**, Robinson T.T., Armstrong C.G., Marques S., Vasilopoulos I., Meyer M., Parametric design velocity computation for CAD-based design optimization using adjoint methods, Engineering with Computers, 2017.
* **Agarwal D.**, Kapellos C., Robinson T.T. and Armstrong C.G., Using parametric effectiveness for efficient CAD-based automotive design driven by adjoint sensitivity maps, EUROGEN conference, Madrid, Spain, 13-15 September 2017.
* **Agarwal D.**, Marques S., Robinson T., Armstrong C.G., Aerodynamic Shape Optimization Using Feature based CAD Systems and Adjoint Methods, 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, AIAA AVIATION Forum, 2017.
* **Agarwal D.**, Vasilopoulos I., Robinson T.T., Meyer M. and Armstrong C.G., Designing low-emission aero engines using adjoint methods, at 4th UK-Japan Engineering Education League workshop, Tokyo, Japan, 5-8 August 2016.
* **Agarwal D.**, Kapellos C., Robinson T.T. and Armstrong C.G., Parametric CAD model based shape optimization using adjoint functions, 11th ASMO UK/ISSMO/NOED2016: International Conference on Numerical Optimisation Methods for Engineering Design, TU Munich, Germany, 18-20 July 2016.
* Vasilopoulos I., **Agarwal D.**, Meyer M., Robinson T. and Armstrong C.G., Linking Parametric CAD with Adjoint Surface Sensitivities, VII ECCOMAS Congress, Crete Island, Greece, 5-10 June 2016.
* Hewitt P., Marques S., Robinson T.T. and **Agarwal D.**, Aerodynamic optimization using adjoint methods and parametric CAD models, VII ECCOMAS Congress, Crete Island, Greece, 5-10 June 2016.

**Training Needs:** |

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| **ESR 11: Ilias Vasilopoulos** Start Date: 15.4.15 **Rolls-Royce De.**Date of Birth: 31.7.92 End Date: 14.4.18 |
| **Project Title: CAD-based and CAD-free aerodynamic optimization of geometrically complex turbomachinery components** |
| **PhD Registration Host:** Kyriakos Giannakoglou (NTUA)**, Supervisor:** Marcus Meyer (RRD) |
| **Overview:**The PhD thesis aims at evaluating the different approaches to CAD-free and CAD-based aerodynamic optimization for the intended application on geometrically complex turbomachinery components. Based on the initial evaluation, the most promising approach or approaches will be selected and implemented into the RR process chain, which comprises of Siemens UG NX as a commercial CAD package, in-house solvers for primal and adjoint, and the open-source post processing tool ParaView. The developed process will be applied to the aerodynamic optimization of industrial turbomachinery components, addressing the challenging aspects that arise, namely (i) the efficient but flexible and automatic geometric parametrisation of complex turbomachinery components, and (ii) the imposition of geometric design constraints. The latter constitues one of the main goals of the IODA project. |
| **Expected progress, project plan:*** M1-6: Evaluation of different approaches to CAD-free and CAD-based aerodynamic optimization, selection of most promising approach or approaches, secondment to QUB.
* M6-18: Implementation of selected approach(es) in Rolls-Royce process chain, application to small test cases, publication of initial results, secondment to QMUL.
* M18-28: Improvement of process chain, application to industry-relevant test cases of medium geometric complexity, focus on constraint specification and incorporation in process chain, publication of results, secondment to KTW and VKI.
* M28-36: Demonstration of developed process chain on turbomachinery components of high geometric complexity and a large number of constraints, PhD thesis.
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| **Current status, achieved progress, changes to plan:*** Improvement of in-house CFD morpher for HYDRA meshes by incorporating constraints and test on baseline applications.
* Assessment and application of design velocity approach (QUB) to turbomachinery test cases, publication of initial results (ECCOMAS Congress 2016).
* Development of CAD-based optimization workflow used to optimize the TU Berlin TurboLab Stator (report for D6.2), presentation of results (NOED Conference 2016) and paper submission (ASME Turbo Expo 2017).
* First steps towards CAD-free optimization of the TurboLab Stator.
* Multiobjective optimization of the TurboLab Stator using a BFGS-based methodology.
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| **Interaction with other project partners and work packages and secondment arrangements:*** **QUB** to learn about the design velocity approach to CAD parameter sensitivity calculation in order to assess and apply it to turbomachinery applications (30/9-28/10/15).
* **QMUL** to learn about the CAD-free and STEP-based approach to parameter sensitivity calculation in order to assess and apply it to turbomachinery applications (18/9-16/10/16).
* **NTUA** to apply multiobjective gradient-based methods to turbomachinery components (19/4-19/5/17).
* **VKI** to learn about the CGNS mesh format and create a writer to native HYDRA format (18-29/9/17).
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| **Next steps:*** Comparison between CAD-based and CAD-free optimization of the TurboLab Stator (ISROMAC Conference 2017).
* Improvement of RRD optimization workflow by integrating Parablading and mesh morpher.
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| **Any training needs not covered:** None |

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| **ESR 12 : Mladen Banovic** Date of Birth: 27.5.87 | Start Date: 1.7.15 University of PaderbornEnd Date: 30.6.18 |
| **Project Title: Efficient automatic differentiation of CAD systems** |
| **PhD Registration Host: University of Paderborn Supervisor: Prof. Dr. Andrea Walther** |
| **Overview:**While a geometry definition for the design is available in the CAD system, the geometry itself is not used in the computation of gradients. Therefore, in order to provide derivatives with respect to model parameters, the goal is to provide AD enabled version of OpenCascade Technology using the software tool ADOL-C (Automatic Differentiation by OverLoading in C++). This will close the gap in the design chain for a derivative-based optimization.Risks: The differentiation of OCCT is novel. The differentiation in pure forward mode is likely to succeed. The adapted combination with the reverse mode of AD for an improved efficiency has inherent risks. The differentiation of the mesh to CAD algorithms is a new application of AD bearing very moderate and manageable risks. |
| **Expected Progress, Project plan**:M6-M18: Familiarisation with OCCT, Efficient automatic differentiation in forward mode of the open-source CAD program OCCT, demonstration on small test-case. Secondment to OCC (WP4).M18-M28: Extension of the methodology to the reverse mode of AD at suitable parts of the differentiated OCCT package for improved efficiency. Secondment to QMUL. (WP4).M28-M36: ~~Automatic differentiation of mesh to CAD algorithms~~. Secondment to VKI. (WP3).M36-M42: Integration with in-house solver for demonstration/evaluation, linking as a plugin into ParaView using the IODA API (WP6). |
| **Current status, achieved progress, changes to plan**:Deliverable 4.6 resolved – Differentiated Open CASCADE Technology with extended kernel. The automatic differentiation of OCCT has been performed by integrating ADOL-C in forward traceless mode. Due to a large code modification, original functionality of OCCT has been tested by its own automated testing system. Final testing results, after fixing the run-time errors, have shown a success rate of 97%. Furthermore, this differentiated OCCT kernel has been validated in a derivative-based optimization of the pressure losses in a squared U-bend pipe.Deliverable 4.12 resolved – Improved differentiation of Open CASCADE Technology. It has been developed by integrating ADOL-C in trace-based reverse mode. Compared to deliverable 4.6, the reverse mode of AD can dramatically reduce the temporal complexity of derivative computation. So far, OCCT differentiated in reverse mode was successfully validated on two test-cases: U-bend and TU Berlin TurboLab Stator. The results have shown that by using the reverse mode of AD, one benefits in approx. 50% improved efficiency on the derivative computation.Deliverable 3.5 cancelled – Automatic differentiation of mesh to CAD algorithms, due to a cancelled preceding deliverable from Engys. Instead, replacement work is proposed. Additional development is performed on top of Deliverable 4.12, related to the reverse differentiation of OCCT. 1) Exploring code structure of the differentiated OCCT in order to modify it and improve its performance on the TU Berlin Stator test-case. 2) Validate the new functionality “activity analysis” of ADOL-C that can improve the efficiency of differentiated OCCT even further. New secondment (1M) to Rolls-Royce Deutschland is added to the project plan, where the automatic differentiation will be applied to their in-house CAD tool and integrated into existing optimisation workflows.**Next steps**: Implement replacement work for Deliverable 3.5 |
| **Interaction with other project partners and work packages and secondment arrangements**:Close cooperation with ESR 2 – Orest Mykhaskiv (QMUL) and ESR 9 – Salvatore Auriemma (OCC). Submitted a joint paper entitled “Algorithmic Differentiation of the Open CASCADE Technology CAD Kernel and its coupling with an Adjoint CFD Solver” to the journal “Optimization Methods and Software”, as a post-conference publication of 7th International Conference on Algorithmic Differentiation (AD2016). The paper is under second review.Attended a meeting in OCC (15.05.2017 – 19.05.2017) where the purpose was to discuss possibilities of integrating the efforts developed within IODA project into the main development of the OCCT kernel.Secondment to VKI planned for the period: 15.01.2018 – 02.02.2018.Secondment to RRD planned for the period: 30.10.2017 – 01.12.2017.Secondment to QMUL completed in the period: 25.09.2016 – 19.10.2016.Secondment to OCC completed in the period: 12.10.2015 – 11.12.2015.Everything done so far, i.e., the automatic differentiation of the OCCT kernel and its validation, is a part of the work package 4.**Publications to date**:O. Mykhaskiv, M. Banovic, S. Auriemma, P. Mohanamuraly, A. Walther, H. Legrand and J.-D. Müller: “NURBS-based and Parametric-based shape optimisation with differentiated CAD kernel”, 14th Annual International CAD Conference in Okayama, Japan, August 2017. S. Auriemma, M. Banovic, O. Mykhaskiv, H. Legrand, J.-D. Müller, T. Verstraete and A. Walther: “Optimisation of a U-Bend using a CAD-Based Adjoint Method with Differentiated CAD Kernel”, ECCOMAS Congress 2016 (7th European Congress on Computational Methods in Applied Sciences and Engineering) in Crete, Greece, June 2016.**Outreach activity**:The event under the title: “Automatic calculation of derivatives in C++ source codes and their application in an aerodynamic shape optimization of CAD-based models” was held on 11.01.2017 in Osijek, Croatia, in a form of one-hour presentation. This lecture was a part of the volunteering-based educational programme “CodeCamp”, organized by the IT community “Osijek Software City” from Croatia.**Training Needs: None** |

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| **ESR 13 - Ismael Sanchez Torreguitart** Start Date: 19.10.15 VKI Await update Feb17Date of Birth: 26.8.89 End Date: 18.10.18 |
| **Project title**CAD based adjoint optimization of turbomachinery componentsPhD Host: UPC Barcelona Supervisor: Tom Verstraete |
| **Overview:**Part design starts from a CAD geometry and has to deliver the optimised geometry in CAD. However, there is currently no practicable way of either optimising directly on CAD geometries or generating a CAD model from the optimisation results. The currently practised manual capture is inefficient and loses important geometric details. This project will explore different strategies to incorporate the CAD system to represent shape during the optimisation process, with its defining parameters acting as the design variables. |
| **Expected progress, project plan**\*Start at M6\*M6-M8: Development of forward differentiation framework as reference test case for later validation of developed adjoint code.\*M8-M12: Development of reverse propagation of geometrical sensitivities of CAD based model.\*M12-M18: Propagation of grid sensitivities in reverse mode to CAD model.\*M18-M30: Integration with in-house adjoint CFD sover for demonstration/evaluation.\*M30-M42: Application of method to industrial test cases, extension to multi-point.  |
| **Current status**\* Development and validation of forward differentiation framework completed for the VKI LS89 axial turbine aerofoil (2D case as a first demonstrator)\* Papers submitted to ECCOMAS2016, ETC2017, EUROGEN2017 \* Implicit 2D Multi-Block structure smoothing grid by solving elliptic equations completed\* One shot method with propagation of grid sensitivities in reverse mode using implicit smoother (WIP)\* Parametrization effectiveness evaluation (WIP)\* Multilevel optimization and adaptive geometry parameter selection during optimization (WIP)  |
| **Interaction with other project partners**\*June 2017: 1M Scnd to Paderborn University\*March 2018: 1M Scnd to NTUA\*April 2018: 1M Scnd to RRD  |
| **Next steps**\* Demonstrate the potential of obtaining the grid sensitivities in reverse mode using the implicit smoothing approach with the one shot method\* Compare the different method to compute the grid sensitivities\* Compute parametrization effectiveness and individual parameter effectiveness\* Investigate the potential of using multilevel optimization and adaptive geometry parameter selection during optimization |
| **Any training needs not covered**TBD |

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| **ESR14** : Marc SchwalbachDate of Birth: 9.3.90 | Start Date: 22.7.15 VKIEnd Date: 21.7.18 |
| **Project Title**: Adjoint optimization of turbomachinery components under mechanical constraints  |
| **PhD Host**: TU Kaiserslautern **Supervisor**: Prof. Nicolas R. Gauger |
| **Overview:**The aim of this project is to make developments towards a framework for the CAD-based multidisciplinary adjoint optimization of turbomachinery components. In addition to aerodynamic efficiency, the structural feasibility is to be taken into consideration as a constraint to the optimization problem. The focus of this project is the development and inclusion of the structural constraints. Gradient-based optimization methods are used in this project, for which the sensitivities of the structural analysis with respect to the design parameters are required. These are to be computed using the adjoint method, which requires the differentiation of the structural mechanics solver using algorithmic differentiation. Additionally, turbomachinery components experience centrifugal loads, which lead to structural deformations when in operation. To take this into account, a cold-to-hot transformation framework is to be developed and integrated into the optimization loop. |
| **Expected Progress, Project plan:**1. M6-M9: Development of a fully parametrized CAD model of the solid part of the blade.
2. M9-M12: Development of methodology for cold-to-hot transformation of CAD model.
3. M12-M22: Computations of the sensitivities from stress and vibration analysis
4. M22-M30: Development of a mesh deformation method for the structural model link to CAD. Secondment to QMUL.
5. M30-M42: Application with structurally constrained adjoint optimization of turbomachinery components. Secondment to RRD.
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| **Current status, achieved progress, changes to plan:*** Milestones 1 to 4 achieved on time
* Milestone 5 on track to complete on time
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| **Interaction with other project partners and work packages and secondment arrangements*** Secondment to QMUL completed
* Secondment to RRD finalized for 04.03.18 – 31.03.18
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| **Publications to date:**PAPERS* Schwalbach, M. and Verstraete, T., 2016. Towards Multidisciplinary Adjoint Optimization of Turbomachinery Components. ECCOMAS Congress 2016.

TALKS* A Comparative Study of Two Different CAD-Based Mesh Deformation Methods for Structural Shape Optimization. EUROGEN 2017. 13.-15. September 2017. Madrid, Spain
* Adjoint Optimization of Turbomachinery Components Under Mechanical Constraints. The 8th VKI PhD Symposium / IFAR Virtual Conference. 1.-3. March 2017. Sint-Genesius-Rode. Belgium
* Developments of a Discrete Adjoint Structural Solver for Shape and Composite Material Optimization. The 7th International Conference on Algorithmic Differentiation. 12.-15. September 2016. Oxford. United Kingdom
* Towards Multidisciplinary Adjoint Optimization of Turbomachinery Components. ECCOMAS 2016 5.-10. June 2016. Crete. Greece
* Differentiating a Structural Solver for Turbomachinery Design. 19th EuroAD Workshop 7.-8. April 2016. Kaiserslautern. Germany
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| **Training needs:** |

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| **ESR 15: Christos Kapellos Start Date: 1.4.15 VW****DOB 22.1.91 End Date: 31.3.18** |
| **Project Title: Constrained shape optimization for automotive design****PhD Host: NTUA Supervisor: Carsten Othmer** |
| **Overview:**The main aim of this project is firstly to suggest and provide test cases on which the various optimisation modules developed in the IODA project will be validated and secondly to implement and validate the modules developed by QUB, NTUA, ENGYS and QMUL into VW workflow. These methods, namely CAD finite-differences, RBF, NURBS, SQP-algorithms and Harmonic Coordinates have been barely used in strictly-constrained industrial cases, the complexity of which can always be a challenge. However, the evaluation and integration of these modules in such a framework, as well as their coupling, is a key aspect to enable them to be truly useful for the automotive part design. Thus, this will contribute to the developed methods of the IODA project, by taking them one step further, from their conception and validation in academic cases to their full industrialisation. |
| **Expected progress, project plan:*** M6-M12**:** CAD parameter sensitivities 1: Adoption and integration into workflows of finite differences (QUB)
* M12-M18**:** Constrained NURBS-based parameterisation: Adoption and integration into workflows of NURBS module from QMUL, ESR1 and of SQP-algorithms from NTUA, ESR8
* M18-M24**:** CAD-free parameterisation: Adoption and workflow integration of RBF-Morphing from NTUA, ESR8 and Harmonic Coordinates from ENGYS, ESR4
* M24-M30**:** CAD parameter sensitivities 2: Adoption and workflow integration of the differentiated OCCT (QMUL, ESR2)
* M30-M40**:** Completion of optimisation loop by integrating the Return-to-CAD-module, comparative evaluation on selected test cases
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| **Current status, achieved progress, changes to plan:**Current status: * Adoption and integration of differentiated OCCT kernel in VW Workflow (Collaboration with ESR2)
* Completion of optimisation loop and comparative evaluation on selected test cases

Achieved progress (M1-M30):* M30: Parametric effectiveness used for CAD based automotive optimisation
* M23: Adoption and integration of Volumetric B-Splines method in VW Workflow
* M23: Completed secondment at NTUA, familiarisation with volumetric B-Splines method
* M22: Presentation of Sphericity and implicit smoothing at NAFEMS CFD-Seminar
* M21: Adoption and integration of Sphericity and implicit method in VW Workflow
* M31: Collaboration with ESR 10 from QUB to further develop the CAD finite-differences method: Add features like parametric effectiveness

Publications:* Using parametric effectiveness for efficient CAD based automotive design driven by adjoint sensitivity maps, EUROGEN 2016
* The adjoint method for automotive optimisation using a sphericity based morpher, NAFEMS 2016
* "Parametric CAD model based shape optimization using adjoint functions", NOED2016
* A continuous adjoint approach for vehicle interior noise reduction, ECCOMAS Congress 2016

Changes to plan:* Harmonic Coordinates method replaced by Sphericity method (WP4, ESR4 Engys)
* Industrial integration of the NURBS-module from QMUL pushed back
* RBF method replaced by Volumetric B-Splines method (WP2,4 NTUA)
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| **Interaction with other project partners*** QUB and NTUA secondments completed (31st October-28th Novermber 2015, 29th October – 27th November 2016 respectively)
* Collaboration with ESR 2 from QMUL on differentiated OCC module
* Collaboration with ESR 9 from OCC on Back-to-CAD method
* Collaboration with ESR 4 from ENGYS on Sphericity and implicit smoothing method
* Collaboration with ESR 10 from QUB on CAD Finite Differences
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| **Next steps:*** Integration of Return-to-CAD module (Collaboration with ESR8)
* Completion of optimisation loop and comparative evaluation on selected test cases
* M38 Secondment at ENGYS
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