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More Accurate Predictions with Transonic Navier-Stokes Methods Through Improved Turbulence Modeling

by

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Because the aerodynamic characteristics of aircraft in the transonic regime are so sensitive to viscous effects, the selection of the turbulence model for a transonic prediction method is no less important than the selection of the numerical algorithm. Yet, the usual practice in transonic airfoil, Reynolds-Averaged, Navier-Stokes codes has been to employ "equilibrium" algebraic turbulence models. Satisfactory results are obtained with these turbulence models for weak interaction cases (i.e., cases where the upper surface shock wave is too weak to have a major effect on the turbulent boundary layer). Such is not the situation for cases where the shock wave is sufficiently strong to cause separation. The danger in using these "equilibrium" turbulence models for airfoil design is that they can result in unduely optimistic projections of aircraft performance at off-design conditions.

Significant improvements in predictive accuracies for off-design conditions are achievable through better turbulence modeling; and, without necessarily adding any significant complication to the numerics. One well established fact about turbulence is it is slow to respond to changes in the mean strain field. With the "equilibrium" algebraic turbulence models no attempt is made to model this characteristic and as a consequence these turbulence models exaggerate the turbulent boundary layer's ability to produce turbulent Reynolds shear stresses in regions of adverse pressure gradient. As a consequence, too little momentum loss within the boundary layer is predicted in the region of the shock wave and along the aft part of the airfoil where the surface pressure undergoes further increases.

Recently, a "nonequilibrium" algebraic turbulence model was formulated which attempts to capture this important characteristic of turbulence. This "nonequilibrium" algebraic model employs an ordinary differential equation to model the slow response of the turbulence to changes in local flow conditions. In its originial form, there was some question as to whether this "nonequilibrium" model performed as well as the "equilibrium" models for weak interaction cases. However, this turbulence model has since been further improved wherein it now appears that this turbulence model performs at least as well as the "equilibrium" models for weak interaction cases and for strong interaction cases represents a very significant improvement.

The performance of this turbulence model relative to popular "equilibrium" models is illustrated for three airfoil test cases of the 1987 AIAA Viscous Transonic Airfoil Workshop, Reno, Nevada. A form of this "nonequilibrium" turbulence model is currently being applied to wing flows for which similar improvements in predictive accuray are being realized.

TRANSONIC FLOW TURBULENCE MODELING AIRFOIL AND WING FLOWS

WHY BE CONCERNED ABOUT THE TURBULENCE MODEL?

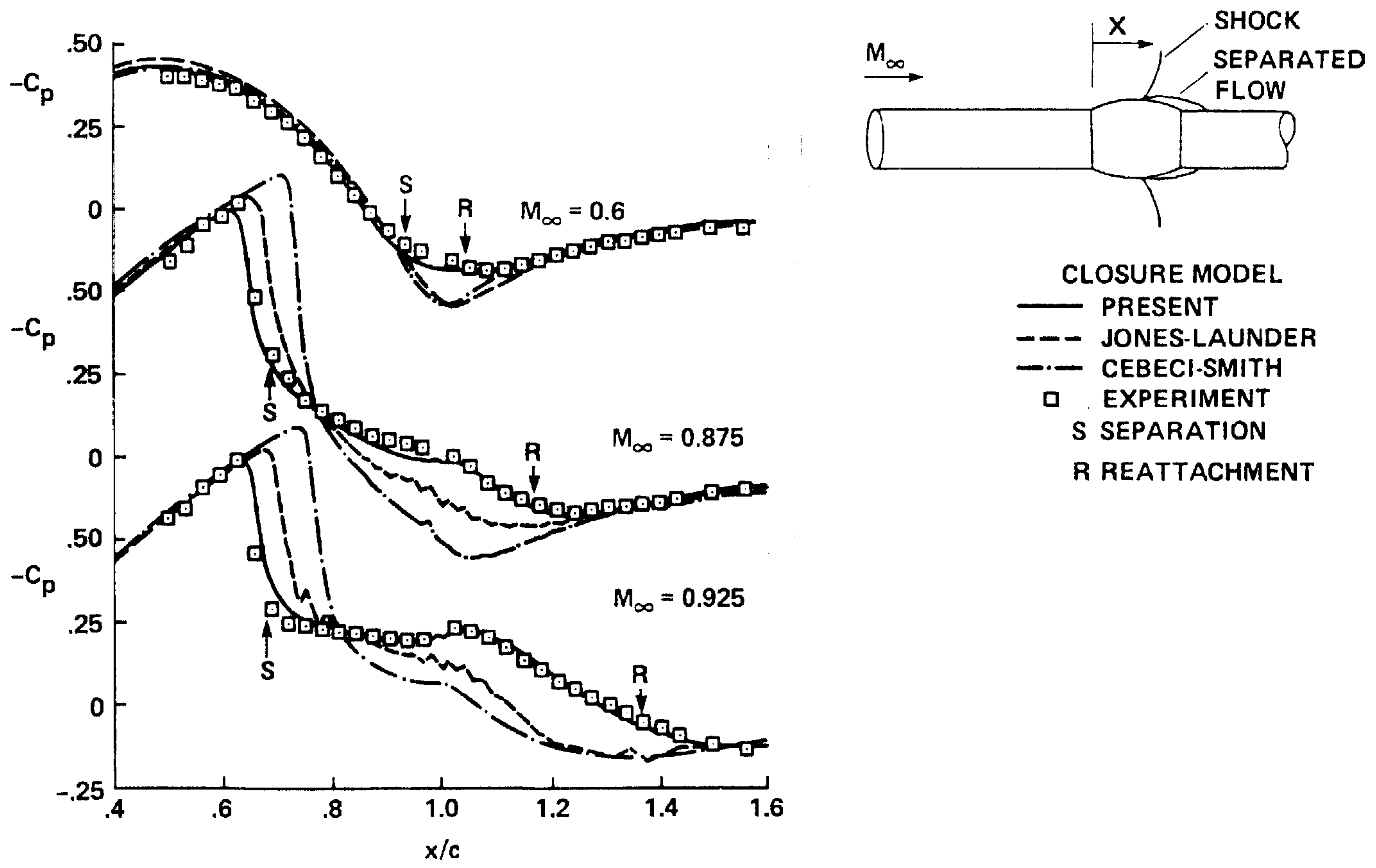
- NUMERICAL PREDICTIONS CAN BE EXTREMELY SENSITIVE TO TURBULENCE MODEL IN TRANSONIC REGIME

- WIDELY USED EQUILIBRIUM ALGEBRAIC TURBULENCE MODELS OVERPREDICT AIRCRAFT PERFORMANCE

NONEQUILIBRIUM JOHNSON-KING ALGEBRAIC TURBULENCE MODEL

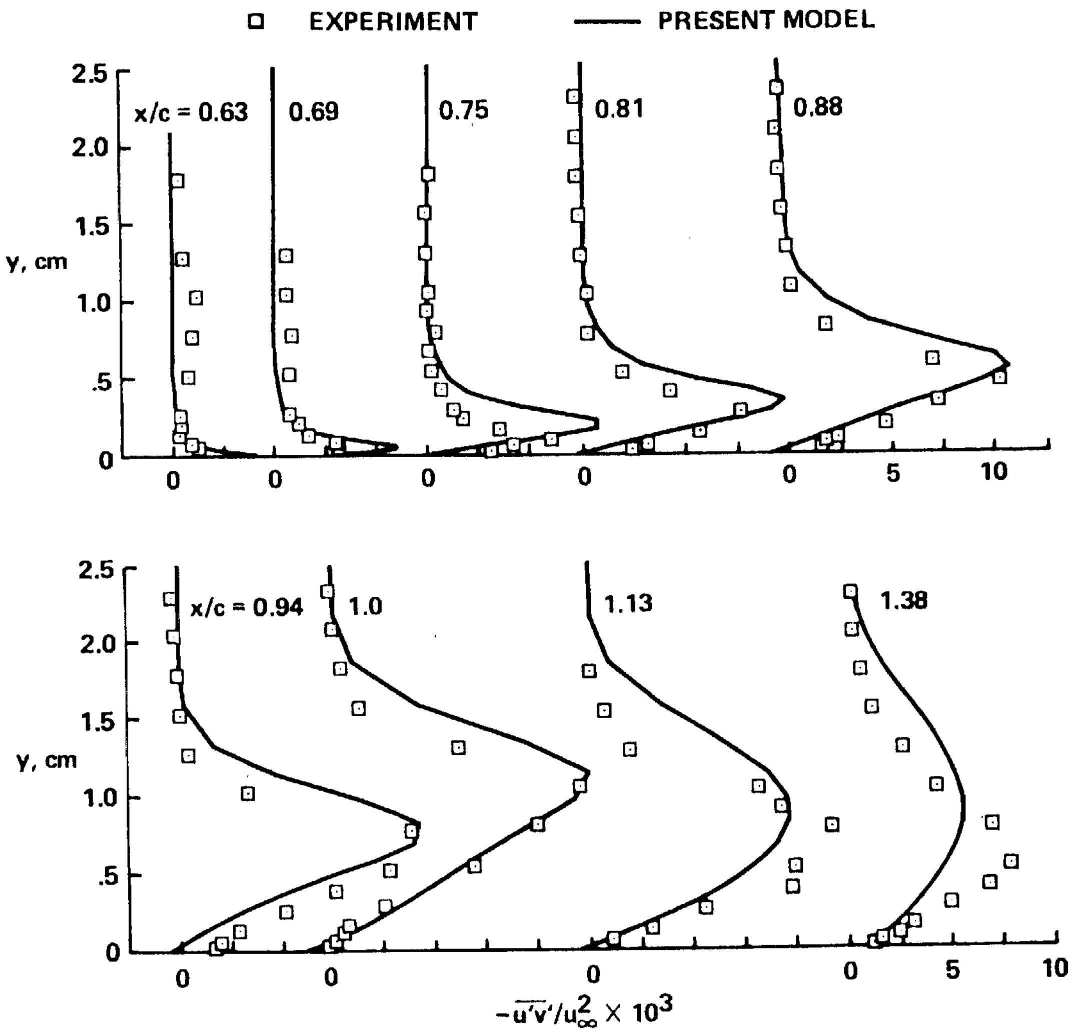
- SLOW RESPONSE OF TURBULENT SHEAR STRESS TO CHANGES IN STRAIN FIELD MODELED
- ORDINARY DIFFERENTIAL EQUATION FOR MAXIMUM REYNOLDS SHEAR STRESS ESTABLISHES EDDY VISCOSITY (SIMPLIFIED "REYNOLDS STRESS" MODEL?)
- DUE TO RECENT IMPROVEMENTS, MODEL PERFORMS BETTER FOR ATTACHED FLOW CASES (SURPRISINGLY, ORIGINAL MODEL WORKED BETTER FOR STRONGLY SEPARATED CASES)

SURFACE PRESSURE COEFFICIENT AXISYMMETRIC BUMP

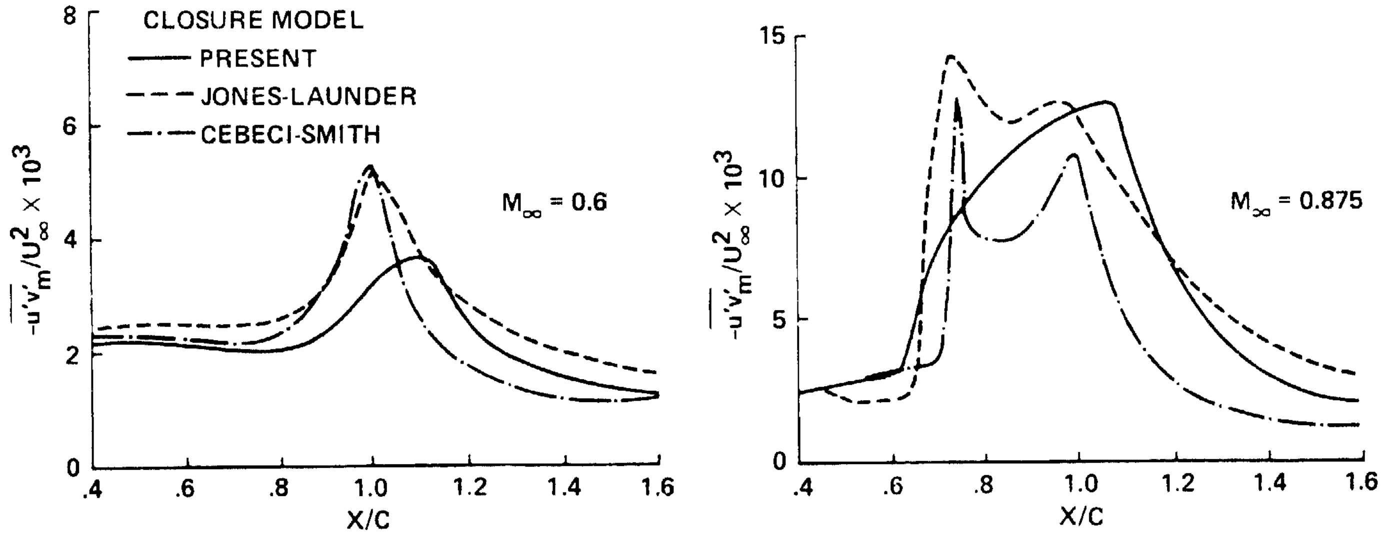


REYNOLDS SHEAR STRESS PROFILES

AXISYMMETRIC BUMP, $M_\infty = 0.875$



MAXIMUM REYNOLDS SHEAR STRESS DISTRIBUTIONS



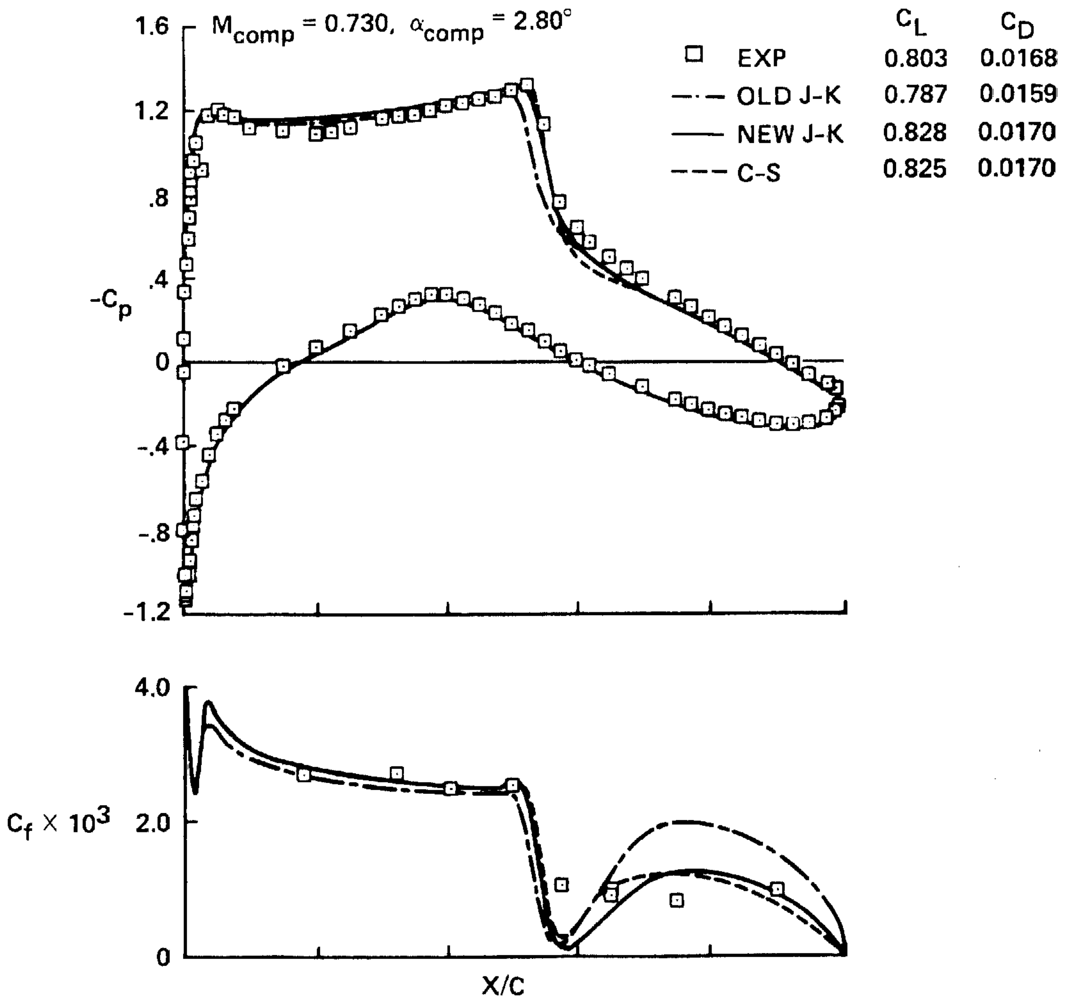
IMPROVEMENTS IN JOHNSON-KING MODEL

NEW INNER EDDY VISCOSITY EXPRESSION

- BETTER SATISFIES "LAW OF THE WALL" FOR ATTACHED ADVERSE PRESSURE GRADIENT CONDITIONS (ORIGINAL MODEL OVERPREDICTED C_f DOWNSTREAM OF SHOCK WAVE)
- INCLUDES VELOCITY SCALE WHICH ACCOUNTS FOR COMPRESSIBILITY

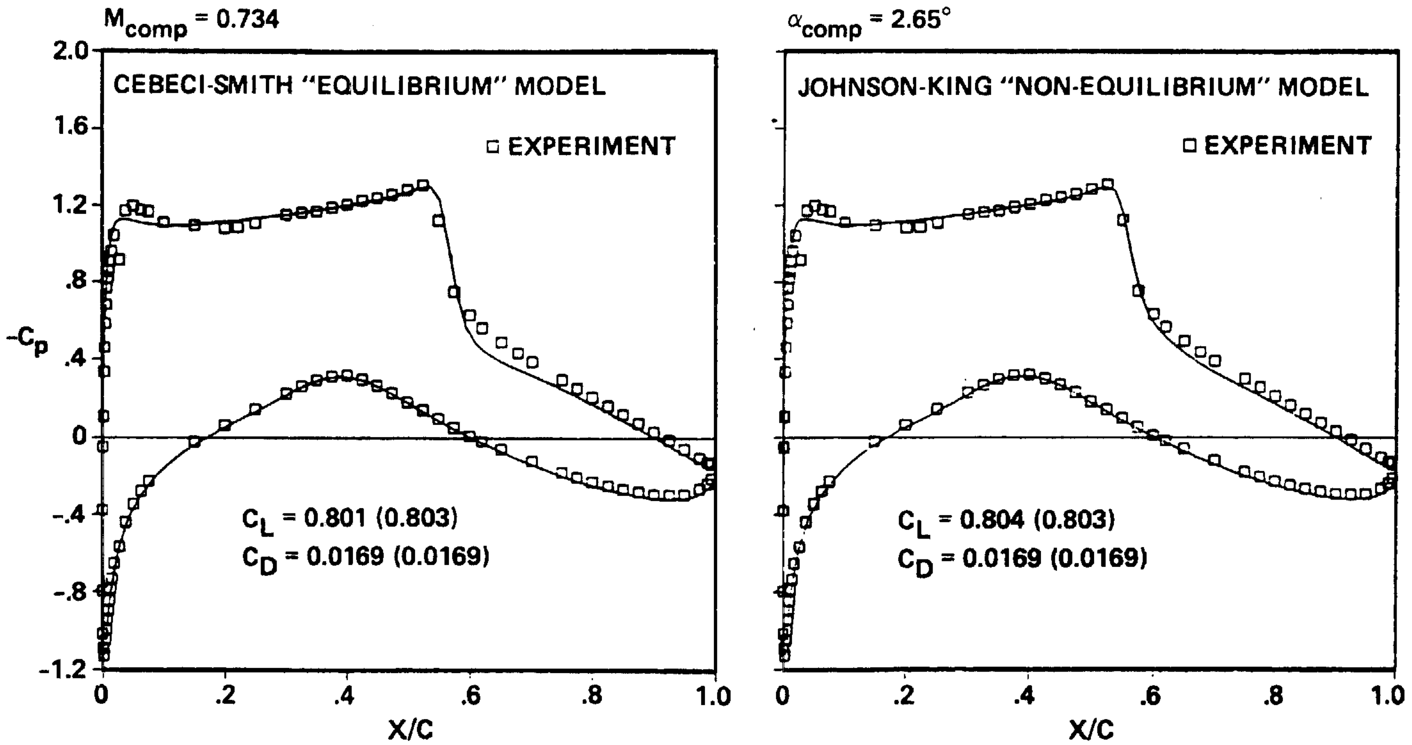
IMPROVEMENTS IN JOHNSON - KING TURBULENCE MODEL FOR WEAK SHOCK WAVE/BOUNDARY LAYER INTERACTIONS

RAE 2822, $M_{exp} = 0.729$, $\alpha_{exp} = 3.19°$



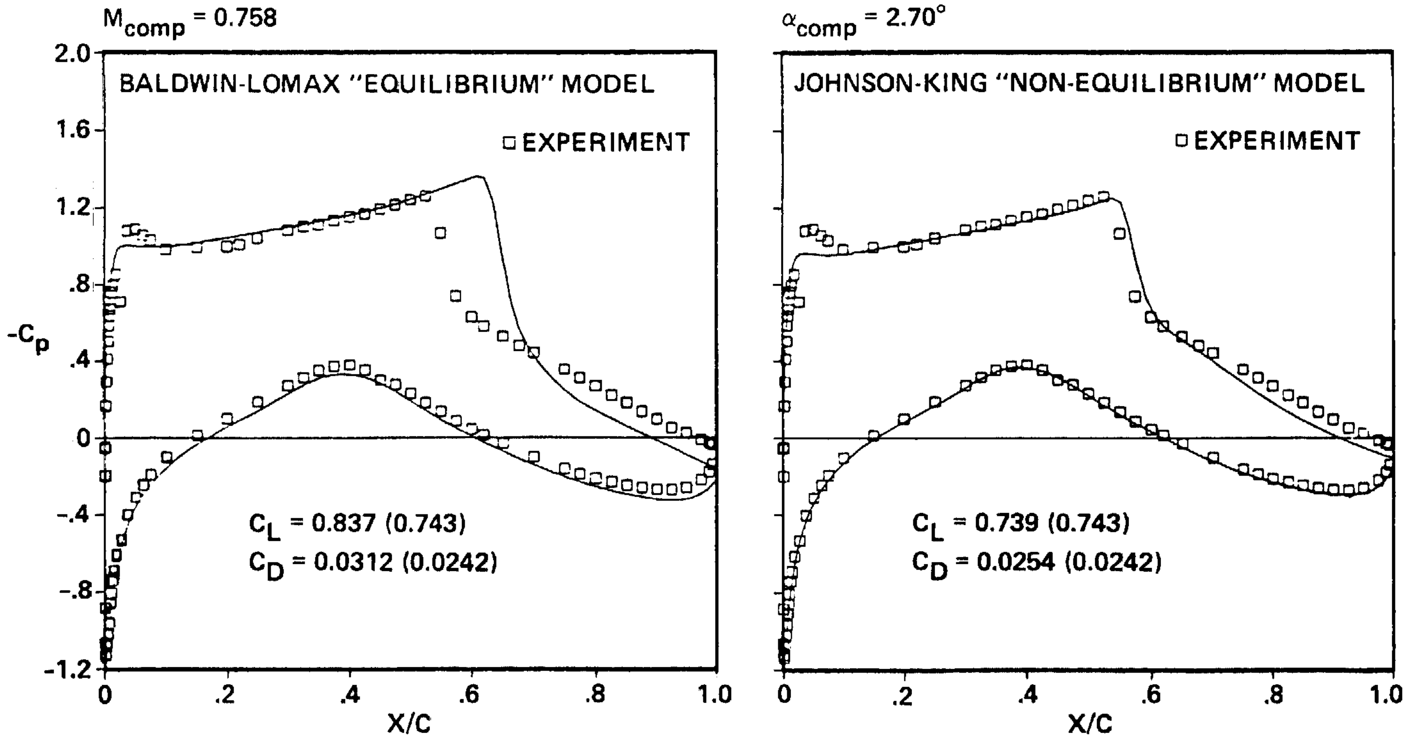
ATTACHED AIRFOIL CASE

RAE 2822, $M_{exp} = 0.73$, $\alpha_{exp} = 3.19°$



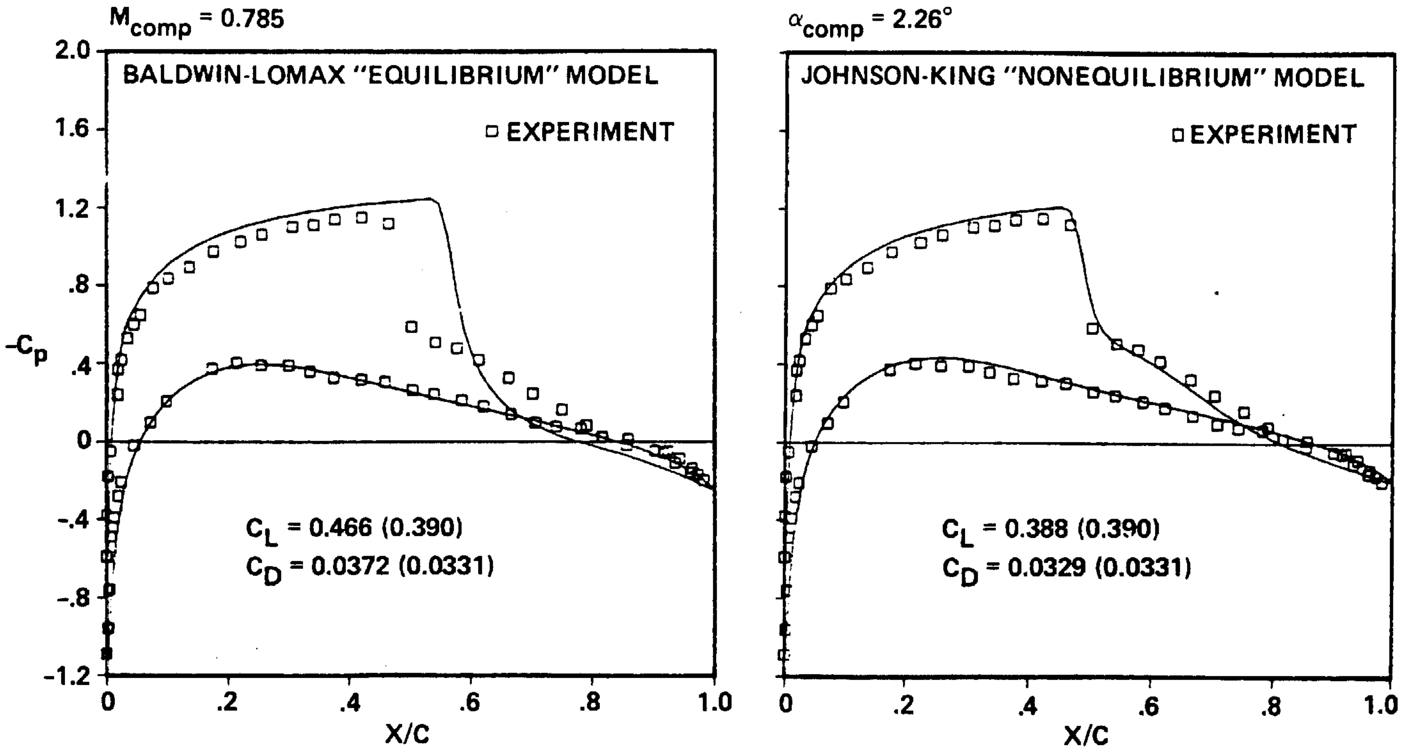
SEPARATED AIRFOIL CASE

RAE 2822, $M_{exp} = 0.75$, $\alpha_{exp} = 3.19°$



SEPARATED AIRFOIL CASE

NACA 0012, $M_{exp} = 0.8$, $\alpha_{exp} = 2.86°$



SUMMARY

SIGNIFICANT IMPROVEMENTS IN PREDICTIVE ACCURACY WITH NONEQUILIBRIUM ALGEBRAIC TURBULENCE MODEL

PRESENT APPROACH IS TO MODEL MOST RELEVANT PHYSICS WHILE MAINTAINING MATHEMATICAL SIMPLICITY

NEGLIGIBLE INCREASE IN COMPUTATIONAL EFFORT COMPARED TO EQUILIBRIUM ALGEBRAIC TURBULENCE MODELS

SESSION IV

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