LASTRAC.3d: Transition Prediction in 3D Boundary Layers

Recent work discussing 3D issues in e**n work, also 3D PSE-type analyses. Nice review.

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Langley Stability and Transition Analysis Code (LASTRAC) is a general-purpose, physics-based transition prediction code released by NASA for Laminar Flow Control studies and transition research. This paper describes the LASTRAC extension to general 3D boundary layers such as finite swept wings, cones, or bodies at an angle of attack. The stability problem is formulated using a body-fitted non-orthogonal curvilinear coordinate system constructed on the body surface. The non-orthogonal coordinate system offers a variety of marching paths and spanwise waveforms. It is shown that in the extreme case of an infinite swept wing boundary layer, marching with a non-orthogonal coordinate produces identical solutions to those obtained with an orthogonal coordinate system using the earlier release of LASTRAC. Several methods to formulate the three-dimensional parabolized stability equations (PSE) are discussed. A surface-marching procedure akin to that for 3D boundary layer equations may be used to solve the 3D parabolized disturbance equations. On the other hand, the local line-marching PSE method, formulated as an easy extension from its 2D counterpart and capable of handling the spanwise meanflow and disturbance variation, offers an alternative. A linear stability theory or parabolized stability equations based N-factor analysis carried out along the streamline direction with a fixed wavelength and downstream-varying spanwise direction constitutes an efficient engineering approach to study instability wave evolution in a 3D boundary layer. The surface-marching PSE method enables a consistent treatment of the disturbance evolution along both streamwise and spanwise directions but requires more stringent initial conditions. Both PSE methods as well as the traditional LST approach are implemented in the LASTRAC.3d code. Several test cases for tapered or finite swept wings and cones at an angle of attack are discussed.

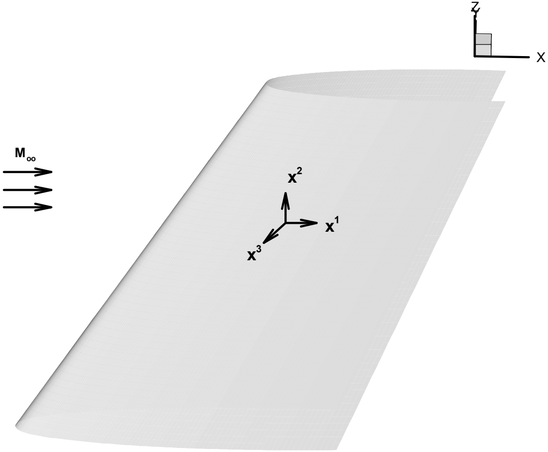


Figure 1: Non-orthogonal body-fitted curvilinear coordinate over a 3D surface.

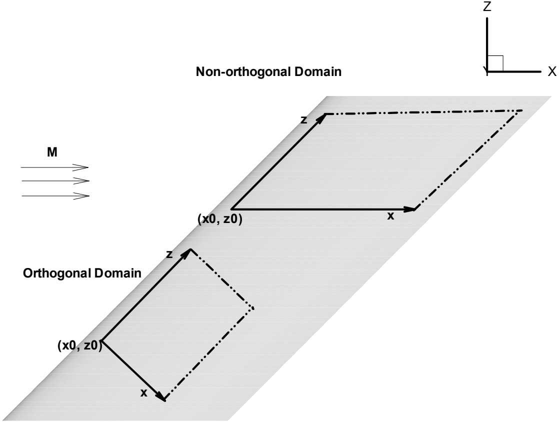
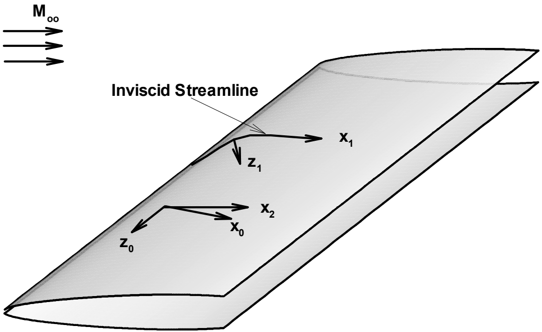
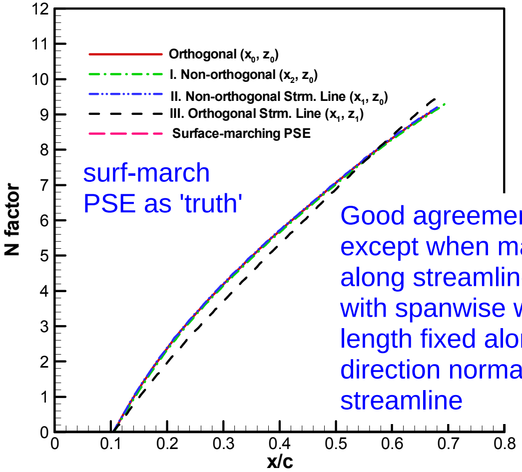


Figure 2: Rectangular domains for surface-marching PSE calculations



3 directions here: along chord normal (x0), along freestream (x2), along inviscid streamline (x1). Also, spanwise wavelength fixed in one of two ways: parallel to l.e. (z0) or along normal to inviscid str. (z1)

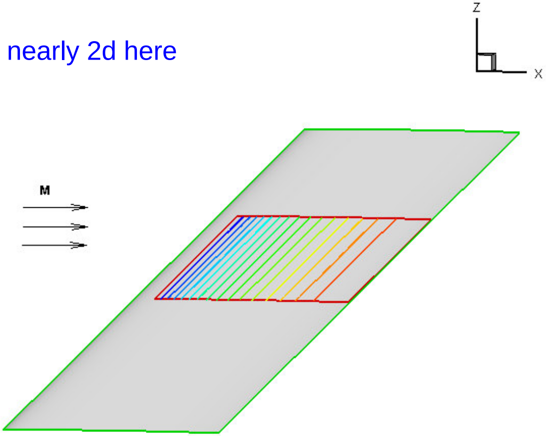
Figure 3: Three different marching coordinates for an infinite swept wing boundary



surf-march PSE as 'truth'

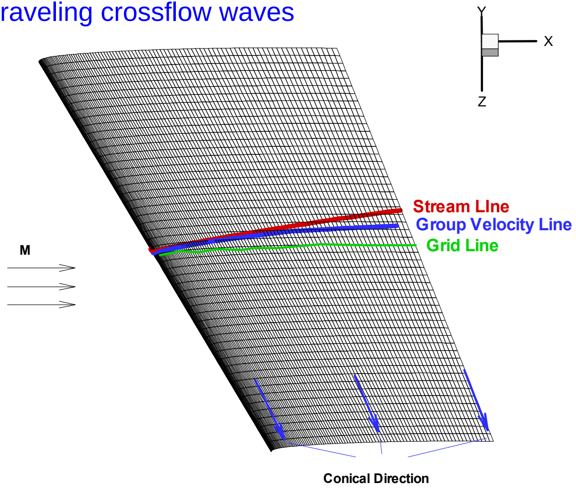
Good agreement except when march along streamline with spanwise wave length fixed along direction normal to streamline

Figure 4: Comparison of PSE N factors for a stationary crossflow mode using various coordinate systems and surface-marching PSE for an infinite swept wing boundary layer



nearly 2d here

Figure 5: N-factor distribution calculated by surface-marching PSE for the infinite swept-wing boundary layer using a non-orthogonal domain

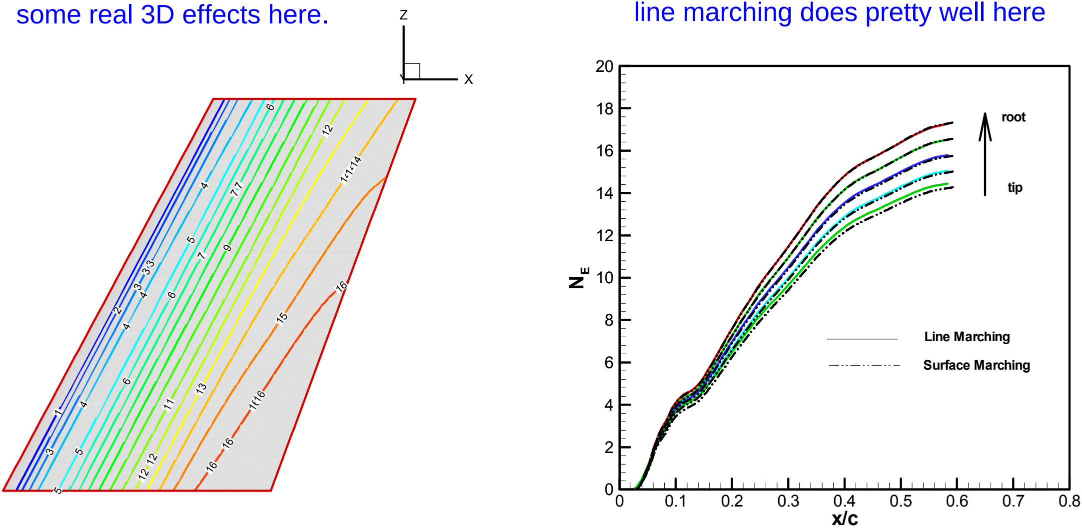


one of the choices. Mach 0.8.
traveling crossflow waves

Figure 6: Geometry and surface grid for a transonic tapered wing, showing three marching paths and the conical spanwise coordinate

some real 3D effects here.

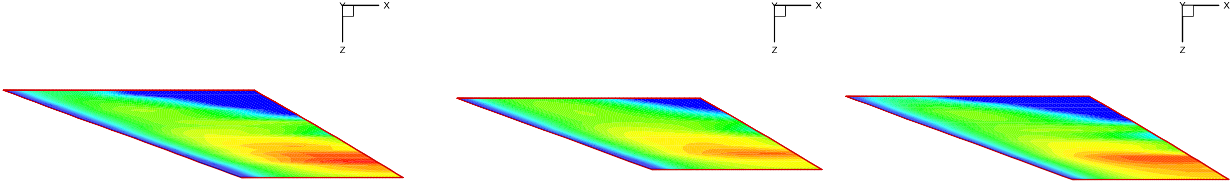
line marching does pretty well here



(a)

(b)

Figure 9: Non-parallel N-factor (based on disturbance kinetic energy) distribution for f=1.5kHz, λ = 12mm. on the transonic tapered wing surface obtained by surface-marching PSE: (a) N-factor contours on the surface (b) Compared with N-factors from local line-marching at various spanwise locations



N factor difference is significant (not given quantitatively, but difference stated as about 1 or 2). Not clear at the moment which is better, need measurements.

(a) (b) (c)

Mach 2 flow past a 56-deg. swept finite wing. local line marching with and without a real irrotational condition for the spanwise wave number (irrotational with const. spanwise wavenumber, with and without an additional correction that varies modal wavenumber).

Figure 14: Comparison of N-factor evaluated by total kinetic energy obtained by (a) surface-marching (b) local line-marching with spanwise correction (c) local line-marching without spanwise correction

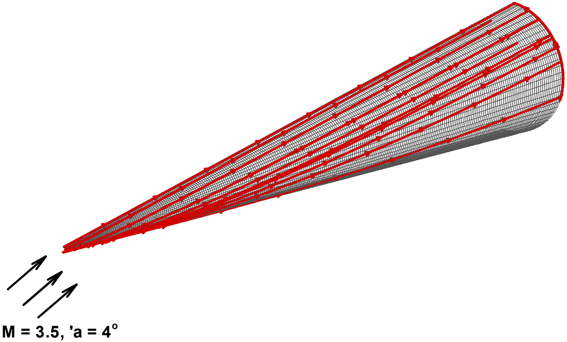
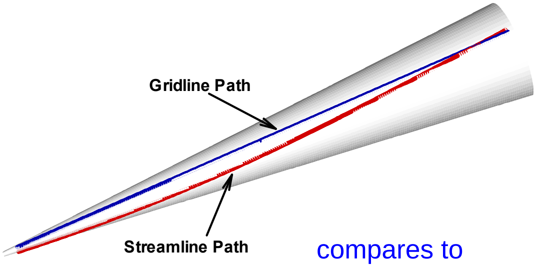
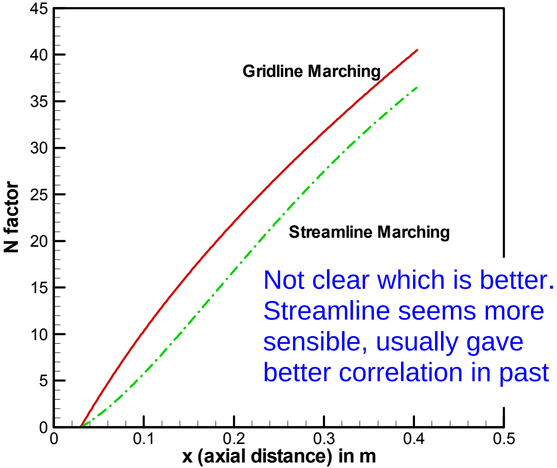


Figure 15: Surface mesh and streamlines for a Mach 3.5 flow over a cone at 4 degree angle of attack



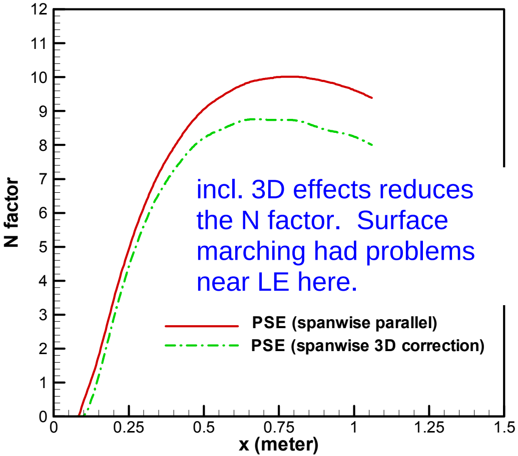
compares to
King expt.

Figure 16: Two marching paths on a Mach 3.5 flow over a cone at 4 degree angle of attack



Not clear which is better. Streamline seems more sensible, usually gave better correlation in past

Figure 17: Linear PSE N factors computed by two different marching paths on the Mach 3.5 cone surface



incl. 3D effects reduces the N factor. Surface marching had problems near LE here.

Figure 18: N factor calculated by linear PSE using local line-marching along the inviscid streamline with and without spanwise meanflow and disturbance correction