STAND-ALONE PROJECT - FINAL REPORT

Project title Interaction theory of turbulent marginal separation

(Turbulent marginal separation)

Project leader **Univ.-Prof. Dipl.-Ing. Dr. Alfred KLUWICK**

P16555-N12 **Project number**

Part 1 of the project report is intended for interested members of the public; **parts 2-4** are addressed to reviewers and must be submitted in the language of the original application. **Part 5** provides an opportunity to report to the FWF on interactions with the administration during the course of the project.
The complete report must be submitted in hardcopy and on electronic medium (CD or floppy disc) in Word for Windows format. Guidelines and forms for the final report can be downloaded from the FWF web site (http://www.fwf.ac.at/de/faq/einzelprojekte/evaluierung.html)

1. Zusammenfassung für Zwecke der Öffentlichkeitsarbeit

Ein vorrangiges Forschungsergebnis stellt die Entwicklung einer neuartigen asymptotischen Beschreibung inkompressibler turbulenter, im zeitlichen Mittel ebener marginal ablösender Grenzschichtströmungen dar. Hier ist der Begriff „asymptotisch“ als im Sinne beliebig hoher Reynolds-Zahlen *Re* zu verstehen. Diese dimensionslose Kennzahl charakterisiert den Strömungszustand als Quotient des Produktes einer für das Hauptströmungsfeld typischen Referenzlänge mit einer entsprechenden Referenzgeschwindigkeit und der kinematischen Zähigkeit des betrachteten Fluides. Im für technische Anwendungen äußerst wichtigen Fall sehr hoher Reynolds-Zahlen machen sich die – etwa für die Ermittlung des auf die betrachtete Bewandung des umströmten Festkörpers ausgeübten Strömungswiderstandes zu eruierenden - zähen Reibungseffekte in der Strömung näherungsweise nur innerhalb einer relativ dünnen „Grenzschicht“ entlang jener Wand bemerkbar. Bei hinreichend hohen Werten von *Re* (ab der Größenordnung von 6 bis 7 Zehnerpotenzen etwa) wiederum muss diese Grenzschicht als ausgeprägt turbulent betrachtet werden. Die damit verbundene typische Hierarchie vieler gleichzeitig vorhandener räumlicher und zeitlicher Skalen lässt eine mathematische Formulierung der Strömung im Rahmen der Grenzschichtskalierung nur auf Basis der zeitlich bzw. statistisch entsprechend gemittelten Bewegungsgleichungen zu. Nun lässt sich zeigen, weshalb es den jahrzehntelangen Bemühungen versagt war, im Rahmen der klassischen asymptotischen Beschreibung einer turbulenten Grenzschicht das technisch extrem wichtige (da, aufgrund der Behaftung mit hohen Verlusten, unerwünschte) Phänomen der Strömungsablösung theoretisch vorherzusagen. Dies gelingt nun, zumindest für das Auftreten „marginaler“, d. h. grenzschichtinterner, Ablöseblasen, durch den neuen Formalismus im Rahmen einer selbstkonsistenten Theorie: Diese beruht nur auf der mathematischen Struktur der Bewegungsgleichungen für hohe Werte von *Re*, wenn man von einem Minimum an durch physikalische Plausibilitätsargumente gestützten Annahmen bezüglich der Modellierung der vom Mittelungsprozess herrührenden Zusatzterme absieht. Als ein sehr wichtiger und äußerst überraschender Aspekt ist die Erkenntnis zu werten, dass die Schlankheit der Grenzschicht durch einen dimensionslosen, jedoch (im Gegensatz zur klassischen Formulierung) von *Re* unabhängigen Parameter beschrieben wird, der mit den in allen gängigen Mittelungsmodellen enthaltenen numerisch kleinen Modellkonstanten identifiziert werden kann. Dadurch wird das Verhalten des dicken Außenteiles der Grenzschicht nahezu unabhängig von jenem der stark viskositätsbeeinflussten dünnen Wandschicht. Die mathematische Anpassung dieser Schichten unter Berücksichtigung der lokalen Wechselwirkung der Grenzschicht mit der Außenströmung, welche im Rahmen der klassischen Theorie nur für stets anliegende Grenzschichten möglich ist, erlaubt dann die Vorhersage des Verschwindens der Wandschubspannung, und damit von Ablösung.

2. Summary for public relations work

The development of a novel asymptotic description of incompressible turbulent boundary layers undergoing marginal time-mean separation represents a paramount cornerstone of the outcome of the present research efforts. Here the notion "asymptotic" refers to the limit of arbitrarily large values of the Reynolds number *Re*. That non-dimensional parameter characterises the state of the flow as it is formed by a reference length times a reference velocity, both typical for the bulk flow, divided by the kinematic viscosity of the considered fluid. In the, from an engineering point of view, extremely important case of very large values of *Re* viscous effects on the flow along a rigid impermeable wall are seen to be essentially confined to a relatively slender so-called boundary layer adjacent to that surface. A most accurate estimate of those viscous effects is of major relevance, e.g. in order to determine the drag the flow exerts on that surface. Finally, in the case of sufficiently large values of *Re* (i.e. for ten to the power 6 to 7) that boundary layer flow must be considered to be fully turbulent. The associated typical hierarchy of different spatial and temporal scales allows for a mathematical description solely based on the boundary layer scales by taking into account the time- or, equivalently, statistically averaged equations of motion only. Now one can demonstrate why, despite the pronounced effort made during the last decades, the prediction of the phenomenon of flow separation is always hampered within the framework oft the classical asymptotic flow description. The new formalism, however, allows for the prediction of at least "marginally“ separated flows, i.e. of closed reverse-flow regions encompassed by the boundary layer, in a fully self-consistent manner: that theory only relies on the properties of the time-averaged equations of motions for large values of *Re*, supplemented with a minimum of physically feasible assumptions concerning the modelling of the additional terms in the equations originating from the averaging process. As a most important and rather surprising result, amongst others, it has been shown that the slenderness of the boundary layer is measured by a non-dimensional small parameter that, in striking contrast to the classical approach, is essentially independent of *Re*. Moreover, this slenderness parameter can be identified with some of the small numbers that are inherently included in any of the commonly adopted turbulence models. As a consequence, the flow in the outermost main portion of the boundary layer turns out to be almost independent of the flow in the extremely thin strongly viscosity-affected near-wall region. The mathematical procedure of so-called matching these regions having different physical meanings then allows for the prediction of vanishing wall shear stress, or, in other words, flow separation. Furthermore, the correct mathematical description of separation crucially takes into account the local interaction of the boundary layer flow with the external inviscid flow - a strategy which in the classical framework predicts firmly attached flows only.

2. Brief project report

2.1 Report on the scientific work

2.1.1 Information on the development of the research work

- Originally the primary target consisted of the development of a theoretical flow picture, based on the Reynolds-averaged Navier—Stokes equations in the limit of arbitrarily large values of a globally defines Reynolds number *Re*, of the separation process of an incompressible fully developed turbulent boundary layer along an impermeable and solid surface, where the averaged flow is assumed to be two-dimensional and nominally steady (i.e. its statistical properties are assumed to be found from usual time-averaging). This objective has been achieved, whereas particular emphasis has been placed on the local behaviour near separation: there a mathematical strategy has been adopted successfully, in the theory of laminar flows referred to as the *triple-deck* concept, which properly takes into account the interaction of the boundary layer with the external potential flow and, thus, allows for a fully self-consistent flow description. The most interesting open points include (i) the behaviour of the strongly viscosity-affected near-wall flow adjacent to the surface under consideration and close to the point of separation, and (ii) a more stringent explanation for the asymptotic splitting of the boundary layer based on first principles rather than on a hypothesis that is used at present and based on physically intuitional reasoning. In both of these cases the asymptotic analysis of the time mean-flow can not provide a satisfactory answer to the questions addressed.
- Apart from the tackled goal outlined above, two changes in direction were made which was not intended at the time of submission of the research proposal: (i) First, as an extension of the classical theory predicting an asymptotically small streamwise velocity defect with respect to the external bulk flow - and as a first step towards a more general approach which also accounts for separating flows - it has been shown that the velocity defect may become *moderately* large and essentially independent of *Re,* i.e. it remains still asymptotically small. It has been demonstrated that also this case can be treated by rigorous asymptotic analysis on basis of the Reynolds-averaged Navier—Stokes equations, independent of the choice of a specific Reynolds stress closure. The asymptotic investigation predicts the remarkable result that in the special case of quasi-equilibrium flows the transition from classical small-defect to a pronounced wake flow is accompanied by double-valued solutions for a single prescribed pressure distribution, a phenomenon seen to agree well with early experimental observations. Furthermore, by adopting a time-averaging method which allows for the treatment of weakly unsteady flows the solution having a larger defect has been proven to be unstable. Most important, the results summarised so far strongly indicate that turbulent boundary layers having a moderately large velocity defect represent the "missing link" between the classical *small*-defect and *large*-defect boundary layers which exhibit a velocity deficit of $O(1)$ and even might undergo separation. (ii) Secondly, a major focus has been placed on the direct numerical treatment of the fundamental elliptical problem governing the separation process within the framework of the aforementioned triple-deck formalism. This proved necessary as all numerical methods designed for triple-deck problems available so far are based on downstream sweeps and, therefore, do not suitably cope with the fact that the sought solution represents a non-trivial eigensolution of the problem, triggered by a "non-trivial" state of the flow which is described by a self-similar solution holding far downstream. However, that new method has been exploited successfully also in mathematically closely related interactive flow problems during the course of two PhD thesis carried out at the research institution.
- The relevant publications are found in Lists 1 and 2 of the Attachments.

2.1.2 Most important results of the research

The classical rational approach to turbulent wall-bounded shear flows in the limit of large Reynolds number *Re* has been extended in two directions which cope with different orders of magnitudes of the streamwise velocity defect with respect to the external potential flow. Firstly, it was shown that the classical two-tiered boundary layer structure having a non-dimensional velocity deficit of $O(1/\ln Re)$ is included as a special case of a more general theory which describes flows exhibiting a so-called moderately large velocity defect. That wake-type flow turns out to be characterised by asymptotically large values of the so-called Rotta--Clauser parameter, which, according to the literature available, is chosen to serve as an appropriate measure for the moderately large defect and, hence, as a second perturbation parameter besides *Re*. As a highly remarkable consequence of the underlying three-tiered asymptotic splitting of turbulent boundary layers, the velocity deficit in the outermost main regime is found to be small and, in the most general case, essentially independent of *Re*. Furthermore, the theory provides an explanation on a firm rational basis of the frequently observed phenomenon of non-uniqueness: for a single prescribed pressure distribution there exist two solutions which differ, among others, by the size of the velocity defect which then is much larger than $1/\ln Re$ but still depends on *Re*. In addition, a numerical treatment of the nonlinear boundary layer equations, supplemented with an asymptotically correct shear stress closure which provides the well-known logarithmic velocity portion close to the surface, confirms those theoretically predicted results for large but finite values of *Re*. The solutions exhibit good agreement with experimental data taken from the literature and convergence to the asymptotic limit obtained analytically. As a minor but nevertheless interesting point, certainly relevant for engineering applications, it is found that the effect of the wall curvature, which must be included in the analysis in the case of a moderately large velocity defect from a strict rational point of view, on the irrotational bulk flow which, in turn, provokes near-equilibrium boundary layers allows for self-similar solutions of the former. They describe flows along curved diffuser ducts. As a consequence of the aforementioned non-uniqueness of the solutions, such flow configurations are seen to withstand the maximum pressure rise possible in order to maintain equilibrium. Moreover, a stability analysis by means of a multiple-scales technique in the case of weakly unsteady flows (i.e averaged over a time interval which properly scales with *Re*) shows that the solution having a larger defect is unstable, a result that also agrees well with early experimental observations.

Secondly, and as the primary goal of the research project, an asymptotic theory of turbulent marginal separation has been devised, at least as far as outer wake-type regime of the boundary layer is concerned. In essence, this theory is based on the argument, strongly supported by the commonly applied turbulence closures, that the thickness of boundary layers having a velocity defect of O(1) is measured by a small slenderness parameter denoted by α, even in the limit of infinite Reynolds number. Again, in the case of self-preserving flows, this flow description may be interpreted as the asymptotically correct continuation of moderately-large defect flows to such having a large velocity deficit. Combining this appealing conclusion with rather weak assumptions regarding the local properties of the mixing length at the base of the wake regime, allows for the development of a novel boundary layer theory where α serves as the principal perturbation parameter. The asymptotic analysis of that general type of turbulent boundary layers has been completed as far as the limit $\alpha \to 0$, $1/Re=0$ is concerned. This primary limit gives rise to weakly singular solutions of the resulting shear layer approximation of the wake flow if the prescribed adverse pressure gradient is controlled suitably. The local behaviour of these solutions has been studied analytically: For a critical distribution of the pressure gradient the surface slip velocity forming at the base of the outermost main layer vanishes at a single location but immediately recovers. This weakly singular behaviour resembles the well-known flow situation which leads to the concept of laminar marginal separation, if the slip velocity is replaced by the wall shear. However, in striking contrast to the laminar case, turbulent marginal separation is characterised by a strong acceleration of the flow downstream, which is associated with the occurrence of a specific non-trivial local eigensolution. In addition, this behaviour indicates marginally separated flow for finite values of both α and *Re*.

However, a correct treatment of the separation process has been shown to necessarily take into account the locally strong interaction of the boundary layer with the external potential flow. In order to eliminate the singularity, which signals a breakdown of the hierarchical boundary layer concept where the pressure gradient is taken to be imposed, an interaction theory has been developed, which accounts for the feedback effect of the external pressure induced by the locally rapidly varying boundary layer edge as separation is approached. As a consequence, turbulent marginal separation is described within the framework of well-known triple-deck theory. Similar to its laminar counterpart, the resulting elliptical fundamental problem appears to be controlled by a single similarity parameter, say, Γ. This parameter accounts for the deviation of the imposed pressure gradient from its critical value, where the marginal separation singularity arises in the solution of the non-interactive boundary layer equations. As a most representative result, closed reverse-flow regimes are seen to occur for a certain range of values of Γ. Furthermore, the numerical solutions confirm that the turbulent separation process is governed by non-trivial eigensolutions of that triple-deck problem which matches the aforementioned eigensolution far downstream on a lengthscale which measures the streamwise extent of the interaction region. The associated spontaneous branching of the flow is triggered by the aforementioned non-trivial downstream state and has never been observed in conventional laminar subsonic triple-deck flow configurations. However, the most surprising and physically instructive result is the finding that the local deceleration of the flow upstream of separation due to the pressure gradient induced by the boundary layer displacement provides the relevant physical mechanism leading to flow detachment. This is a characteristic which definitely contrasts the accelerating effect of the local pressure drop on the upstream side in laminar interacting-boundary-layer problems known so far. As one future task, the numerical results showing pronounced closed reverse-flow regions are to be compared with data obtained both experimentally and by, respectively, LES and DNS.

We note that in order to solve the canonical fundamental elliptic partial integro-differential equation, an efficient direct numerical method has been developed (and is still being refined). As that numerical procedure effectively copes with the problem of seeking an eigensolution of the interaction problem which is triggered by prescribing an appropriate downstream state, it has been applied to a broader class of related problems arising in interacting-boundary-layer theory also. In this context we mention, amongst others, the presently intensely debated phenomenon of non-uniqueness and the occurrence of turning points in the solutions of laminar triple-deck problems, the asymptotic formulation of weak hydraulic jumps observed in single- or two-layered thin-film flows, and critical transonic slender-nozzle flows.

Interestingly, and in striking contrast to what is known from laminar marginal separation, the limiting case of very large deviations from the aforementioned critical state referring to the marginal separation singularity, is, at least in the light of the present research, seen to be associated with firmly attached flow. Hence, the question arises if that limit is accompanied with the onset of double-valued solutions for a single value of Γ. For the time being, that branching is presumed to result from the coexistence of attached flow and massively separated flow, respectively. The latter type of flow, which is undoubtedly of great importance for engineering applications, is the topic of a subsequent research project to be proposed. As a first step in this direction, it has been demonstrated that the boundary layer solutions terminate in a singularity if the imposed pressure gradient belongs to a potential flow that is sought in the class of solutions exhibiting a free streamline which departs smoothly from the surface. Most important, here a self-consistent rational description of the separation process seems feasible if the strength of the pressure gradient is chosen such that the position of that singularity coincides with the location of inviscid flow detachment in the primary limit $\alpha \to 0$, $1/Re=0$. In addition, it has been shown that an asymptotic description of a turbulent boundary layer that undergoes separation requires a streamwise velocity deficit of $O(1)$ in the fully turbulent main part of the initially attached oncoming flow. The rationale for the asymptotic time-mean scaling of the boundary layer merely relies on semi-heuristic arguments and dimensional reasoning. Still, a current question of interest is how the scaling and the multi-layered structure of turbulent boundary layer flow can be traced back to a minimum number of physical assumptions in a more stringent manner and, in turn, be `derived' from first principles. Some interesting progress in this direction has already been possible, also by taking into account the effects due to high but finite values of Re, by applying a multiple-scales technique to the Navier—Stokes equations and anticipating a turbulent shear layer having a slenderness of $O(\alpha)$: amongst others, it is shown that in the primary limit near the surface a sublayer accounts for the constrained movement of the large-scale eddies with a diameter of the same magnitude. Remarkably, the analysis then corroborates a common finding of the time-mean analysis, namely, that the mixing length varies linearly with distance from the wall at the base of that inner layer.

The asymptotic description of turbulent (marginal) separation in the primary limit $\alpha \to 0$ elucidated so far has served as a basis for the investigation of the influence of high but finite values of Re on the flow close to the surface, which is in progress. In a first step, a rather complex multi-layered asymptotic splitting of the flow has been detected by accordingly perturbing the present wake-type formulation of a turbulent boundary layer near separation and taking into account the interaction strategy outlined above. The resulting uniformly valid flow description explains the gradual transformation of the celebrated logarithmic law of the wall holding for attached flow towards the square-root behaviour matching the streamwise velocities in the viscous wall layer and the wake regime on the verge of separation. It is found, however, that the asymptotic analysis of the time-mean motion is not capable of providing the correct continuation of the skin-friction law into regions showing reverse flow. We therefore propose to supplement it with a rational investigation of the coherent motions characterising the viscous near-wall region in the limit $Re \to \infty$. This study is planned to be carried out also in a future research project.

2.1.3 Information on the running of the project, use of the available funding

- Duration: 3 years (08/2003-02/2006, 10/2006-02/2007)
- Use of personnel: 1 Postdoc research fellow (DI Dr. Bernhard Scheichl)

2.2 Personnel development – importance of the project for the scientific careers of those involved (including the project leader)

- In progress: Habilitation of DI Dr. Bernhard Scheichl
- Special possibilities opened up by the project: apparent extension of the theory developed so far strongly suggests funding of follow-up project on turbulent large-scale separation.
- Importance of these new possibilities: Turbulent gross separation provides one of the major long-standing unsolved problems in theoretical hydrodynamics: Its solution is of significant relevance for engineering applications.
- Effects of the project and of research performed in the framework of the project on the international reputation of the project leader and co-workers: publications have been greatly acknowledged by highly renowned colleagues in the field.
- Establishment or intensification of international collaborations: joint work with Prof. F. T. Smith from UCL, Department of Mathematics / London, U.K. (c.f. List 3 of the Attachments)

2.3 Effects of the project outside the scientific field

- In the long run, the theoretical results may foster the development of CFD codes which correctly deal with flow separation. Here we emphasise that at present none of the commonly employed turbulence models enables the prediction of flow separation on a physically satisfactory level.
- The theoretical prediction of double-valued boundary layers withstanding the maximum possible prescribed pressure gradient for a given Reynolds number might be of interest in the design of flow diffusers.
- The project will have relevance for teaching graduate students in (turbulent) boundary layer theory in future courses to be held at the institution.

3. Information on project participants

not funded by the FWF			**funded by the FWF (project)**		
co-workers	**number**	**Person-months**	**co-workers**	**number**	**Person -months**
non-scientific co-workers	0	0	non-scientific co-workers	0	0
diploma students	0	0	diploma students	0	0
PhD students	0	0	PhD students	0	0
post-doctoral co-workers	0	0	post-doctoral co-workers	1	36
co-workers with “Habilitation” (professorial qualifications)	0	0	co-workers with “Habilitation” (professorial qualifications)	0	0
professors	1	36	professors	0	0

4. Attachments

List 1

1.a. Scientific publications[1]
with an indication of the status (published, in press, submitted, in preparation)

Publications may only be listed if they relate directly to the project. **Up to three of the most important publications** should be indicated (e.g., printed in bold letters; for books, two originals should be supplied if the book has already been published, otherwise a brief description should be given together with the name of the publishing house).

1.a.1. Peer-reviewed publications (journals, contribution to anthologies, working papers, proceedings etc.)

1) B. Scheichl & A. Kluwick: **Turbulent Marginal Separation and the Turbulent Goldstein Problem.** *AIAA Journal*, Vol. 45 (2007), No. 1 / DOI: 10.2514/1.23518, 20 - 36 (see also *AIAA Paper 2005-4936*)
2) B. Scheichl & A. Kluwick: **On Turbulent Marginal Separation: How the Logarithmic Law of the Wall is Superseded by the Half-Power Law.** *Int. Journal of Computing Science and Mathematics*, Special Issue on the *International Conference on Boundary and Interior Layers (BAIL) 2006, Göttingen, Germany; July, 24 - 28, 2006* (in press, see also proceedings on CD-ROM ed. by G. Lube, G. Rapin, Georg-August University Göttingen, Germany, ISBN: 3-00-019600-5, 978-3-00-019600-3, http://www.num.math.uni-goettingen.de/bail/).
3) B. Scheichl & A. Kluwick: **Asymptotic Theory of Turbulent Bluff-Body Separation: A Novel Shear Layer Scaling Deduced from an Investigation of the Unsteady Motion.** Proceedings of the *IUTAM Symposium on Unsteady Separating Flows and Their Control; Dassia, Corfu, Greece; June 18 - 22, 2007* (the two enclosed preprints are available on CD-ROM edited by the Institute de Mécanique des Fluides de Toulouse, book in press at Springer-Verlag).
4) B. Scheichl & A. Kluwick: Non-unique turbulent boundary layer flows having a moderately large velocity defect. A rational extension of the classical asymptotic theory. *Theoretical and Computational Fluid Dynamics* (submitted in revised form).
5) B. Scheichl & A. Kluwick: Non-unique Self-similar Turbulent Boundary Layers in the Limit of Large Reynolds Numbers. In: *Progress in Turbulence*, ed. by J. Peinke, A. Kittel, S. Barth, M. Oberlack; Springer-Verlag, Springer Proceedings in Physics, Vol. 101 / Berlin, Heidelberg, New York (2005), ISBN: 3-540-23216-8; 111 – 114.
6) B. Scheichl & A. Kluwick: Turbulent Marginal Separation: A Novel Triple-Deck Problem for Turbulent Flows. In: *Progress in Turbulence II*, ed. by M. Oberlack, G. Khujadze, S. Guenther, T. Weller, M. Frewer, J. Peinke, S. Barth; Springer-Verlag, Springer Proceedings in Physics, Vol. 109 / Berlin, Heidelberg, New York (2007), ISBN: 978-3-540-32602-1; 165 – 168.

Please note that also the associated abstracts submitted ahead of the respective conference were peer reviewed throughout. For the corresponding conferences please also see List 2.

1.a.2. Non peer-reviewed publications (journals, contribution to anthologies research reports, working papers, proceedings, etc.)

1 The publication list must mention for each work: all authors; full title; series/journal title; year; volume; and page numbers.

none

1.a.3. Stand-alone publications (monographies, anthologies)

none

1.b. publications for the general public and other publications

such as films, exhibitions, preparation of a home page etc. with an indication of the status (published, submitted / in preparation)

1) personal homepage (currently in preparation):
   http://www.fluid.tuwien.ac.at/institute/people/bernhard_scheichl

List 2 project-related participation in international scientific conferences
(with an indication of the conference date, name of speaker is underlined) – 4 subunits:

2.1. Conference participations - invited lectures

1) B. Scheichl & A. Kluwick: Turbulent Marginal Separation and the Turbulent Goldstein Problem; Talk: *4th AIAA Theoretical Fluid Mechanics Conference, Westin Harbour Castle, Toronto, Ontario, Canada; June 6 - 9, 2005*. Proceeding in: 2005 AIAA Meeting Papers on Disc, American Institute of Aeronautics and Astronautics (AIAA), 10/11-12 (2005), ISBN: 1-56347-763-7; Paper ID AIAA 2005-4936, 27 pages.
2) B. Scheichl: Survey on an Asymptotic Description of (Marginally) Separating Turbulent Boundary Layers; Talk: *Applied Mathematics Seminar Series, School of Mathematics, The University of Manchester, Manchester, U.K.*; *September 9, 2006*.

2.2. Conference participations - lectures

1) B. Scheichl & A. Kluwick: Non-unique Self-similar Turbulent Boundary Layers in the Limit of Large Reynolds Numbers; Talk: *ITI Conference on Turbulence 2003, Bad Zwischenahn, Germany; September 21 – 24, 2003*.
2) B. Scheichl & A. Kluwick: Non-Unique Quasi-Equilibrium Turbulent Boundary Layers; Talk: *XXI International Congress on Theoretical and Applied Mechanics (ICTAM 04), Warsaw, Poland; August 15 – 21, 2004*. Extended abstract in: ICTAM04 Abstracts Book and CD-ROM Proceedings, ed. by W. Gutkowski, T.A. Kowalewski; IPPT PAN, Warsaw (2004), ISBN: 83-89687-01-1; Paper ID FM2L_11083, 2 pages.
3) B. Scheichl & A. Kluwick: Asymptotic Structure of Turbulent Boundary Layers: Multi-Valued Solutions and Boundary Layer Separation; Talk: *2005 APS Division of Fluid Dynamics 58th Annual Meeting (DFD05), Chicago, IL, USA; November 20-22, 2005*.
4) B. Scheichl & A. Kluwick: On the Brillouin-Villat Condition in Connection with Turbulent Massive Separation; Talk: *International Symposium on Trends in Applications of Mathematics to Mechanics (STAMM), Vienna, Austria; July 10 – 14, 2006*. Extended abstract: see http://**stamm**06.mechanik.tuwien.ac.at.
5) B. Scheichl_, A. Kluwick: A general asymptotic description of turbulent boundary layers; Talk: *The 6th Euromech Fluid Mechanics Conference (EFMC6), Stockholm, Sweden; June 26 – 30, 2006*.

2.3. Conference participations - posters

1) B. Scheichl & A. Kluwick: Turbulent Marginal Separation: A Novel Triple-Deck Problem for Turbulent Flows; Poster: *ITI Conference on Turbulence 2005, Bad Zwischenahn, Germany; September 25 – 28, 2005*.

2.4. Conference participations - other

none

For publications see also the publication list for Dr. Bernhard Scheichl generated by the publication database of TU Vienna:

http://pub-mb.tuwien.ac.at/publist.php3?lang=2&pers=425&func=0&sort=3&inv=1&zeit=0&from=2003&to=2003&num=1&ext=1&head=%3cbody%20background%3d%22.%2faux%2fimg%2fwhitebg.gif%22%3e&ptyp=1&revonly=0&scionly=0&sfeld=0&stext=&nomsg=1&nojava=0

List 3 Development of collaborations

Indication of the most important collaborations (maximum 5), that took place (initiated or continued) in collaboration please give the name of the collaboration partner (name, title, institution) and a few words about the scientific content. Please also assign one of the following **categories** to each collaboration:

N			Nature		**N** (national); **E** (European); **I** (other international cooperation)
	E		Extent	**E1** **E2** **E3**	**low** (e.g. no joint publications but mention in acknowledgements or similar); **medium** (collaboration e.g. with occasional joint publications, exchange of materials or similar but no longer-term exchange of personnel); **high** (extensive collaboration with mutual hosting of group members for research stays, regular joint publications etc.)
		D	Discipline		**D** within the discipline **T** transdisciplinary

N	E	D	Collaboration partner / content of the collaboration
E	E1	D	1) Name: Frank T. Smith Title: Prof. Institution: UCL, Department of Mathematics / London, U.K. Content: acknowledgement in publication
			2) Name: Title: Institution: Content:
			3) Name: Title: Institution: Content:
			4) Name: Title: Institution: Content:
			5) Name: Title: Institution: Content:

Note: general scientific contacts and occasional meetings should not be considered as collaborations in the above sense.

List 4 "Habilitations" (professorial qualifications) / PhD theses / diploma theses
with an indication of the status (in progress / completed)

Note: It will not be possible to assign a "Habilitation" to a single project; what is required here is a mention of those "Habilitations" for which the project was important. A similar caveat applies to PhD and diploma theses: the FWF does not support thesis work but rather funds the scientific work that forms the basis for theses.

4.1. Professorial Qualifications

1) In progress: Habilitation of DI Dr. Bernhard Scheichl

List 5. Effects of the project outside the scientific field

5.1. Organization of scientific events

none

5.2. Particular honours, prizes etc.

none

5.3. Information on results relevant to commercial applications

none

5.4. Other effects beyond the scientific field
Please describe briefly any implications / presentations for social, ecological, medical, economic and/or technical or cultural areas.

5.5. Relevance of the project in the organization of the relevant scientific discipline

none

List 6. Applications for follow-up projects
with an indication of the status (submitted / approved) and the funding organization.

6.1 Applications for follow-up projects (FWF projects)
(with an indication of the project type, e.g. stand-alone project, NFN, SFB, WK, fellowship, contribution to a stand-alone publication)

1) **stand-alone project: in preparation**

6.2 Applications for follow-up projects (Other national projects)
(e. g. FFG, CD Laboratory, a K-plus Centre, funding from the Austrian National Bank, the Federal Government, the provincial government or similar)

none

6.3 Applications for follow-up projects (International projects)
(eg. ERA project, ESF)

none

5. Zusammenarbeit mit dem FWF

Sie werden gebeten folgende Aspekte der Zusammenarbeit mit dem FWF zu bewerten. **Anmerkungen (Ausführungen)** unter Verweis auf den entsprechenden Referenzpunkt bitte auf Beiblatt.

Skala
-2 sehr unzufriedenstellend,
-1 unzufriedenstellend;
0 angemessen;
+1 zufriedenstellend;
+2 sehr zufriedenstellend.
X nicht beansprucht

Regelwerk
(Richtlinien für Programm, Antrag, Verwendung, Bericht) **Wertung**

Antragsrichtlinien	Umfang	**-1**
	Übersichtlichkeit	**+1**
	Verständlichkeit	**+1**

Verfahren (Einreichung, Begutachtung, Entscheidung)

	Beratung	**+1**
	Dauer des Verfahrens	**+1**
	Transparenz	**0**

Projektbegleitung

Beratung	Verfügbarkeit	**+2**
	Ausführlichkeit	**+1**
	Verständlichkeit	**+1**

Durchführung Finanzverkehr (Überweisungen, Gerätebeschaffungen, Personalwesen)	**+1**

Berichtswesen/ Prüfung/ Verwertung

	Aufwand	**X**
	Transparenz	**X**
	Unterstützung bei Öffentlichkeitsarbeit/ Verwertung	**X**

Anmerkungen zur Zusammenarbeit mit dem FWF:

Die Zusammenarbeit war bis jetzt insgesamt sehr zufriedenstellend. Allerdings wird der verlangte Aufwand für die Erstellung eines (in diesem Fall: Folge-) Antrages, sowie jener für das Abfassen des Endberichtes als zu umfangreich empfunden, wenn man bedenkt, dass die Anstellung des Projektbearbeiters nur für 36 Monate gesichert ist, und diese Zeit ja größtenteils der eigentlichen inhaltichen Arbeit zur Verfügung stehen sollte. So dürfte - wohl nicht nur in unserem Fachgebiet - eine Obergrenze des inhaltlichen Teiles des Antrages mit etwa 7 Seiten den Gutachtern wohl ebensogut zu einer hinreichenden Information verhelfen, um ein angemessenes Urteil über die geplante Forschungarbeit fällen zu können. Insbesondere erscheint uns die Möglichkeit einer etwas vereinfachten Antragstellung für ein inhaltlich nahtlos anschließendes Folgeprojekt, gerade in Hinblick auf die Habilitation des Bearbeiters, als ein dringendes Gebot der Stunde, um Unterbrechungen in der Anstellung des Betroffenen möglichst hintanzuhalten. Außerdem würde im Bereich der Postdoc-Förderung die Möglichkeit von Verträgen mit einer Laufzeit von mindestens 4 Jahren der Realität Rechnung tragen, dass die heimischen Universitäten den wichtigen Nachwuchs-Wissenschaftlern in dieser Karrierephase in absehbarerer Zukunft praktisch keine Laufbahnstellen anbieten.