

Summary of available Publications for the Development of MFC actuated UAVs started by Dan Inman, Onur Bilgen and John Ohanian at Virginia Tech

The development of so called Solid State Roll Control Fixed Wing Aircrafts using the MFC (Macro Fiber Composite) started at CIMSS, Virginia Tech in 2007. The team at Virginia Tech demonstrated in the following years the first fixed-wing aircraft roll control in-flight demonstration using MFCs and, to our knowledge the first *solid-state* roll control in-flight demonstration with piezoelectric materials.

This publication lists in chronically way all available publications which were published during the course of the development project.

Onur Bilgen MS Thesis (5/22/07)

Bilgen, O., 2007, "Macro Fiber Composite Actuated Unmanned Air Vehicles: Design, Development, and Testing," M.S. Thesis, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.

<http://scholar.lib.vt.edu/theses/available/etd-05222007-093740/>

Onur Bilgen PhD Dissertation (8/14/10)

Bilgen, O., 2010, "Aerodynamic and Electromechanical Design, Modeling and Implementation of Piezocomposite Airfoils," Ph.D. Dissertation, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.

<http://scholar.lib.vt.edu/theses/available/etd-08142010-142319/>

John O. Ohanian PhD Dissertation (5/12/11)

Ohanian, O. J., 2011, "Ducted Fan Aerodynamics and Modeling, with Applications of Steady and Synthetic Jet Flow Control," Ph.D. Dissertation, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.

<http://scholar.lib.vt.edu/theses/available/etd-05122011-155823/>

(ASME / BOEING 2008 Structures & Materials Award: Awarded for Best Paper in AIAA SDM 2007 Conference)

Bilgen, O., Kochersberger, K., Diggs, E. C., Kurdilla, A. J. and Inman, D. J., 2007, "Morphing Wing Micro-Air-Vehicles via Macro-Fiber-Composite Actuators," **ASME / Boeing Best Paper Award**, AIAA-2007-1785, 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, HI.

Onur Bilgen MS Thesis (5/22/07) (the link includes downloadable video)

Bilgen, O., 2007, "Macro Fiber Composite Actuated Unmanned Air Vehicles: Design, Development, and Testing," M.S. Thesis, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.

<http://scholar.lib.vt.edu/theses/available/etd-05222007-093740/>

Direct Video Link:

http://scholar.lib.vt.edu/theses/available/etd-05222007-093740/unrestricted/MS_thesis_video_compress.mov

Relevant journal publications:

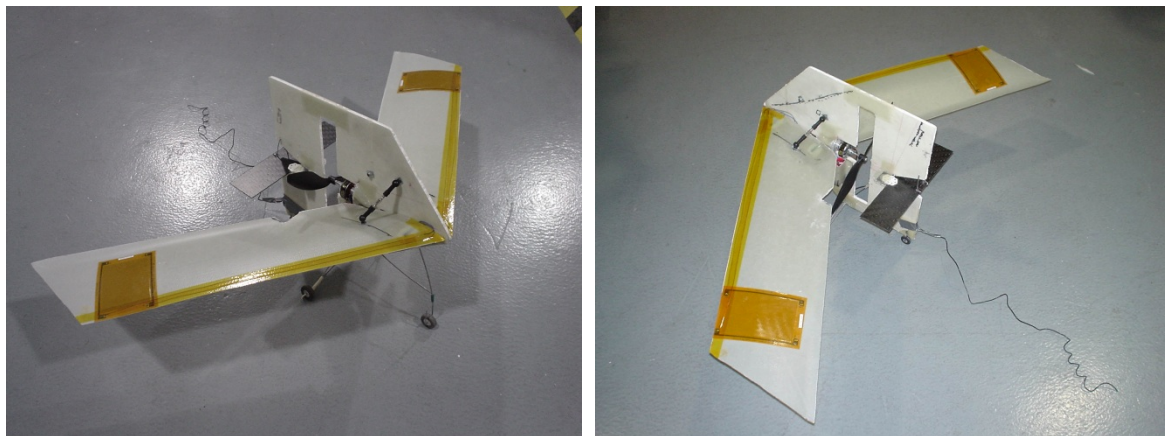
Bilgen, O., Kochersberger, K. B. and Inman, D. J., 2009, "Macro-Fiber Composite Actuators for a Swept Wing Unmanned Aircraft," *Aeronautical Journal, Special issue on Flight Structures Fundamental Research in the USA*, publication of Royal Aeronautical Society, Vol. 113, No 1144.

Relevant conference presentations:

Diggs, E. C., Bilgen, O., Kurdila, A. J., Kochersberger, K. B., Inman, D. J. and Vignola, J., 2007, "Structural characteristics via SLDV for a class of morphing micro-air-vehicles," Unmanned Systems Technology IX. Proc. SPIE, Volume 6561, pp. 65611F.

Bilgen, O., Kochersberger, K., Diggs, E. C., Kurdilla, A. J. and Inman, D. J., 2007, "Morphing Wing Aerodynamic Control via Macro-Fiber-Composite Actuators in an Unmanned Aircraft," AIAA-2007-2741, AIAA Infotech @ Aerospace Conference, Rohnert Park, CA.

Bilgen, O., Kochersberger K. B., Diggs, E. C., Kurdilla, A. J. and Inman, D. J., 2007, "Development and Testing of a Macro Fiber Composite Actuated Unmanned Air Vehicle," Presentation at the IKTS ISPA 2007 Conference, Dresden, Germany.



Virginia Tech Solid-State Roll Control Fixed-Wing Aircraft. The picture shows two MFC M8557-P1 actuators, one on each wing.

Citation:

Bilgen, O., 2007, "Macro Fiber Composite Actuated Unmanned Air Vehicles: Design, Development, and Testing," M.S. Thesis, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.



Virginia Tech Solid-State Roll Control Fixed-Wing Aircraft before its first flight on Feb 28, 2007 in Danville, Virginia.

Citation:

Bilgen, O., Kochersberger, K., Diggs, E. C., Kurdilla, A. J. and Inman, D. J., 2007, "Morphing Wing Micro-Air-Vehicles via Macro-Fiber-Composite Actuators," **ASME / Boeing Best Paper Award**, AIAA-2007-1785, 48th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, HI.

2008-2012: Characterization of Unimorph Structures with MFCs

Conference Papers:

- Erturk, A., Bilgen O., Fontenille, M. and Inman, D. J., 2008, "Piezoelectric energy harvesting from macro-fiber composites with an application to morphing-wing aircrafts," 19th International Conference on Adaptive Structures and Technologies, Ascona, Switzerland.
- Bilgen O., Erturk, A., Inman, D. J. and Kochersberger, K. B., 2008, "Macro-Fiber Composite Actuated Thin Clamped-Free Benders and Thin Simply-Supported Morphing Airfoils," 19th International Conference on Adaptive Structures and Technologies, Ascona, Switzerland.

Journal Paper:

- Bilgen, O., Erturk, A. and Inman, D.J., 2010, "Analytical and Experimental Characterization of Macro-Fiber Composite Actuated Thin Clamped-Free Unimorph Benders," *Journal of Vibration and Acoustics*, Vol. 132, 051005-1.
- Bilgen, O., Wang, Y. and Inman, D. J., 2012, "Electromechanical Comparison of Cantilevered Beams with Multifunctional Piezoceramic Devices," *Mechanical Systems and Signal Processing*, Vol. 27, pp. 763-777, doi:10.1016/j.ymssp.2011.09.002.

2008-2011: SOLID STATE VARIABLE CAMBER AIRFOILS USING MFCs

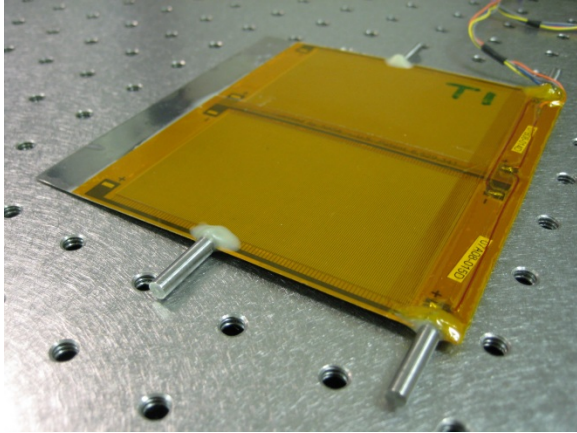
These solid-state or semi-solid-state airfoils are all unique and they have all been tested and successfully worked in wind-tunnel experiments.

Journal Papers:

- Bilgen, O., Kochersberger, K. B., Inman, D. J. and Ohanian, O. J., 2010, "Novel, Bi-Directional, Variable Camber Airfoil via Macro-Fiber Composite Actuators," *Journal of Aircraft*, Vol. 47, No. 1, pp. 303-314.
- Bilgen, O., Kochersberger, K. B., Inman, D. J. and Ohanian, O. J., 2010, "Macro-Fiber Composite Actuated Simply-Supported Thin Morphing Airfoils," *Smart Materials and Structures*, Vol. 19, 055010.
- Bilgen, O., Inman, D. J. and Friswell, M. I., 2011, "Theoretical and Experimental Analysis of Hysteresis in Piezocomposite Airfoils Using the Classical Preisach Model," *Journal of Aircraft*, Vol. 48, No. 6, pp. 1935-1947, doi: 10.2514/1.56694.

Conference papers:

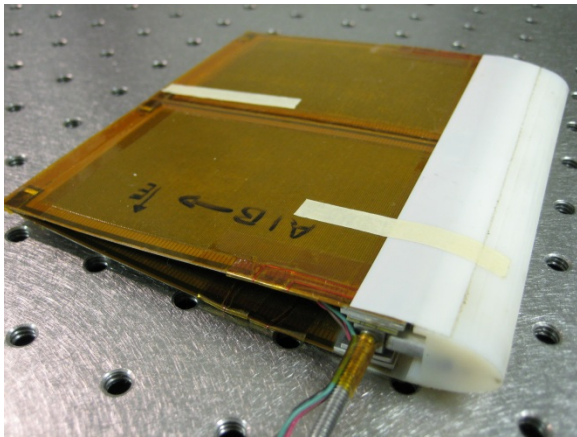
- Bilgen, O., Kochersberger, K. B. and Inman, D. J., 2008, "An Experimental and Analytical Study of a Flow Vectoring Airfoil via Macro-Fiber-Composite Actuators," *Proc. of SPIE Vol. 6930, SPIE Smart Structures & NDE 2008*, San Diego, CA.
- Bilgen, O., Kochersberger, K. B. and Inman, D. J., 2008, "A Novel Aerodynamic Vectoring Control Airfoil via Macro-Fiber-Composite Actuators," *AIAA-2008-1700, 49th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Schaumburg, IL.
- Erturk, A., Bilgen O., Fontenille, M. and Inman, D. J., 2008, "Piezoelectric energy harvesting from macro-fiber composites with an application to morphing-wing aircrafts," *19th International Conference on Adaptive Structures and Technologies*, Ascona, Switzerland.
- Bilgen O., Erturk, A., Inman, D. J. and Kochersberger, K. B., 2008, "Macro-Fiber Composite Actuated Thin Clamped-Free Benders and Thin Simply-Supported Morphing Airfoils," *19th International Conference on Adaptive Structures and Technologies*, Ascona, Switzerland.
- Bilgen, O., Ohanian, J. O., Kochersberger, K. B. and Inman, D. J., 2009, "Novel, Bi-Directional, Variable Camber Airfoil via Macro-Fiber Composite Actuators," *AIAA 2009-2133, 50th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference*, Palm Springs, CA.
- Bilgen, O., Friswell, M. I., Kochersberger, K. B. and Inman, D. J., 2011, "Surface Actuated Variable-Camber and Variable-Twist Morphing Wings Using Piezocomposites," *19th AIAA/ASME/AHS Adaptive Structures Conference*, Denver, CO.
- Bilgen, O., Saavedra Flores, E. I. and Friswell, M. I., 2011, "Optimization of Surface-Actuated Piezocomposite Variable-Camber Morphing Wings," *ASME 2011 Conference on Smart Materials, Adaptive Structures and Intelligent Systems (SMASIS2011)*, Scottsdale, AZ.
- Bilgen, O., Barbarino, S. and Friswell, M. I., 2011, "Static Aeroelastic Optimization of Surface Actuated Variable-Camber Piezocomposite Morphing Wings," **Invited plenary session talk at the 5th ECCOMAS Thematic Conference on Smart Structures and Materials (SMART'11)**, Saarbrücken, Germany.



Thin Bimorph Airfoil with Pinned Boundaries employing 4x MFC M8557-P1 Actuators. Measured two-dimensional lift coefficient change of roughly 1.46 for peak-to-peak excitation.

Citation:

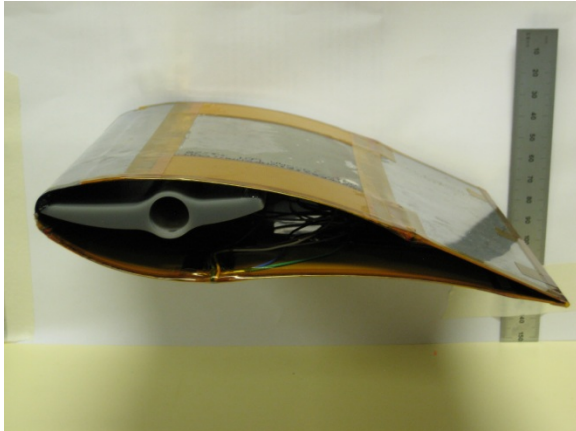
Bilgen, O., Kochersberger, K. B., Inman, D. J. and Ohanian, O. J., 2010, "Macro-Fiber Composite Actuated Simply-Supported Thin Morphing Airfoils," *Smart Materials and Structures*, Vol. 19, 055010.



Cascading Bimorph Airfoil with Semi-Solid-State Internal "Soft" Hinge employing 8x MFC M8557-P1 Actuators. Measured two-dimensional lift coefficient change of roughly 1.41 for peak-to-peak excitation.

Citation:

Bilgen, O., Kochersberger, K. B., Inman, D. J. and Ohanian, O. J., 2010, "Novel, Bi-Directional, Variable Camber Airfoil via Macro-Fiber Composite Actuators," *Journal of Aircraft*, Vol. 47, No. 1, pp. 303-314.



Solid-State Airfoil with Continuous Surface employing 12x MFC 8528-P1 actuators. This airfoil is equivalent to a symmetric NACA 0012 airfoil when excitation is zero. The picture demonstrates the response at maximum positive excitation. The airfoil is capable of reaching roughly 6% change in camber under aerodynamic loading for peak-to-peak excitation.

Citation:

Bilgen, O., Saavedra Flores, E. I. and Friswell, M. I., 2011, "Optimization of Surface-Actuated Piezocomposite Variable-Camber Morphing Wings," ASME 2011 Conference on Smart Materials, Adaptive Structures and Intelligent Systems (SMASIS2011), Scottsdale, AZ.

2009: Aerodynamic Flow Control using MFCs

John O. Ohanian PhD dissertation (5/12/11)

Ohanian, O. J., 2011, "Ducted Fan Aerodynamics and Modeling, with Applications of Steady and Synthetic Jet Flow Control," Ph.D. Dissertation, Mechanical Engineering Department, Virginia Tech, Blacksburg, VA.

<http://scholar.lib.vt.edu/theses/available/etd-05122011-155823/>

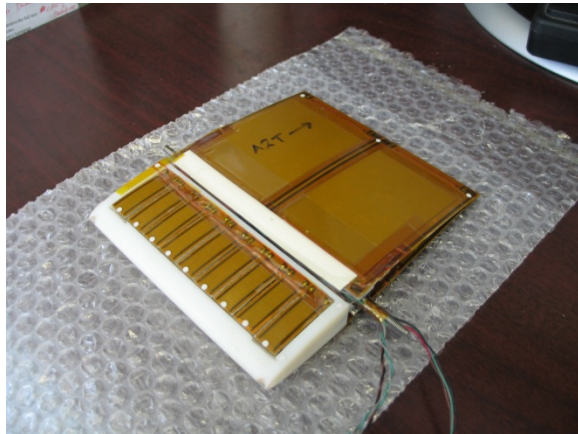
Journal Papers:

Bilgen, O., De Marqui Junior, C., Kochersberger, K. B. and Inman, D. J., 2010, "Piezoceramic Composite Actuators for Flow Control in Low Reynolds Number Airflow," *Journal of Intelligent Material Systems and Structures*, Vol. 21, No. 12, pp. 1201-1212.

Bilgen, O., De Marqui Junior, C., Kochersberger, K. B. and Inman, D. J., 2011, "Macro-Fiber Composite Actuators for Flow Control of a Variable Camber Airfoil," *Journal of Intelligent Material Systems and Structures*, Vol. 22, No. 1, pp. 81-91.

Conference papers:

Bilgen, O., De Marqui, C., Kochersberger, K. B. and Inman, D. J., 2009, "Flow Control via Piezoceramic Actuators with an Application to a Variable-Camber Airfoil via MFCs," Paper and Poster Presentation, 20th International Conference on Adaptive Structures and Technologies, Hong-Kong, China.



Airfoil with Variable-Camber Trailing Edge and Flow Control Leading Edge. The leading edge employs 9x unimorph beams with MFC M4010-P1 actuators. (The latex skin covering the airfoil is removed for clarity.)

Citation:

Bilgen, O., De Marqui Junior, C., Kochersberger, K. B. and Inman, D. J., 2011, "Macro-Fiber Composite Actuators for Flow Control of a Variable Camber Airfoil," *Journal of Intelligent Material Systems and Structures*, Vol. 22, No. 1, pp. 81-91.

2010: ALL SOLID STATE CONTROL for FIXED WING AIRCRAFT

Journal Paper (Pending Approval from AIAA)

Bilgen, O., Butt, L. M., Day, S. R., Sossi, C. A., Weaver, J. P., Wolek, A., Mason, W. H. and Inman, D. J., 2011, "A Novel Unmanned Aircraft with Solid-State Control Surfaces: Analysis and Flight Demonstration," *Journal of Aircraft*, submitted on May 23, 2011.

Conference Papers

Butt, L., Bilgen, O., Day, S., Sossi, C., Weaver, J., Wolek, A., Inman, D.J. and Mason, W.H., 2010, "Wing Morphing Design Utilizing Macro Fiber Composite," Society of Allied Weight Engineers (SAWE) 69th Annual Conference, Virginia Beach, VA, Paper Number 3515-S.

Bilgen, O., Butt, L. M., Day, S. R., Sossi, C. A., Weaver, J. P., Wolek, A., Mason, W. H. and Inman, D. J., 2011, "A Novel Unmanned Aircraft with Solid-State Control Surfaces: Analysis and Flight Demonstration," 52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials, Denver, CO.

YouTube Video Link:

<http://www.youtube.com/watch?v=KxTJBp53nO0>

PBS NOVA Video Link which aired the first flight of the solid-state control aircraft

<http://video.pbs.org/video/1786635771/>

Program: NOVA

Episode: Making Stuff: Smarter

Explore a new generation of ingenious materials, including real-life invisibility cloaks.

Host: **David Pogue**

Duration: (53:08), Premiere Date: 02/09/2011, Episode Expires: Mon 10 Feb 2014



Virginia Tech Wing Morphing Design 2009-2010 Team during a preliminary wind-tunnel test. This is a Smart-Material Corp. and CIMSS-VT Sponsored Senior Design Project between the Departments of Mechanical Engineering and Aerospace and Ocean Engineering. From left to right: Steven Day, Craig Sossi, Lauren Butt, Artur Wolek and Joseph Weaver.



Virginia Tech Wing Morphing Design 2009-2010 Team Aircraft with all solid-state MFC actuated control surfaces. The picture is taken before first flight on April 29, 2010 in Kentland Farm, Blacksburg, Virginia.

Citation:

Butt, L., Bilgen, O., Day, S., Sossi, C., Weaver, J., Wolek, A., Inman, D.J. and Mason, W.H., 2010, "Wing Morphing Design Utilizing Macro Fiber Composite," Society of Allied Weight Engineers (SAWE) 69th Annual Conference, Virginia Beach, VA, Paper Number 3515-S.

2011-2012: Bi-Stable Solid State Aircraft Wings / Aerodynamic Surfaces with MFCs

Description:

These papers present one of the first examples of realistic bi-stable wing structures (cantilevered plates) where snap-through between two stable states can be induced and controlled using MFC actuators.

Journal Papers (Pending JIMSS Approval):

Arrieta, A. F., Bilgen, O., Friswell, M. I. and Hagedorn, P., 2011 “Morphing dynamic control for bi-stable composites,” special issue in *Journal of Intelligent Material Systems and Structures*, submitted October 18, 2011.

Conference Papers:

Arrieta, A. F., Bilgen, O., Friswell, M. I. and Hagedorn, P., 2011, “Morphing dynamic control for bi-stable composites,” 22nd International Conference on Adaptive Structures and Technologies (ICAST), Corfu, Greece.