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Enabling Exascale Fluid Dynamics Simulations
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D4.1 – Exploitation Plan

WP4: Dissemination and Exploitation

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Executive Summary

This deliverable describes the work to be done and results to be achieved related to the exploitation of the ExaFLOW results during the project lifetime. This deliverable also includes the content and findings of the IPR Management and Registry.

The main objective of this deliverable is to describe the exploitation process to be followed and organise the currently available exploitation content. During the lifetime of the ExaFLOW project the exploitation activities will go through different phases of intensity. In the first 6 months of the project we focused on planning the processes and activities. In the upcoming months M6-M12 we will focus on IPR logging and establishing relevant contacts to project stakeholders, direct and indirect beneficiaries. In months M12-M18 the first project outputs could be demonstrated. After M18 the exploitation team will actively seek stakeholders and communities interested in the uptake of the project results. At the same time all partners are responsible for pursuing their individual exploitation plans.

In general, all core partners are involved in the exploitation activities and will contribute to the work to be done.

This document is mainly intended for internal reference and use, i.e. by all project participants; however it could also act as a reference for other projects to define their dissemination and communication plans.

Contents

1 Introduction

In this deliverable we provide the Consortiums initial plans for exploitation. These plans will be updated throughout the project's execution, as the production of this deliverable is at M6.
The document is organised as follows. First, the project's overall exploitation management process, which emanates from the research and development activities and will enforce strong focus on exploitation, is presented. . We then list the exploitable assets, mostly taken verbatim from the "Description of the Action" document. These will be updated with additional data as the project progresses.
Then, we present the position of ExaFLOW project in relation to other national and international initiatives. We also outline the currently known value-chain analyses, which will help in focusing of the exploitation efforts. Then, we provide the current exploitation plans as outlined in the project proposal and later on, in the "Description of the Action" document.
We name this state as the currently known exploitation horizon, which will be further updated with the inputs from the Scientific Advisory Board (SAB), and the technological landscape around the project.
Finally, we provide the timeline of the follow up deliverables.
To sum up, the purpose of this document is to provide the initial outlook on the ExaFLOW project's technological surroundings, our exploitation plans and to provide a good basis for the exploitation efforts that will be carried out throughout the project's lifetime, ensuring impact and relevance of the ExaFLOW project's outcomes.

2 The ExaFLOW project exploitation process

This section presents the ExaFLOW project exploitation process, which is also depicted in Figure 1. It consists of the project Research, Development, and Implementation activities (on the left) and corresponding Exploitation, Steering, and intellectual property rights (IPR) (on the right). We first provide the high-level overview of the diagram and then go further into the details. The left side describes the internal logic of the production of Exploitable Results (ER), as a consequence of the project's Objectives and Results, measured by Key Performance Indicators (KPI). Basically, this is the main Research and Implementation effort of the project.

However, the aforementioned effort needs to be steered towards the final exploitation goals - the ultimate outcome of the ExaFLOW project is to provide specific components and the overall technology as relevant building blocks for the potential users' needs.

On the right side we see the Consortium Bodies and Roles, which are instrumental to steering of the implementation efforts (Project Management Board, Scientific Advisory Board, Project Coordinator and Work package Leader). Each of these roles and bodies provides their input into the exploitation effort and plans, either directly (Work package Leader and Project Coordinator) or indirectly (Project Management Board and Scientific Advisory Board).

The Exploitation efforts are divided into three distinct areas, where the Use Case showcasing is the most prominent one. The two remaining activities are the standard EU project activities - the exploitation plans generation and implementation as well as the careful tracking and documentation of IPR.

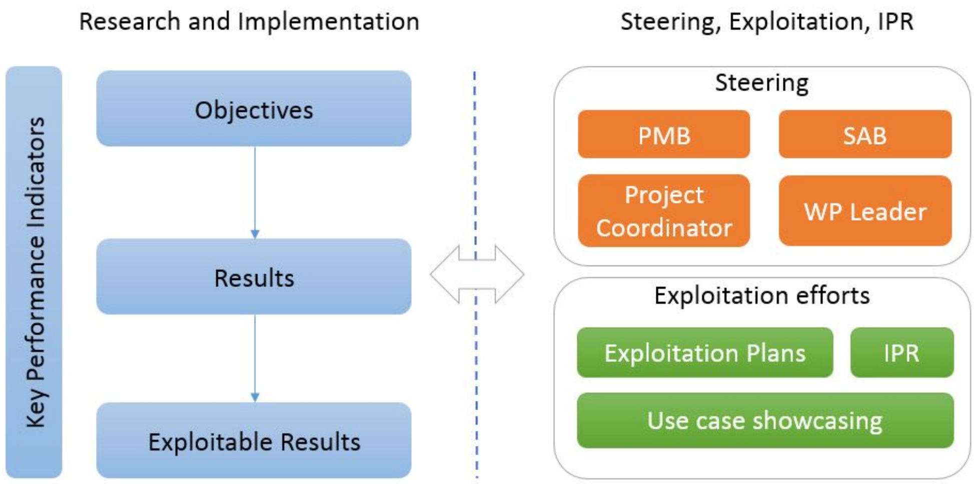

Figure 1 - the overall ExaFLOW project exploitation process

2.1 Research and Implementation

The Research and Implementation effort (on the left in Figure 1) follows the implementation as envisaged in the project. This means following the objectives of the project and at the same time targeting the results, which are then distilled into Exploitable Results. Key part of this project is the definition and measurement of Key Performance Indicators. Some of these are rather simple to define, while others are not, especially in this early phase of the project's execution. The fully developed KPIs have been developed and recorded in deliverable D5.2. We provide the currently defined Exploitable Results in Section 3. In the case of the ExaFLOW project, the results are being generated iteratively, on yearly basis, through the collaboration of the use case partners with the code owners and HPC centres.

2.2 Steering, Exploitation and IPR activities

The Steering, Exploitation, and IPR efforts (on the right in Figure 1) are composed of the two major components: Consortium level bodies and roles and Consortium level activities.

Consortium Bodies and Roles are instrumental to steering of the implementation efforts:

- The Work Package leaders are responsible for coordination of all of the exploitation efforts within the project, as well as for tracking and documenting IPR after communicating with the Project Coordinator.

- The SAB consists of the high-profile scientific and business personnel (outside of the Consortium) that steer the exploitation (e.g., provide insights and new business models).
- The Project Coordinator and the Project Management Board are instrumental in exploitation. Both are responsible for IPR management and appropriate licensing of the components, developed by the project (Results and Exploitable Results).

The above mentioned people and bodies are working continuously in order to maximise the exploitable outcomes of the project. This means asking the Consortium members for updates of their exploitation plans, continuous management of IPR, IPR review process, etc. The two bodies are assembled once or twice per year. The outcome of these meetings are inputs to the exploitation plans, either in the form of newly proposed business models or even propositions regarding the directions of ExaFLOW project, based on the current technological landscape, either in the form of the clearly sorted-out IPR management.

The Use Case showcasing is the most prominent area in the exploitation efforts. They are used for practical showcasing (i.e., practical demonstration of the ExaFLOW project's selling points) in the exploitation (and evangelisation) efforts. The four use cases of the ExaFLOW project were designed in a way that directly target the potential beneficiaries of the ExaFLOW project, as the use case providers in ExaFLOW project can be seen as the early adopters of the project's outcomes.

Finally, the Individual and Joint Exploitation plans, are the activities performed by each of the individual partners in the Consortium and coordinated by the Work package leader and the Project Coordinator. Given the nature of the components, the joint exploitation plan is of utmost importance.

2.3 Interaction between the Research and Implementation and the Steering, Exploitation and IPR activities

While the research and implementation activities are always running, most of the exploitation activities are being run in intervals. In other words, while we're constantly exploring the possible exploitation opportunities, we need to synchronize them with the actual developments in the project, the technological landscape as well as outside inputs. Finally, we are also bound with the Grant Agreement, which specifies the outcomes of the project.

This means we can exactly quantify only repeated events - the SAB and PMB meetings (to be done twice per year and to provide inputs to the project). All other exploitation ideas and possibly results are transferred into the development of the project in a much softer way, and possibly even rejected, if they would present significant deviation of the current development towards the results of the project.

To sum up - interaction is not completely formalized (with the exception of the SAB and PMB meetings), however it will be regularly documented, using internal reporting mechanisms of the project, as well as in the official follow-up exploitation deliverables.

3 Exploitable assets

3.1 Main purpose of ExaFLOW project

The main goal of the project is to address current algorithmic bottlenecks to enable the use of accurate CFD codes for problems of practical engineering interest. The focus will be on different simulation aspects including:

- accurate error control and adaptive mesh refinement in complex computational domains;
- solver efficiency via mixed discontinuous and continuous Galerkin methods and appropriate optimised preconditioners;
- strategies to ensure fault tolerance and resilience;
- heterogeneous modelling to allow for different solution algorithms in different domain zones;
- parallel input/output for extreme data, employing novel data reduction algorithms;
- energy awareness of high-order methods.

To summarise, **the goal of ExaFLOW is to address key algorithmic challenges in CFD to enable simulation at exascale, guided by a number of use cases of industrial relevance, and to provide open source pilot implementations.**

ExaFLOW will produce a number of clearly defined innovations in the area of exascale computing and CFD.

Innovations	Success Metrics
Innovation 1: Mesh Adaptivity, Heterogeneous Modelling, and Resilience: Mesh adaptivity will reduce the cost of large-scale simulation through a more efficient use of resources, simplified grid generation and correctly calculated results. Heterogeneous modelling will enable capturing of the relevant flow physics for complex geometries at a reasonable cost. The development of translational algorithms will ensure fault tolerance and resilience and enhance the use of an exascale facility.	Reduction of simulation costs of up to 50%.
Innovation 2: Strong scaling at Exascale through a mixed CG-HDG: This approach will exploit the benefits of next-generation exascale computing resources by allowing individual jobs to be executed efficiently on a larger number of cores than presently possible. This will in turn allow	Improved absolute performance will be greater than, or comparable to, existing individual schemes for current levels of

large-scale complex flow simulations to be executed in shorter wall clock times. Time reductions for execution of high-fidelity simulations will accelerate the design cycle for a range of industrial applications.	parallelism and improved for larger levels of parallelism available on exascale systems.
Innovation 3: I/O data reduction via filtering: The approach of alleviating the I/O bottleneck in exascale computing by considerable data-reduction before I/O will deal with feature extraction in raw data. The absence of this process is at the moment a bottleneck for efficient simulations in many disciplines in science and engineering.	Reduction of operation time for the complete workflow, i.e. simulation (data generation), data processing and data I/O
Innovation 4: Energy Efficient Algorithms: will reduce the amount of energy and power required to perform CFD computations at Exascale while at the same time optimize the performance and scalability of the applications.	Quantifiable reduction of the total energy consumption and instantaneous power draw for the co-design applications. We expect 20% gain (depending on the application).

Table 1: Innovations of the ExaFLOW project and their metrics

All ExaFLOW innovations are clearly targeted to enhance the efficiency and exploitability of an important class of applications on large-scale (Exascale) systems.

3.2 Exploitable results of ExaFLOW project

Below we describe the expected impact generated in the ExaFLOW project in relevance with the project objectives. The result of the expected impact leads to concrete exploitable results (ERs) of the ExaFLOW project.

Objectives	Expected Impact
Objective 1: Mesh adaptivity, heterogeneous modelling and resilience.	The main outcome of this objective comprises novel formulations for the error estimation in realistic turbulent situations, which are i) well adapted to high-order discretisation methods, and ii) suitable for simulations at Exascale. These estimators will allow new, ground breaking and resilient simulations in situations where the use of high-order hexagonal meshes was previously difficult. This includes, for example, highly resolved flows around an airfoil geometry, and the modelling of shock-boundary layer interactions for compressible flows.
Objective 2: Strong scaling at	The proposed algorithmic developments will exploit the benefits of next-generation exascale computing resources

Exascale using a mixed Continuous Galerkin-Hybridizable Discontinous Galerkin (CG-HDG) approach.	by allowing individual jobs to be executed efficiently on a larger number of cores than presently possible. This will in turn allow large-scale complex flow simulations to be executed in shorter wall-clock times. Improvements to the simulation time of high-fidelity simulations will accelerate the design cycle for a range of industrial applications, including aerospace engineering and Formula 1. This will be realised through direct engagement with industrial partners.
Objective 3: I/O in ExaFLOW	Knowledge, experience and software that alleviates the foreseeable I/O bottleneck in exascale computing by (i) best-practice use of parallel I/O strategies, software and hardware features, and (ii) considerable data-reduction before I/O. The second path has additional potential beyond the present goals as it deals with feature extraction in raw data, which is important for many other disciplines in science and engineering. Even though only problems from computational fluid dynamics containing structures with different length- and time-scales will be studied here, the findings will be similarly applicable to other disciplines that use high-performance computer simulations to generate large amounts of raw data.
Objective 4: Validation and application use cases	Knowledge and experience gained from challenging applications. Costs and scaling identified for practical problems. • Industry partners become aware of potential of Exascale and develop internal company plans for possible exploitation. • Identification of best-practice with respect to problem definition, error control, I/O.
Objective 5: Energy efficient algorithms	The expected impact of the energy efficiency is: • an increased understanding of the impact of algorithm design on energy and power consumption; • a more efficient use of energy (as opposed to CPU-hour) budgets, which are likely to be introduced in exascale systems to some extent; • an ability to scale to larger core counts while remaining inside a fixed power envelope.

Table 2: Objectives of the ExaFLOW project and their expected impacts

The exploitable results of the project have been developed in such a way that it is possible to exploit them as standalone solutions. This approach of clearly driven developments was intentional so that the project outcomes would reach a maximum marketability and penetrate niche markets effectively. Here we list the exploitable results as outcomes of the objectives listed above. Each exploitable result corresponds to an objective. Next to the exploitable results we list the partners who plan to exploit them during the project as part of their individual exploitation plans, depending on the current needs of each organisation.

Exploitable results	**Exploitation by partners**
ER1: Novel formulations for error estimators and resilient algorithms in realistic turbulent situations suitable for exascale	Priority for: **KTH, IC, SOTON, EPFL** Secondary for: UEDIN, USTUTT, McLaren, ASCS
ER2: Novel mixed CG-HDG algorithms	Priority for: **IC, EPFL** Secondary for: KTH, SOTON, UEDIN, USTUTT, McLaren, ASCS
ER3: Novel I/O strategies based on feature extraction	Priority for: **UEDIN, USTUTT** Secondary for: KTH, IC, SOTON, McLaren, ASCS
ER4: Efficient Open Source Pilot Implementations	Priority for: **KTH, IC, SOTON, UEDIN, USTUTT, McLaren, ASCS**
ER5: Energy-efficiency driven algorithm designs	Priority for: **UEDIN, USTUTT** Secondary for: KTH, IC, SOTON, McLaren, ASCS

Table 3: ExaFLOW project project exploitable results/exploitable assets

In the following sections we also investigate the added value each exploitable result offers to potential users and IPR the consortium considers applying to each exploitable result.

4 Positioning the ExaFLOW project

The outputs of the ExaFLOW project and its position have been established at the proposal stage. The sections below present our current level of understanding of the external environment. However, we provide the timeline of updating this document in Section 6.

4.1 The ExaFLOW project TRL

The ExaFLOW project will reach technology readiness level TRL 6 - technology demonstrated in relevant environment for its development. The starting point of the project is new methods and algorithms that currently are at TRL 2 - technology concept formulated with the concepts formulated in this proposal.
WP1 will fully develop those concepts and provide initial proof-of-concept implementations, pushing the TRL to level 3 - experimental proof of concept. The further software engineering efforts in WP2 will push the TRL to level 4 - technology validated in lab. The project's access to state-of the-art HPC systems will allow to validate all developments in relevant environments, reaching TRL 5 - technology validated in relevant environment. The guidance of the project receives from the industrial and academic use cases as defined in WP3 the demonstration of the results in those use cases on systems relevant for industrial and academic usage finally pushing the results to TRL 6 - technology demonstrated in relevant environment.

4.2 Positioning the ExaFLOW project

The project is embedded in a rich network of national and international efforts, specifically in the exascale and CFD areas that will provide a stimulating environment for the ExaFLOW project developments as well as their dissemination and uptake.

Specifically, the project is well anchored in the ETP4HPC as well as exascale research projects such as EESI and CRESTA ensuring full alignment with the ETP4HPC's strategy.

KTH is a member of the European Technology Platform for High Performance Computing (ETP4HPC), and through the Swedish National Infrastructure for Computing (SNIC) a member of PRACE, EUDAT, and EGI, with KTH being the coordinator of the Swedish participation in PRACE. KTH coordinates the EPiGRAM project (http://www.epigram-project.eu), which investigates exascale programming models and is a partner of the FP7 exascale flagship project CRESTA. In these projects, KTH focuses on application scalability as well as performance analysis directly relevant to ExaFLOW. KTH is also the lead partner of the Swedish e-Science Research Centre (SeRC), a national large-scale e-Science initiative. KTH is also the home of the internationally recognised Linné FLOW Centre which focuses on fundamental aspects of fluid dynamics. A number of EU Projects (e.g. RECEPT) within fluid mechanics are coordinated by KTH.

IC is a member of the UK Turbulence consortium coordinated from SOTON and which has a significant allocation of the UK HPC facility, Archer, for the fundamental study of fluid mechanics using DNS and LES. IC has been involved in the Framework VII project IDIHOM on the use of high-order methods on industrial applications as well as the ITN project ANADE focussed on the development of high-order methods for separated flows. Sherwin at IC is also the Chair of the e-Infrastructure Strategic Advisory Team for EPSRC, which provides strategic oversight on Engineering and Physical Sciences UK HPC software and hardware initiatives.

SOTON has led the UK turbulence consortium, with funding from the Engineering and Physical Sciences Research Council in the UK, since its inception in 1995. The consortium's annual meetings provide a forum in the UK for shared experiences in high-performance computing, including support for code optimisation and development. SOTON is a partner in the South of England e-Infrastructure South consortium, together with Oxford, Bristol, and UCL, which shares hardware, including the Emerald GPU test bed machine. A current EPSRC-funded project in collaboration with Oxford and Bristol is developing an OPS version of the SBLI code, aiming to future-proofing software to possible future hardware scenarios.

UEDIN runs the UK's national HPC service on behalf of the UK government and is a member of its e-Infrastructure leadership council. UEDIN is a member of ETP4HPC and has led the UK's technical involvement in all the PRACE projects to date. UEDIN coordinates a number of leading collaborative projects, including CRESTA, Fortissimo, and Adept. UEDIN is also a partner in the European Exascale Software Initiative project.

USTUTT is participating with two institutes: HLRS and IAG. HLRS is one of the three German national supercomputing centres, which form the Gauss Centre for

Supercomputing (GCS). HLRS is a member of the ETP4HPC and participates in the PRACE project. The institute is actively involved in the development of distributed programming models, e.g. through active participation in the OpenMPI and the MPI standardization body MPI Forum.

EPFL participates with the Chair of Computational Mathematics and Simulation Science (MCSS) as well as the unit of Scientific IT and Application Support (SCITAS), which hosts and supports all HPC infrastructures at EPFL. Hesthaven is the academic lead of SCITAS. Hesthaven at EPFL has been involved in numerous HPC related activities in the US during the last decade, including projects at DoE and substantial activities in GPGPU accelerated efforts.

Thus, the ExaFLOW project is fully aligned with the objectives of the strategic research agenda (SRA) of the ETP4HPC4, and the recommendations of the EESI projects. Specifically, it has been recognized by the ETP4HPC that *most algorithms will face re-writing challenges to work well on the fastest machines*. While ExaFLOW does not have the resources to fully re-write existing applications, it develops important algorithms and methods that will impact CFD codes and the prototypes produced by the project will successively be integrated with the widely used codes owned by the project participants. By providing these new algorithms and improved parallel implementations ExaFLOW will contribute to reach ETP4HPC's milestone *MPROG- LIB-4: new parallel algorithms parallelisation paradigms.*

Another important challenge identified by the ETP4HPC is the *inefficient performance utilisation of storage (applications unable to obtain the performance they require or expect)*, which requires to *balance compute, I/O and storage performance.* ExaFLOW is addressing this challenge in two ways: increase the parallelization and performance of I/O in CFD and exploit novel hardware features such as burst buffers and in future non-volatile memory, and reduce the data amount through innovative filtering techniques.

Energy efficient algorithms and energy-aware performance metrics are highlighted in the ETP4HPC SRA as a research topic towards exploiting exascale systems. ExaFLOW will contribute to this topic through its direct incorporation of energy efficiency and awareness in the algorithm design process.

The ExaFLOW project results will impact:

• I*mportant segments of the broader and/or emerging HPC markets, especially extreme-scale HPC systems.*

ExaFLOW is contributing to a segment that is currently one of the biggest users of HPC technologies, both in academia and industry, and the importance of this segment is expected to rise as new HPC capabilities, particularly exascale systems become available. CFD has a clear need for and the potential to reach exascale and the ExaFLOW project is making important contributions both on the algorithmic/method level and the software engineering for exascale aspects.

• *Standards bodies and other relevant international research programmes and frameworks.*

While for the developments in this project there are no standardization bodies as such, the community is impacted through large community events like ECCOMAS, ERCOFTAC, EUROMECH, ICOSHAOM, and ICCFD, which will particularly be targeted by the dissemination activities described below. This is complemented through national efforts like the UK Turbulence Consortium (UKTC). In addition, the developments of ExaFLOW will use and follow the developments of standards and community best practices for exascale computing such as MPI, OpenMP, OpenACC/CUDA, etc.

4.3 The initial value-chain analysis

In this section we present the first overarching value-chain analysis for the partners in the project. The detailed analyses are to be provided based on individual exploitation plans in the future versions of this deliverable, as the project and its outcomes become more tangible.

Next we provide two levels of beneficiaries. Those that will be directly impacted by the project results, the direct beneficiaries or primary users; and a second level of target users, indirect beneficiaries, which push towards the utilisation of the project results by the primary users. For example, scientists in our scientific community (e.g. in future EU and national projects) can take up well-proven concepts from the ExaFLOW project to develop high-level programming frameworks for heterogeneous systems. Some of these stakeholders are often under the influence of governmental institutions, which encourage early adaptation in order to gather data with the intention to validate metrics and methods before including them in actual legislation drafts. These are users that will benefit by others using ExaFLOW project technologies.

To sum up, the innovation of the ExaFLOW project will directly and indirectly impact a wide range of beneficiaries as explained in below in Table 4 and Table 5 below.

Direct beneficiary	**Value proposition**
CFD-based research Groups	The innovations of ExaFLOW in new algorithms and methods will allow new and larger problems to be simulated.
ISVs and academic application providers	The pilot implementations provided will allow a quick take-up of the algorithms and methods developed in both commercial and academic CFD applications, contributing to the European application excellence.
HPC resource service providers	The improved performance and power efficiency of CFD methods and I/O will directly result in more efficient use of the HPC resources, both in terms of science throughput and energy consumption.

Table 4: Value proposition for direct beneficiaries

Indirect beneficiary	**Value proposition**
Automotive &	CFD is a key technology for the automotive and

Aerospace Industry	aerospace industries. The improvements made by ExaFLOW will allow them to use better simulation models contributing to their market competitiveness. ExaFLOW has included representatives in the consortium to ensure the developments are guided by industrial needs and industry will indeed be able to pick them up.
CFD User Community	CFD is used in many different disciplines as described above. The improvements made by ExaFLOW will provide them with means to produce faster and more efficient simulations having the potential for significant economical and societal impact.
HPC research and user community	New feature extraction and data-compression algorithms will benefit the wider HPC research and user community.
HPC research	The advancement of the state of the art in algorithm development for community improved scalability and efficiency will progress knowledge and thus benefit the wider HPC research community.
HPC hardware vendors	The increased use of large-scale simulations will stimulate the HPC market and the developments of ExaFLOW will contribute to making a case for exascale developments.

Table 5: Value proposition for indirect beneficiaries

4.4 IPR and Licensing

The ExaFLOW consortium defined all matters related to confidentiality and IPR handling in the Consortium Agreement. This agreement formalises project management procedures, IPR issues, and exploitation of results. This agreement ensures that the IPR of third parties will be respected by registering and tracking all use of third party components to ensure that license conflicts are not generated. The IPR of participants will also be protected by ensuring that the impact of the licenses of any third party software is analysed prior to its use (particularly concerning GPL and other viral open source licenses). All background owned by the institutes is clearly stated in the project's Consortium Agreement and the IPR policies clarified. IP created during the project will be the property of the partner who creates it, however, all IP created during the project will be available to other partners for use on the project without payment. Use of that property following the conclusion of the project will be subject to the normal considerations. All deliverables produced by the project that do not include financial information or security-related issues will be made public, and the project follows an open source policy for the technologies and interface developed in the project to facilitate technology transfer to the business sector and encourages the uptake of the results in third-party products.

The initial background included comprises the existing CFD methods as implemented in the pilot codes as well as use case geometries. This particularly includes:

- Nek5000 code, available under GPL license at https://nek5000.mcs.anl.gov/

- Nektar++ code, available under the MIT license at www.nektar.info
- SBLI code, currently available for collaborators from the University of Southampton, an open-source release is underway.
- McLaren front wing geometry, protected by McLaren, will be made available under NDA to the academic consortium members.
- NACA 4412 airfoil geometry, standardised geometry published by the National Advisory Committee for Aeronautics (NACA) Report 460, 1935.
- Jet in crossflow geometry, published by Peplinski, Schlatter and Henningson,
- Eur. J. Mech. B/Fluids (2014).
- Opel Astra rear part geometry, protected by ASCS and its member Adam OPEL AG, could be made available under NDA to the consortium members.

Moreover, the licensing of the project results has been considered by the consortium from the very beginning of the project in a joint effort made by technical and exploitation teams. The consortium has decided from the very beginning that the project should be "as open as it can be". However, due to the manifold underlying licenses as well as the commercial partners ASCS and McLaren, there are obstacles which lead to a more complex licensing and IPR management. As a result, in the table below we list the licence types the consortium considers applying to each of its exploitable results.

Exploitable results	Licence type
ER1: Novel formulations for error estimators and resilient algorithms in realistic turbulent situations suitable for exascale	Open publication
ER2: Novel mixed CG-HDG algorithms	MIT licence
ER3: Novel I/O strategies based on feature extraction	License of surrounding application
ER4: Efficient Open Source Pilot Implementations	Open source
ER5: Energy-efficiency driven algorithm designs	Copyright of the consortium

Table 6: ExaFLOW project exploitable assets' licences

5 Exploitation plans

5.1 Exploitation strategy

The list below describes the main objectives and also includes the supporting dissemination and communication actions that will help both commercial and non-commercial exploitation tasks to leverage impact creation with the project results. These options demonstrate potential routes to seek in our contacts with stakeholders.

- **Stakeholder outreach.** We plan to identify and contact stakeholders demonstrating to them the value of the results through example tools, documents and code as well as giving an introduction into "How to Adopt" the ExaFLOW project exploitable results. We will seek the possibility to jointly initiate a sustainability path, thus establishing and nurturing relations and collaborations with third parties.

Exploitation is of clear importance to the impact generation, in particular with regards to uptake of open source project results. The results of ExaFLOW will be communicated to industrial beneficiaries, both through the industrial links of the partner organisations and the ETP4HPC. Table 4 below lists the main industrial contacts of the project partners.

Partner	**Main Industrial Contacts**
KTH	SAAB, Scania, Vattenfall, Huawei
IC	McLaren, Airbus, BP, British Gas
SOTON	Airbus, Vestas
UEDIN	Rolls Royce, ICON CFD, Prospect FS, BAE Systems
HLRS	Porsche, Daimler, RECOM
EPFL	HyperComp Inc (US)
ASCS	Porsche, Daimler, Opel, HONDA, TECOSIM, Altair, CD-adapco, MentorGraphics, ESI

Table 7 - Main Industrial Contacts

Moreover, ASCS has established a series of workshops for keynote speakers on the subject of automotive simulation using the HPC technologies. One of the main aims of the workshops is the promotion of the results of Exaflow, with an accent on the last developments of innovative CAE and HPC methods and the creation of synergies between the companies active in this field. The series of annual "simpulseday CFD workshops" organised by ASCS is an opportunity for Exaflow project partners to cooperate with key players of the automotive industry, during as well as after the project.

- **Partner-specific exploitation strategies** seeking to enhance their own products or services, feeding research outcomes into business and product development.

- **Establish parallel actions to create impact and sustainability with ExaFLOW project results:** this strategy tries to create as much impact as possible with the exploitable assets resulting from the project under the identified value and value propositions. These strategies will provide alternatives, such as creation of possible joint exploitation routes among the partners.

- **Participation of third party organisations.** The consortium is considering this option for those cases where a certain stage on the resulting value chain will not be present in the consortium; or where there is lack of specific resources or exploitable assets. In this regard, the consortium will carry out efforts during the second year to approach stakeholders in order to promote and create awareness; to leverage the adoption of the results; and to seek for possible synergies and collaboration to develop and continue the future evolution of the project.

All these efforts are underpinned by the idea of seeking future potential contributions and adoption by the CFD and HPC communities and other potential early adopters of the project exploitable results.

The overall exploitation of ExaFLOW project is based on:

- Individual exploitation plans[1].
- Ad-hoc exploitation of combinations of components by partners (or a subgroup of partners), given their current needs.

Each of these pillars is explained below. Currently, the plans are mostly the same as they were during the proposal and now, early project phase. Some changes have already been introduced, however this part should be taken mostly as verbatim copy of the project's documentation and also as the baseline for the exploitation plans during the project's execution.

5.2 Individual Exploitation Plans

The paragraphs below show individual exploitation plans, mostly as reported during the proposal and project phase.

5.2.1 KTH

KTH will integrate the results of the project into the NEK5000 code, which is used in a number of academic and industrial research projects and one of the most used codes on the KTH HPC resources. Thanks to the open source nature of NEK5000 the results will also be readily available to the wider research community and KTH will continue developing the code after the end of the project. KTH is particularly committed to exploit ER1 and ER4 and ER2, ER3, and ER5 will likely also have impact on KTH's future development of NEK5000. KTH will also exploit the results via its HPC Center, PDC, which will make NEK5000 publicly available on its resources and use the results, specifically ER1 and ER2 in technology transfer activities with its many academic and commercial CFD users. A first tangible exploitation result is the development of a proposal for a Swedish Center of Excellence for High Performance CFD Applications in Engineering to the Swedish Innovation Agency (Vinnova). This proposal, that comprises the KTH groups participating in ExaFLOW, two other Swedish universities, and a number of key Swedish Engineering industries, will, if funded, directly apply the ExaFLOW results to industrially relevant CFD problems.

5.2.2 IC

IC will integrate the results of the project into the Nektar++ code, which is used in a number of academic and industrial research projects. Components of this code are also linked to the NEK5000 code and so, as necessary, results will also be updated into this codebase. Thanks to the open source nature of Nektar++ and NEK5000 the results will also be readily available to the wider research community and IC will continue developing the code after the end of the project.

[1] Partners will exploit the final outcome of the project. However, some of the partners have expressed their interest to exploit specific parts of the project (listed in Exploitable Results), as these components explicitly correspond to their primary activities and could be exploited in different scenarios, falling under their overall exploitation activities.

The main focus will be on ER1, ER2, and ER4, with ER3 and ER5 likely playing a role as well.

5.2.3 SOTON

SOTON will integrate the results of the project into the compressible flow SBLI code, which is used for a number of mainly academic research projects and is one of the main codes of the UK Turbulence Consortium. New features will be made available in open source so that they are available to the wider community and the code will be further developed after the end of the project. Besides improvements in the code we also expect to exploit large-scale applications developed during the project to demonstrate advanced flow modelling of industrially relevant problems. The main focus will be on ER1, and ER4, with ER2, ER3 and ER5 likely playing a role as well.

5.2.4 UEDIN

The University of Edinburgh, through its supercomputing centre EPCC, has set exascale computing research as its key computational science research priority over the next decade. Power efficiency of HPC and software scalability on a massive scale are two crucial parts of the research that needs to be undertaken on the path to exascale. UEDIN firmly believes that a long-term solution can only be found in close collaboration with experts from across all computing and science segments; thus ER3, ER4 and ER5 are of particular interest to UEDIN. ExaFLOW is an important component in our strategy to achieve our goal of moving HPC into the exascale era. For UEDIN, multiple exploitation channels exist for the output of ExaFLOW. These include publications, the production use of the software developed in the project, continued research and development of the software and ideas developed during the project, and the transfer of the results into the scientific and industrial domain. In more detail we will:

- Publications: publish our research results in academic journals, and in presentations and papers at conferences;
- Production use: offer the ExaFLOW algorithms and prototype implementations to the users of UEDIN HPC services, and exploit the expertise gained in understanding power usage of HPC algorithms in our day-to-day work as a supercomputing centre.
- Continuing R&D: take the results forward in subsequent and on-going projects and other activities such as novel hardware design projects with vendors, based on knowledge gained from efficient algorithm design and implementation; Technology-transfer: use the results in our work with our many academic and commercial customers who use CFD applications in their daily business.

5.2.5 USTUTT

ExaFLOW is helping USTUTT-IAG and -HLRS in first instance by allowing for further scaling of CFD codes. HLRS as provider of facilities for large scale capability jobs has a vital interest of the further development of scalability of computational fluid dynamic codes because these take the major part of the computing cycles of all machines of the centre and thus are a major consumer of resources and energy. USTUTT-IAG will be able to increase the overall performance of their analysis by the proposed approach (by providing and using techniques of doing faster IO and by showing ways of extracting the physically and technically relevant flow features of an unsteady flow). This approach which will at the end lead to a reduction of storage needs is also a vast interest for USTUTT-HLRS as this will avoid unnecessary investments in excessive increases of storage capabilities. Furthermore, USTUTT-HLRS will gain valuable knowledge understanding the implications of the appearance of large sized non-volatile memory for large scale computing. Finally, the energy efficiency aspects of ExaFLOW will provide another aspect for the Green IT and energy reduction activities of HLRS to reduce costs and minimize the environmental impact. In addition USTUTT-HLRS will use its synergies with the Institute of High Performance Computing (IHR) at the university and embed the research and technical objectives as subject in its lectures and of doctorate thesis work. Furthermore the results and experiences of this project will enrich USTUTT-HLRS´ training activities which will be enhanced and increased with the construction of a dedicated training centre and the release of new, improved training plans.

5.2.6 EPFL

EPFL will focus on the development and analysis fault tolerant and resilient algorithms at the exascale, including the development of suitable approaches for in-situ model development and fault detection strategies. EPFL will also be involved in the development of new scalable solvers and their implementation. The developments will be transitioned to the Nektar++ code and, through shared code base, to NEK5000.

5.2.7 McLaren

The application of time average RANS CFD simulation is the lead technology behind McLaren Racing's aerodynamics design. A natural evolution of this important design tool is the introduction and wider application of transient flow modelling to achieve even greater aerodynamic performance. For this type of modelling to be applied to a full car simulation undertaking complex manoeuvring conditions within a suitable timescales for design will require exascale levels of compute based on the tools provided by Exaflow. Successful application of this technology is therefore seen as not only a key enabler in McLaren Racing's race winning objectives but will also feed into their other applications of luxury automotive car design and technology transfer through McLaren Advanced Technology division.

5.2.8 ASCS

As an applied research institute the ASCS is interested in the results of ExaFLOW in order to maintain the position of a transfer platform in the field of future-oriented virtual vehicle development. The current very strong trend of increasing computing time in CFD simulations using scale resolving modelling methods benefits the penetration of new exascale technologies in the automotive sector. The ASCS wants to increase the awareness and knowledge of exascale solutions for this application. The gained expertise will be the basis for further conception and implementation of research projects in the field of CFD simulations for the future-oriented vehicle development process. Furthermore the conflation of forces engaged in research with industrial practice for the purpose of reciprocal exchange on current issues, the dissemination of scientific results relating to modelling and simulation in exascale environments, to be used in practical applications including the method-oriented support of users is focused with this project.

5.3 Ad hoc exploitation of combinations of components

Certain partners in the project have a track record of collaboration and have the capacity (personnel) to force an agreement for joint exploitation of a subset of ExaFLOW project components, with specific exploitation goals. The ExaFLOW project IPR Log makes such decisions easy and straightforward, as the ownership of each component is explicitly known. Moreover, the Consortium will seek to establish as many partnerships as possible with third parties, in order to achieve the maximum exploitation of the ERs. We note that the ER groups described below are based on the current understanding of the Consortium and its Results.

5.3.1 ER4 and ER5

The Efficient Open Source Pilot Implementations (ER4) will be used in combination with Energy-efficiency driven algorithm designs (ER5) by USTUTT, EPCC and KTH to address the needs of Resource providers in Exascale HPC environments. Moreover, HPC vendors as well as ISVs and the geneal HPC research community can benefit significantly from the combination of these project results.

5.3.2 ER2, ER3 and ER4

IC foresees a strong cooperation with McLaren and ASCS for a common exploitation of ER2, ER3 and ER4. During this cooperation better scaling efficiency to the test cases proposed by McLaren and ASCS will be demonstrated using the improved CG-HDG algorithms. Beneficiaries of the combined use of these two ERs are CFD-based research groups in academia and the CFD community in general, as well as CFD-based industries such as the ones of automotive and aerospace. ISV providers can also greatly benefit from the exploitation of these results.

5.3.3 ER1, ER3 and ER4

A combined exploitation of novel formulations for error estimators and resilient algorithms in realistic turbulent situations suitable for Exascale (ER1) with Novel I/O strategies based on feature extraction (ER3) and Efficient Open Source Pilot Implementations (ER4) is of major interest to KTH, USTUTT, SOTON and EPFL. These partners will focus their exploitation activities on helping the CFD community run more efficient simulations and the ISV providers use the methods developed in both commercial and academic CFD applications.

5.4 The exploitation plan timeline

Following the initial Exploitation Plans (outlined in this deliverable), the next version of the Exploitation Plans and the corresponding report will be provided at M18 (March 2017).
The outline of the next steps of the exploitation plans development are:

- *Periodic reviews of initial exploitation plans by each of the Consortium partners.*

Each of the partners is closely following its field from the business perspective. We will ask the partners to update their exploitation plans for ExaFLOW project every 6 months, which will allow for faster response of the exploitation effort.
The updates of the exploitation plans, the objectives of the project and the exploitable results will follow the execution of the project.

- *Development of questionnaires, based on the current knowledge of the project, development and perceived user needs (as currently set in the Joint Exploitation Plan) and conducting a survey among the interested communities.*
  Questionnaires will be developed by the exploitation WP, using inputs from other Work Packages, partners in the Consortium and other interested stakeholders.

- *Obtain and amalgamate the SAB inputs into the project.*
  The complete SAB has been announced in M6 and we will hold a first SAB meeting at the all-hands meeting planned at M7, as a starting point for obtaining inputs. The SAB members will be provided with status reports on the projects, the state of the technology and given glimpse into our plans for the future development and exploitation. We will hold a video conference call where we shall record their further response.

- *Update the deliverable with the so-obtained plans and analyses and evaluate the development with the baseline, set in this deliverable.*
  The update of the deliverable will follow each major event of this plan. We plan to update it at M10, M14 and then after SAB meetings and major exploitation events and meetings. Final update will be performed in M18, to ensure completeness of the deliverable for the second review.

In Year 1 exploitation of the project is not directly expected. However, the commitment of the project that it will result in continuous innovation delivery and thus exploitation by M36 should hold.

6 Next steps and upcoming Deliverables

As the software results of the project mature, the exploitation plans outlined in this deliverable will be updated and further on evaluated by all partners. An exit strategy will also be described.

At the same time the Exploitation team will refine further the project Exploitation plan, allocating specific activities to specific partners and communicating the results to the consortium for internal discussion and decision making.

Last but not least, as already planned, during the second year, the Exploitation team will reach out to the market in a more active manner, carrying out efforts to tackle real stakeholders (identify, reach, promote, attract interested early adopters and do our best effort to “make sales” to either create potential sustainability routes or leverage the adoption of the results). We want to establish these contacts with the purpose of nurturing relationships, and be prepared for when the solution is fully ready to be shown for adoption. The full list of contacted stakeholders by the consortium during this period will be provided.

Below, the list of deliverables related to exploitation is given:

Number	Title	Due	Status
D4.1	Exploitation Plan	PM6	Current document
D4.2	Exploitation Plan – revision 1	PM18	To be submitted
D4.3	Exploitation Plan – revision 2	PM36	To be submitted

Table 8: Overview of upcoming deliverables