

PROGRAMME REVIEW

Research Master in Fluid Dynamics

von Karman Institute for Fluid Dynamics

Brussels - May 2021

PROGRAMME REVIEW RESEARCH MASTER IN FLUID DYNAMICS

VLUHR Quality Assurance
Ravensteingalerij 27
1000 Brussels
T +32 (0)2 792 55 00

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Legal deposit number: D/2021/12.784/2

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Preface VLUHR Quality Assurance Board

This assessment report deals with the programme review of the Research Master in Fluid Dynamics. This programme review was conducted by an independent panel of experts in February 2021.

This report is intended for all stakeholders of the programme and provides a snapshot of its quality following the review principles for quality assurance for programme assessments in Flanders. As chair of the VLUHR Quality Assurance Board I hope that the panel's findings, judgements, recommendations and commendations will advance this research programme. Additionally, this report intends to provide information regarding the quality of the programme to a wider audience. For this reason, this report is published on the website of VLUHR QA.

I would like to thank all members of the panel for the time they invested and the dedication they showed carrying out this programme review. At the very same time, this review was only possible because of the commitment of all those involved in the programme. I hope this assessment report does justice to their efforts.

Petter Aaslestad

Chair VLUHR Quality Assurance Board

PROGRAMME REVIEW

Introduction

This assessment report presents the findings, judgements, commendations and recommendations regarding the Research Master in Fluid Dynamics at the von Karman Institute for Fluid Dynamics. For the administrative details of the institution and the programme involved see Annex 1.

This programme review was carried out in accordance with the Manual for Programme Review.¹ Patrick Van den Bosch, Policy Advisor at VLUHR QA, was project manager of this programme review.

Panel composition

The proposal of candidate panel members was approved by the VLUHR Quality Assurance Board on 4 December 2020. The composition of the panel was ratified by the VLUHR Quality Assurance Board on 8 January 2021.

The panel was composed as follows:

- GertJan van Heijst, full professor in fluid dynamics in the Department of Applied Physics at Eindhoven University of Technology (TU/e), scientific director Burgerscentrum, The Netherlands
- Peter Flohr, Lecturer and Department Head of the Institutes in Applied Maths, Computational Physics, Data Analysis, and Sustainable Development, School of Engineering of the Zurich University of Applied Sciences, Winterthur, Switzerland
- Bernard Geurts, Multiscale Modeling and Simulation in the Department of Applied Mathematics at the University of Twente, The Netherlands
- Thibo Lodewijckx, Master of Science in Electromechanical Engineering Technology, Universiteit Gent, Belgium

A short cv of the panel members is included as Annex 2.

Review principles

The programme review was conducted in accordance with the eight quality features. These features are the characteristics of a high-quality higher education programme, defined by the Accreditation Organisation of the Netherlands and Flanders (NVAO) and tied in with the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG, 2015). For each programme whose quality is satisfactory, the presence of the following quality features is guaranteed:

1. The programme's learning outcomes constitute a transparent and programme-specific interpretation of the international requirements regarding level, content, and orientation;
2. The programme's curriculum ties in with the most recent developments in the discipline, takes account of the developments in the professional field, and is relevant to society;
3. The staff allocated to the programme provide the students with optimum opportunities for achieving the learning outcomes;
4. The programme offers the students adequate and easily accessible services, facilities, and counselling;
5. The teaching and learning environment encourages the students to play an active role in the learning process and fosters smooth study progress;
6. The assessment of students reflects the learning process and concretises the intended learning outcomes;
7. The programme provides comprehensive and readable information on all stages of study;
8. Information regarding the quality of the programme is publicly accessible.

¹ <https://www.qualityassurance.vluhr.be/documents>

In addition, a programme ensures the involvement of internal and external stakeholders on the one hand and external and independent peers and experts on the other hand, in a continuous pursuit of quality development. If applicable, the programme must also comply with relevant regulations with respect to the admission of graduates to corresponding posts or professions.

Preparation

In preparation of the programme review, the programme compiled a self-evaluation report in accordance with the VLUHR QA Manual for Programme Review. The panel received the self-evaluation report well in advance and studied this document and its annexes thoroughly. The panel also studied a wide selection of Master's theses and consulted the virtual learning environment of the programme.

On the 22 January 2021 the panel members attended a training session organised by VLUHR QA. During this session, the panel members were informed about the programme review process. Special attention was given to the status of the programme, quality assurance in Flanders and Europe, the Review Principles and interviewing techniques. Also, a schedule for the site visit was agreed upon, enclosed as Annex 3.

Site visit

Given stringent COVID-19 regulations, the review of the programme was conducted online on the 22 and 23 February 2021. The panel received a presentation about the facilities at the campus before the online site visit. During the site visit, the panel conducted interviews with all those involved in the programme in order to gain insight into the quality of the programme, including management, students, teaching staff, alumni and professional field. These interviews took place in an open and constructive atmosphere and provided the panel, in addition to the documents studied (see Annex 4 for an overview), relevant insights regarding the quality of the programme. In order to give all stakeholders the opportunity to talk confidentially to the panel there was a free consultation. At the end of the site visit, the panel discussed its findings, judgements, recommendation and commendations with the programme management in a co-creative session. After a final panel meeting, the panel shared its main conclusions with the programme management in an oral report.

Assessment report

In the subsequent assessment report the panel provides the findings, judgements, recommendations and commendations regarding the quality of the programme. At the end of this report a conclusion, readable for a wide audience and including an advice for accreditation is formulated, as well as a list of commendations and recommendations. The programme management was given the opportunity to respond to the draft of this report before finalisation.

Programme report

This report covers the evaluation of the **Research Master in Fluid Dynamics** at the **von Karman Institute for Fluid dynamics (VKI)**. The research master programme is a **nine-months master-after-master programme**. VKI has been founded in 1956 by Theodore von Karman as an international centre for the study of fluid dynamics. The main motivation for establishing the institute was the need to intensify the research in the field of fluid dynamics and the dissemination of the results in order to cope with the fast developments in the field of aeronautics and astronautics.

The VKI is an **International Not-for-Profit Association**. The association is composed of full members represented in the general assembly. The board of directors is the executive and administrative governing body of the VKI, with the assistance the VKI managing director. The dean is responsible for the daily affairs of the VKI educational activities.

The programme is **organised in three departments**. The main differences between the departments are in the topics that are studied. Each department has its own teaching staff.

- Aeronautics and Aerospace Department (AR) studies mainly the external aerodynamics of airplanes and space vehicles.
- Turbomachinery and Propulsion Department (TU) studies all types of turbomachines used in industrial processes, energy production as well as propulsion.
- Environmental and Applied Fluid Dynamics Department (EA) studies applied fluid dynamics problems such as atmospheric flows, wind energy, industrial safety, multiphase flows, and aeroacoustics.

The **educational committee** monitors the pedagogic quality of the teaching. It is composed of the dean (chairman), the student representative, and a representative of the VKI alumni association. The educational committee may invite more faculty members, honorary professors and research engineers involved in teaching for reasons of their competence in specific matters. The committee meets at least at the end of each semester and when it has to deliver a report to the assessment committee. The chairman is responsible for a day-by-day follow up of all matters related to the quality of education during the whole year. Depending on the information received, an extra call for a committee meeting can be send out at any time.

The educational committee takes many different steps to ensure the quality of the programme. This is evident from the documents that the panel was able to examine and from the conversations with the various stakeholders. This works well currently. The panel believes that a more systematic approach could bring the programme to a higher level in terms of **quality culture**, which will be further elaborated upon throughout this report.

The programme starts the first week of October and finishes end of June of the next calendar year. The Self Evaluation Report (SER) states that **the main characteristic** of the programme is the specialised training in fluid dynamics research. This takes place in a multinational context combined with a hands-on training in project management, reporting and presentation of research results in technical English. This is reflected by the 30 ECTS out of 60 ECTS allocated to the master thesis.

The panel recognises that VKI focuses on fluid mechanics and, from its inception, has had an **international reputation in experimental facilities for demanding conditions**. The panel learned from its meetings that in past decades also computational modelling has been introduced and that these days a highly respected institution for fluid mechanics is recognised, building on both experimental and simulation strengths. This research heritage strongly shapes the programme.

The programme management shows in the SER that the programme **benchmarks** itself with other renowned programmes worldwide. The programme focusses strongly on research and development in its three domains of specialisation (in line with its three departments). The panel states that the SER demonstrates that the programme's objectives are also in line with the requirements of the Flemish qualification structure for a master's programme.

VKI is **financed** by several NATO countries, the Belgian federal government and by the income from sponsored research activities. The financing organisations are member of the association and represented in the general assembly. Citizens of NATO countries which contribute to the funding of VKI² can benefit from a fellowship to cover living expenses while in Belgium. Furthermore, for accepted applicants from these countries, tuition is free. Citizens of non VKI-financing NATO countries³, can enrol in the programme but are subject to payment of a tuition fee of € 10.000, while students from other non-contributing countries pay a tuition fee of € 25.000. Both are not eligible for the VKI fellowship.

Each year VKI accepts approximately 32 students that have completed their **previous studies** at different universities. During the past 5 years VKI has accepted students from 72 Universities. The incoming students have also a large variety of different master's degrees. A five-year engineering or science degree from a European university or a master's degree from an American, Canadian or Turkish University and a working knowledge of the English language (level B1) reflect the required qualifications.

The reason for **accepting students with a large variety in background** is because fluid dynamics plays an increasingly important role outside the traditional fields of application, e.g., in biomechanics, ventilation, offshore wind energy, industrial processes, pollution dispersal and nuclear reactors. The scientific knowledge and techniques taught in the programme are equally applicable in all those fields. Hence incoming students have a very dispersed background in terms of curriculum as well as in terms of evaluation systems. A remediation of a deficit in the student's previous curriculum is done in a dedicated coherent program of 14.5 ECTS, complemented by specialised short optional courses and by setting up a highly individualised master's curriculum for each student, during the initial weeks of the programme.

Students are admitted to the programme on the basis of their **application form including three recommendations** from their previous education. The panel learned from the programme management that VKI staff is involved in the admittance, reaching a decision based on their knowledge and experience. A selection committee composed of the dean and heads of department makes a selection after consultation of the faculty. The panel recognises that this selection is based on the extensive experience and expertise of the members of the selection committee. A procedure that effectively checks whether the learning outcomes of the previous education comply with the expected entry level of the VKI master-after-master programme is lacking. A procedure based on the learning outcomes would be helpful in objectively determining which course units a student starting the programme needs to take in order to have the expected basic level to successfully complete this programme.

VKI teaching staff obtained their PhD on a topic related to fluid dynamics. Several of them are also lecturing at Belgian or foreign universities. Their expertise covers both experimental and numerical research. The scientific competences of the staff are kept up to date by personal study, participation in international conferences and workshops, and the research activities (>50% of the time). All teaching staff participates in international research consortia as partner or project leader.

The panel recognises that VKI's teaching staff is specialised in the different aspects of fluid dynamics, focused upon in the three VKI departments. Many of them are worldwide recognised experts in their field of competence, invited speakers at international conferences and institutions and have received international awards. They have built up a **broad global network in the field of fluid dynamics**. As a result, the programme is strongly influenced by the many and intensive contacts between VKI teaching staff and industrial partners in the context of funded research projects. The programme management states that the large (financial) contribution of funded research at VKI has always been a stimulus to keep an eye on the needs of the international professional field and reorient the research topics accordingly. The programme obtains its connections to the professional field in various ways. Relevant stakeholders are industrial partners and academic groups, with which active collaboration may take

² Belgium, Bulgaria, Czech Republic, France, Germany, Greece, Hungary, Iceland, Italy, Luxemburg, Norway, Portugal, Romania, Turkey, and The United States of America

³ Such as The Netherlands, Canada, Spain, UK and Denmark

place. The (international) network with such stakeholders is maintained by these individual staff members. This happens in a rather ad hoc way (on the basis of collaboration in the form of, e.g., separate PhD research projects) and not in a more formalised way.

The panel recommends giving more attention to a **more formalised collaboration with stakeholders** in the form of long-term working relations, including a more systematic approach in connecting the research master students with industry. This may particularly be beneficial for those who do not continue with a PhD after the programme. A (part-time) appointment of an industrial collaborator as VKI staff member may formalise and substantiate such a collaboration. Building a long-term relationship with leading companies in the field of fluid-mechanical technology may be beneficial to the students, to the diversity in the programme and help raise additional funding. There are good working examples of academic research groups that maintain such relationships over extended periods without it affecting the independence of the research, while contributing to its impact and valorisation. Possibly industry-funded research chairs could be targeted by VKI. In this way, the programme will also establish its relevance to Belgian governing bodies and be visible in the academic funding landscape. The latter is crucial for the viability of the institute and hence its programme. The panel emphasises that contacts with *multiple* partners are after all essential to keep the required academic freedom of operations and long-term perspective, while enhancing ways of the professional field to co-develop the future shape of the programme, e.g., in targeted VKI-industry workshops. Exchanging ‘best practices’ among departments may be an excellent way to create more coherence among staff across the VKI focal points.

The **involvement of students** in the programme is anchored through a systematic survey at the end of each individual course. The outcome of these questionnaires is in the first place communicated to the respective staff teaching the course. The surveys are also communicated to and analysed by the educational committee. Students participate also in the monthly departmental meeting, together with all researchers, technicians, and lecturers, where all problems related to education and project planning are discussed. The panel learned that this practice could lead to curriculum or organisational changes being made to the programme.

The panel noted in its meeting with VKI’s management that they are reflecting on the **exploration of future directions for VKI** and its programme that go beyond the immediate needs. With the above-mentioned suggestions on stakeholder participation, the panel encourages the management to take further steps with this reflection and involve this broad group of stakeholders, including students, teachers, alumni, and the industry.

The programme has been significantly altered since October 2020, considering the comments of the alumni and of the last accreditation report. This has resulted in a grouping of courses as much as possible to prevent fragmentation of the programme. At the start of the academic year the programme for each student is formulated following discussions with department members and the faculty supervisors. Initially, 14.5 ECTS is dedicated to a series of **common courses mandatory for all students**, aiming at providing a solid background on the 4 main pillars of fluid dynamics research: Experimental Methods, Numerical Methods, Scientific Modelling and Data Processing. An essential aspect of the VKI Research Master in Fluid Dynamics is the master’s thesis, an independent individual research project, which accounts for the remaining 30 ECTS required to obtain the degree.

Optional courses are open to all students. They target as well on specific competences and techniques as on introductory knowledge. The first ones allow a rapid and efficient response to some specific needs of the research project. The latter provide some basic insight into matters of general interest and may have a rather introductory character. They will be taken only by those students who want to widen their knowledge, explore an alternative approach to their project or to facilitate communication between researchers doing experimental and numerical research. Optional courses in excess of common and specialised courses are limited to a maximum of 5 ECTS and encouraged only if useful for the project. Students who are interested in classes beyond their curriculum can join freely, without including them into their curriculum.

Ample attention is given to the **Master Thesis** (research project of 30 ECTS) carried out by each student. Both numerical and experimental projects are performed on the VKI infrastructure. The presence of the students during working hours is mandatory. This individual hands-on training in research is a way of enhancing and verifying that the students have the competences, skills, and attitudes to perform independent research. The computational projects are mostly related to software development. The experimental projects often involve

the study of a phenomenon to help the understanding of a complex flow, the validation of a numerical model or the development of a new flow model. Most projects are part of a larger industrial research project performed at VKI which increases the application relevance of the student's projects. This not only gives access to advanced equipment and instrumentation used for industrial projects, but also favours multidisciplinary contacts with other research teams working on other parts of the complete project. Most research projects in which students participate are precompetitive, i.e., more fundamental and allow the publication of the results. Some master theses are VKI funded and of more exploratory nature i.e., related to the development of new measurement/numerical techniques.

The panel commends that the programme offers a **very interesting set of courses**: a rich variety of topics, both experimental, theoretical, and numerical. Also, the general courses are useful, in order to provide to all students the same general background level. The panel examined a comprehensive set of course materials. Some courses cover 'classical' topics, which are relevant for a good understanding of the matter. Others cover novel elements (such as measurement methods, numerical techniques, machine learning), which are reflecting novel developments in the field of fluid dynamics. Some of the courses concern even direct applications (such as turbomachines) in an industrial setting.

The panel believes that the programme is **well-founded in the technical expertise needed to address complex fluid mechanical challenges**. The programme has made steps toward inclusion of modern topics in simulation, machine learning and data science, to complement the more traditional fluid mechanics programme that has been nurtured since the very beginning of the programme. In doing so, complementary ad hoc renewal of programme items is achieved which improves the relevance of its graduates and allows them to find excellent positions in academia and industry. In this way the small and highly focused programme achieves its primary societal relevance, i.e., training intelligent young people to become the future scientists in academia and leading innovators in industry. The close links between research and education also reflects in the large importance given to the master thesis.

It is clear to the panel that the programme aims to prepare its students for **academic and industrial positions in the field at an elevated international level**. The panel recognises that to this end the programme has an up-to-date curriculum, spread over the expertise of the three different departments. New insights and models are readily incorporated into the educational programme and reference is made to international publications. The specific aspect of the research orientation is transparent in the programme's intended learning outcomes, albeit in a rather implicit manner. This implicit character is found throughout the SER and in discussions with management, staff, students, and alumni. It appears a natural consequence of the close interaction teaching staff has with the students it is programme - this 'DNA' of VKI is its charm but may also be a challenge that deserves attention.

The panel suggests that the educational committee **makes its procedures clearer regarding curriculum development**, e.g., by orientation to new developments in the field. In its meeting with teaching staff, the panel learned this was done on an informal and ad hoc basis. As a result of the many contacts between teachers and the professional field mentioned earlier, this does happen in practice, but the educational committee cannot guarantee that it happens structurally. This could be done in a more structured, formalised way, by having meetings with the teaching staff on a regular basis. An annual meeting with experts from the NATO countries provides some input for new, strategic initiatives, and it may be worth developing and updating this concept further with fresh insights from academia and industry.

Although **new courses** are mostly proposed by individual faculty members, they are first discussed during the faculty meetings or in the respective departments before they are implemented in the programme. It is the responsibility of the educational Committee to verify that the educational programme is coherent, that the content delivers the required competences and skills and that the information provided is complete and correct.

As mentioned earlier, a number of **learning outcomes** is formulated. Some of these are assumed to be present in the student prior to arriving at VKI and are 'further' developed in the curriculum of the programme. The more technical requirements are fully recognisable in their implementation in the programme. Also, the alumni indicate that there is sufficient attention to experimental techniques, teamwork, fluid dynamics, and literature

search. Teaching of environmental problems and ethical issues as well as oral and written communication, however, might receive more attention, according to the alumni met by the panel.

The relevance of '**soft skills**' to students in the programme was underlined several times during the site visit and supported clearly by the reports of alumni. Yet, the approach to this topic appears not very systematic and differs quite a bit from year to year and from department to department. The panel suggest the departments to learn from each other's good practices. Students mention the development of presentation and writing skills as major contributions to their profile. Also, the confidence derived from learning to manage their own project appears a main asset in preparing students for their careers, e.g., preparing for positions of leadership.

The panel recommends a more structural approach to **make the skills that are worked on implicitly more explicit in the curriculum and in the students' examination**. The inclusion of more collaborative elements in the programme may help to further develop team-player skills among the students. Introducing more group assignments may be a practical way forward, although this should not be seen as a goal in itself. Implementing some key group assignments for all students of all departments will, in addition, enhance the relevance of all students toward their professional careers afterwards. On the other hand, soft skills are also improved by learning to present the research projects to a broader audience. That these soft skills are taught, albeit implicitly, was something the panel was able to verify through conversations with the alumni. After discussing this topic with the alumni, they all said that VKI gave them a confidence boost and they really learned to give a presentation in a conference-like setting.

The panel learned from its meetings and its examination of documents that a large **variety of teaching forms** is used. The general and specialised courses that aim to transmit knowledge are mostly taught in formal lectures (68%) eventually complemented by exercises (18%) and hands-on lab sessions (14%) to help students in acquiring the competences and skills needed to apply the theoretical knowledge in practical cases. Except for some introductory courses, all courses refer to the worldwide scientific literature. The students informed the panel that in the courses of some departments, there is more teamwork than in other. This teamwork is experienced by the students as pleasant and instructive. Therefore, the panel suggests that also for this topic the departments should learn from each other's good practices.

The programme management emphasises that it considers the **physical interaction** that takes place between teaching staff and students to be one of the unique strengths of this small-scale programme. Students and alumni confirm this wholeheartedly. After the COVID 19 pandemic, the programme management wants to return to the previous situation as soon as possible. However, the panel suggests that the programme - in consultation with the students - should reflect on the lessons it wants to draw from the educational situation in this pandemic.

Due to the **COVID 19 pandemic** most of the teaching had to be switched to an online format. The panel commends that due to the strong commitment of the staff, this went quite smoothly. The courses went online, chat boxes were opened, and additional assignments were prepared for the students. Students witness that it stimulated working in teams. In the coming period, this needs some refinement to establish it as a reliable and predictable resource to students. The panel suggests extending the efforts toward refining this infrastructure and documenting written and video material such that students can consult and review specific parts also asynchronously to the lectures. After all, students indicate that certain aspects, such as being able to review some courses online, have a clear added value for them. This especially is an asset when preparing for the exams.

The **online uniformity** deserves some attention - after the necessarily rushed initial introduction of all material online in view of the pandemic crisis, a good information environment should be developed by refining the presentation of materials, improving uniformity of quality and completeness, thereby enhancing effectiveness for the students.

The **information on the programme** appears exhaustive and well accessible through VKI's exchange server. This includes, e.g., an overall description of the programme and its objectives, regulations including the admission requirements, educational organisation, evaluation procedures, conditions to receive the diploma, how complaints and conflicts will be handled, and financial aspects. The panel commends the **detailed course syllabus** of the programme. This syllabus contains all information about the curriculum, its learning outcomes, its teaching staff and teaching and examination methods.

On the VKI website, all information about the objectives of the programme, the admission procedure, and the added value of the programme can be found. In addition, the fully detailed syllabus is online. In this way, VKI succeeds in **communicating transparently** about its research master's programme to all who are interested.

The relatively small size of the programme allows for **good interaction between the students and the staff**. This interaction certainly promotes playing an active role in the programme. Students met by the panel stated that the staff is very open, approachable, and always ready to help the students. The panel learned that the VKI environment promotes a very good connection between teachers and students. Because of the small groups, mentoring is really 1-to-1, so the students are well-supported. In case of any serious problems, students can rely on an ombudsperson. The panel states that the students they met are active and prove that they take their own initiative when they are facing any potential problems. One student is also a member of the educational committee and can speak up for the students in this meeting.

Next to teaching staff, VKI has a large number of **PhDs and PDs**. Currently, this part of VKI staff is included in the teaching programme in an ad hoc manner - it may be beneficial to approach this more systematically and develop a pool of support for students next to the teaching staff, to help with technical understanding and as 'peer examples'. This may be also beneficial to the PhDs and PDs and could reduce some of the variations in the quality of student guidance as mentioned occasionally.

The panel learned that the programme was in the past **traditionally structured** in a top-down 'teacher-centred' fashion where much was 'pre-arranged' by the staff, for students to 'absorb'. This is still largely true for the first semester dedicated to foundational courses. The research project has a different character and active personal initiative of students is much stimulated. Students can play a role in shaping the programme by providing direct feedback to the staff. This improves the learning process from the perspective of the students and enhances study progress. An active role of students is less prominent when longer-term aspects of the courses are concerned. Input from alumni and gauging the courses also against other institutions internationally could be included by the staff more fully to also shape the long-term appeal of the learning process. An example of this is that there are exceptional courses which, for practical reasons, are taught later in the curriculum but which, because of their content, would be better taught before the start of the research project.

The curriculum was recently re-structured considerably. An example is a mandatory course designed to bring the students in a cohort up to a comparable level, before taking more advanced classes. The first experiences appear positive, but more 'engineering' of this introductory block seems wise. For that process, the explicit inclusion of students can bring new dynamics in the way this course will take shape in the coming years. This will not only benefit the course itself, but also introduce more 'student-centred' aspects in the programme next to the largely '**teacher-centred**' components. The increased 'diversity' of teaching models could be beneficial for the programme as particular models may be better suited to reach particular learning goals than just adhering to a teacher-centred model. Teaching staff may benefit from exchanging 'best practices' as developed in the three departments and form a more recognisable trait of courses across VKI.

This advocates a **shift towards an organisation that is more student-centred**, in which 'somewhat formalised' structures complement the existing mode of working to create a safety net in case of unforeseen situations. Closer involvement of students will also contribute to the curriculum development.

The panel was informed by students and alumni that the **workload** is high for the students and appears to vary quite a lot over time. The panel suggests that much could be gained if teaching staff would increase coordination between different courses of the curriculum, so that not all requirements to the students, e.g., for handing in work or sitting in on exams, coincide in time. Coordination among teachings staff and careful timing may shave off the peaks in the workload. It is the panel's opinion that including students in the design of the 'timetable' appears sensible, thereby 'weaving' a coherent course framework with a more manageable workload. This will improve assessment of students as preparation for certain tasks can be more balanced over time.

The panel examined a sample of **evaluations**. The learning outcomes are well tested in the very challenging exams which appear to cover the material very well. Students and alumni indicate that the exams are challenging but achievable. The panel stated that there is a good variety of examination methods. Courses, covering the basic theories or providing better understanding of fluid-dynamics principles, are mostly evaluated by oral exams

with theoretical questions whereby mainly the understanding and insight of the student is measured. The panel commends that a second evaluator is present at oral exams. Other evaluation types that are used are open book exams, presentation of a lecture, and the evaluation of attitudes, general scientific competences, and the ability to do scientific research. The latter are mostly evaluated during the project evaluation team meetings, public presentations, and reports. In some courses there are group assignments. The panel suggest increasing this type of evaluations. It will broaden the palette of teaching models for students to enjoy and, in particular, appreciate own initiative and group dynamics. Due to the COVID 19 crisis, examination methods had to be switched. The panel was informed by students and teaching staff that this worked smoothly. Exchange of knowledge on how examination in covid times can work is not discussed between teaching staff of the different departments. The panel suggests implementing such experiences with *all* staff.

The main **master's thesis** is well positioned and monitored regularly in terms of the learning outcomes, e.g., project planning and communication. The panel read a sample of 10 recent master's theses. These master's theses clearly demonstrate the excellence of the students. The panel commends the high quality that the programme and its students achieve in the master's theses. With this quality of masters, the programme can rest assured that their graduates are sought-after candidates in the research market. It is therefore not surprising that many students start a PhD after completing the programme, either at VKI or elsewhere. Especially during the master thesis, the programme pays attention to the evaluation of soft skills. As indicated earlier, this could be addressed more strongly throughout the whole programme.

The panel's observation after meeting the students and alumni is in line with a survey conducted by VKI. This survey reveals that 86% of the alumni confirm that the **VKI diploma creates additional opportunities** to find an interesting job. 89% indicate that their present position is in line with their education, which means that the extra effort to obtain a second master's degree is rewarded by their employer. 95% of the freshly graduated alumni use the technical and scientific knowledge they acquired in the programme.

Results of the examinations are communicated and discussed with the student before being archived in the secretariat where they can be verified at any moment by the student. Students are invited to discuss the outcome and eventual remedying measures with the professor. Grades of less than 50% are considered unsatisfactory.

The programme management informed the panel that foreign students face extra efforts and expenses to study at VKI. Passing **repeat exams** in September is much more difficult for students studying abroad in a nine-month programme, than for those involved in a four- or five-year study. Repeat exams are therefore organised shortly after the publication of the initial result. The panel believes that strict adherence to the 9-month programme may not always be optimal. Although staff and management defended such a strict deadline, e.g., training students to work effectively, also under pressure, and be forced to manage time and priorities well, there seems much to be gained from a slight relaxation of this deadline. This will likely benefit the lower ranks of the student population, which should be equally respected and accommodated. All students can benefit from this as they would learn how best to defend adaptations to plans and re-schedule activities according to newly acquired insights in the progress that is being made.

As mentioned earlier, the staff members have a very solid scientific background. Their expertise and knowledge of the field **guarantees the required knowledge base for a high-level training and supervision of the master students**. During the interviews with students and teaching staff it became clear that there is a very good relation between them: staff is devoted to teaching and supervision, and this is highly appreciated by the students. This was also reflected in an enquiry among the alumni which confirms that the level of teaching, the competences of the staff and in particular the international and multidisciplinary character prove major assets of the programme.

The staff has acquired practical teaching skills, largely from '**on-the-job**' training. While this appears effective for transferring technical knowledge, there may be further benefits if the total staff becomes more knowledgeable also where the 'science of teaching' is concerned. A University Teaching Qualification (UTQ) programme may help junior staff develop their portfolio and senior staff to interpret and polish their established teaching styles. Such more formal training can introduce benefits to the entire programme in terms of more explicit communication of learning goals, more predictable and uniform quality of courses and sharing of best

practices across the staff. It will also introduce external input regarding teaching methods to enrich the entire staff.

The central position of research in the programme also assumes a **pool of high-quality scientists** that can provide 'working examples' to the students. Staff training and development regarding their research profile should be stimulated by VKI management and facilitated. The panel suggests stimulating staff to enter joint appointments including a secondment at an academic institution - there are several examples among the current staff, and this could be extended: aiming for visible personal achievements among the staff, e.g., awards, ERC grants, Marie-Curie fellowships, and engaging in partnerships in EU projects and long-term VKI-industry programmes. This would set accolades that underpin staff activity and quality.

The panel noted that some **alumni of the programme subsequently obtain their PhD and become teaching staff** at the programme. This not only shows that the programme and the alumni have a strong connection. It also has the advantage that the teaching staff in many cases are familiar with the habits and customs of VKI and its master's programme. Nevertheless, diversity is needed to remain innovative. As long as VKI continues to be able to attract - as it is doing now - enough fully external people who can bring in other insights and experiences with regard to the programme, the employment of former students as staff currently is a strong point of the programme.

In line with the recommendation from the previous programme assessment, the programme has **expanded its teaching staff** by six people. The teaching staff appears largely male - attracting more female staff would be an obvious enhancement of the appeal of the course as it will automatically create examples of successful role models that can inspire students.

The staff displayed a **remarkable commitment to the well-being and study progress of the students** in the programme. This is particularly clear during the masters' thesis, but also the first semester, in which most of the foundational courses are delivered, is designed such that frequent and close interactions between students and staff arise. Although the pandemic crisis affected this aspect negatively, the staff stepped in quickly to develop new working models that support students also online. This intense working model is crucial for achieving the learning goals and through dedication of the staff the best conditions for achieving this are provided. This situation appears a natural consequence of the small size of the programme and the fact that the majority of the staff participated in the research master themselves. This creates a particular uniformity of expectations and style of working to which the students are exposed, to mutual benefit of both staff and students, as was learned from the interviews during the site visit.

Before the site visit, the panel received many films that provided a broad overview of VKI's facilities. The VKI disposes a number of **specialised test facilities**, equipped with advanced instrumentation and a powerful computer centre. Most facilities have been specially designed by VKI staff members and manufactured and build by VKI personnel. Some of them are unique and/or amongst the most advanced in the world. They are all dedicated to different aspects of fluid dynamics research. These specialised test facilities and advanced instrumentation, developed for and financed by the funded research projects, are at the disposal of the students. Some investments seem desirable in order to make some equipment more up to date. The present financial situation allows renovation of laboratories, meeting and computer rooms, and offices. An extra-ordinary budget by the Belgian Government, the USA contribution, and a new way of contract work management in the so-called "Project Office", has allowed for ongoing investments in new buildings, facilities, instrumentation, as well as renovating the existing site. The panel commends VKI's facilities. They are exemplary, supporting the fluid-mechanical experimental infrastructure, the computing environment, and the student training at a high level. The plans for extension of the facilities and for renovation of the historic core buildings at the VKI site are a wonderful completion that will also benefit the research master students and add much to the viability of the programme.

Conclusion

The panel found that the programme excels in many ways. The programme has a profile that can stand the test of excellence worldwide. This in turn translates into a programme that offers a rich variety of topics, both experimental, theoretical, and numerical. The programme is thus well-founded in the technical expertise needed to address complex fluid mechanical challenges. ‘Learning research by doing research’ is an underlying principle of this highly structured and orchestrated 9-month programme. VKI’s facilities are exemplary, supporting the fluid-mechanical experimental infrastructure, the computing environment, and the student’s education at a high level.

Over the years a very informal way of working emerged in which students have close and frequent interaction with staff, in the courses that are offered and in the final project of 30 ECTS. This way of working is found to be very suitable for a programme of the size and style as found at VKI. It is noticeable that the programme is rather teacher-centred and the role of the students in the programme could be systematically strengthened to benefit the overall viability of the programme.

Another point of excellence is the subject-specific quality of the teaching staff. The alumni confirm that the scientific level of VKI teaching, the competences of the staff and in particular the international and multidisciplinary character are the major assets of the VKI education. Many of them are worldwide recognised experts in their field of competence, invited speakers at international conferences and institutions and have received international awards. The organisation of VKI into three departments has a strong impact on the organisation of the programme. The panel indicates that improvements can be made in various areas if the departments would work more closely together and share expertise among all the teaching staff involved in the programme.

The educational committee directs the programme. This committee has already realised many transparent processes, one example of which is the highly elaborated syllabus for students. In this way, the committee also succeeds in safeguarding the quality of the programme. Some processes could be more formalised. In practice, these are running smoothly at the moment, partly due to the small scale of the programme and the strong personal involvement in the programme. The panel has in mind, among other things, the more structural involvement of stakeholders, a structural didactic professionalisation offer for lecturers and the structural embedding of the sharing of good practices among all teaching staff.

Both on the basis of the panel’s discussions and of surveys carried out by VKI as part of its internal quality assurance system, it appears that alumni are very satisfied with their programme. The high quality of the graduates is reflected in the quality of the master’s theses. The programme proves to have great added value for them in their later careers. Many graduates start a PhD after finishing this programme.

The panel finds that the programme meets the review principles and thus the presence of the quality features is guaranteed. The panel therefore gives a positive final judgement and recommends further accreditation of the programme.

Summary of commendations

- VKI has international reputation in experimental facilities for demanding conditions. It is a highly respected institution for fluid mechanics, building on both experimental and simulation strengths.
- The programme benchmarks itself with other renowned programmes worldwide.
- VKI's teaching staff is specialised in the different aspects of fluid dynamics linked to the three VKI departments. Many of them are worldwide recognised experts in their field of competence, invited speakers at international conferences and institutions and have received international awards. All teaching staff participates in international research consortia as partner or project leader. Their expertise and knowledge of the field guarantees a high-level training and supervision of the master students.
- Teaching staff have built up a broad global network in the field of fluid dynamics.
- The programme offers a very interesting set of courses: a rich variety of topics, including experimental, theoretical, and numerical dimensions. Also, the general courses are useful, in order to provide to all students, the same general background level. The programme is well-founded in the technical expertise needed to address complex fluid mechanical challenges.
- Due to the strong commitment of the staff, switching to an online format because of the COVID 19 pandemic went quite smoothly.
- The information on the programme appears exhaustive and well accessible through VKI's exchange server. The course syllabus of the programme is detailed. It contains all information about the curriculum, its learning outcomes, its teaching staff, and teaching and examination methods.
- On its public website, VKI succeeds in communicating transparently about its research master's programme to all who are interested.
- The relatively small size of the programme allows for good interaction between the students and the staff. The staff is very open, approachable, and always ready to help the students.
- The learning outcomes are well tested in the very challenging exams which appear to cover the material very well.
- A second evaluator is present at oral exams.
- The programme and its students achieve in the master's theses high quality. With this quality of master theses, the programme can rest assured that their graduates are sought-after candidates in the research market. It is therefore not surprising that many students start a PhD after completing the programme, either at VKI or elsewhere.
- VKI's facilities are exemplary, supporting the fluid-mechanical experimental infrastructure, the computing environment, and the student's education at a high level.

Summary of recommendations

- Establish a more formalised collaboration with stakeholders.
- Make a procedure that effectively checks whether the learning outcomes of the previous education align with the expected entry level of the programme.
- Make the procedures for curriculum development, in line with the learning outcomes, clearer.
- Make 'soft skills' more explicit and more early in the curriculum.
- Make the programme more student-centred.
- Increase the amount of group assignments.
- Relax the strict adherence to the 9-month programme.
- Ensure that teachers can strengthen their didactical skills and the total staff becomes more knowledgeable where the 'science of teaching' is concerned.
- Improve the gender balance of the staff.
- Share best practices across all departments and create more coherence between the staff of the 3 departments. Best practices can be shared on, e.g.:
 - stakeholder participation
 - teachings methods including teamwork
 - uniformity and completeness of providing materials online
 - student-centred approaches
 - online examination

ANNEX 1: ADMINISTRATIVE DETAILS

Name of the institution	von Karman Institute for Fluid Dynamics (VKI)
Address, phone, e-mail, institution website	Waterloosesteenweg 72 1640 Sint-Genesius-Rode, Belgium +32.2.3599611 secretariat@vki.ac.be www.vki.ac.be
Name of the programme (degree, qualification)	Research Master in Fluid Dynamics
Tracks	/
Level and orientation	Master-after-Master
(Parts of) field(s) of study	/
Language of instruction	English
The location where the programme is organised	Sint-Genesius-Rode, Belgium
Study load (in ECTS)	60 ECTS

ANNEX 2: CV PANEL MEMBERS

GertJan van Heijst is professor in fluid dynamics at Eindhoven University of Technology, the Netherlands. His research interests include geophysical and environmental fluid mechanics, in particular vortices and turbulence in rotating and stratified flows, two-dimensional turbulence, dispersion in turbulent flows, and erosion and sedimentation processes. He has been associate editor of *Physics of Fluids* and of *Geophysical and Astrophysical Fluid Dynamics*, and co-editor-in-chief of the *European Journal of Mechanics B/Fluids*. He is member of the Royal Netherlands Academy of Arts and Sciences (since 1997), member of the Russian Academy of Natural Sciences (since 2010), and recipient of the Dutch Physica Award (2006). From 2013 he served as President of EUROMECH, and since 2018 he is Vice-President of that society. Since 1991 he has been one of the local directors of the J.M. Burgers Centre, the national research school for fluid dynamics in The Netherlands. He became scientific director of the Burgers Centre in 2014, a position that he still holds.

Bernard Geurts is professor and chair of Multiscale Modeling and Simulation at the Department of Applied Mathematics, University of Twente in the Netherlands. He also holds a chair in Multiscale Physics of Energy systems at Eindhoven University of Technology, in the Center for Computational Energy Research. His interests include computational modeling for transport processes and for the prediction of properties of hybrid materials. Specifically, he is active in numerical mathematics for (stochastic) differential equations, which he applies to computational fluid mechanics of turbulent and multiphase flows, to climate and environmental modeling, to material sciences and to biofluid dynamics. He is associate editor of *Computer and Fluids*, of *FTAC* and of the *Journal of Turbulence*. He is recipient of a Canada Research Chair on High-performance computing and was honored with the Wim Nieuwpoort prize for Computing in 2018. From 2010 he served as Chair of the Scientific Program committee of ERCOFTAC and was the founding Director of 3TU.AMI, the Applied Mathematics Institute in the Netherlands, and chair of the Innovation committee of PWN, the Dutch platform for Mathematics.

Peter Flohr is Lecturer and Department Head of the Institutes in Applied Maths, Computational Physics, Data Analysis, and Sustainable Development, at the School of Engineering of the Zurich University of Applied Sciences, Switzerland. He holds a degree in Aerospace Engineering from the University of Stuttgart (Germany), and a Ph.D. in Applied Maths from Cambridge University (England). Peter has spent over 20 years in the power generation industry in various engineering functions and leadership roles at ABB, Alstom and GE, most recently as executive leader of gas turbine engineering. His areas of technical expertise include combustion & numerical analysis, turbine & manufacturing technologies, and testing methodologies.

Thibo Lodewyckx is a master student in Industrial Engineering Technology - electromechanics at Ghent University. In 2020 he achieved his bachelor's degree, having studied among other things the basics of fluid dynamics. He is a member of the program committee for 3rd bachelor - 1st master of the Industrial Engineering Technology education, and a member of the faculty council for engineering students (FRiS).

ANNEX 3: SITE VISIT SCHEDULE

Monday 22 February 2021

9:00	11:00	panel's private discussion
11:15	12:15	interview with the programme management
12:15	12:30	panel's private discussion
12:30	13:20	lunch
13:20	14:20	interview with the students
14:30	15:00	panel's private discussion
15:00	16:00	interview with the teaching staff
16:00	16:45	panel's private discussion
17:00	18:00	interview with the alumni and professional field

Tuesday 23 February 2021

9:00	10:00	consultation hour
10:00	12:00	panel's private discussion
12:00	12:45	lunch
12:45	14:15	interview with the programme management
14:30	15:00	panel's final private discussion
15:00	15:30	oral report

ANNEX 4: DOCUMENTS CONSULTED

- Self-evaluation report
- Selection of master theses
- Samples of teaching and learning material
- Samples of examinations
- VKI Alumni Survey
 - Report_on_all_VKI_alumni_enquiry.pdf (since 1956)
 - Report_on_recent_VKI_alumni_enquiry.pdf (2013-2020)
 - Students_enquiry_RMCourses_2019_2020.pdf
- VKI CV of Faculty
 - VKI Educational Committee documents
- VKI Intranet document
 - Final_year_Grading_Procedure.pdf
 - ombudsperson.pdf
 - VKI agenda_20-21.pdf
- VKI Research Master Schedules
 - RM_19-20_EXAM SCHEDULE_Final Public Presentations.pdf
 - RM_20-21_important dates.pdf
 - RM_20-21_COURSE SCHEDULE_firstsemester.pdf
- VKI Syllabus
- <https://www.vki.ac.be>
 - VKI Research Master: <https://www.vki.ac.be/index.php/research-master-in-fluid-dynamics>
 - VKI Syllabus: <https://www.vki.ac.be/images/download/education/SYLLABUS2020-2021.pdf>
 - VKI Test and Facilities: <https://www.vki.ac.be/index.php/facilities-other-menu-148>
 - VKI LinkedIn: <https://www.linkedin.com/company/vki-vonkarmaninstitute> .
 - VKI Twitter account: https://twitter.com/vki_vonkarman
 - VKI Instagram: <https://www.instagram.com/vonkarmaninstitute/>
 - VKI Facebook: <https://www.facebook.com/vonKarmanInstitute/>
 - VKI YouTube Channel: <https://www.youtube.com/c/vonKarmanInstituteforFluidDynamics>
- VKI Alumni Website
 - <https://www.vki-alumni.org>
 - <https://www.linkedin.com/groups/133875/>