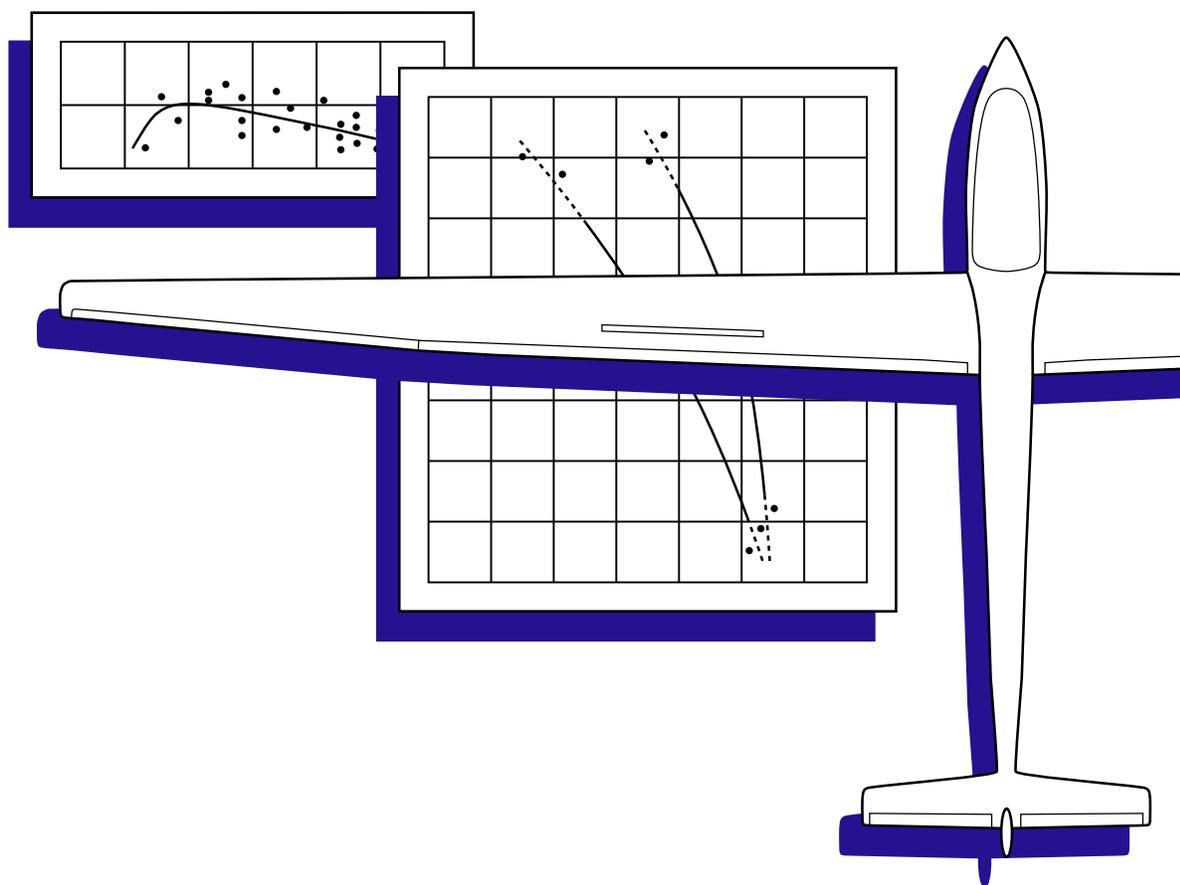


Technical Soaring

An International Journal



- **Call for Papers, OSTIV Congress XXXIII**
- **Extensible Skin Variable Geometry Leading Edge**

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**Highly Extensible Skin of a Variable Geometry Wing Leading
Edge of a High-Performance Sailplane**

Matthias Weinzierl, Johannes Achleitner, Horst Baier 4

Technical Soaring (TS) documents recent advances in the science, technology and operations of motorless aviation.

TS is published quarterly by the Organisation Scientifique et Technique Internationale du Vol à Voile (International Scientific and Technical Organization for Gliding, OSTIV), c/o TU Braunschweig, Institute of Fluid Mechanics, Hermann-Blenk Str. 37, D-38108 Braunschweig, Germany. E-mail: president@ostiv.org; URL: www.ostiv.org.

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Submitted research papers will be peer-reviewed. Guidelines for preparation and submission of manuscripts can be found in this issue and on the OSTIV website in the 'editor' section.

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Preparation of Manuscripts for Submission to *Technical Soaring*

Technical Soaring (TS) seeks to document recent advances in the science, technology and operations of motorless aviation. *TS* welcomes original contributions from all sources.

General Requirements Manuscripts must be unclassified and cleared for public release. The work must not infringe on copyrights, and must not have been published or be under consideration for publication elsewhere. Authors must sign and submit a copyright form at time of submission. The form is available at www.ostiv.org.

Layout Submit manuscripts in **single-column, double line-spacing** format. This is not a “camera-ready” layout but facilitates review and typesetting. Set up margins so the pages will print on both US Letter and A4. Use approximately 1 1/4 in. (3 cm) margins.

Language All manuscripts submitted to *TS* must be in English. Submissions requiring extensive editing may be returned to author for proofreading and correction prior to review.

Electronic files Acceptable data file formats for text are, in order of preference, PDF, DVI, Latex Source, Open Office, and all others including Microsoft Word. If in doubt, ask the Editor. Submit one file containing the complete paper including all figures and tables (for review purposes), and, separately, a complete set of graphics files containing the individual figures, one per file. Graphics files must be in one of the following formats: EPS (preferred), EPSF, PS, PDF, JPG (JPEG), GIF, TIF (TIFF), PNM, PBM, PGM, PPM, PNG, SVG, or BMP.

Length There is no fixed length limit. At the discretion of the Editor, manuscripts exceeding approximately 50 double-spaced pages (including figures and tables one per page) may be returned to the author for reduction in length.

Font For the text, use any common font in 12pt — e.g. Times, Helvetica, Courier or equivalents.

Structure Organize papers in sections, subsections, and, as needed, subsubsections. Preferred heading style is section headings centered in bold face; subsection headings left-justified in bold face; and subsubsection headings left-justified in italics. Do not number sectional units. Capitalize first letters only — do not use “all-caps” in headings.

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Abstract All papers require a summary-type abstract. Abstracts must consist of a single, self-contained paragraph. Suggest 100 to 150 words. Acronyms may be introduced in the abstract, but do not cite references, figures, tables, or footnotes.

Nomenclature If the paper uses more than a few symbols, list and define them in a table in a separate section following the abstract. Define acronyms in the text following first use in text — not in the Nomenclature list.

Introduction The Introduction should state the purpose of the work and its significance with respect to prior literature, and should enable the paper to be understood without undue reference to other sources.

Conclusions Although the Conclusions section may review the main points of the paper, it must not replicate the abstract. Do not cite references, figures, or tables in the Conclusions section as all points should have been made in the body of the paper.

Acknowledgments This section may be used to acknowledge technical assistance, organizational sponsorship, or financial or other support. Inclusion of support and/or sponsorship acknowledgments is strongly encouraged.

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References The list of References is placed after the body of the text, after the Conclusions but before any Appendices. List references in order of first citation in the text. Any format is acceptable as long as all citation data are provided. At a minimum, all types of entries require title, year and manner of publication. Provide full names of all authors. Do not list Internet URLs as sources.

Tables Tables must be provided as editable text. Do not submit graphic images of tables.

Figures Place figures and tables at the end of the manuscript, one per page, each with its caption.

Captions All figures and tables require captions. Captions should state concisely what data are presented. Brief explanatory comments are acceptable but any discussion of the data presented in a figure or table should be placed in the section of the text referring to it — not in the caption. Provide captions as editable text separate from the figure or table it presents. Do not use the caption to explain line styles and symbols — use a legend instead.

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Footnotes Use footnotes sparingly. Do not footnote to cite literature.

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Abbreviations Do not begin sentences with abbreviations. Otherwise, use “Fig.” for “Figure” and “Ref.” for “Reference.” Do not abbreviate “Table”. The abbreviations “i.e.” and “e.g.” are not italicized.

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1. The manuscript begins with a title block and a summary-type abstract.
2. A nomenclature list is provided or, if only a few symbols are used, they are defined in the text.
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9. A completed and signed copyright form has been provided.

Charges *Technical Soaring* does not require a publication page-charge.

From the Editor

All *Technical Soaring* back issues now available online!

Congratulations to Ward Hindman, who has completed the monumental task of scanning the full set of *Technical Soaring* back issues going back to the first issue (July, 1971) and posting them to the *TS* website at journals.sfu.ca/ts. This is a tremendous service to the soaring science and technology community. Thanks to Ward, *TS* readers and authors now have ready access to a significant body of soaring research.

Open Access Policy

One of the most frequent questions the *TS* Editorial team hears comes from authors who wish to post their articles on their personal or other websites. To clarify this and related matters, OSTIV has adopted the following Open-Access Policy for *TS*, effective immediately. The policy is inspired by the “HowOpenIsIt Open Access Spectrum Guide,” published by the Scholarly Publishing and Academic Resources Coalition (SPARC, www.sparc.arl.org/) along with the Public Library of Science (PLOS, www.plos.org) and Open Access Scholarly Publishers Association (OASPA, www.oaspa.org).

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Machine Readability After twelve months, article full text, metadata, and citations may be crawled or accessed without special permission or registration.

This policy will be posted in future issues of *TS* on the Table of Contents page and updated from time to time as needed.

OSTIV Congress XXXIII

OSTIV Congress XXXIII will be held in conjunction with the 34th World Gliding Championships in Benalla, Australia, 8–13 January, 2017. The call for papers appears in this issue. We encourage everybody to attend and present their latest work.

Octave Chanute ... now in Paperback

Simine Short writes to advise us that her book, “Locomotive to Aeromotive” (reviewed in *TS* 38:1, January-March 2014) has been published in paperback. The hardcover edition is out of print but one might still find a copy from the usual used book sources.

Reminders to Authors

Please submit all manuscripts, revisions, figures etc. directly to the Editor-in-Chief. You should receive confirmation of receipt within a few days. If not, please drop me a line.

As previously announced, OSTIV has elected to discontinue the paper version of *TS* journal. *TS* will be available only in electronic form to registered subscribers at *TS*-online (journals.sfu.ca/ts). To register, please contact our OSTIV webmaster, Jannes Neumann at Jannes.Neumann@t-online.de.

Despite this change, the question of whether to include color graphics in articles remains. Certainly color photographs present no problem, but we strongly discourage the use of color in data presentations. For one thing, papers should be legible when printed on B&W printers. Second, even when viewed in color, chances are that some readers will have difficulty distinguishing certain color pairs. Rather than color, please present data in figures and graphs in B&W and use line style, different symbols, and/or fill patterns to differentiate data.

Publication Date

This issue kicks off Volume 39 of *TS* corresponding to calendar year 2015. For the record, we are going to press in February, 2016.

Acknowledgments

We gratefully acknowledge Associate Editor Helmut Fendt, who oversaw the review of the Weinzierl, et al. paper in this issue.

Respectfully,

Judah Milgram
Editor-in-Chief, *Technical Soaring*
milgram@cgpp.com



www.ostiv.org

Call for Papers

XXXIII OSTIV Congress, Benalla, Australia

8–13 January, 2017

The XXXIII Congress of the International Scientific and Technical Organisation for Soaring Flight (Organisation Scientifique et Technique Internationale du Vol à Voile, OSTIV) will be held at the site of the 34th FAI World Gliding Championships in the Open, 18m and 15m Classes, Benalla, Australia from 8 to 13 January, 2017. The Congress addresses all scientific and technical aspects of soaring flight including motorgliding, hang gliding, paragliding, ultralight sailplanes and aeromodelling.

Opportunity for presentation and discussion is given in the following categories:

Scientific Sessions: Meteorology, Climatology and Atmospheric Physics as related to soaring flight.

Technical Sessions: Aerodynamics, Structures, Materials, Design, Maintenance and Sailplane development.

Training and Safety Sessions: Training and Safety, Coaching, Health and Physiology.

Joint Sessions: Scientific and technical topics, reviews or news, presented in an informative and entertaining way for the broader interest of the World Gliding Championships and OSTIV.

Topics on instrumentation, electronics, statistics and other system technologies will be included in the sessions for which the application of the technology is most relevant.

Typical and Suggested Topics

Scientific Sessions

- Meteorology:
 - Meteorological data acquisition and service for gliding operations
 - Weather forecasting for soaring flight
- Climatology:
 - Climates that support soaring flight
 - Climate-change and soaring
- Atmospheric Physics:
 - Mesoscale and small convective, baroclinic or orographically induced phenomena
 - New observations; measurements or analysis of convergence lines, cellular patterns, shear structures, standing and moving waves, short period cycles, turbulence, boundary layer in complex terrain

- Analytical techniques of delineating thermal and mesoscale structures from routine or experimental ground or flight data, or from remote sensors
- Modeling of thermals, mesoscale or microscale structures

Technical Sessions

The technical sessions will cover all aspects of design, development and operation of sailplanes, motorgliders, ultralights and solar- or human-powered aircraft. Topics may include, but are not limited to:

- Airworthiness, structural concepts, new materials, fatigue, crashworthiness, manufacturing processes
- Aerodynamics and flight mechanics
- Trajectory optimization
- Stability and control
- Airframe vibration and flutter
- Propulsion systems
- Design integration and optimization
- New developments in flight testing
- Airworthiness requirements
- Cockpit instruments, including navigation instruments (GPS etc.)
- Autonomous soaring

Training and Safety Sessions

Training and Safety sessions will be held on subjects covering disciplines such as

- Flight training, theory and analysis of techniques and results, psychology, objectives, training facilities and material
- Human and medical factors in aircraft design and operation
- Piloting techniques
- Flight operation in controlled airspace
- Safety devices

Joint Sessions

Joint Sessions cover topics of general interest in the field of gliding such as

- Soaring history
- General philosophy of competition classes
- Documentation of badge and record flights
- Common interests with other air sports like hang gliding, paragliding, microlights and ultralights
- Human-powered flight; Solar-powered flight

Deadline for Abstracts and Summaries

The deadline for the Abstracts — max. two A4 pages including figures — is **15 July, 2016**. Letters of acceptance will be mailed by **30 July, 2016**. Final two-page summaries of your contribution will be included in the conference booklet and are due by **1 November, 2016**. Full papers are not required but presenters are encouraged to prepare full papers for submission to *Technical Soaring* (www.ostiv.org/publications.html), OSTIV’s refereed international journal.

Please use the form below to send a copy of your Abstract to the OSTIV Secretariat, clearly marked for either the Scientific, Technical, Training and Safety, or Joint session.

Oral presentations at the Congress will be limited to 30 minutes.

There is **no registration fee** for the Congress!

If you would like to attend the Congress, please complete the form below and send it to the OSTIV Secretariat at admin@ostiv.org. Fur-

ther information about OSTIV and the Congress can be obtained from the Secretariat or from the OSTIV website, www.ostiv.org.

Best Student Papers Awards

Awards of EUR 200 will be presented to the students delivering the best presentations in the Scientific and Technical Sections. To be eligible, presenters must be the first author and submit an abstract and two-page summary by the aforementioned deadlines, as well as a manuscript to *Technical Soaring* prior to the Congress. Students who are unable to attend the Congress may designate a representative to present the work on their behalf.

Call for nominations OSTIV Plaque / Klemperer Award

During the Opening Ceremony of OSTIV Congresses the OSTIV Plaque and Klemperer Award may be presented to the person who has made the most noteworthy scientific and/or technical contribution to soaring flight in recent years. All Active and Individual OSTIV Members can send in nominations. In making such nominations, particular attention should be given to recent contributions to soaring flight by the nominee, although earlier outstanding work also will be taken into account. Nominations should include details of the nominee’s contributions and a short biography. All nominations for the OSTIV Plaque / Klemperer Award must be received by R. Radespiel, OSTIV President, c/o TU Braunschweig, Institute of Fluid Mechanics, Hermann-Blenk Str. 37, D-38108 Braunschweig, Germany, president@ostiv.org by **15 July, 2016**.

Note of interest / Pre-Registration Form and Extended Abstract, XXXIII OSTIV Congress, 8–13 January, 2017

Please send this pre-registration form to admin@ostiv.org no later than 15 July, 2016

- Please, send general information about OSTIV
- Please, put my name on the mailing list for further information about the XXXIII OSTIV Congress
- I wish to attend the XXXIII OSTIV Congress.
- I wish to present at the XXXIII OSTIV Congress in the:
 - Scientific Session
 - Technical Session
 - Training and Safety Session
 - Joint Session

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Abstract (maximum 2 pages):

Highly Extensible Skin of a Variable Geometry Wing Leading Edge of a High-Performance Sailplane

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Abstract

In 2011 the Akafieg München e.V. began research on a variable geometry wing of a sailplane. The advantage of a leading edge with a variable camber was investigated by Wießmeier on the basis of the ASW 27 airfoil. The results show a great potential of achieving a higher wing loading and a higher cruising speed along with excellent low-speed flight characteristics. Subsequently, different designs of the technical implementation of a variable geometry wing leading edge are considered. This paper presents the results of a study whose principal aim is to design and analyse a highly extensible section of a variable geometry wing leading edge. This section is designed as a sandwich, composed of an accordion honeycomb core with elastomeric top layers. It has a high bending stiffness as well as a high extensibility into one direction, allowing for the wing leading edge to morph downward.

Nomenclature

c_d	Drag coefficient of the profile
c_l	Lift coefficient of the profile
C_{D_i}	Induced drag coefficient of the wing
C_L	Lift coefficient of the wing
el	Distance between two cells
h	Distance between two bars
h_{bar}	Height of the bar
h_{core}	Height of the core
k	Induced drag factor
l	Length of the bar
t	Thickness of the bar
t_h	Thickness of the cross stud
x -axis	Direction of flight
y -axis	Spanwise direction
A	Cross sectional area of the core
θ	Opening angle of the accordion
Λ	Aspect ratio

Introduction

Modern airfoils of flapped sailplanes have a laminar low drag bucket ranging from a lift coefficient of $c_l = 0.1$ to $c_l = 1.5$ [1]. For higher wing aspect ratios combined with higher wing loadings to be realized, the low drag bucket needs to be widened

towards higher lift coefficients. Liebeck, Wortmann and Selig each developed single-element high-lift airfoil designs, which show a maximum lift coefficient of around $c_l = 2.3$ [2–4]. Especially Wortmann’s FX-74CL series shows very high lift coefficients of $c_l = 2.0$ combined with acceptable drag coefficients of $c_d = 13 \cdot 10^{-3}$ in the upper end of the laminar low drag bucket, as shown in Fig. 1. A possible solution for the widening of the low drag bucket is shown by Wießmeier with a profile derived

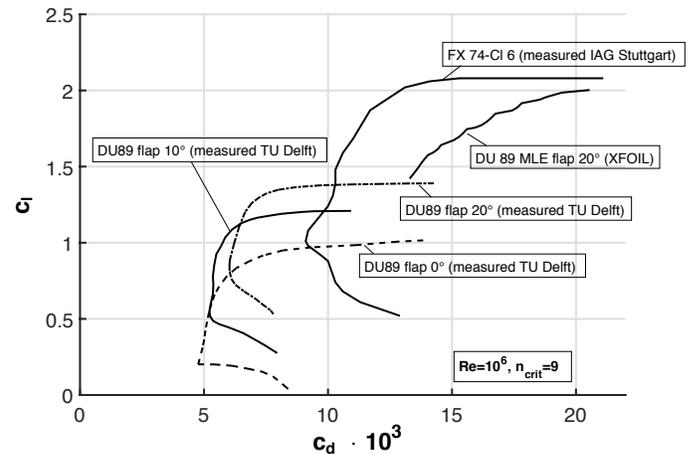


Fig. 1: Comparison of the polar curves of the DU89 and the FX-74CL profile.

Presented at the XXXII OSTIV Congress, Leszno, Poland, 6–11 August, 2014

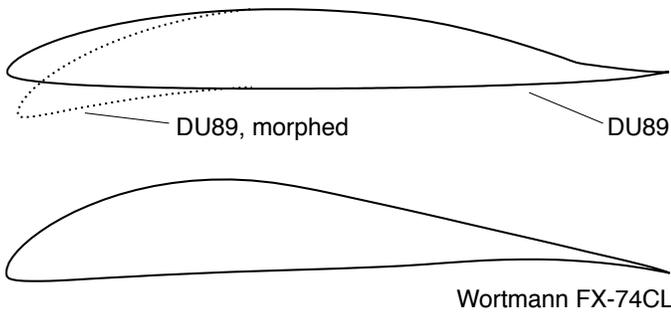


Fig. 2: Comparison of the DU89 profile, the morphed DU89 and the FX-74CL.

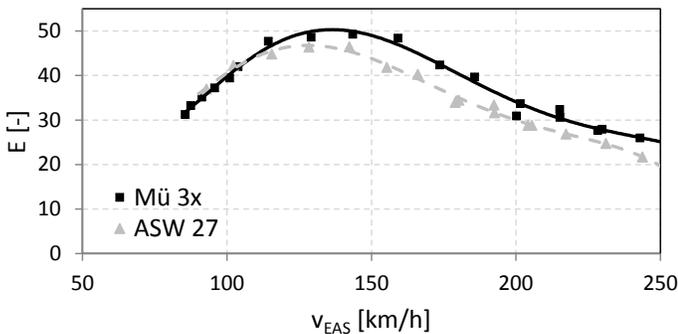


Fig. 3: Comparison of the glide ratio of the ASW 27 versus the Mü 3x at maximum take off mass (MTOM) [5].

from the DU89 profile, which is used as the main wing airfoil of the ASW 27. A comparison of the FX-74CL, the DU89 and the morphed version of the DU89 by Wießmeier can be seen in Fig. 2 [5]. The upper end of the laminar low-drag bucket of the morphed version of the DU89 is at a 20% higher lift coefficient compared to the unmorphed version.

During low-speed flight a higher induced drag coefficient is caused due to higher lift coefficient, as can be seen in the following equation:

$$C_{Di} = \frac{C_L^2}{\pi \Lambda} k \quad (1)$$

This higher drag coefficient can be compensated by a higher aspect ratio of the wing. Subsequently this higher aspect ratio and a higher wing loading have no impact on the low-speed performance but lead to an excellent performance within and above the range of the best glide ratio, compared to modern flapped sailplanes. Wießmeier estimated an empty weight of the morphing wing aircraft increased by 45 kg compared to that of the ASW 27 [5]. However, he pointed out that a higher mass is not necessarily a disadvantage, due to the fact that the morphing wing aircraft has limited water ballast capacity.

A polar of a sailplane with a variable geometry leading edge can be calculated by subtracting the profile drag and the induced drag from a known total drag polar of the sailplane. This results in a fuselage drag, an interference drag and a tailplane drag. By adding the envelope of the profile drag of the new profile with

the variable geometry leading edge to the induced drag of the new wing calculated in Eq. 1, a theoretical polar of the new sailplane has been achieved. Although this way of calculating the polar is an approximation due to neglecting different profile sections on the wing and different interference drags, an estimation of the gain in performance could be given. Wießmeier showed a remarkable performance improvement using his new profile and a wing with a surface area reduced by 20% compared to the ASW 27, as can be seen in Fig. 3. The data of the DU89 and the FX-74CL have been measured at TU Delft and IAG Stuttgart whereas the data of the DU89MLE have been calculated with *XFOIL*. Concerning maximum lift and performance at high lift coefficients, *XFOIL* significantly overestimates airfoil performance in some cases [6–10]. A comparison between the lift coefficient of the DU89 calculated with *XFOIL* and the one measured at TU Delft is shown in Fig. 4. In the calculation with 0° flaps *XFOIL* overestimates the lift coefficient by approximately 8% while in the calculation with 20° flaps *XFOIL* underestimates the lift coefficient by approximately 3%. In further research, an airfoil optimized for a morphing wing should be designed and verified with wind tunnel tests.

For commercial aircraft, the “Deutsches Zentrum für Luft- und Raumfahrt” (DLR), investigates different drop nose and morphing trailing edge concepts [11–17]. These drop nose concepts are based on a widespread extension in the entire leading edge, which is designed of fiberglass. The DLR has built several demonstrators of their drop nose concepts and now attempts to implement the design in an aircraft.

In 1978, Burkhart Grob Luft- und Raumfahrt GmbH developed the 15 meter class sailplane “G104 Speed Astir,” which can be seen as a pioneer in morphing wing design. The flaperons were designed as elastic flaps, which reduce the drag otherwise created by the gap between the trailing edge and the flap. The skin in this area is highly flexible around the y-axis [18].

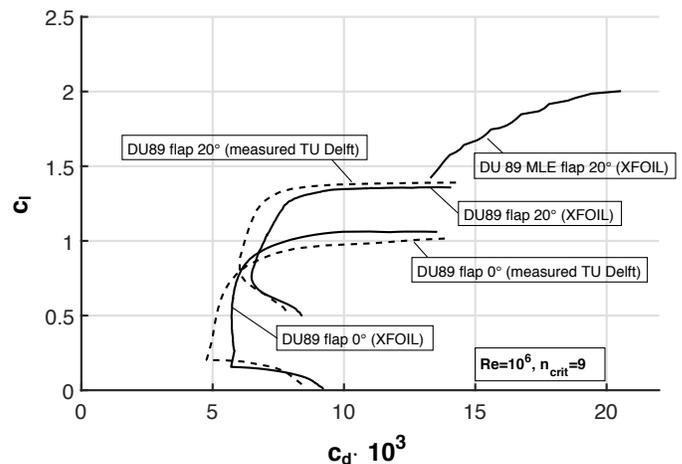


Fig. 4: Comparison of the calculated and the measured polar curves of the DU89.

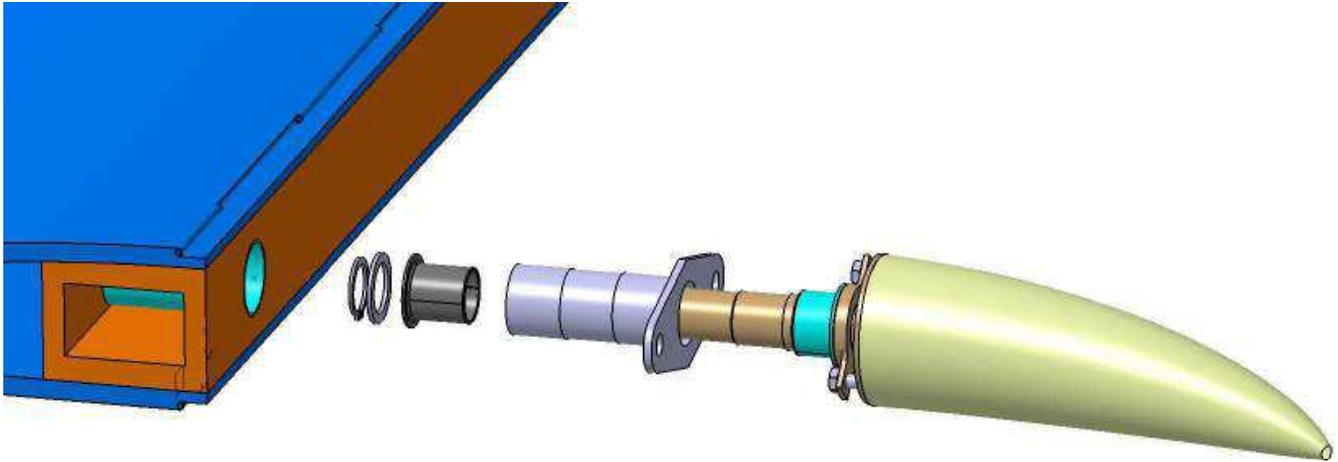


Fig. 5: Rotary Drive System (RDS) with horns [5].

Structural-mechanical implementation of a variable geometry leading edge

The technical implementation of the variable geometry leading edge represents a challenge. Wießmeier suggested a Rotary Drive System (RDS) with multiple horns to morph the leading edge down, which can be seen in Fig. 5 [5]. These horns are placed in front of the wing spar. Turning the horn changes the contour of the leading edge surface. The first contour is the one of the non-cambered leading edge while the second contour is the one of the fully cambered leading edge. This second contour is turned by 90° compared to the non-cambered one. By turning the horns, the profile can be cambered from the original shape to a high-lift contour. This leads to a high extension in the upper shell of the wing. In the late 1990s the RDS concept for a morphing trailing edge was extensively researched by Müller [19]. He reached a technology readiness level of 4 by accomplishing a full scale demonstrator, which reached a deflection of the trailing edge of $\pm 15^\circ$. In the following paragraph an approach is presented, using a highly extensible section designed in a sandwich construction and placed in front of the main spar.

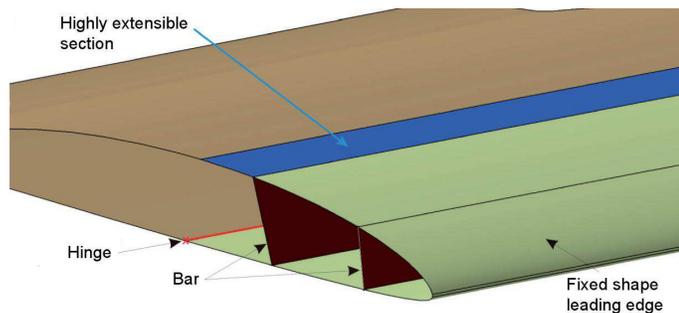


Fig. 6: Highly extensible section [20].

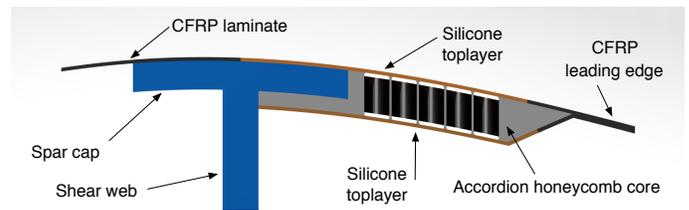


Fig. 7: Connection of the highly extensible section to the fixed shape leading edge [21].

Highly extensible section

One possible solution to implement a morphing leading edge with a RDS is the use of a highly extensible section placed in front of the main spar in the upper shell of the wing, as shown in Figs. 6 and 7.

This version with the highly extensible section splits the leading edge in two different parts: The main part approximately keeps its original shape while the highly extensible section becomes severely deformed. The requirements on this highly extensible section are on the one hand an extensibility of 30% in the direction of flight (x -direction) and a low bending stiffness around the y -axis (spanwise direction) [20]. On the other hand the highly extensible section needs a high bending stiffness around the x -axis to withstand the aerodynamic loads [21].

For achieving such a highly extensible section, a sandwich structure with anisotropic material parameters seems to be a possible solution. Therefore, a core without lateral contraction can be combined with elastomeric top layers. A core without any lateral contraction and a high extensibility in the x -direction is called a zero-Poisson honeycomb core or an accordion honeycomb core [22, 23]. The geometrical parameters of such a honeycomb core are shown in Fig. 8.

In a parametric study different combinations of the geometrical parameters of the accordion honeycomb core are investigated and compared with each other. The goal of the parametric

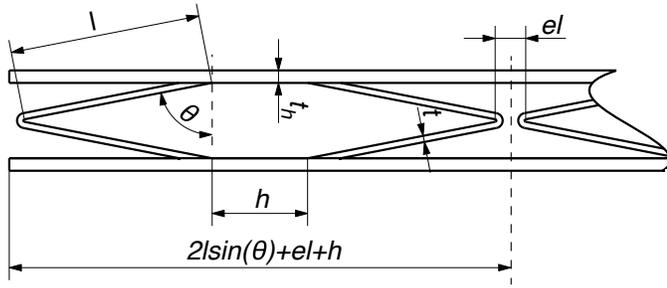


Fig. 8: Geometrical parameters of an accordion honeycomb core [24].

Table 1: Chosen parameters of the final version of the accordion honeycomb core of the Mü 3x [21].

Parameter	Value
θ	79.0°
l	16.0 mm
t	0.5 mm
h_{bar}	12.0 mm
h_{core}	10.0 mm

study is a configuration with a large ratio of global strain to local strain in the x -direction compared with a relatively high bending stiffness around the x -axis. As a final version an accordion honeycomb core with a height of 10.0 mm and a thickness of the spars of 0.5 mm is chosen. All parameters are listed in Table 1. In this configuration the local strain in the material is 0.4% while the global strain of the core is 30%. The local strain of the core is shown in Fig. 9.

With the parameters listed in Table 1 a first prototype is built, as can be seen in Fig. 10. The prototype is built by additive manufacturing and as material the polyamide PA 2200 is chosen, which is based on a PA-12. The material data of the PA 2200 from the supplier are listed in Table 2. Material data of environmental effects (e.g. moisture or temperature) are not available.

To validate the results of the Young's modulus and the strength results of the numerical calculation, the prototype is submitted to a tensile strength test. Between the measured values of the Young's modulus and the calculated ones is a difference of about 1.2%, which can be considered negligible. A linear elastic material behavior appears up to 50% global strain and the fracture strain is ca. 230%. The linear elastic material behavior can be seen in the stress-strain curve in Fig. 11. The stress gets normalized to the cross sectional area $A = [2l \sin(\theta) + el + h] \cdot h_{core}$ of the unit cell. Due to this relatively large cross section, the value of the Young's modulus becomes 0.01 MPa.

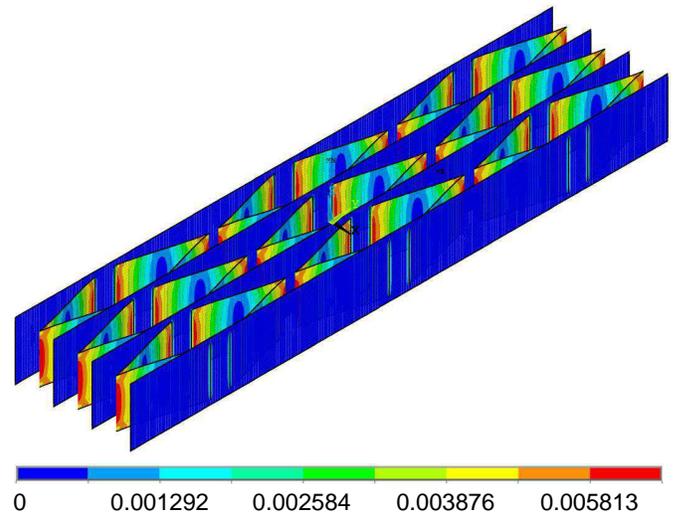


Fig. 9: Local strain within the accordion honeycomb core [21].

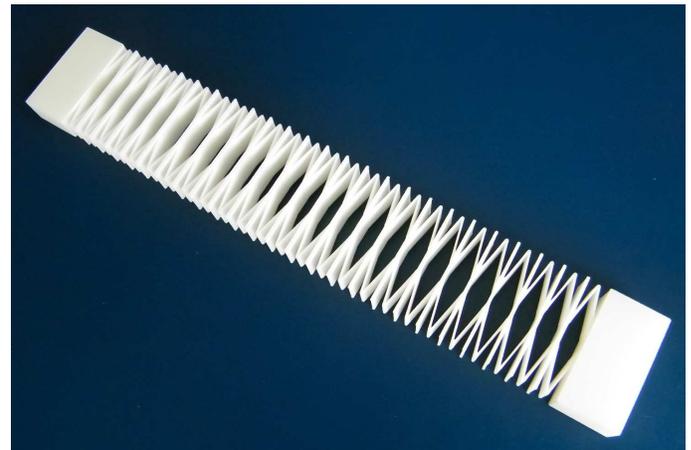


Fig. 10: Prototype of the final version of the accordion honeycomb core [21].

Surface layers

For achieving a smooth surface and a higher bending stiffness of the highly extensible section, top layers are needed. In a first attempt they are designed in pure silicone. Every layer has a thickness of 1.0 mm. For material the pure silicone ALPA-SIL 32 is chosen. With the first prototype two major problems occur: First the silicone detaches itself from the core material and second the lateral contraction of the silicone causes constraining forces and stress in the sandwich. To achieve a better bonding of the silicone top layers to the polyamide core, a form-fitting connection is realized, as can be seen in Fig. 12. With this improvement a second prototype of the sandwich including the accordion honeycomb core and the silicone top layers is built, as can be seen in Fig. 13.

Table 2: Material data for PA 2200 [25].

Average grain size	56	μm
Density laser sintered	0.93	g/cm^3
Tensile modulus	1700	MPa
Tensile strength	48	MPa
Elongation at break	24	%
Bending modulus	1500	MPa
Bending strength	58	MPa
Melting point	180	$^{\circ}\text{C}$
Shore hardness D	75	[-]
Poisson's ratio	0.4	[-]

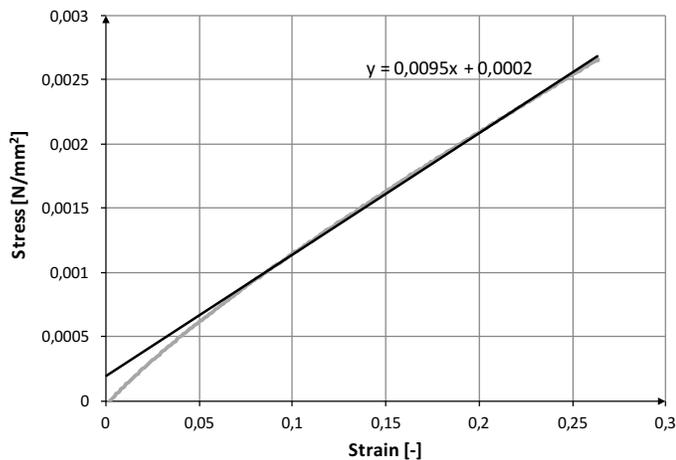


Fig. 11: Stress-strain curve of the accordion honeycomb core [21].

Conclusions

A morphing leading edge seems to be advantageous for a sailplane in different aspects. To implement such a leading edge, a RDS combined with a highly extensible section in the upper shell of the wing is a possible solution. The highly extensible section can be designed as a sandwich with an accordion honeycomb core with silicone top layers. This sandwich has a high extensibility in the x -direction without any lateral contraction. By choosing the appropriate parameters of the accordion honeycomb core, an expansion ratio of 75 between the global strain and the local strain can be achieved. The final design of the accordion honeycomb core fulfills all requirements on the core structure. In further studies the material behavior of top layers should be characterized as well as the bonding of the top layers to the core structure. The use of fiber-reinforced elastomers as top layers could also prove advantageous.

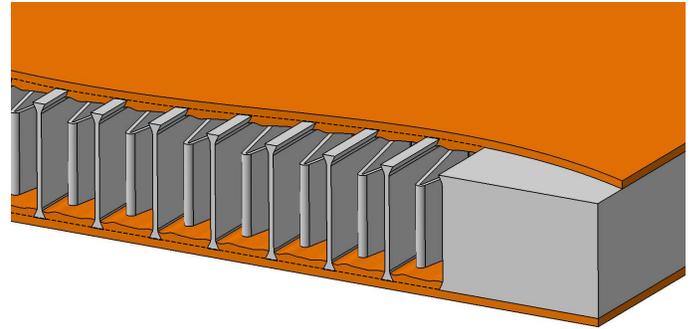


Fig. 12: Form-fitting core and top layers [21].



Fig. 13: Sandwich with accordion honeycomb core and silicone top layers [21].

References

- [1] Boermans, L., "Research on Sailplane Aerodynamics at Delft University of Technology," *Technical Soaring*, Vol. 30, No. 1/2, 2006.
- [2] Liebeck, R. and Ormsbee, A., "Optimization of airfoils for maximum lift," *Journal of Aircraft*, Vol. 7, No. 5, Sept. 1970, pp. 409–416.
- [3] Althaus, D., *Niedriggeschwindigkeitsprofile*, Vieweg Verlag, 1996.
- [4] Selig, M. and Guglielmo, J., "High-Lift Low Reynolds Number Airfoil Design," *Journal of Aircraft*, Vol. 34, No. 1, Jan. 1997, pp. 72–79.
- [5] Wießmeier, M., *Konzept einer formvariablen Tragflügelvorderkante bei einem Segelflugzeug mit innenliegender Ansteuerung über ein Rotary Drive System (RDS)*, Semester thesis, Technische Universität München, Aerospace Department, 2011.
- [6] Maughmer, M. and Coder, J., "Comparisons of Theoretical Methods for Predicting Airfoil Aerodynamic Characteristics," Tech. Rep. RDECOM TR 10-D-106, The Pennsylvania State University, Aug. 2010.
- [7] Drela, M., "XFOIL: An Analysis and Design System for Low Reynolds Number Airfoils," *Low Reynolds Number Aerodynam-*

- ics, edited by T. Müller, Vol. 54 of *Lecture Notes in Engineering*, Springer Berlin Heidelberg, 1989, pp. 1–12.
- [8] Ragni, D., Ferreira, C. S. a., and Correale, G., “Experimental investigation of an optimized airfoil for vertical-axis wind turbines,” *Wind Energy*, Vol. 18, No. 9, 2015, pp. 1629–1643.
- [9] Björck, A., “Coordinates and Calculations for the FFA-WI-xxx, FFA-W2-xxx and FFA-W3-xxx Series of Airfoils for Horizontal Axis Wind Turbines,” Tech. Rep. FFA TN 1990-15, Flygtekniska Försöksanstalten, The Aeronautical Research Institute of Sweden, Aerodynamics Department, 1990.
- [10] Somers, D. and Maughmer, M., “Theoretical Aerodynamic Analyses of Six Airfoils for Use on Small Wind Turbines,” Tech. Rep. NREL/SR-500-33295, Airfoils, Inc., Port Matilda, Pennsylvania, 2002.
- [11] Kintscher, M., Monner, H., and Heintze, O., “Experimental Testing of a Smart Leading Edge High Lift Device for Commercial Transportation Aircrafts,” *27th International Congress of the Aeronautical Sciences (ICAS)*, Sept. 2010.
- [12] Monner, H. and Kintscher, M., “Design of a Smart Droop Nose as Leading Edge High Lift System for Transportation Aircrafts,” *50th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, May 2009.
- [13] Monner, H., *Erzielung einer optimierten Tragflügelverwölbung durch den Einsatz formvariabler Klappenstrukturen*, Ph.D. dissertation, Institut für Faserverbundleichtbau und Adaptronik, Institut für Strukturmechanik, DLR, 2000.
- [14] Monner, H., Sachau, D., and Breitbach, E., “Design Aspects of the Elastic Trailing Edge for an Adaptive Wing,” *Research and Technology Agency, Ottawa, Canada*, Oct. 1999.
- [15] Thill, C., Etches, J., Bond, I., Potter, K., and Weaver, P., “Morphing skins,” *The Aeronautical Journal*, Vol. 112, No. 1129, 2008, pp. 117–139.
- [16] Morishima, R., Guo, S., and Ahmed, S., “A Composite Wing with a Morphing Leading Edge,” *51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, April 2010.
- [17] Molinari, G., Quack, M., Dmitriev, V., Morari, M., Jenny, P., and Ermanni, P., “A Multidisciplinary Approach for Wing Morphing,” *21st International Conference on Adaptive Structures and Technologies (ICAST)*, 2010.
- [18] Simons, M., *Sailplanes: 1965–2000*, EQIP Werbung & Verlag GmbH, 2004.
- [19] Müller, D., *Das Hornkonzept - Realisierung eines formvariablen Tragflügelprofils zur aerodynamischen Leistungsoptimierung zukünftiger Verkehrsflugzeuge*, Ph.D. dissertation, Fakultät Luft- und Raumfahrttechnik, Universität Stuttgart, Jan. 2000.
- [20] Kraus, D., *Auslegung einer formvariablen Tragflügelvorderkante eines Hochleistungssegelflugzeugs*, Semester thesis, Technische Universität München, Aerospace Department, Institute of Lightweight Structures, 2013.
- [21] Weinzierl, M., *Design der hochelastischen Sektion einer formvariablen Tragflächenvorderkante der Mü 3x Wölbflaps*, Semester thesis, Technische Universität München, Aerospace Department, Institute of Lightweight Structures, 2013.
- [22] Bubert, E., Woods, B., Lee, K., Kothera, C., and Wereley, N., “Design and Fabrication of a Passive 1D Morphing Aircraft Skin,” *Journal of Intelligent Material Systems and Structures*, Vol. 21, No. 17, 2010, pp. 1699–1717.
- [23] Olympio, K. R. and Gandhi, F., “Zero Poisson’s Ratio Cellular Honeycombs for Flex Skins Undergoing One-Dimensional Morphing,” *Journal of Intelligent Material Systems and Structures*, Vol. 21, No. 17, 2010, pp. 1737–1753.
- [24] Xu, X., *Morphing skin design for form variable airfoil cambers using a sandwich concepts*, Master’s thesis, Technische Universität München, Aerospace Department, Institute of Lightweight Structures, 2012.
- [25] Optical Systems, *Material data sheet PA2200*, Dec. 2008.

