

REPORT DOCUMENTATION PAGE

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14. ABSTRACT This fundamental study served to formulate and predict numerically incompressible airfoil and wing performance in terms of entropy generation and develop a useful understanding of its role in design. This work is part of a larger effort to define system-level energy-based design across the spectrum of aircraft size and speed. Work was performed at both AFRL and at Clemson with the intent of developing in-house expertise at AFRL. Both a 2-D airfoil model and a 3-D wing model study are underway for incompressible, steady flow conditions. Methods for computing both the local and the full field entropy generation rates from the numerical solutions have been validated. Baseline cases have been validated against known solutions and lifting line theory. A methodology to quickly define twisted wings and create high resolution numerical grids was implemented. We are able to predict the entropy generation rate for an airfoil and a wing of arbitrary shape and to correlate this to exergy destruction in the flow field. In the remaining months of this project, we will take a closer look at improved turbulence models and grid independence and recommending some changes to AFRL's					
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ENERGY-BASED DESIGN METHODOLOGY FOR AIR VEHICLE SYSTEMS: AERODYNAMIC CORRELATION STUDY

AFOSR: FA9550-04-0111/Dr. John Schmisser AFOSR-NA

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Research Objectives

The specific objectives of this work are:

1. demonstrate a methodology to optimize two-dimensional airfoils with shape manipulation based on computational fluid dynamic flow estimates of exergy destruction,
2. participate and contribute on a fundamental numerical study with AFRL/VAAC to evaluate entropy production for wings,
3. collaborate with AFRL in its energy-based design program, and
4. prepare joint publications with AFRL on these studies.

Objective 2 was modified so as to study the effect of different wing twists on energy utilization, such as might occur with a morphing flexible wing of fixed planform responding to different wing loadings at various mission segments. This fit better with AFRL needs. Originally, we were to vary Reynolds number by length scale variation.

Status of Effort

This fundamental study served to formulate and predict numerically incompressible airfoil and wing performance in terms entropy generation and develop a useful understanding of its role in design. This work is part of a larger effort to define system-level energy-based design across the spectrum of aircraft size and speed. Work was performed at both AFRL and at Clemson with the intent of developing in-house expertise at AFRL.

Both a 2-D airfoil model and a 3-D wing model study are underway for incompressible, steady flow conditions. Methods for computing both the local and the full field entropy generation rates from the numerical solutions have been validated. Baseline cases have been validated against known solutions and lifting line theory. A methodology to quickly define twisted wings and create high resolution numerical grids was implemented. We are able to predict the entropy generation rate for an airfoil and a wing of arbitrary shape

and to correlate this to exergy destruction in the flow field. In the remaining months of this project, we will take a closer look at improved turbulence models and grid independence and recommending some changes to AFRL's in-house code.

Accomplishments

A two-dimensional airfoil numerical parametric study of the entropy generation rate of an NACA 0012 airfoil was tested against existing lift and drag data. A steady RANS equation with a realizable $k-\epsilon$ turbulence model was used with a proposed volume-averaged entropy production model. For an airfoil in steady flight, all drag can be equated back to entropy generation rate. We found good agreement for the predicted entropy rate using the effective viscosity (Figure 1). Differences were related to the turbulence model.

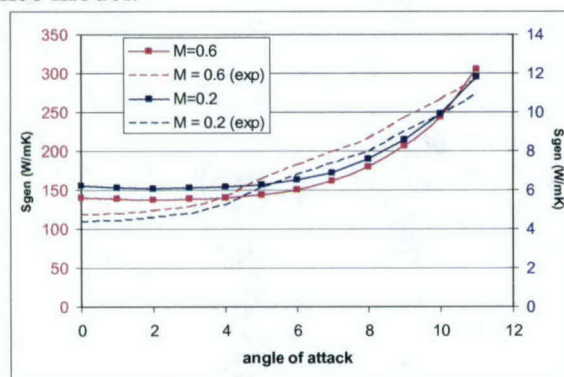


Figure 1. Comparison of predicted entropy generation rate and estimated value based on measured drag coefficient for NACA 0012 airfoil

The entropy generation rate of a flexible, rectangular flying wing with specified lift distribution was predicted numerically and correlated with lifting-line theory. This study initiates the effort to morph wings to meet mission segments. The time-accurate, compressible, RANS equations with a $k-\omega$ turbulence model were used. Two lift distributions were applied: the elliptical distribution, known to develop the least induced drag, and the parabolic distribution, purported to minimize the entropy generation rate. These form the precursor to a study of arbitrary lift distribution. To develop a specified lift distribution on a rectangular wing requires imposing a spanwise twist. A method for twisting the wing to the correct shape and applying a numerical grid on that shape was

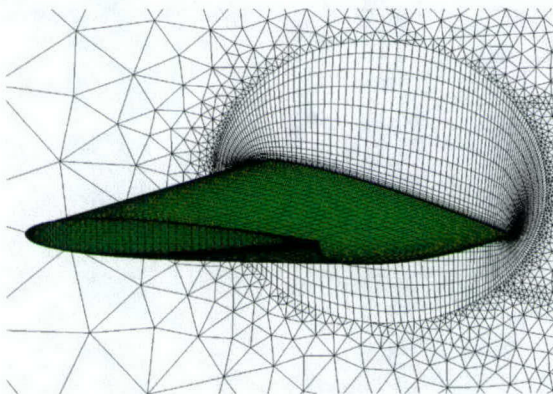


Figure 2. Twisted wing (parabolic case) and example of flow grid.

developed (Figure 2). The entropy generation rate trends were consistent with predicted and anticipated flow convection. Highest entropy generation rates were found in the

leading edge, boundary layer, and downstream in the wing tip vortex (Figure 3). This study is continuing.

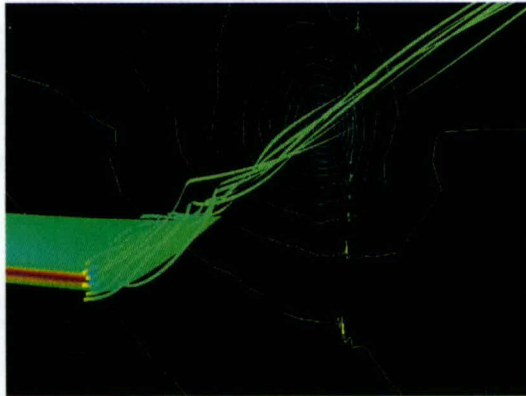


Figure 3. Wing tip vortex and pressure contours with overlay of local entropy generation rate contours predicted for elliptic case of morphing wing ($M = 0.2$, $AR = 6$, $c = 1$ m).

Personnel Supported

- a. Faculty
Richard Figliola, Professor, Clemson University
- b. Graduate Students
Jason Stewart, MS degree candidate, Clemson University

Publication

Li, H., Figliola, R., Stewart, J., "Exergy Based Design Methodology for Airfoil Shape Optimization," Proc. AIAA MAO Conference, September 2004.

Two additional publications are in preparation this fall.

Interactions/Transitions

- a. Participation

Figliola, R, Exergy Study for Aircraft Systems Integration: Entropy Estimation, VASD Symposium, AFRL, August 2004.

Stewart, J, Exergy Study for Aircraft Systems Integration: Wing Aerodynamics Assessment, VASD Symposium, AFRL, August 2004.

Figliola, R. "Exergy Based Design Methodology for Airfoil Shape Optimization," AIAA MAO Conference, September 2004. with H. Li (Clemson graduate student)
- b. Consultative/Advisory Functions

Second law analysis team member, Air Force Research Laboratory, VASD/VAAC, May 17 – July 30, 2004. Spent three weeks at AFRL interacting with AFRL staff, summer students, and contractors on (1) numerical approach to

second law analysis, and (2) on setting numerical boundary conditions on a high speed ejector. AFRL staff involved: D. Moorhouse, J. Camberos, D. Jackson.

c. Transitions

Validation of entropy calculations in Cobalt-60/AVUS and suggested changes to code for broader applicability to wing/vehicle design. AFRL. Dr. Jose Camberos.

New Discoveries/Inventions/Patents

None.

Honors/Awards

None.