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INTRODUCTION

Since June 1975 the Fluid Mechanics and Wind Engineering Program at Colorado State University has been engaged in a three-year research project to determine which locations are most favorable for wind-power installations. Wind-tunnel modeling techniques are used to analyze systematically the effect of characteristic topographical features on different flow regimes. The research which is primarily experimental includes evaluation of wind characteristics over simple two-dimensional and three-dimensional shaped hills with different upstream flow conditions.

The Fluid Dynamics and Diffusion Laboratory at Colorado State University has unique facilities for purposes of modeling of the atmospheric surface layer. Much experience with the modeling of atmospheric phenomena has been obtained in the last fifteen years and more than ten studies of flow over mountainous terrain have been completed. In recent years verification that natural wind characteristics are simulated to a high degree of approximation by a long-test-section type wind tunnel has been reported by Cermak et al. (1966). The Meteorological Wind Tunnel in which most of the experiments are carried out can produce a working shear layer of several feet in depth. Also stratification can be modeled from highly stable to unstable flow conditions. The detailed structure of the boundary layer formed in the long test section is varied by changing roughness characteristics of the lower boundary (floor).

In addition to the results of this research being used to predict the most favorable location for a wind-power site, the results enable numerical analysts to verify their models. Moreover this research may give guidance to field programs.

THE RESEARCH PROGRAM

The objectives of this research are specifically

1. To determine local flow phenomena over topography--boundary layer displacement, separation, reattachment--as effected by hill or ridge profile, upwind surface roughness, insolation, and stratification.

2. To develop knowledge of integral wind effects on topography which will lead to criteria in terms of upwind topography type and placement for the prediction of effect on speedup and gustiness.

3. To establish how the local flow environment such as gustiness and mean wind speeds are affected through the combined action of the individual effects listed above.

4. To relate the new knowledge gained through laboratory measurements and through analysis to real meteorological events and to provide a "methodology" of site selection for wind-power purposes.

Two broad classes of variables are incorporated in the general research plan:

1. Natural wind characteristics

2. Topographical features

Variables of each class are changed systematically to analyze their particular influence on the wind as it is affected by the topography.

I. WIND CHARACTERISTICS

Flow characteristics of major concern are magnitudes and spatial distribution of mean velocities, turbulence spectra, turbulence intensities and temperature gradients. Variation of these characteristics are obtained by changing the surface roughness, heating or cooling of the surface and by changing the speed and temperature of the air at the entrance of the test section. The natural growth of the boundary layer at the location where the hill model will be placed yields characteristics which are dynamically in equilibrium. Changes in the characteristics when the flow passes the hill model are then solely due to the surface obstacle.

Free stream velocities for neutral flow conditions are set at 9.14 and 15.24 m/sec and for stable flow conditions at 3.05, 6.10 and 9.14 m/sec. The boundary layer thickness at the hill model is .55 m.

II. TOPOGRAPHICAL FEATURES

The following list summarizes the variations in geometry of this study:

1. Two-dimensional hill, height 5.08 cm

   a. triangular--slopes 1:2, 1:3, 1:4, 1:6 and 1:20

   b. sinusoidal--slopes (averaged values) 1:3 and 1:4

   c. typical hills with roughness added

   d. typical hills with stable stratification

2. Three-dimensional hills, height 5.08 cm

   a. cone--slopes 1:4, 1:6

   b. bell (Gaussian) slope about 1:4

3. Ridge sections with gaps with different gap width ratios

Other geometries may be included as the research indicates the occurrence of significant flow behavior at intermediate values of the geometrical parameters.

ACCOMPLISHMENTS TO DATE

A review of wind site selection procedures, a description of the research program, a review of laboratory simulation procedures, the experimental program and initial results have been reported in the Annual Report: First Year (ERDA/NSF 00702/75/1).

Measurements have been completed over the triangular and sinusoidal hill models.

-- For neutral flow conditions it includes detailed measurements over the hills of wind speed, static pressure variation and turbulence intensity. These data have been prepared into a data supplement and submitted as the sixth-month progress report under the second grant year. It has appeared as report ERDA/Y-76-5-96-2438/7611. Additional turbulence data have been obtained; information about Reynolds shear stresses, power spectra, autocorrelation, and probability density functions of the velocity fluctuations of the flow over the 1:4 and 1:20 triangular hills will be reported soon.

-- For stable flow conditions measurements have been completed for the wind speed, the static pressure variation, the temperature distribution, longitudinal turbulence intensity and the temperature fluctuations.

-- Flow visualizations over a number of alternate two-dimensional hill shapes have been made.

-- Data management programs have been prepared which normalize and sort experimental data. Results are expressed in tables, the velocity distribution, static pressure distribution, etc., are expressed also in contour plots, and streamline patterns over hills are plotted.

In the third grant year similar data will be collected over the three-dimensional hill models. A field validation study will be started. The field site has not yet been selected, although those reviewed by Orgill (1977) are currently being evaluated.

Some typical results of the velocity distribution over hill models will now be presented. In Figure 1 velocity profiles at the foot of the hill and at the crest are given for different hill shapes with the same height length ratio. One may see that the triangular shape has the largest speed up close to the surface. A little further away from the surface the last three flow cases of Figure 1 show similar profiles with large speed-up effects in comparison with the first three flow cases. Velocity and longitudinal turbulence intensity contours for typical flows over triangular hills are given in Figure 2 and Figure 3, namely:

a. flow with separation (slope of hill 1:2)

b. flow with maximum speed-up effects (slope 1:4)

c. flow over a gentle sloped hill (slope 1:20)

d. flow over the same hill as "b" but now roughness is added on the surface.

The following conclusions may be drawn from these figures for hills deeply embedded in the atmospheric boundary layer.

1. Large surface roughness reduces significantly the speed up of the wind. This effect is less with increasing height.

2. Speed-up effects close to the surface are optimal if the surface gradually increases in height.

3. The speed-up of the wind over a specific hill is most favorable approximately below the level where the height equals half the length of the hill (assuming that no separation occurs).

4. If the wind separates at the crest then the largest speed-up effects occur just downwind of the hill. However high turbulence intensities exist in this region.

5. Longitudinal turbulence intensities at the crest are lower than their upstream values while the vertical turbulence intensities are higher. However changes in turbulence intensities remain relatively small (less than 20%).

Efforts are underway to interpret the data. A preliminary analysis shows and the data validate that for steep hills deeply embedded in the boundary layer the inviscid flow model can predict the velocities to a high degree of approximation. For the gentle sloped hills (e.g., slope 1:20) this model cannot predict the velocities accurately close to the surface; however, for larger distances above the surface there is reasonable agreement.

REFERENCES

1. Cermak, J. E., et al., "Simulation of Atmospheric Motion by Wind-Tunnel Flows," Technical Report for Army DA-AMC-28-043-920, 1966, Fluid Dynamics and Diffusion Laboratory, Colorado State University.

2. Orgill, M. M., "Survey of Wind Measurement Field Programs," Report BNWL-2220 WIND-3 UC-60, 1977, Battelle, Pacific Northwest Laboratories.

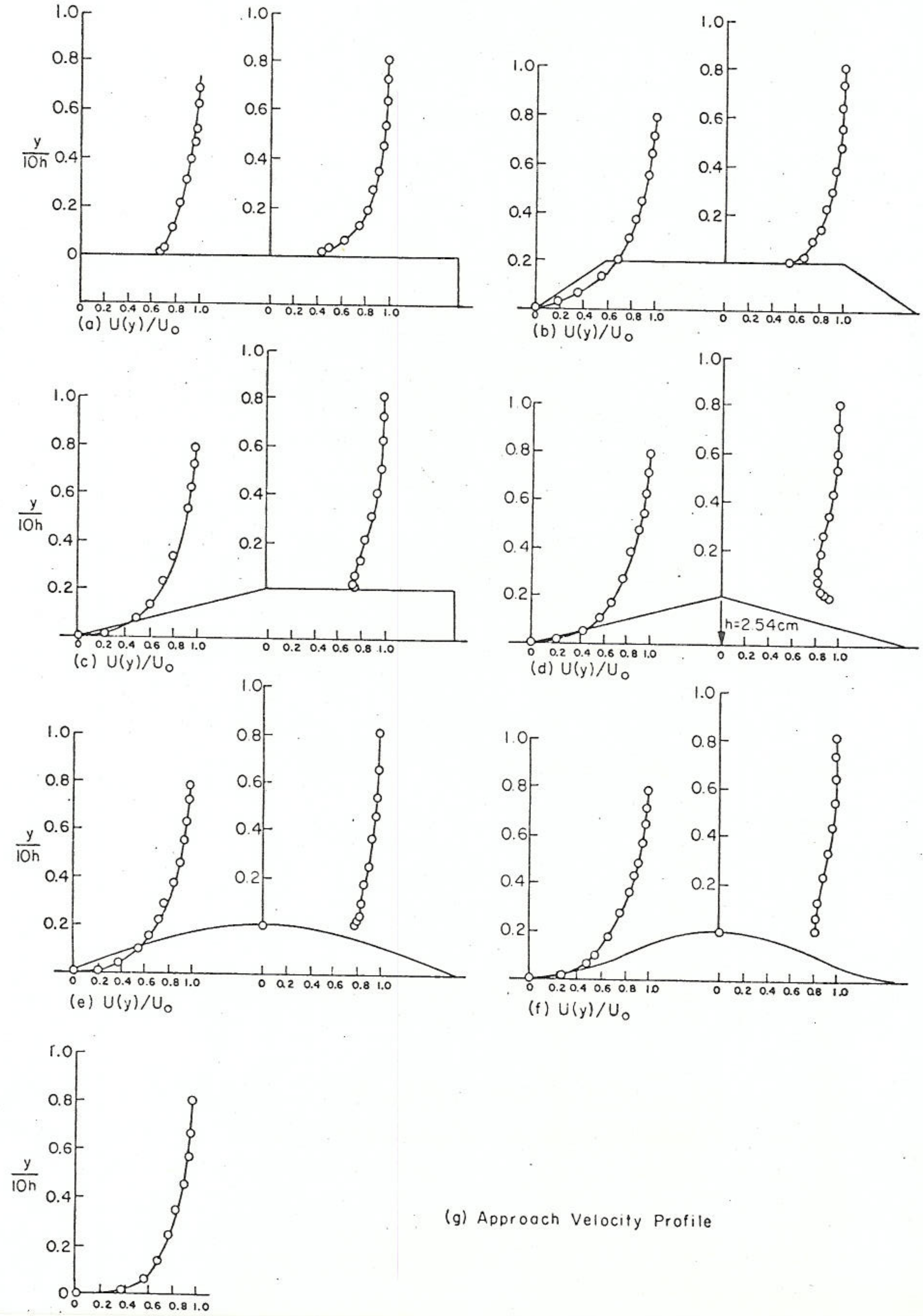


Figure 1. Velocity profiles over alternate hill shapes.

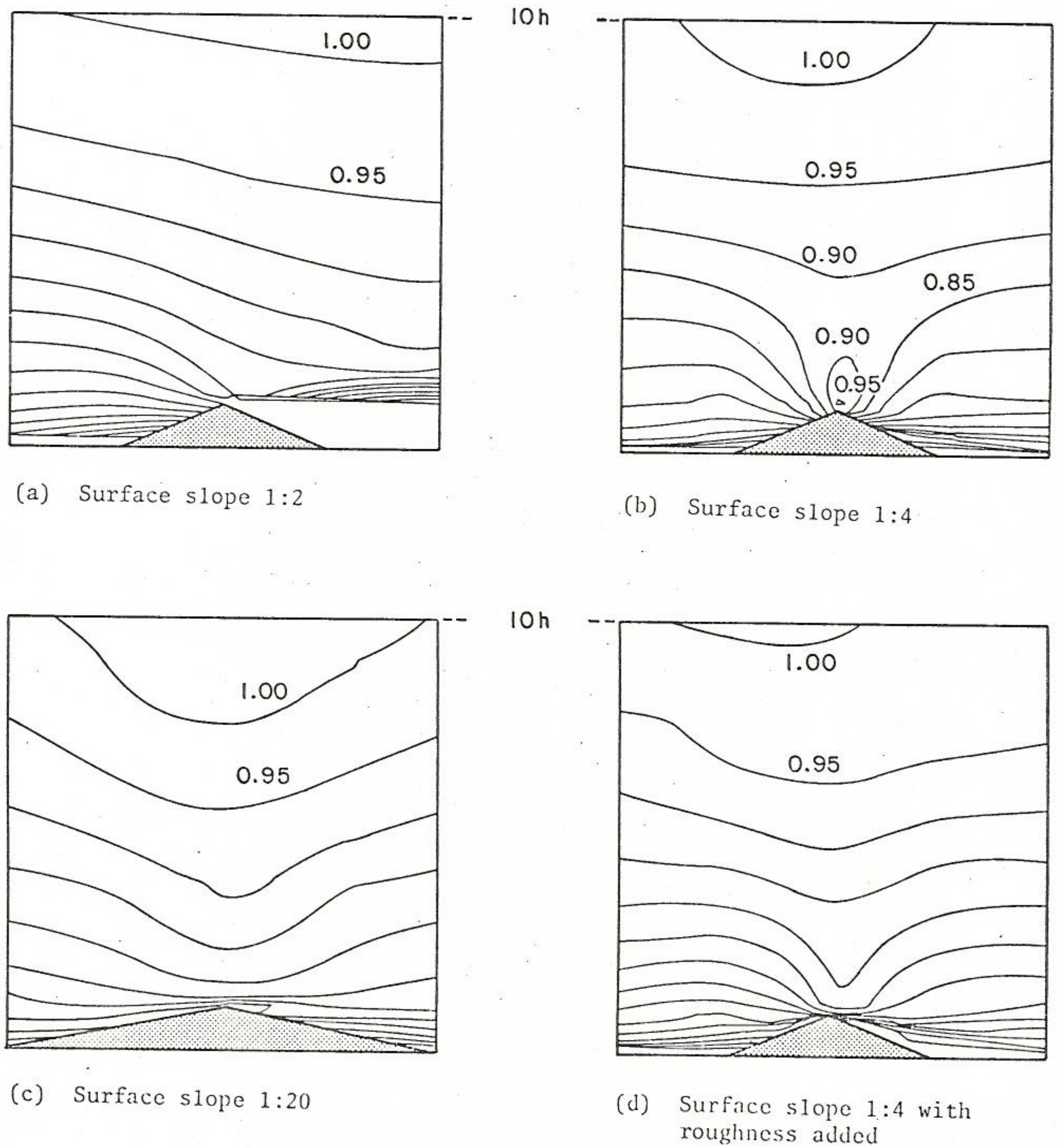
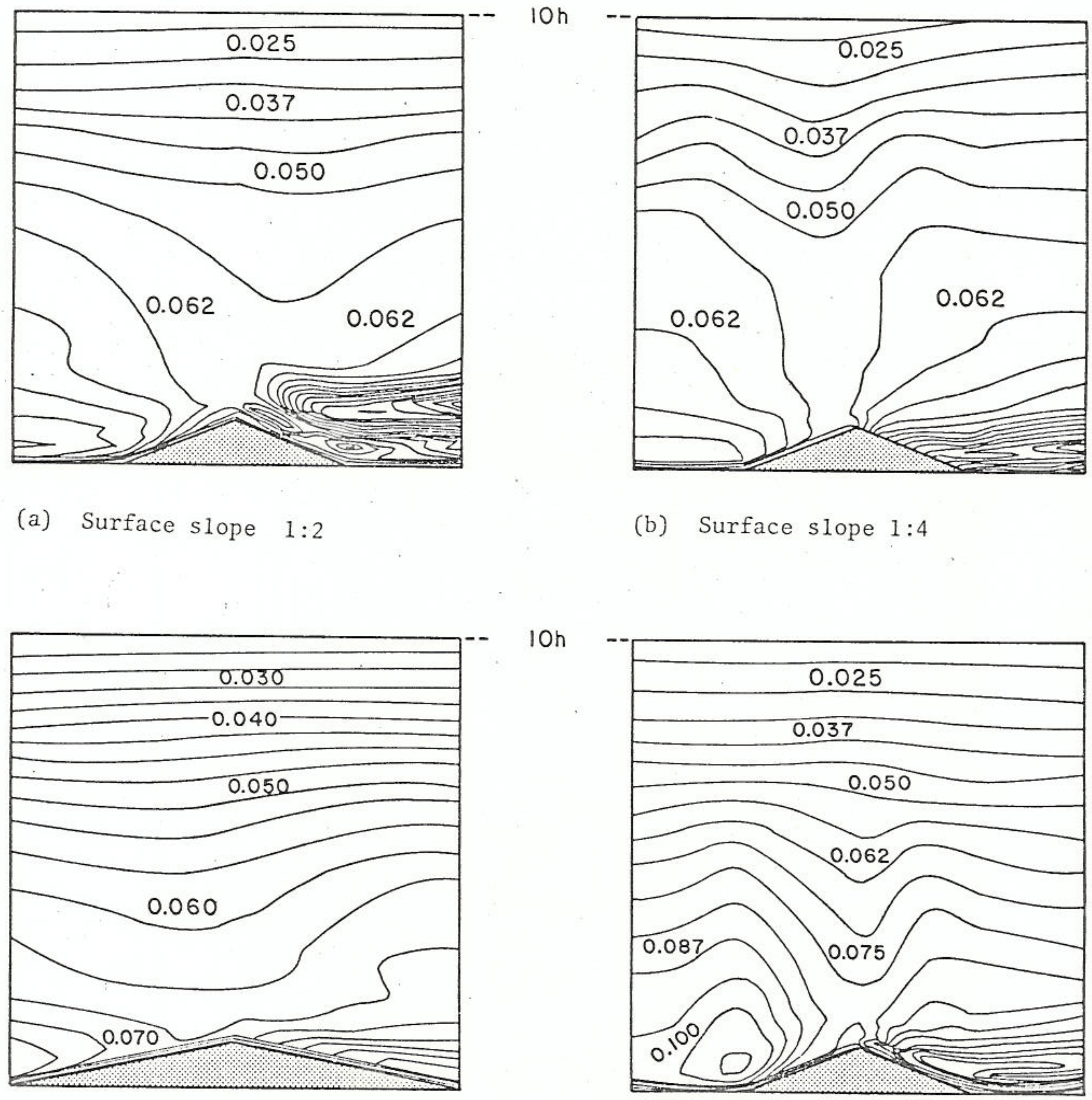


Figure 2. Isovelocity contours (nondimensionalized with respect to freestream velocity; contour interval .05).



(a) Surface slope 1:2

(b) Surface slope 1:4

(c) Surface slope 1:20

(d) Surface slope 1:4 with roughness added

Figure 3. Contours of longitudinal turbulence intensity (nondimensionalized with respect to freestream velocity)