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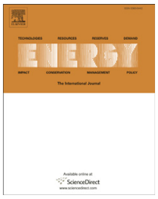

Evaluation of the local exergy destruction in the intake and fan of a turbofan engine

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ABSTRACT

Modern air crafts and aviation industry are dominant consumers of fuel. The application of exergy analysis is powerful tool in the design and performance judgment of these systems. In this study, the local entropy generated and exergy destroyed in the intake and fan of a turbofan engine are investigated. The fan in concern has a highly twisted blade and is installed in the CF6-50 turbofan engine. The flow field is solved at the flight condition. Furthermore, the local entropy generated, including thermal and viscous types, is computed from the predetermined flow field. Results show regions of entropy production at the boundaries as well as across the blade-to-blade passage. Moreover, remarkable entropy is generated at the wake region near the trailing edge, at the supersonic bubble attached to the leading edge, and across the blade-to-blade passage shock wave. Exergy destruction calculated computationally through the fan and the intake shows a good agreement with that calculated analytically. It is found that, under the cruise condition, the fan contributes by 1.95 MW of losses in useful work potential while this value for the intake is found to be neglected compared with the fan, 4.6 kW.

1. Introduction

Exergy analysis, entropy generation minimization, and thermoeconomics are powerful tools in the design, and performance judgment of any energy system. Exergy is the key parameter in determining the maximum theoretical limits of energy efficiency of engineering devices. The most important issue is to identify the components of a system which are responsible for losses and try to minimize these losses and the associated costs of this system. The concept of exergy or availability analysis has been used for several years for the analysis of ground-based power producing systems and other many cogeneration systems. However, its application to the aerospace vehicles and other propulsion systems has to some extent been limited in the literature.

Energy systems for modern air crafts are important industrial sector that is an ideal candidate for the application of exergy analysis and thermodynamic optimization [1]. According to the IEA(International Energy Agency), aviation oil consumption rises on average by 2.5% per year and it is projected to reach about 2.6% of the global energy consumption in 2030. Today there are more than 16,800 commercial aircraft in operation. This number is expected to grow by 3.8% per year reaching more than 44,000 by year 2030 [2].

Aircrafts are very complex systems that are composed of a large number of components which are exposed to changeable and unsteady environmental conditions. Different studies involving commercial aircraft systems have been developed to apply exergy analysis. One of these works related to exergy analysis for aircraft engines was done by Turgut et al. [3]. They investigated the exergy destroyed for the components of a general electric CF6-80 turbofan engine at sea level. According to the results it is found that the most exergy destructive unit in the propulsion system is the combustion chamber which contributed by about 35.76 MW of useful work lost. Moreover, the fan is the second high irreversible unit after the combustor which contributed by about 3.61 MW of exergy destruction. In another study, Turgut et al. [4]. performed availability computations of a turbofan kerosene-fired engine with an afterburner at sea level and at an altitude of 11,000 m. Exergy destructions in each of the engine components are determined and the exergy efficiency values for both altitudes are calculated. In the fan, exergy destruction was found to be 2.52 MW (total engine is 198.68 MW) with an exergetic efficiency of 80.6% at sea level. At cruise conditions exergy destruction in the fan was found to be 0.78 MW (total engine is 67.48 MW) with an exergetic efficiency

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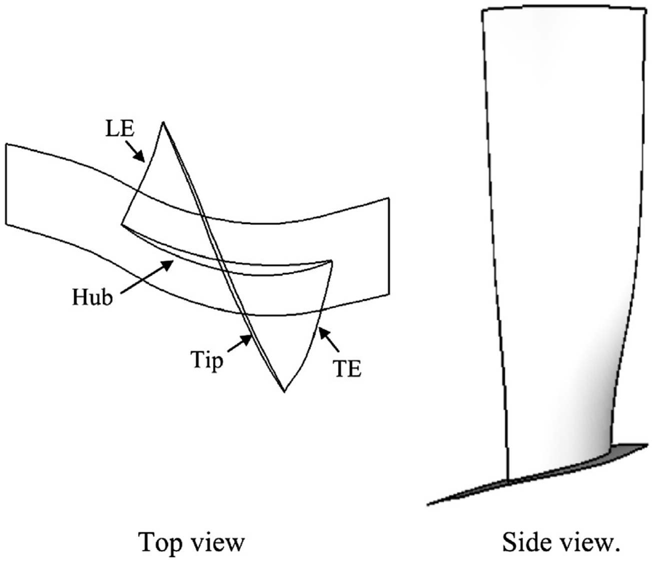

Fig. 1. Fan blade profile and geometry.

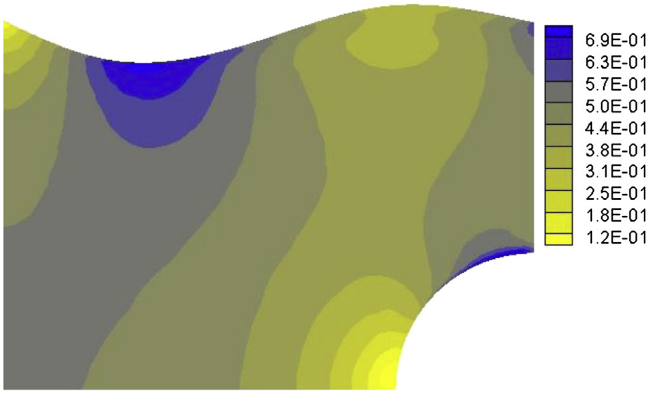

Fig. 3. Contours of absolute Mach number through an axisymmetric section through the intake.

of 86.9%. The total exergy efficiency of the engine was found to be 66.1% at sea level and 54.2% at 11 km altitude cruise conditions.

Etele and Rosen [5] applied an exergy analysis to a turbojet engine over flight altitudes ranging from sea level to 15,000 m in order to examine the effects of using different reference environment models. The results of this analysis using a variable reference environment, which is equal to the operating environment at all times, are compared to the results obtained using two constant reference environments; sea level and 15,000 m altitude. They found that the actual rational efficiency of the turbojet decreases with increasing altitude, ranging from a value of 16.9% at sea level to 15.3% at 15,000 m altitude. In the most extreme cases considered, the rational efficiency calculated using a constant reference environment varies by approximately 2% from the variable reference environment value. One of the more recent work related to exergy analysis for aircraft engines is done by Tona et al. [6]. They presented an exergy-based analysis as to evaluate the global performance of a typical turbofan engine and its components. The study presented values for exergy efficiency over the whole flight cycle and flight phases considering exergy destruction and estimating internal and exhaust flow costs. An exergy analysis of advanced hypersonic vehicles like the scramjet is presented and discussed as well by many researchers [7–12].

The analytical thermodynamic analysis of entropy generation rate for a system is just like a black box analysis which is not suitable to provide the complete picture for what is happening inside that system. That is because details of the locations, causes, and sources of irreversibilities cannot be obtained from this analysis concept. In other words, the overall thermodynamic analysis takes into account the states of fluid at inlet and exit ports only considering the system a black box. However, the specific local features of irreversibilities in fluids engineering systems are necessary for its phenomenological interpretation. The local rate of entropy generation is an important issue to assess if and where the design could be improved. Moreover, entropy generation mapping provides the designer with detailed and clear information about the causes of the intrinsic flow irreversibilities [13]. Previous studies have often dealt with losses of availability on a global scale. However, local irreversibilities can be tracked in complex configurations computationally. Therefore, engineering devices can be redesigned locally in order to enhance the overall performance. This objective can be attained when the entropy-based design is performed with the knowledge obtained from CFD(computational fluid dynamics) and experimental techniques [13]. Exergy based CFD analysis is of high fidelity and has a significant advantage as a tool for system synthesis and design. CFD analysis of exergy and entropy production helps identifying the source and specific location of highest entropy production. However, the work related to CFD analysis of exergy and entropy generation is limited in literature.

The flow field in a low specific speed radial compressor stage is performed with a commercial CFD package by Iandoli and Sciubba [14]. The entropy generation rate is computed locally, to assess if and where the design could be improved. Their results confirm that

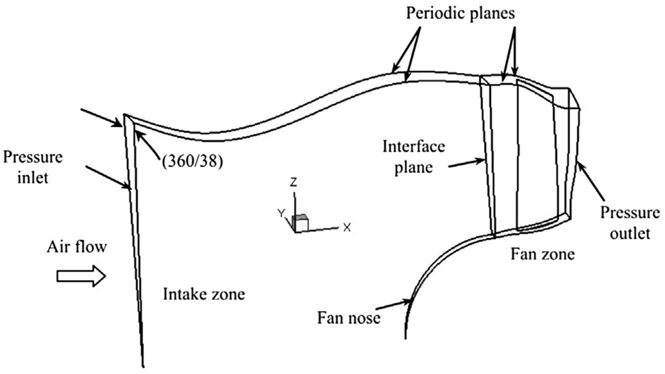

Fig. 2. The domain of the solution and the boundary conditions.

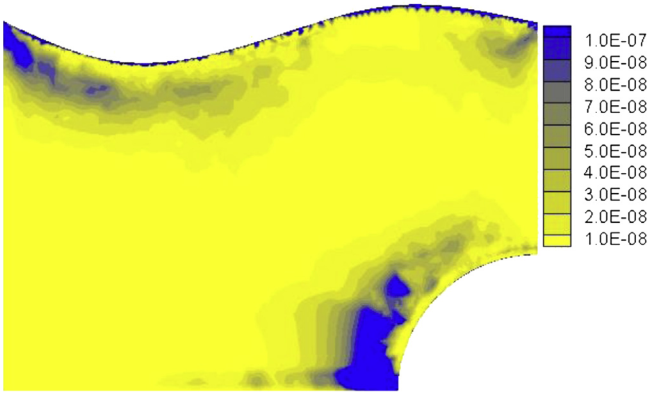

Fig. 4. Contours of entropy generated in an axisymmetric section through the intake, W/K.