Combined morpHing Assessment software usiNG flight Envelope data and mission based morphing prototype wing development, CHANGE; an Overview Presentation

Yavuz YAMAN

Department of Aerospace Engineering, Middle East Technical University
Ankara, 06800, Turkey
yyaman@metu.edu.tr
http://www.ae.metu.edu.tr/~yyaman

Abstract

CHANGE is an FP7-AAT-2012-RTD-1, AAT.2012.1.1-2: Aerostructures Project with Grant No: 314139. It's consortium is composed of TEKEVER ASDS-Portugal (Coordinator), DLR, Deutsches Zentrum für Luft und Raumfahrt-Germany, ARA, Aircraft Research Association-UK, Universidade da Beira Interior-Portugal, Cranfield University-UK, Swansea University-UK, INVENT GmbH-Germany, Middle East Technical University-Turkey, Delft University of Technology-Netherlands. The project started on 01 August 2012 and will end on 31 July 2015.

Morphing in aircrafts is of the upmost importance in order to offer a greater efficiency, versatility and performance during the assigned mission. Moreover an aircraft with the capability to adapt itself to each given situation tends to achieve positive results to a range of different missions instead of requiring a specific aircraft to conduct each specific mission.

The main objective of this project is to study and develop a novel morphing system which integrates up to four different morphing mechanisms (Leading edge and tailing edge camber changes, twist change, swept wing and telescopic wing) into in a single wing and to demonstrate this new ability in flight. In order to achieve this four main flight phases (Take-off, loiter, high-speed dash and landing) will be considered and various materials will be studied, and if necessary developed, for aerodynamically efficient as well as structurally durable and producible wing/ control surfaces. The design will first be verified by computational aerodynamic and structural analyses. The produced wing/ control surfaces then will be subjected to ground vibration tests and wind tunnel tests. Finally the aircraft, having the developed wings, will undergo flight tests.

Keywords Morphing wings; unconventional control surfaces; aerodynamic efficiency, compliant structures

1. CHANGE Project Work Packages and Intented Project Impact

The CHANGE project is composed of nine Work Packages, WPs. Their brief definitions and together with the critical milestones to be achieved are given in the following section (CHANGE DoW, 2012).

1.1. *Work packages*

- WP1: Project Management
- WP2: Requirements and Application– This Work Package defines the requirements and validation scenarios of the morphing wing and assessment software to be developed in CHANGE. Conceptual design parameters required for the aerodynamic design of the morphing wing in take-off, loitering, high speed to insertion mission and landing are also decided in WP2. The materials to be used and the system and the flight test requirements are also specified here.
- WP3: Development of software to assess best morphing layout tailored for UAV applications – This WP will deal with the design and development of the morphing assessment software that determines the optimal shape a given wing should morph into, given a set of optimisation targets and constrains. An aerodynamic performance prediction for the isolated wing is simultaneously provided with the actuator settings corresponding to that aerodynamically optimal outer shape

- WP4: Mission based design of the morphing system prototype – This WP structurally designs the morphing prototype wing focusing on four missions.
- WP5: Mission based detailed design of the morphing technologies for UAV – This WP will be devoted to the detailed design of the morphing system prototype applied to the UAV. This WP will ensue after the Critical Design Review and will be in charge of designing the integration of the different morphing systems which will integrate the wing
- WP6: Skin development – This WP will be assigned for the development of the membrane material of the morphing system prototype. The design and development activities for the skin tooling and the development and manufacture of the skin will also be accomplished in WP6.
- WP7: Development and manufacture of the prototype wing – This WP will manufacture the designed morphing wing with all the integrated morphing technologies
- WP8: Experiment and flight tests – Ground Vibration Tests, Wind Tunnel Tests and Flight Tests will be conducted in this WP. WP8 will also intend to validate the morphing assessment software through detailed comparison with the data obtained from the wind tunnel testing
- WP9: Dissemination, Exploitation and Technology Watch- The definition of exploitation strategies, dissemination and promotion of the project results and to the determination of potential contributions to standardisation communities will achieved in WP9. The project Web page www.change-fp7.eu is also maintained within WP9.

1.2. *Project impact*

The primary aim of the CHANGE Project is to increase the performance and efficiency of an aircraft at all phases of the flight. The CHANGE consortium will address this by developing a software that will provide the designer, a tool that gives out the most efficient wing shape for any given mission, given the type of morphing that the aircraft is able to perform. The project also intends to construct a wing which combines several morphing technologies, such as wing camber, wing twist, telescopic wing and wing twist, into a single wing. This is shown in Figure 1.

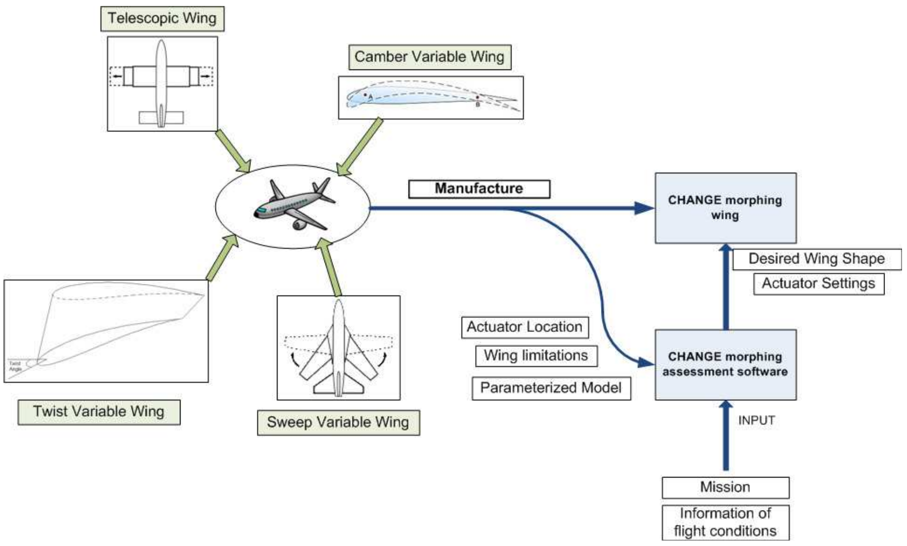

Fig. 1. The scope of CHANGE Project (CHANGE DoW, 2012)

The objective of those is to enable an aircraft to fulfil several types of missions with the best performance in each of these missions. This is the most direct impact from project CHANGE, to increase the performance of wings and this boost in performance during the flight of an aircraft will undoubtedly decrease the amount of fuel emissions during the mission of the aircraft. Those expected impacts can further be elaborated as follows.

1.2.1. Reduce the overall fuel consumption and hence CO2 and NOx emissions of future air transport aircraft by continuous optimal adaptation of the wing to the flight phase

(Rypdal, 2000; Imperial College Document , 2008) estimate that 5-20% of the fuel consumed throughout the flight is due to the landing and take-off cycle (LTO), which comprises all activities near the airport taking place below 1000m as shown in Figure 2. If the flight is a short range flight, the LTO cycle activities will further increase the total fuel consumption. CHANGE Project is intended to enable the aircraft to be able to fly at increased performance at any flight phase including the LTO phases of take-off and landing and hence will contribute to advantageous results of less emissions.

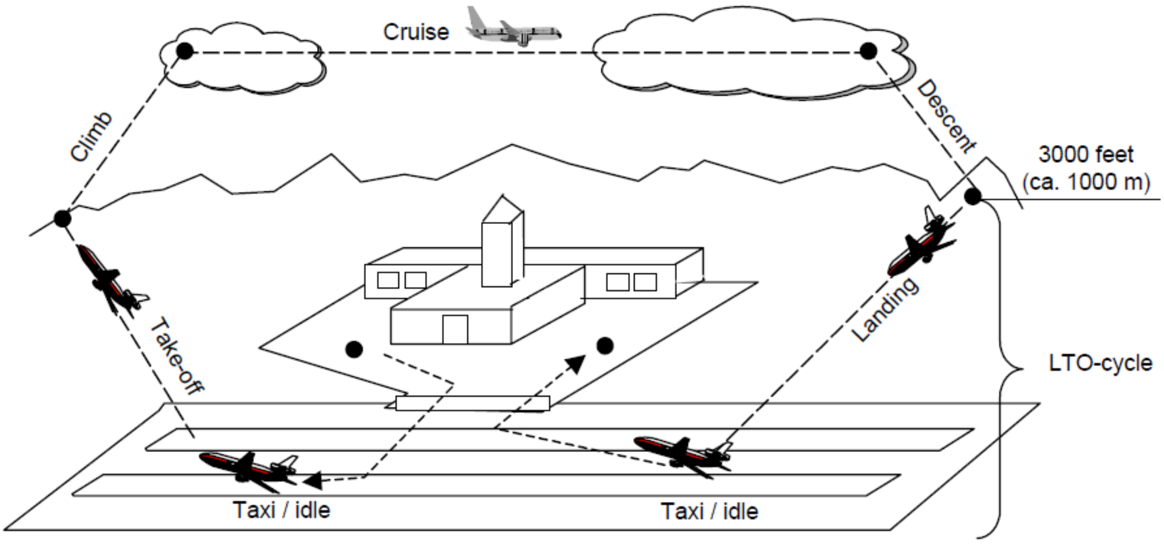

Fig. 2. Usual transport aircraft operations during a mission (Rypdal, 2000)

The technology to be developed within CHANGE Project will be originally validated at a smaller scale by applying that to a Unmanned Arial Vehicle (UAV), but the Project's long-term vision is to transfer it for applications in transport aircraft. A study performed by NASA revealed that only "1% of reduction of fuel consumption can produce savings of as much as $140.000 each year for each aircraft" (Gilyard *et al.*, 1999). Hence it is believed that future commercial morphing wing applications will be able to lead to huge savings as well.

1.2.2. Develop a support tool/software for the design of future morphing wings

The developed tool/ software can be used for the design of future morphing wings of passenger aircraft. The software would have total control over the morphing actuators of the wing, enabling the full automatization of the wing's shape morphing. With this kind of automatic software, the aircraft would at all times fly with the highest performance possible, since that the software would automatically and continuously change the shape of the wing to the most efficient wing shape possible regarding the information provided by the environment.

1.2.3. Enable aircraft to recover from situation prone for accident

The morphing wing to be developed within CHANGE Project could change its shape in an emergency situation, such as the involuntary stall of the aircraft's wing or engine malfunction, by increasing its planform area and therefore decreasing the stall speed and increasing the L/D ratio of the aircraft in order to salvage the aircraft from an impendent crash (e.g. This would enable the aircraft to recover its flight preventing a possible accident, since the aircraft would now be able to fly at a lower speed).Two examples of aircraft flight which culminated in unfortunate accidents of these kinds, are the Birgenair Flight 301 (1996) and Air France Flight 447 (2009). In both those accidents the pilot had a false value of speed indicated by a faulty air speed indicator (ASI), indicating a higher speed than the one in which the aircraft was flying (Boeing 757, 1999; AF Flight 447, 2011). Due to these erroneous airspeed indications, the pilot decreased the velocity until it had passed the stall speed of the aircraft. Unable to recover from this state, both aircraft crashed. The wing of CHANGE would enable such situations to be fully recoverable, applying the required changes to the wing shape in such situations to restore the original flight plan.

1.2.4. Enable UAVs to perform civilian missions that are not possible today or with better performance

Current UAV platforms have been designed for one specific mission type with no real capability to perform other missions without requiring a large amount of modifications to the wing and aircraft. Future UAVs comprising a morphing wing similar to that developed in CHANGE Project would be able to fly at their optimum performance during all their flight phases. Consequently a single UAV would be able to operate various missions which would otherwise require several different UAVs to perform different types of missions.

1.2.5. Decrease of the aircraft's level of acoustic emissions

The wing to be developed in CHANGE Project will alter its shape in order to fly with the highest performance possible during the whole course of the flight. This performance increase will require a high lift over drag ratio at all phases of the flight. That would be achieved by an increase in the laminar flow over the wing that is also responsible for decreasing the level of noise emitted from the aircraft.

1.2.6. Increase the passenger's comfort during the flight

In a climb or descent condition, since the wing will be at all time at its peak performance, the required actions will be performed more smoothly than usual and hence the passengers will not fell discomfort.

1.2.7. Enhance EU's level of expertise in this field.

The morphing technology studies and the manufacture of the wing will provide a larger level of expertise for the consortium partners in manufacturing these kind of structures. One other achievements of CHANGE Project consists in developing a software capable of assessing the best wing shape possible for each given mission or activity. The consortium in CHANGE Project was assembled in order to promote synergy and collaboration between experts in the field of morphing technologies and structures (e.g. DLR, UBI, SU, METU, TUD), skin materials experts (e.g. INVENT, CU) and an SME and UAV manufacturer (TEK).

1.3. *Project intentions and achievements*

Table I gives the targeted objectives and intended technical achievements of CHANGE Project together with the respective work packages. Table II, on the other hand, outlines the intended CHANGE main contributions for call AAT.2012.1.1-2.

Table I – CHANGE Targeted Objectives & Technical Achievements (CHANGE DoW, 2012)

CHANGE Targeted Objectives	CHANGE Technical Achievements	Expected from WP
Design and develop an assessment software tool to evaluate best morphing configuration	Creation of a software module applicable to commercially available software, capable to evaluate the best morphing configuration using different complementary morphing systems in one platform.	WP3
Design a morphing prototype wing comprised of different morphing systems given four different performance driven missions	Design of a prototype wing with complementary morphing systems capable to morph to the highest performance configuration given four different base missions.	WP4 WP5
Demonstration of the functionality and complementarities of the morphing systems including its main advantages for performance increase and possible concerns.	Multi-mission based design of a wing comprising different complementary morphing systems. Validation of the developed in both wind tunnel and real flight testing.	WP4 WP5 WP7 WP8
Analyze the practicability and possibility of integration of various morphing techniques in one wing.	Multi-mission based design and development of different morphing techniques within one wing	WP4 WP5 WP7
Validate the morphing wing.	Validation through wind tunnel testing and flight test with a morphing wing	WP8
Research novel types of skin for morphing applications	Design and manufacture of skin tooling and a skin for the wing developed	WP6
Create a stepping stone for a future cognitive morphing assessment software that automatically retrieves the information from the environment and its flight mission and morphs accordingly, in order to provide the best performance in flight	Design and development of a software capable to evaluate the best morphing configuration given the flight environment and mission status of the aircraft.	WP3
Increase the flight performance of aircraft using innovative systems.	Design and development of both a morphing assessment tool, intended for the design of high performance morphing wings and as a stepping stone for a future coginitive morphing assessment system; and a morphing wing with several complementary morphing systems capable to change its configuration in order to fly with the highest performance during the mission flight.	WP3 WP4 WP5 WP7 WP8
Define a stepping stone for the insertion of CHANGE to air transport	Design and development of a prototype wing for a UAV platform and system's validation through wind tunnel and real flight testing. Positive results will provide a functional system to be used for larger aircraft.	WP4 WP5 WP7 WP8

Table II – Intended CHANGE Main Contributions for Call AAT.2012.1.1-2 (CHANGE DoW, 2012)

AAT.2012.1.1-2Target Outcomes	Project CHANGE Main Contributions
(…)Research work will address a wide range of innovative solutions and technologies for the aircraft, its systems and components for optimum use of energy and reduction of pollution (noise and emissions).	Development of a wing comprising several morphing systems with the benefit of increased performance during all flight missions of the UAV. CHANGE will be devoted to create a stepping stone for use of this system of air transport aircraft through its validation using a UAV platform.
Advanced concepts and technologies for increased and optimised use of light-weight metallic, composite materials, including metal laminates, in primary structures(…)	The CHANGE project envisions the development of an innovative morphing wing with novel structures and skin materials
(…)advanced concepts and techniques for application of(…)'smart' structures and morphing airframes with a potential to reducing green hous gas emissions.	CHANGE will be focused on designing and developing a wing using "smart" structures and morphing systems to increase the aircraft's performance, potentially reduce the fuel burned during flight missions.

The CHANGE consortium members also published some results about the project studies.

Werter *et al.* 2013 presented a two-level approach for the conceptual design of a morphing aircraft. The first level was about the morphing concept to be designed and the second level was a generic morphing aeroelastic optimisation framework designed to optimise the morphing configuration of the wing. The design approach was succesfully applied to the optimisation of both a twisting wing and a shearing wing for a low-speed, 40 mph, and a high-speed, 80 mph, flight, resulting in drag reductions of 0.65% to 7.00% compared to a non-morphing wing. It was also shown from the morphing energy requirement point of view that consideration of twisting mechanism was more beneficial as compared to the shearing mechanism because of the considerable amount of energy required to shear a skin. The results of the specific wing considered also revealed that the shear morphing can lead to more drag reduction than twist morphing.

In another study (Beaverstock et al. 2013 a) a software framework was developed and the potential benefits of span morphing for an Unmanned Air Vehicle (UAV) of 25kg was evaluated for performance and efficiency. The effects of morphing on the flight stability and control was also presented. Figure 3 gives the software framework used.

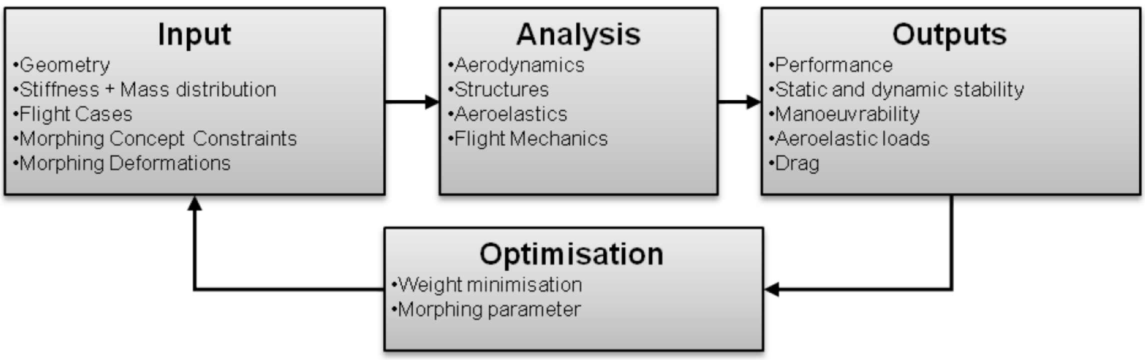

Fig. 3. Outline of morphing software framework (Beaverstock et al. 2013 a)

In another study, where the mission included high speed cruise and loiter phases, the span and twist morphing were modelled in order to investigate their effects on the range and endurance of UAV. (Beaverstock *et al.* 2013b). The results indicated that the optimum speed for aerodynamic efficiency increases with span retraction. Introduction of a linear twist improved the optimum efficiency, though not significantly.The results also shown a reduction in root bending moment for both span and twist morphing which could potentially reduce the weight and increase the mission performance of the UAV.

Two different methodologies for the design of a UAV morphing wing were studied and presented (Ciarella *et al*. 2013). The first one is called the wing-twist design methodology that allows for morphing of only one wing parameter during the optimization which is the twist. Since the optimization uses low-fidelity CFD analysis, the method is relatively fast. The second approach uses camber as well as twist change for the optimization of the wing performance. Compared to the one-step method, it is slower because it uses high-fidelity CFD also during the design. Considering a morphing UAV, like the one in the CHANGE project, it was shown that, in general, both camber and twist morphing have the possibility to generate a better wing performance for each flight phase. It was also clearly shown that the selected airfoil shape was important for the performance of the wing

Acknowledgments

The work presented herein has been partially funded by the European Community's Seventh Framework Programme (FP7) under the Grant Agreement 314139. The CHANGE project ("Combined morphing assessment software using flight envelope data and mission based morphing prototype wing development") is a L1 project funded under the topic AAT.2012.1.1-2 involving nine partners. The project started on August 1st 2012.

References

Werter, N. P. M. and De Breuker, R., Beaverstock, C. S., Friswell, M. I., Dettmer, W. G., (2013) Two-level conceptual design of morphing wings, 54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference 08-11 April 2013, Boston, Massachusetts, USA

Air France Flight 447: Black Boxes Indicate Pilot Error Caused Accident (2011), ABC News website

Beaverstock, C. S. and Ajaj, R. M., Friswell, M. I., Breuker, R., Werter, N. P. M. (2013) Effect of span-morphing on the longitudinal flight stability and control, AIAA Guidance, Navigation and Control Conference, 19-22 August 2013, Boston, Massachusetts, USA

Beaverstock, C. S. and Ajaj, R. M., Friswell, M. I., Breuker, R., Werter, N. P. M. (2013), Optimising mission performance for a morphing MAV, AIAC2013, 7. Ankara International Aerospace Conference, 11-13 September 2013, METU, Ankara, TURKEY

CHANGE, Combined morpHing Assessment software usiNG flight Envelope data and mission based morphing prototype wing development, Grant agreement no: 314139, Annex I - Description of Work, Version date: 2012-03-20

Ciarella, A. and Hahn, M., Wong, P., Peace, A. (2013), Comparison of aerodynamic design methodologies for morphing UAV wings, AIAC2013, 7. Ankara International Aerospace Conference, 11-13 September 2013, METU, Ankara, TURKEY

Erroneous Airspeed Indications Cited in Boeing 757 Control Loss (1999) Flight Safety Foundation – Accident Prevention; Volume 56, Number 10

Gilyard, G., and; Geogie, J., Barnicki, J. (1999) Flight test of an adaptive configuration optimization system for transport aircraft, NASA Center for AeroSpace Information

Rypdal, K. (2000), Aircraft Emissions, Intergovernmental Panel on Climate Change, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Background paper for the energy sector, United Nations Environment Programme, New York, USA

Technical Discussion Document 4.2 (2008), Including Climate Impacts of NOX in a Dynamic Cost Indexing Tool, Innovative Cooperative Actions of Research and Development in EUROCONTROL Programme CARE INO III; Imperial College, London, UK

About the author

Yavuz Yaman yyaman@metu.edu.tr

Dr. Yavuz Yaman is a graduate of METU (B.Sc., 1981, Mechanical Engineering; M.Sc., 1984, Mechanical Engineering) and University of Southampton (Ph.D., 1989, Department of Aeronautics and Astronautics). His research interests are the structural dynamics, smart structures, active vibration control and aeroelasticity. He is the local coordinator of the CHANGE Project at METU and METU is the dissemination leader of CHANGE Project.