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Computational Work to Support FAP/SRW Variable-Speed Power-Turbine Development

Ali A. Ameri
The Ohio State University, Columbus, Ohio

April 2012

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Abstract

The purpose of this report is to document the work done to enable a NASA CFD code to model the laminar/turbulent transition on a blade. The purpose of the present work is to down-select a transition model that would allow the flow simulation of a Variable-Speed Power-Turbine (VSPT) to be accurately performed. The modeling is to be ultimately performed to also account for the blade row interactions and effect on transition and therefore allow accurate accounting for losses. The present work is however limited to steady flows. The low Reynolds number k-ω model of Wilcox and a modified version of same will be used for modeling of transition on experimentally measured blade pressure and heat transfer. It will be shown that the k-ω model and its modified variant fail to simulate the transition with any degree of accuracy. A case is therefore made for more accurate transition models. Three-equation models based on the work of Mayle on Laminar Kinetic Energy were explored and the Walters and Leylek model which was thought to be in a more mature state of development is introduced and implemented in the Glenn-HT code. Two-dimensional flat plate results and three-dimensional results for flow over turbine blades and the resulting heat transfer and its transitional behavior are reported. It is shown that the transition simulation is much improved over the baseline k-ω model.

Introduction

The key goal of the Subsonic Rotary Wing project is to enhance utilization of civil rotorcraft to relieve airport congestion and throughput capacity. One concept that has been advocated for this purpose is the use of tilt rotors to allow vertical takeoff of rotorcraft. In order to bring about fuel efficiency the main-rotor speed varies from 100 percent at takeoff to 50 percent at cruise. This can be achieved by using a transmission driven by a power turbine with minimal speed change. To avoid the added weight of the transmission a variable speed power turbine can be used instead of the transmission or in combination. To investigate the penalties associated with this alternative, various analytic tools are required. Such analysis tools require the capability to perform the physical modeling of these turbines within their operating envelope. This envelope is characterized by low Reynolds numbers, a characteristic of the power turbines, and a wide variation in the incidence angles due to the variation in the shaft speed. Lessons from the operation of Low Pressure Turbines and studies carried out for Low Pressure Turbines may be a source for guidance.

Low Pressure Turbines have been reported to suffer loss of efficiency at higher altitudes under cruise conditions. This condition corresponds to a condition of low Reynolds number. Such low Reynolds number condition gives rise to separation of the flow on the suction side of the blades and in the case of absence of reattachment on the blade would give rise to large losses of efficiency. For the Power Turbine we have the additional requirement to also obtain accurate performance estimates for separation caused by a negative incidence. In short, better guidance for the design of the Power Turbine may be obtained if accurate and reliable simulation tools are available. Even in the absence of separation, the state of the boundary layer has a large effect on the loss in total pressure and must be addressed. Boyle and Ameri (Ref. 1) have shown that the prediction of the state of the boundary layer has a significant impact on the accuracy of the prediction of losses.

Research and development work on analytical tools such as CFD codes utilizing transition models have been ongoing. In recent years, advances in modeling have been reported that may benefit the present work (Refs. 2 to 6).

Use of trusted analytic tools can lead to understanding of the behavior of various designs and their operations under design and off-design conditions. Owing to the expected range of Reynolds numbers, the issue of transition will be paramount. The present report only addresses implementation of transition models and testing under steady conditions. It does not address the wake induced transition. That will be the subject of a future work.

Transition Modeling Options

Implementation of transition models in NASA codes is not a new endeavor. As an example Ameri and Arnone undertook this task as reported in Reference 7 by implementing the then available intermittency models in a three-dimensional code. One of the ways that transition is modeled is to use an algebraic transition criterion within a flow solver. Such transition models are sensitive to the state of the boundary layer and indicate the start and extent of the transition. The progress of transition is marked by an intermittency factor, which is zero for a laminar flow and unity for a fully turbulent flow. This type of modeling implemented as shown in Reference 7 worked rather well but its use was limited by the necessity of computing velocity-profile measures such as momentum thickness. These measures are not readily computable in three-dimensional passages and in codes which use general multi-block grids or unstructured grids. This method of modeling was therefore excluded from the options.

Another option that was entertained was the idea of computing the flow in two stages. The method was to initially carry out a laminar flow computation and to note the point of separation. The second computation would then run the flow as laminar up to separation and then turn the flow turbulent at the point of separation. Again, this scheme was not picked because of lack of generality, as the mode of transition may not be separation-induced.

A viable option involves using intermittency methods along with a two-equation turbulence model. Various researchers have taken up this approach. They appear to have settled on an additional transport equation for a Re_θ (Reynolds number based on momentum thickness) type variable which obviates the need for computation of momentum thickness through boundary layer integration (Refs. 2, 3, and 6).

Another option available is to use transport equations that are set up for transition and turbulence and model them in a phenomenological manner (Ref. 4) without the necessity to compute any boundary layer or integral quantities. In the work we have undertaken, and about to report, the transition prediction using the k-ω model in its original form and a modified form as well as a k-ω based three-equation model developed by Walters and Leylek (Ref. 5) which was developed with emphasis on transition in its development. The newer models were implemented in a NASA code called Glenn-HT and tested. We will report on the various aspects of implementation and the results obtained thus far.

In the event that the performance of the model is not satisfactory, we will explore other options such as the intermittency models described.

In the following, we will first describe the data chosen for testing of various models. Next, we will review the grid generated for the chosen blade model. We will then describe the attempts at prediction of the data. We will emphasize the transition model of Walters and Leylek, its description, implementation and the results obtained.

Source of Transition Data

As described earlier, the flow in turbine blade passages of VSPT is expected to have low Reynolds numbers and thus be subjected to flow transition and separation. Coding turbulence models requires access to data for verification. We have access to data for transition as occurs as by-pass and do not have access to data for separated flows. Suitability of the models to separation induced transition is not

therefore specifically checked. In part two of this work as we vary the incidence angles, separation will be an important aspect of the flow. We will compare the losses under those conditions to the available data for losses. The separation aspect may be an important aspect to investigate in the future.

Data of Giel et al.

The data used for this part of our work is from the experiment of Giel et al. (Ref. 8). They were obtained for an industry provided blade profile designated at NASA Glenn as "GE2." Blade GE2 was a first stage turbine blade for a GE heavy frame power turbine (2500 °F class). Blade loading and nearly full-span heat transfer coefficient (Nusselt number) data were obtained.

The design Reynolds number based on axial chord and exit conditions (designated by subscript '2') was 2.68×10^6. Data were also obtained at 50, 25, and 15 percent of the design value. The design pressure ratio was 1.443. Data were also obtained at −25 and 20 percent of this, and at inlet incidence angles of ±5°. Eight cases were presented in the paper, but data are available for a total of 13 cases. The nominal 15 percent value for Re_2 = 375,000 is used in this report. The case designated as 15 percent is data we will work with in this report.

Table 1 lists the blade dimensions and some pertinent data.

TABLE 1.—GEOMETRIC DATA FOR GE2

Parameter	Value
axial chord	129.8 mm (5.110 in.)
pitch	130.0 mm (5.119 in.)
span	152.4 mm (6.000 in.)
d, leading edge	18.4 mm (0.726 in.)
turbulence grid	25.4 mm square bar
blade passages	11

(*d* = 2 × minimum radius of curvature)

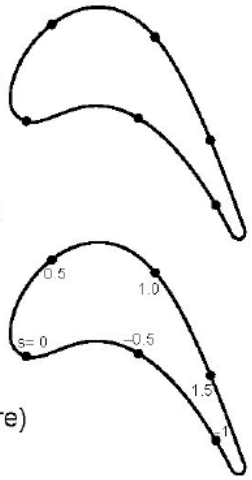


Figure 1, taken from (Ref. 8), clearly demonstrates the effect of Reynolds number on midspan suction surface flow transition. The plot shows clearly the transition from laminar to turbulent blade heat transfer as evidenced by a steep rise in heat transfer on the suction side and by curving up the heat transfer curve (Nusselt number) on the pressure side.

In this work the mid-span data is used for two-dimensional computations. The inlet turbulence was specified as measured at 13 percent and the pressure ratio and the Reynolds number were matched to the experimental conditions. Wall Temperature was specified as constant for the simulation runs.

For the three-dimensional runs the span-wise boundary layer thickness is specified = 37 percent of span.

Other Data

We supplement the data for GE2 with flat plate laminar and heat transfer and friction factor data taken from literature (as presented in Ref. 9). The Mach number chosen was approximately 0.2 and the Reynolds number based on local streamwise position from the leading edge of the plate covers five decades on the log-log plots to be presented. The flat plate case is notional and is for a zero pressure gradient case.

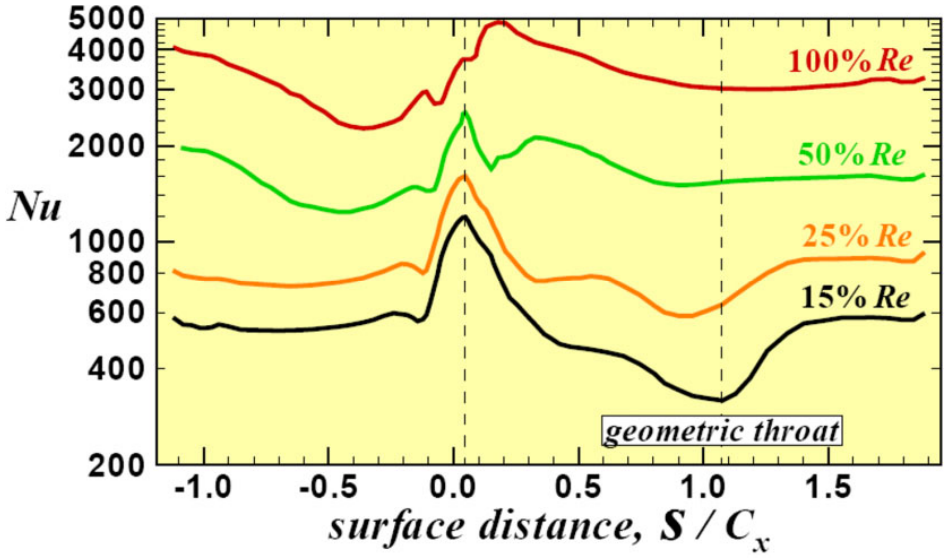


Figure 1.—Nusselt number variation for GE2 blade versus wetted distance on the blade surface for four different Reynolds numbers.

Computational Grid

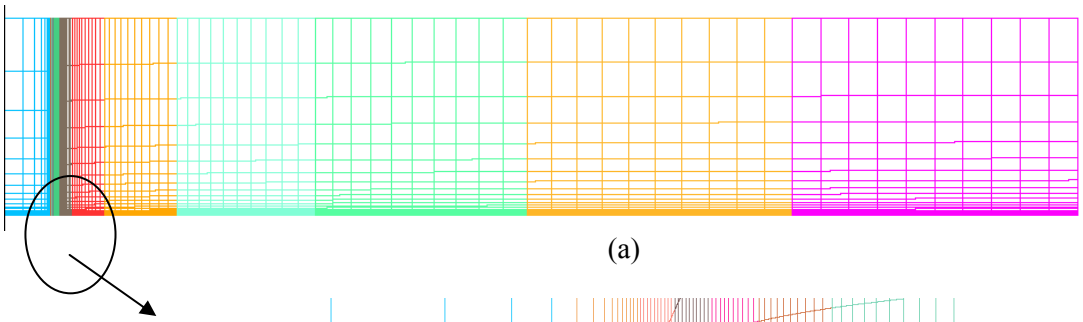
The grids used for CFD computations are generated using a commercial software tool called GridPro (Program Development Corporation). The software uses an elliptic solver to smooth an initial algebraically generated grid. The software generates a multi-block grid.

Two geometries were used for this work. A two-dimensional grid for a flat plate computation and two-dimensional grid for the Giel et al.'s GE2 geometry (Ref. 8). A three-dimensional grid is also generated for GE2 but the details and the results, to be obtained, will be presented in subsequent reports. As shown in Figure 2, the flat plate grid starts upstream of the flat plate. Grid is refined near the leading edge (shown in Fig. 2(b)) and expands proceeding downstream. It is highly refined in the cross-stream direction to allow resolution in the laminar subgrid regime (y+ = 1). The grid is generated in 16 blocks.

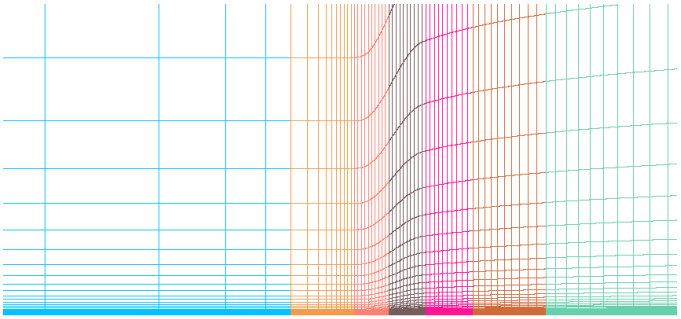
For the GE2 blade, for the three-dimensional grid (results not presented in this report), taking advantage of the symmetry of the passage, only half of the passage is gridded. The grid was constructed using 100 blocks. This applied to both the two-dimensional and three-dimensional cases that were generated. As is the practice with grid generation when using the software GridPro, an inviscid grid is generated first and subsequently viscous grid is generated using clustering. Clustering was done for the blades' surfaces (and the endwall surface for the three-dimensional grid). The spacing was chosen such that the first grid lines were at a dimensionless wall distance (y^+) of near unity. Figure 3(a) and (b) show a two-dimensional and three-dimensional grid for the computations to follow. The inlet plane was situated to match the measurement stations in the experiment namely, at one axial chord upstream of the blade. The exit plane was placed at a measuring station corresponding to approximately two axial chords downstream.

The three-dimensional grid consists of 610,000 grid points with 65 grid points used in the spanwise direction. The two-dimensional grid consists of 9500 points.

Results of the three-dimensional computations are not reported in this document and will be addressed in the future.

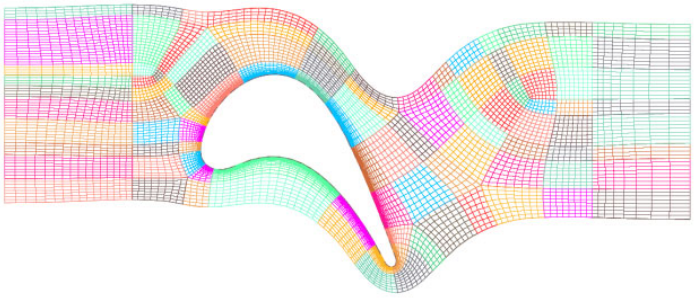


(a)

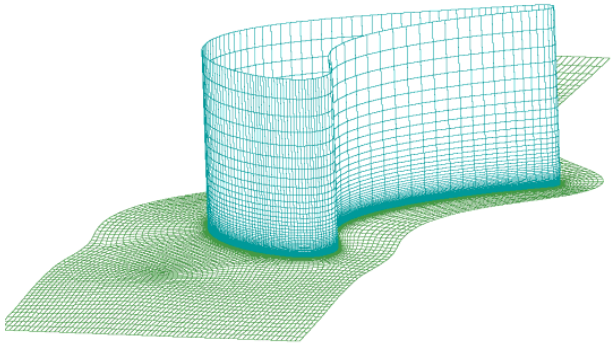


(b)

Figure 2.—(a) Grid for the two-dimensional grid and (b) near leading edge of the plate.



(a)



(b)

Figure 3.—(a) The midspan grid and (b) The full three-dimensional grid.

Glenn-HT Computer Code

The computer code used and modified in this work is the Glenn-HT code. The code has a Graphical User Interface where the capabilities are illustrated. The code can be described as follows.

Glenn-HT is FORTRAN90 code. It is designed to be a multi-physics code and presently is capable of performing solid conduction and compressible fluid flow. It is written in modular form and follows object oriented programming concepts.

The code solves the unsteady compressible Navier-Stokes equations using a multigrid scheme and dual time stepping. An explicit Runge-Kutta solver is used as a smoother. The code uses a Multi-block structured grid but the blocks can be arranged in an unstructured manner. It uses a finite volume formulation. The default solver uses a central difference convective scheme, 4th order artificial dissipation with eigenvalue scaling helps to dampen oscillations and 2nd order differencing is used near shocks. Second order upwind scheme is also available. The code has been used in numerous studies and is held to be a reliable tool.

Parallel Computing

The 100 blocks of the GE2 case or the 16 blocks of flat plate are assigned to multiple CPUs. The relative sizes of the blocks determine how many CPUs may be used in an efficient manner. In this work a maximum of 20 CPUs were used for the GE2 case and 8 for the flat plate.

Modeling Effort

Initial attempt at modeling the heat transfer on the GE2 blade was with the *k*-ω model. Our attempt's lack of success in obtaining good results led us to seek a better transition model. Our experience with the *k*-ω model and Walter-Leylek' s̃ *k*-ω-k_l model is reported below.

K-Omega Model

The low Reynolds number variant (Ref. 10) is implemented in the code. As shown in Figure 4, the modeling produced a laminar flow solution in the immediate vicinity of the stagnation point and as it has been the community's experience, we observe that the model goes through transition prematurely. Figure 4 presents the heat transfer rate described in terms of Nusselt number on the GE2 blade at mid-span. Computations using the low Reynolds number *k*-ω model designated as the default version shows good match with the data at the leading edge. The agreement deteriorates soon after as the flow becomes fully turbulent in a short distance. Wilcox, in his book (Ref. 10), describes a possible way of adjusting the transition process in his model. The manner in which the transition process occurs in the model is described through the illustration shown in Figure 5, in which the friction factor for flow over a flat plate is plotted. There are two locations on the graph marked as $(Re_x)_k$ and $(Re_x)_{\omega.}$ The following expressions are used to compute these two thresholds: The factor 90,000 is known as the minimum critical Reynolds number for infinitesimal disturbances $(Re_x)_{cr}$ when adjusted yields constants for the model that do not violate basic rules. β_0, α, and α^* are constants in the *k*-ω model that determine the location and extent of transition.

$$(Re_x)_k = (Re_x)_{cr} * (\beta_0/\alpha^*) \quad (1)$$

$$(Re_x)_\omega = (Re_x)_{cr} * (\beta_0/\alpha\alpha^*) \quad (2)$$

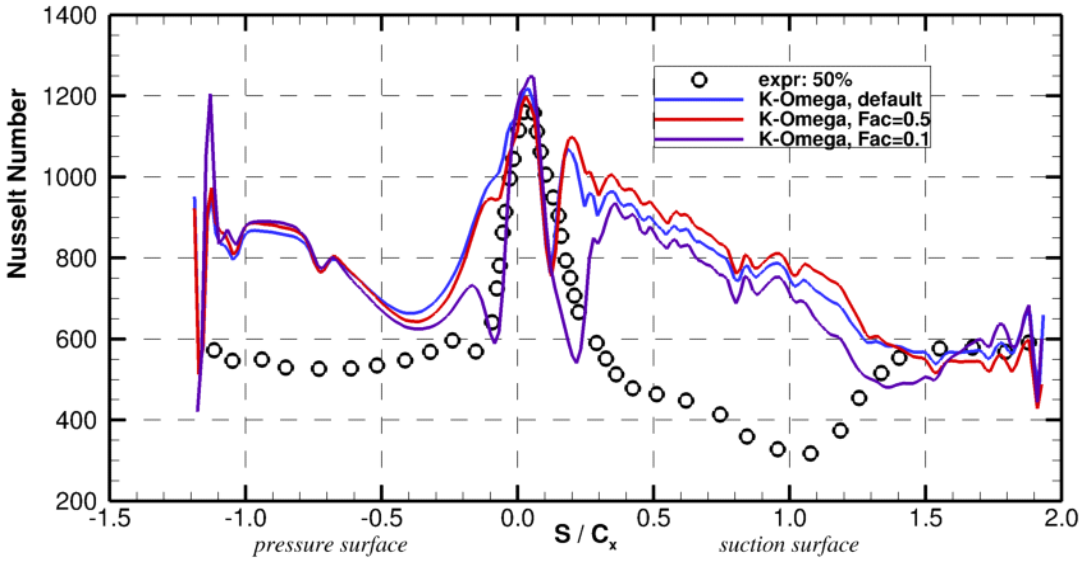


Figure 4.—Nusselt number on GE2 blade with *k*-ω model. The data is form (Ref. 8) for the 50 percent span.

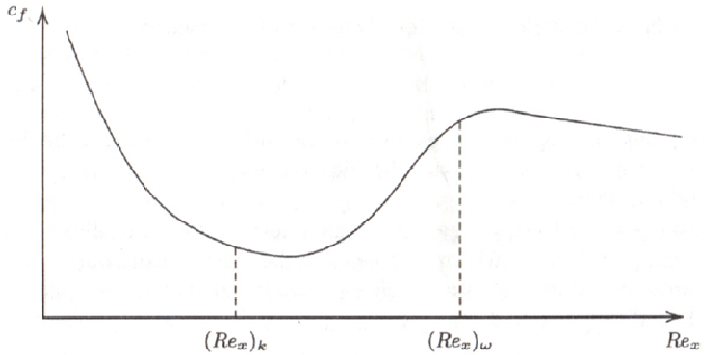


Figure 5.—A schematic of skin friction variation for a boundary layer undergoing transition from laminar to turbulent flow.

The value of $(Re_x)_k$ should be lower than $(Re_x)_\omega$ for transition to first begin and for the latter to stabilize the flow and not allow it to continue amplifying. We chose to multiply both of the two thresholds by a factor ("*Fac*") and thus move the transition downstream. Values of $(Re_x)_k$ and $(Re_x)_\omega$ of 90,000 and 122,500 produce the constants that are the values given by Wilcox.

If $(Re_x)_{cr}$ is replaced by $(Re_x)_{cr}$ /*Fac*, the new form would allow for moving the transition location downstream. As shown in Figure 4, the factor "*Fac*" causes the transition point to shift downstream. The fully turbulent flow results are not changed as would be required by this change. Unfortunately, although there is some effect on transition, the agreement with the data is not satisfactory and does not warrant adaptation as a remedy.

Walters and Leylek Model

To the author's knowledge there are two types of models that allow for transition modeling in a flow field. One type is as described by Suzen and Hwang (Ref. 2) and have been improved in many publications such as those in References 2 and 3. These models cast transition correlations in the form of transport equations thus making them suitable for flow field computations. The other type, such as the model of Walters and Leylek (Refs. 4 and 5), was developed with the process of transition built-in from the start. Walters and Leylek report that in developing their model(s) their intention was for the model to be as "hands off" for the user, requiring no modification for different application cases. It is a phenomenological model as opposed to an empirically based model. It is a single point model and does not require non-local or integral quantities. That latter fact is important enough that we did not choose (and did not see how to implement) the model of Pacciani et al. (Ref. 6) because it requires quantities that were not "single point" although the results of application of the model to two-dimensional separated flows were shown to be quite promising.

Turbulence models and some transition models rely upon turbulence diffusion and interaction with shear to promote transition. Experimental and computational evidence (Ref. 11) suggest that for the bypass transition that may not be the mechanism. The laminar profile starts being affected by free stream turbulence as low as 1 percent by shifting momentum from outer region to inner region near the wall. At the same time, large amplitude and low frequency streamwise fluctuations lead to increase in friction and wall heat transfer resulting in bypass transition as these streamwise fluctuations grow and breakdown. The low frequency aspect is critical. Shown by Moss and Oldfield (Ref. 12), the wall heat transfer does not respond to high frequency spectra in the free stream where as the low frequency oscillations produces an increase in the level of wall heat transfer. Called "Splat Mechanism," described again by Bradshaw (Ref. 13). Volino and Simon (Ref. 14) showed, by measuring the spectra of fluctuations in the free stream and in the boundary layer, that $-u'v'$ in the boundary layer upstream (in the pre-transitional region) occurs at the same frequency as v' in the upstream and thus is responsible for these oscillations. While the streamwise fluctuations do not change the mean velocity profile, they do lead to bypass transition. Boundary layer is selective to certain free stream eddy scales and low-frequency disturbances in the boundary layer are amplified by the mean shear. The dynamics embodied in these streamwise fluctuations, in the model of Walters and Leylek, is captured by a "Laminar Kinetic Energy" equation through a modification of the concept devised by Mayle and Schultz (Ref. 15). Splats occur only for eddies with large length scales relative to the wall distance. Walters and Leylek have distinguished a "wall limited" large scale and "non-wall limited," or small scale eddies in the near wall region as shown from Figure 6 taken from Reference 4. The effective eddy size designated in that figure delineates between larger eddies that contribute to the laminar kinetic energy (k_L) and smaller ones that contribute to the turbulence. Start of transition is initiated by transfer of energy from the laminar kinetic energy to the turbulent fluctuations once a threshold is reached. Additional measures are implemented in the model to allow for natural and mixed mode transition. The turbulence model originally (Ref. 4) consisted of transport equations for laminar and turbulent kinetic energy and rate of dissipation of kinetic energy of turbulence, k_L, k_T, ε. In a later paper (Ref. 5) the transport equations solved were modified to include ω, the inverse turbulent time scale. It is suggested that the latter form leads to a better representation of the breakdown of laminar kinetic energy to turbulence. This form was implemented in the Glenn-HT code.

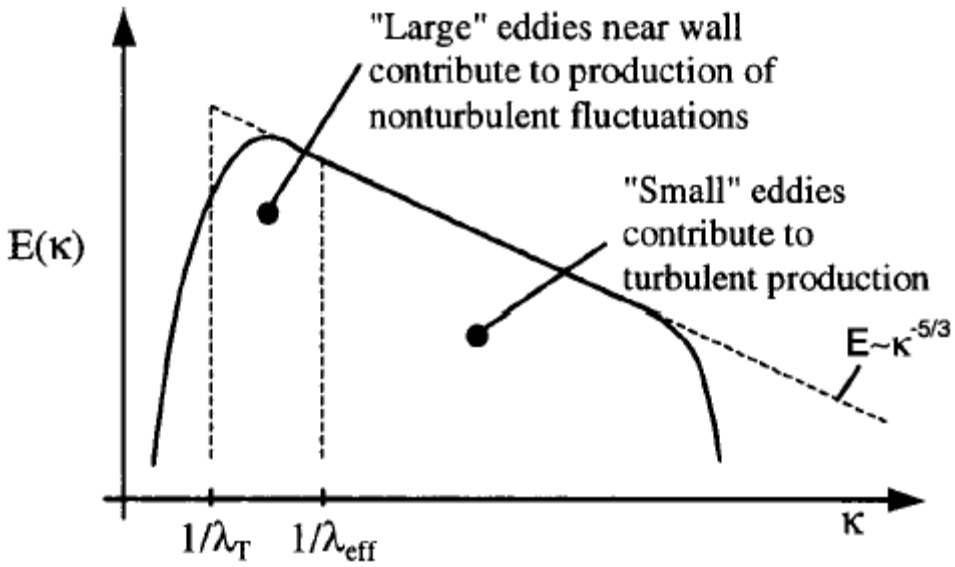


Figure 6.—Delineation of scales relevant to production of laminar and turbulent kinetic energy.

Some Aspects of the Implementation of the Model

The model was implemented into NASA's Glenn-HT code. As the code is primarily an explicit code, the model equations were also implemented in an explicit manner. There are particular considerations about the implementation of the present model that will be briefly addressed.

- Computation of distance to the wall had to be added to the code as the FORTRAN 90 version of Glenn-HT did not include this computation. The basic *k*-ω model which was originally implemented in the code, does not use the distance to the wall. Computation of wall distance as implemented is exclusively done for blocks having a wall boundary. For blocks having more than one wall boundary, the harmonic average of the individual wall distances was used for the effective quantity. For blocks not having a wall boundary the wall distance was designated as "very large." As such, some care needs to be exercised in the process of grid generation not to develop meshes that have blocks neighboring walls that are too thin. As the wall distance within a block spans several orders of magnitude, the practical implementation of this is not very restricting.
- Three variables (instead of one) had to be defined for the eddy viscosity, turbulent thermal diffusivity and turbulence diffusion required by the model. The standard method is to use the eddy viscosity and use turbulent Prandtl number and Schmidt number to model other fluxes.
- Additional model specific variables were defined to store the above and additional variables and to carry the "jacobian" of the source terms.
- The model calls for Neumann boundary conditions for laminar kinetic energy, turbulent kinetic energy and rate of dissipation on the walls as well as Dirichlet boundary conditions for laminar and turbulent kinetic energies. This over-specification was thought to be unsound and as it is the standard practice, we decided to use Neumann boundary conditions for the kinetic energies and Dirichlet for the rate of dissipation.
- As stated earlier the model equations were treated explicitly. Few of the source terms thought to be contributing to the stiffness of the equations were linearized and treated implicitly to help with that issue. This part of the code may require more work and pointwise coupling of the model equations maybe explored. As implemented presently, there is a severe reduction in CFL as it relates to the model equations.

Source code is available on NASA computers upon request.

Results

Flat Plate

The plots of coefficient of friction (C_f) and Stanton number (St) for flow over a flat plate are shown in Figures 7 and 8. Figure 7 shows the variation of friction factor, $C_f = \tau_w / (0.5\ \rho\ u_\infty^2)$, or normalized wall shear stress by the dynamic head against the local Reynolds number. The figure presents two lines belonging to a specific inlet turbulence intensity and computed on two different grid refinement levels. The lines show that the results are converged in grid resolution and that the transition effect appears reasonable. Also, the results of C_f show very good match to both the theoretically based laminar flow solutions and measured turbulent flow values reported in Reference 9.

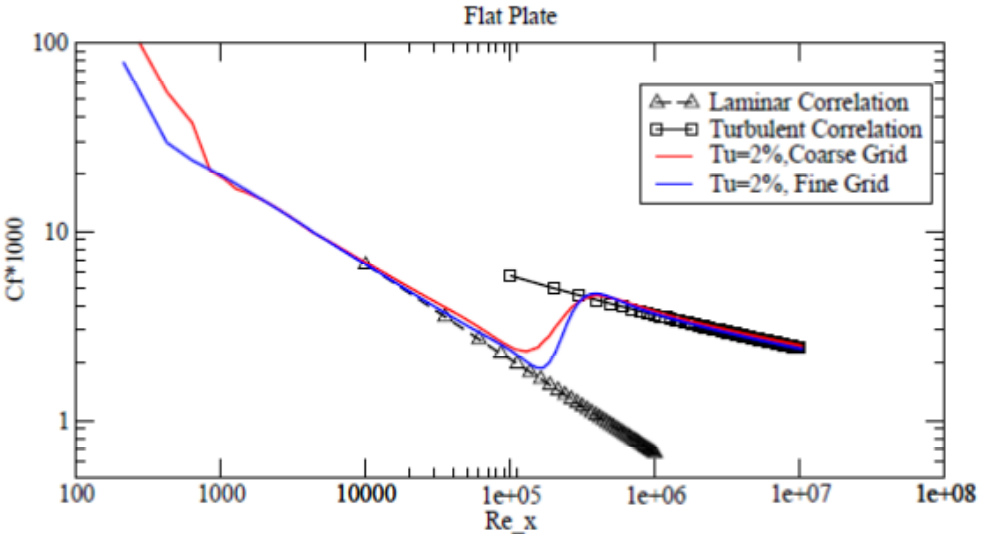


Figure 7.—Friction factor on a flat plate computations with Walters-Leylek model and comparison with data from Reference 9.

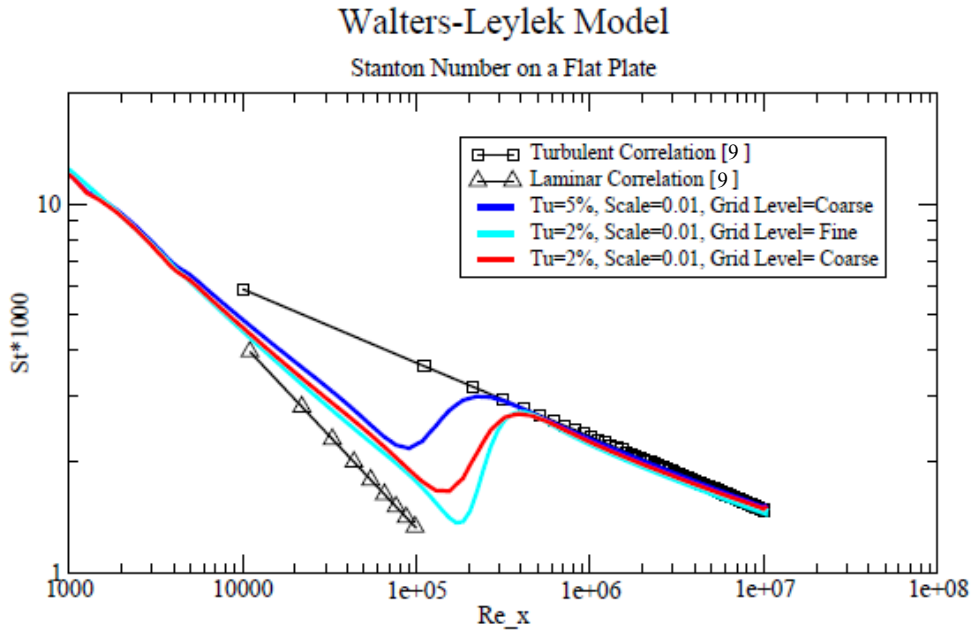


Figure 8.—Transitional Stanton number on a flat plate and comparison with to data from Reference 9.

The plot showing the variation of Stanton number with the local Reynolds number also shows a good match with the turbulent flow correlation reported in Reference 9. The plot of Stanton number of Figure 8 includes two levels of grid resolution as well as two levels of turbulence intensity. Agreement with the laminar flow heat transfer is imperfect showing an enhancement that appears to increase with turbulence intensity. Although this effect is indeed plausible- owing to increase in laminar wall heat transfer due to free stream turbulence- the fact that the agreement with laminar flow improves upon grid refinement suggests that further increase in grid refinement may remove this seeming enhancement. The location of transition shows a physical movement upstream with increase in turbulence intensity which is physically correct. The results make enough physical sense that we can turn our attention to the blade results.

GE2 Blade Comparisons

Pressure

Two-dimensional runs were made to compare with mid-span results of GE2 experiment. As is the case with Glenn-HT code, the computations are started on a coarse grid and once that solution has reasonably converged, the results are interpolated to a twice as refined grid and the iteration scheme is continued until convergence. The results of the "coarse" and "fine" grid are shown in Figures 9 and 10. Figure 9 shows the pressure distribution on the blade. Before discussing the agreement between the computations and the data, it should be remembered that in the experiment, the hub endwall had a very thick boundary layer and thus the pressure distribution from a two-dimensional computation should not match the three-dimensional run. Agreement with pressure will be reviewed when three-dimensional runs are made in the near future.

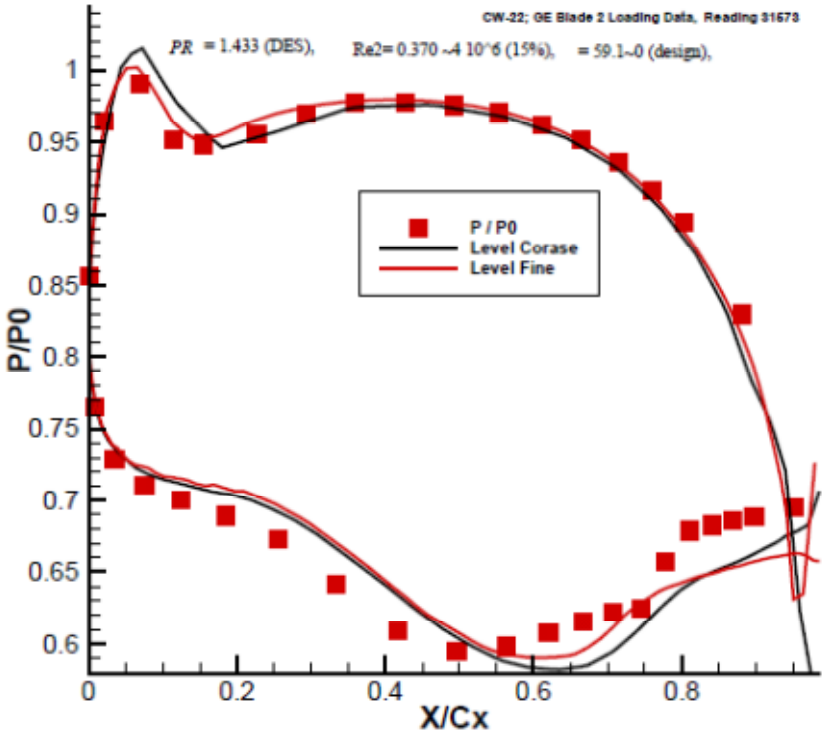


Figure 9.—Pressure distribution at the midspan of GE2 blade and comparison to data from Reference 8.

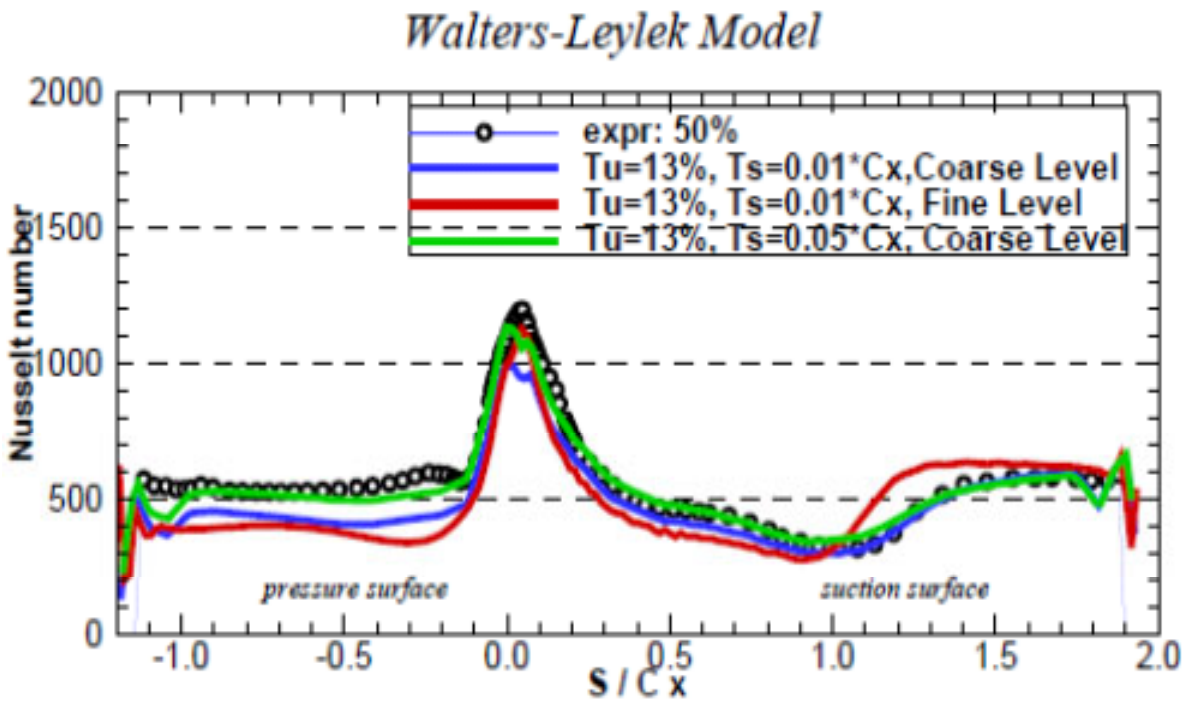


Figure 10.—Nusselt number at midspan of GE2 and comparison with experimental data of Giel et al. (Ref. 8) at 50 percent span.

Nusselt Number

In Figure 10, the ordinate is the Nusselt number and the abscissa is the normalized wetted distance on the suction side and pressure sides. Nusselt number is defined as:

$$Nu_{Cx} = hC_x / k \tag{3}$$

where C_x is the axial chord of the blade k is the thermal conductivity of the fluid and h is the heat transfer coefficient defined as:

$$h = \frac{q_w}{(T_{aw} - T_w)} \tag{4}$$

in Equation (4), q_w is the wall heat flux, T_w and T_{aw} are the wall temperature and the recovery temperature, respectively. The T_{aw} in the experiment (Ref. 8) was computed by an expression involving the recovery factor,

$$r = \mathrm{Pr}^{1/3} \tag{5}$$

where Pr is the Prandtl number which is a physical property of the fluid.

The equation for the recovery temperature is:

$$T_{aw} = T_s\left(1 + r\frac{\gamma - 1}{2}M^2\right) \tag{6}$$

Where M is the isentropic Mach number and is computed from the local wall pressure and inlet total pressure. T_s is the isentropic static temperature corresponding to the given Mach number. Given the above and the wall heat flux, the Nusselt number (Nu) can be computed.

Figure 10 shows the results for the coarse and fine grid solutions at midspan. The data is shown for comparison. There are two turbulence length scales used. The results for the smaller length scale, do not exhibits good agreement on the pressure side where the results appear to suddenly turn turbulent. The suction side heat transfer like the experimental data shows a transitional behavior for which the location and extent of the transition agrees with the data. The lack of agreement on the pressure side and better agreement on the suction side suggested that the length scale may be an issue as the pressure side is more prone to buffeting by the free stream turbulence. The length scale was increased to $0.05*C_x$ and the pressure side heat transfer improved greatly. Grid convergence has not been checked for the higher scale case.

The solutions show that the model is working well and is capable of simulating the transition start and extent. As for the convergence behavior of the two-dimensional solution, the solution was quite slow and required that a small CFL be used for much of the progress of the solution.

This issue needs further attention.

Summary

For the Variable-Speed Power-Turbine work, the flow transition process has been identified as an important process to accurately model. Computational work needs to address this question if the losses are to be predicted correctly. This work has surveyed the literature and has found two suitable candidates. One is intermittency type models (Refs. 2 and 3) and one involving a phenomenological model of the bypass transition. The present work describes the performance of the low Reynolds number k-ω model and the implementation and preliminary results from the Walters-Leylek model (Refs. 4 and 5) on a blade for which experimentally measured data is available. The model was implemented in NASA Glenn-HT code and tested as applied to a turbine blade test case. The location of transition was successfully predicted on the suction side and the transition modeling on the pressure side appears to be promising.

Future Work

Future work should look at further two-dimensional and three-dimensional applications of the model. For the two-dimensional cases, fine grid solution for the higher length scale should be obtained. Three-dimensional solutions should allow for comparison against the pressure distribution and heat transfer on other span locations. Improvement in the robustness of the numerical scheme is another topic that deserves attention. Finally, losses need to be computed and compared with experimental data.

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14. ABSTRACT
The purpose of this report is to document the work done to enable a NASA CFD code to model the transition on a blade. The purpose of the present work is to down-select a transition model that would allow the flow simulation of a Variable-Speed Power-Turbine (VSPT) to be accurately performed. The modeling is to be ultimately performed to also account for the blade row interactions and effect on transition and therefore accurate accounting for losses. The present work is limited to steady flows. The low Reynolds number k-ω model of Wilcox and a modified version of same will be used for modeling of transition on experimentally measured blade pressure and heat transfer. It will be shown that the k-ω model and its modified variant fail to simulate the transition with any degree of accuracy. A case is therefore made for more accurate transition models. Three-equation models based on the work of Mayle on Laminar Kinetic Energy were explored and the Walters and Leylek model which was thought to be in a more mature state of development is introduced and implemented in the Glenn-HT code. Two-dimensional flat plate results and three-dimensional results for flow over turbine blades and the resulting heat transfer and its transitional behavior are reported. It is shown that the transition simulation is much improved over the baseline k-ω model.

15. SUBJECT TERMS
Power turbine; Low pressure turbine; Turbulence modeling; Heat transfer; Losses

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