Nonlinear PSE simulations of the development of TS waves in the presence of optimal Streaks

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Introduction

The growth of Tollmien-Schlichting Waves is reduced in the presence of Streaks in the Blasius boundary layer.

Passive Control:

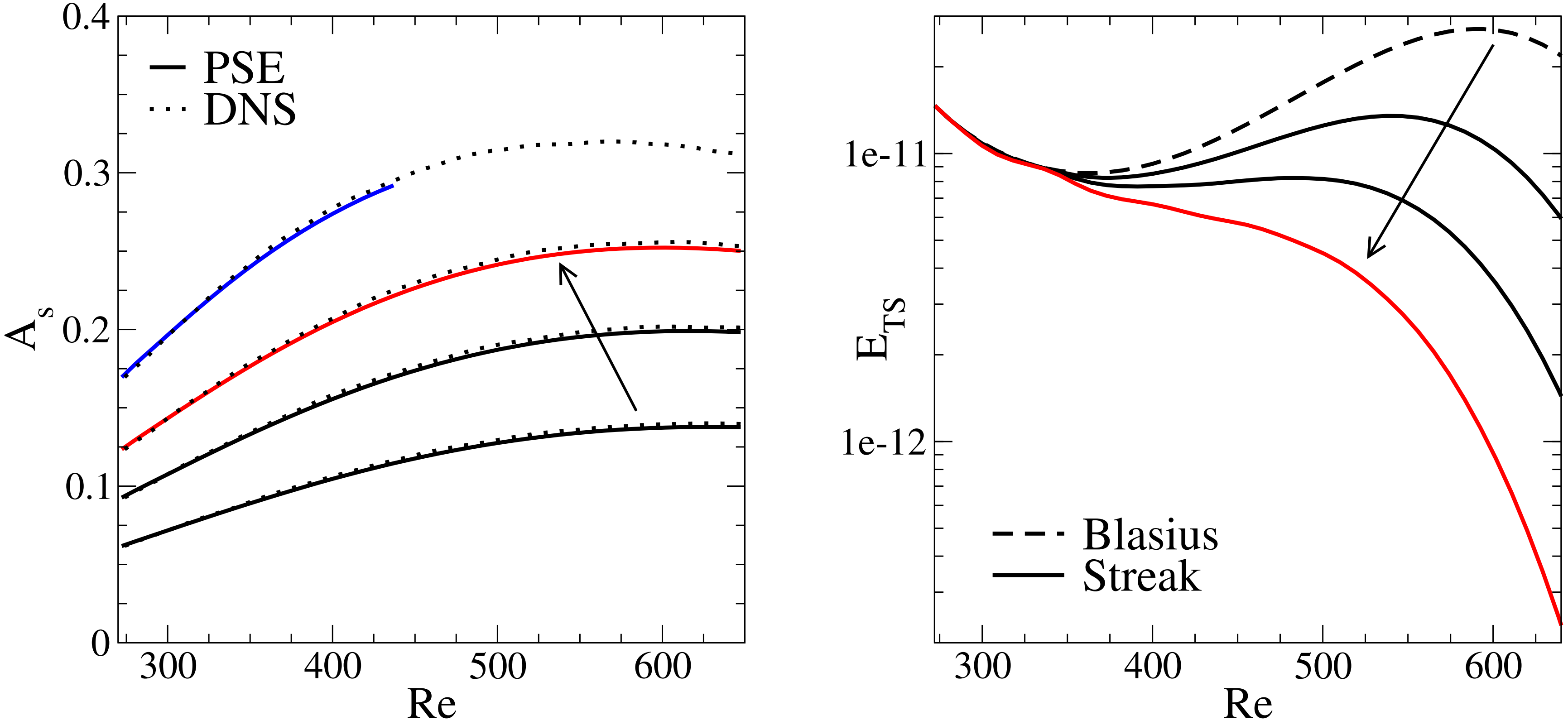
- Use streaks/optimal perturbations to stabilize the boundary layer.
- J. Fransson, A. Talamelli, L. Brandt & C. Cossu

Objective of this work:

- Use the nonlinear PSE (NOLOT) to investigate, the possibilities of optimizing the stabilization process, i.e. what is optimal β?
- Are finite amplitude and 3D disturbances stabilized?

The Effect of Streaks on TS waves.

$$A_s = \frac{1}{2}\left[\max_{y,z}\{u_s\} - \min_{y,z}\{u_s\}\right]$$



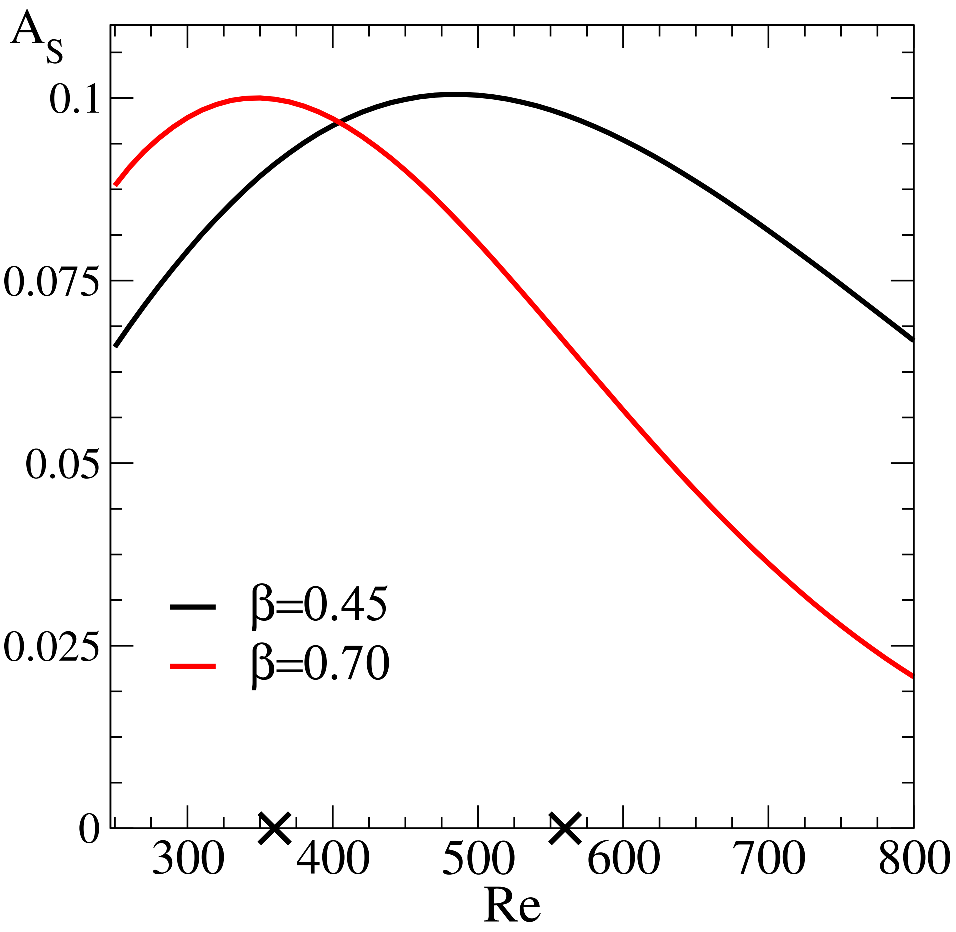
The stabilizing effect increases with the streak amplitude.

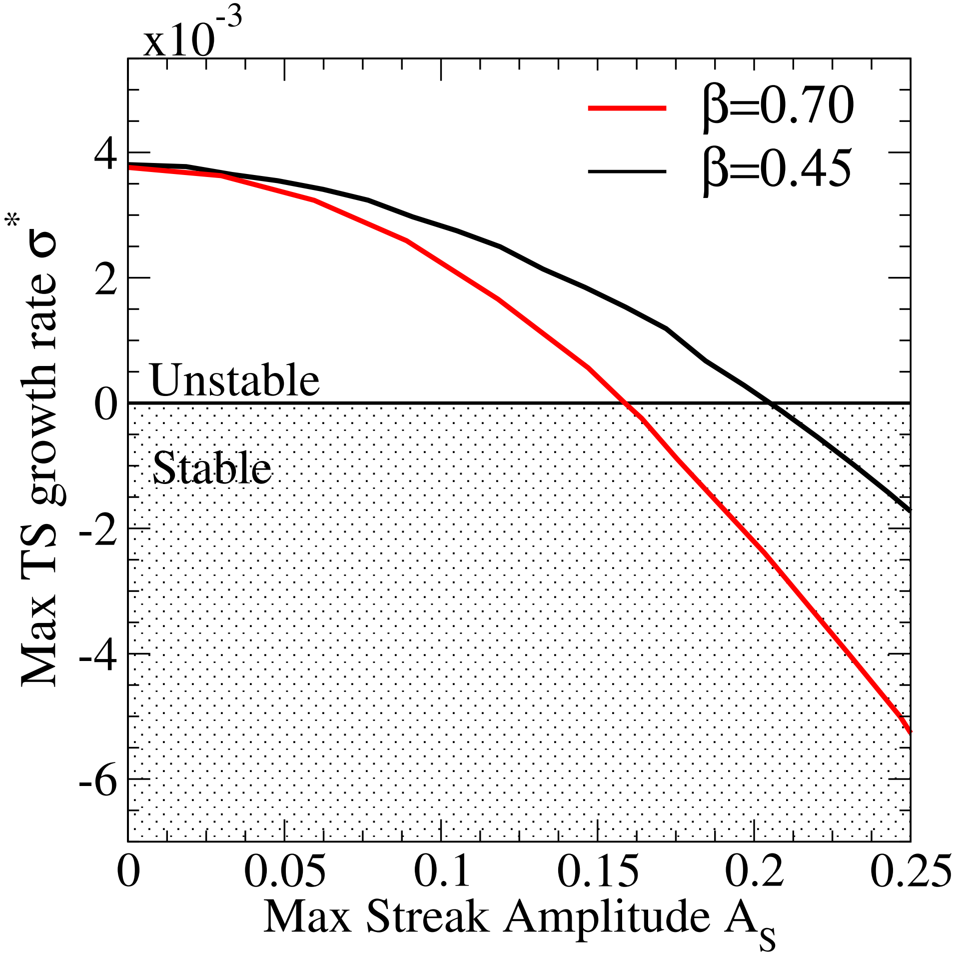
Secondary inviscid instability on the streak if the amplitude is to high ($\sim 26\%$).

Parametric Studies of Streak

- Procedure: Optimal disturbances (linear framework) with different spanwise wavenumbers are used as inflow condition close to the leading edge, where the linear downstream development is followed until a location where the nonlinear computation is initiated by the assignment of different amplitudes.
- Initial streak amplitude A_s is varied between 0–25% of U_∞ while keeping spanwise wavelength fixed, $\beta = 0.45$.
- Spanwise Wavelength of streak β is varied between 0.01–1 while keeping the maximum streak amplitude fixed, $A_s = 10\%$. $\Rightarrow$ "moving" the streak along the flat plate.
(For streaks the spanwise and streamwise scales are coupled, $x\beta^2 = \mathrm{const}$)

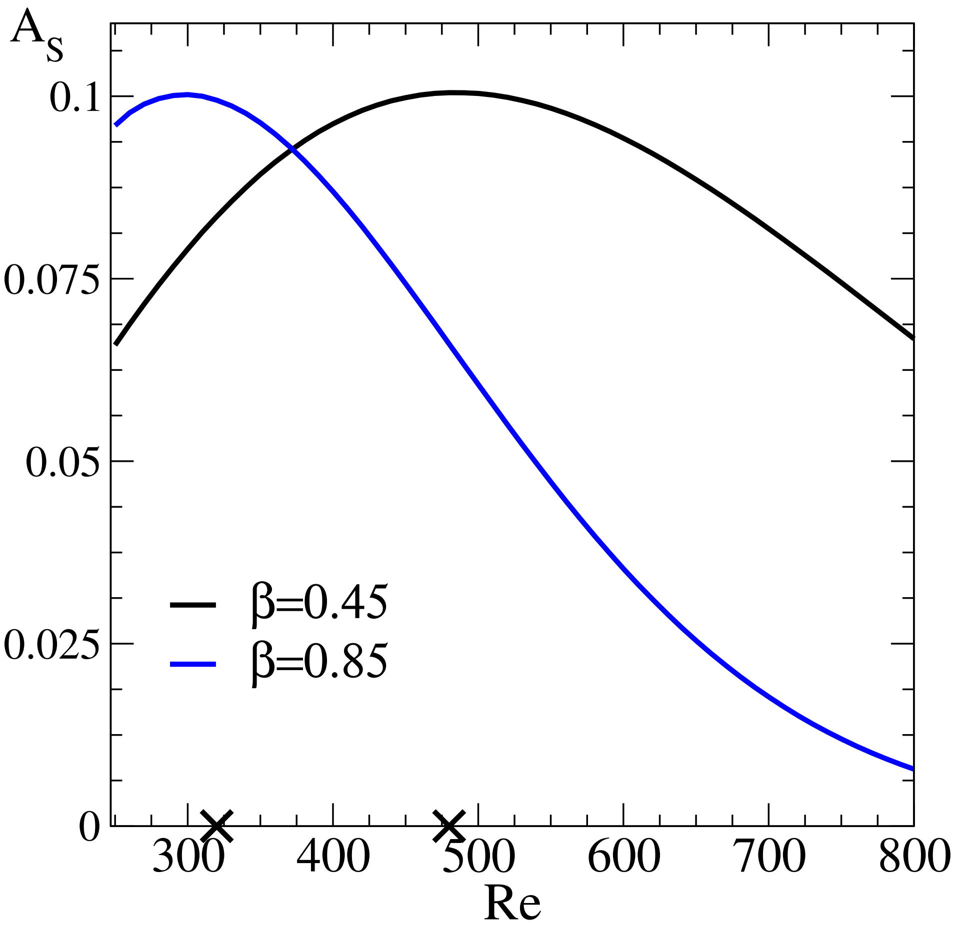
The Optimal Stabilizing Effect

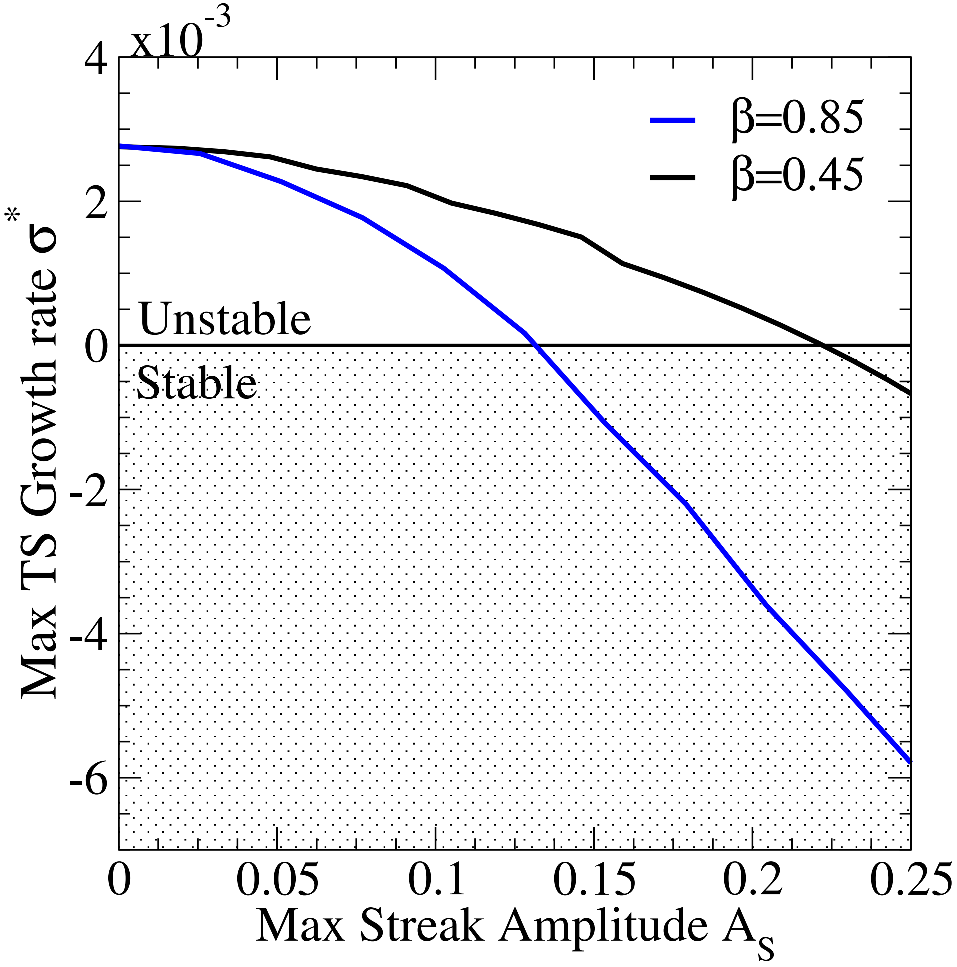




The optimal stabilizing streak attains its maximum amplitude at the location of Branch I of the TS wave $(F = 131E - 6)$.

The Optimal Stabilizing Effect

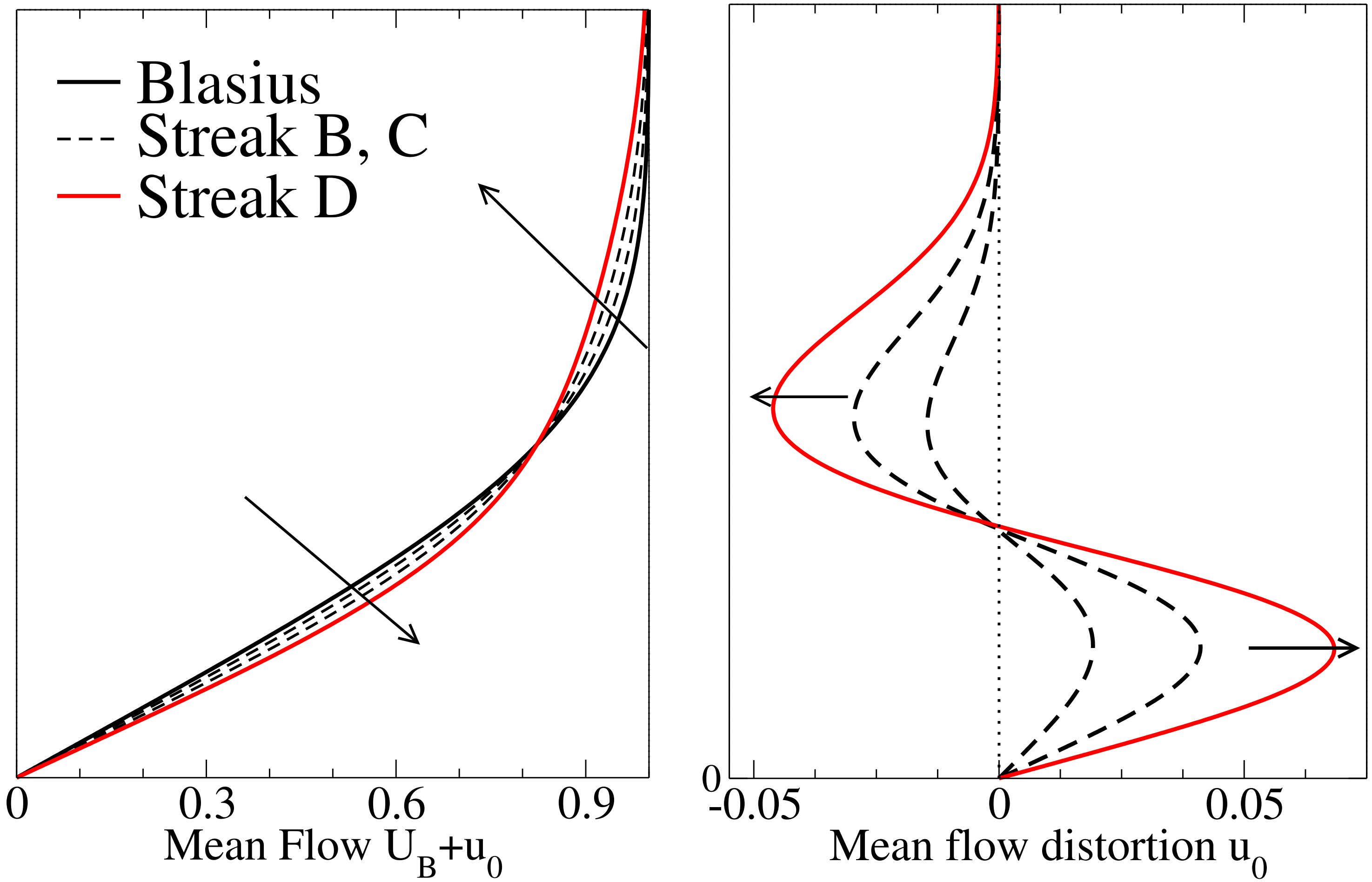




Similar results apply to other frequencies, here a TS wave $F = 170E - 6$.

The streak with $\beta = 0.45$ gives the optimal stabilization of a TS wave of frequency $F = 90E - 6$.

Streaky Boundary Layer

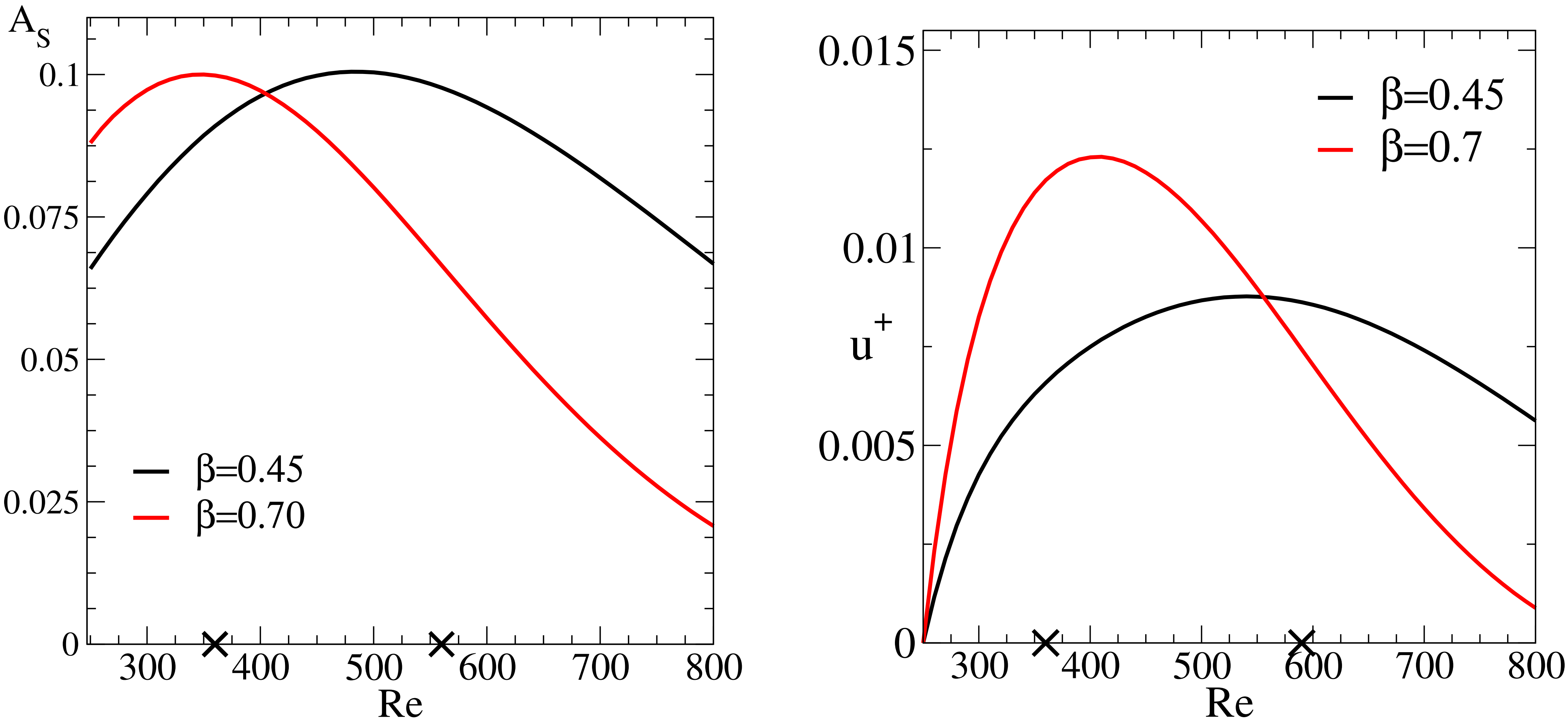


Velocity profile becomes fuller close to the wall and thinner in the outer part.

Define the mean flow excess and mean flow deficit

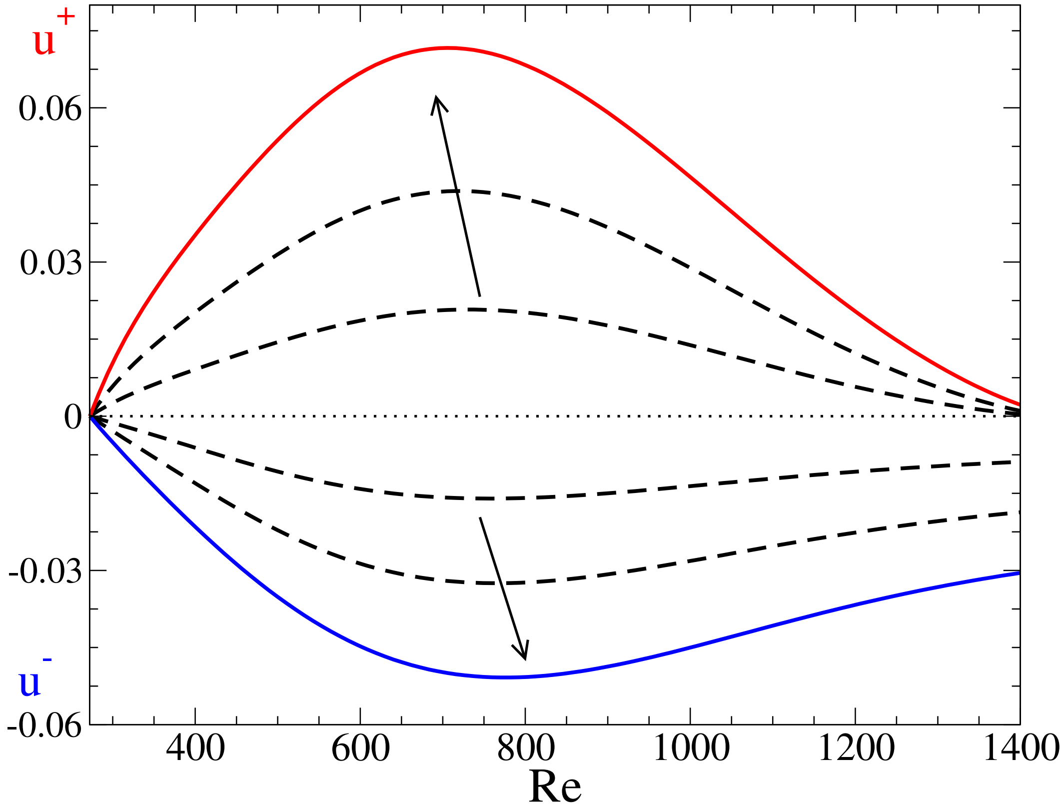
$$u^+ = \max_y\{u_0\} \quad u^- = \min_y\{u_0\}.$$

The Optimal Stabilizing Effect



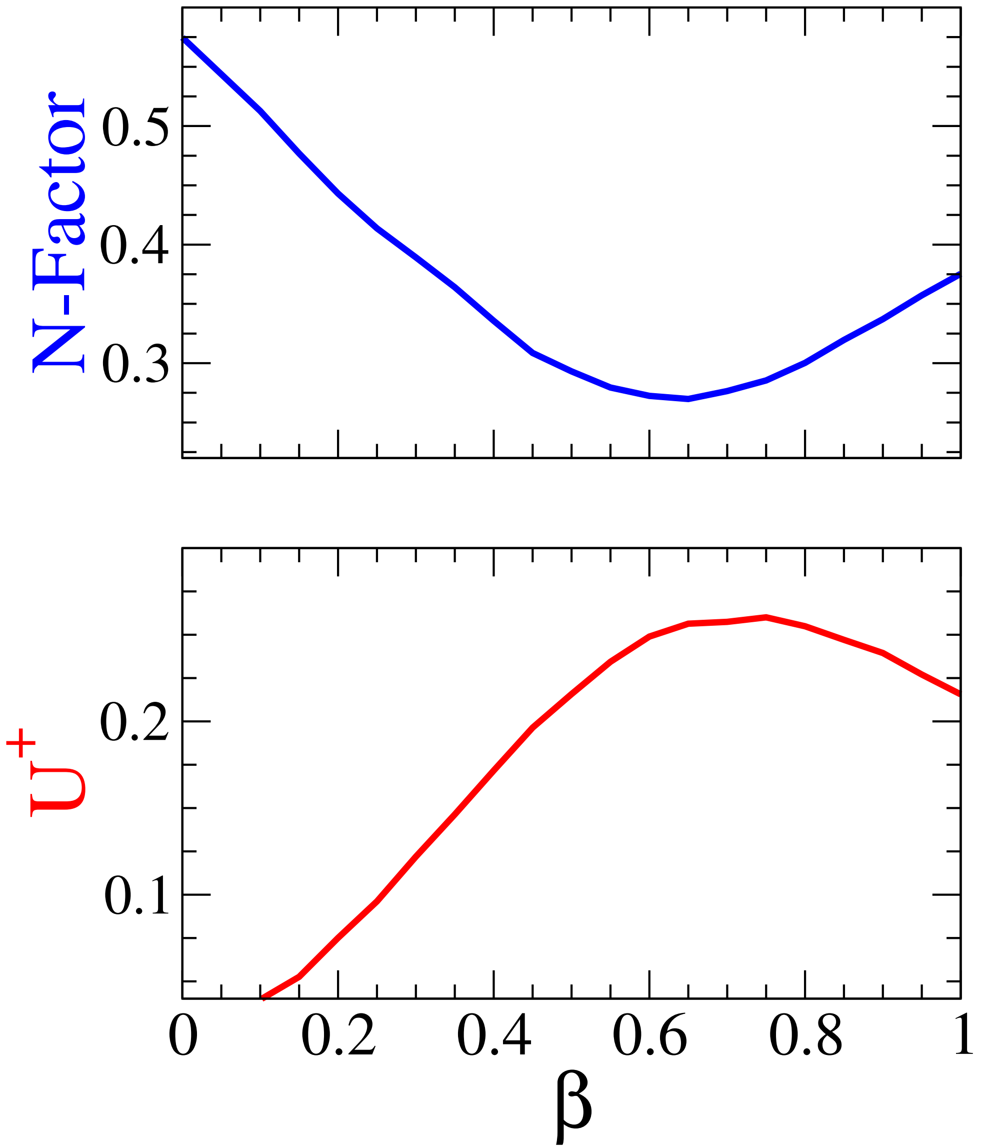
The mean flow excess of streaks is the largest, for streaks that attain their maximum amplitudes near Branch I of TS waves.

Measurement of the boundary layer



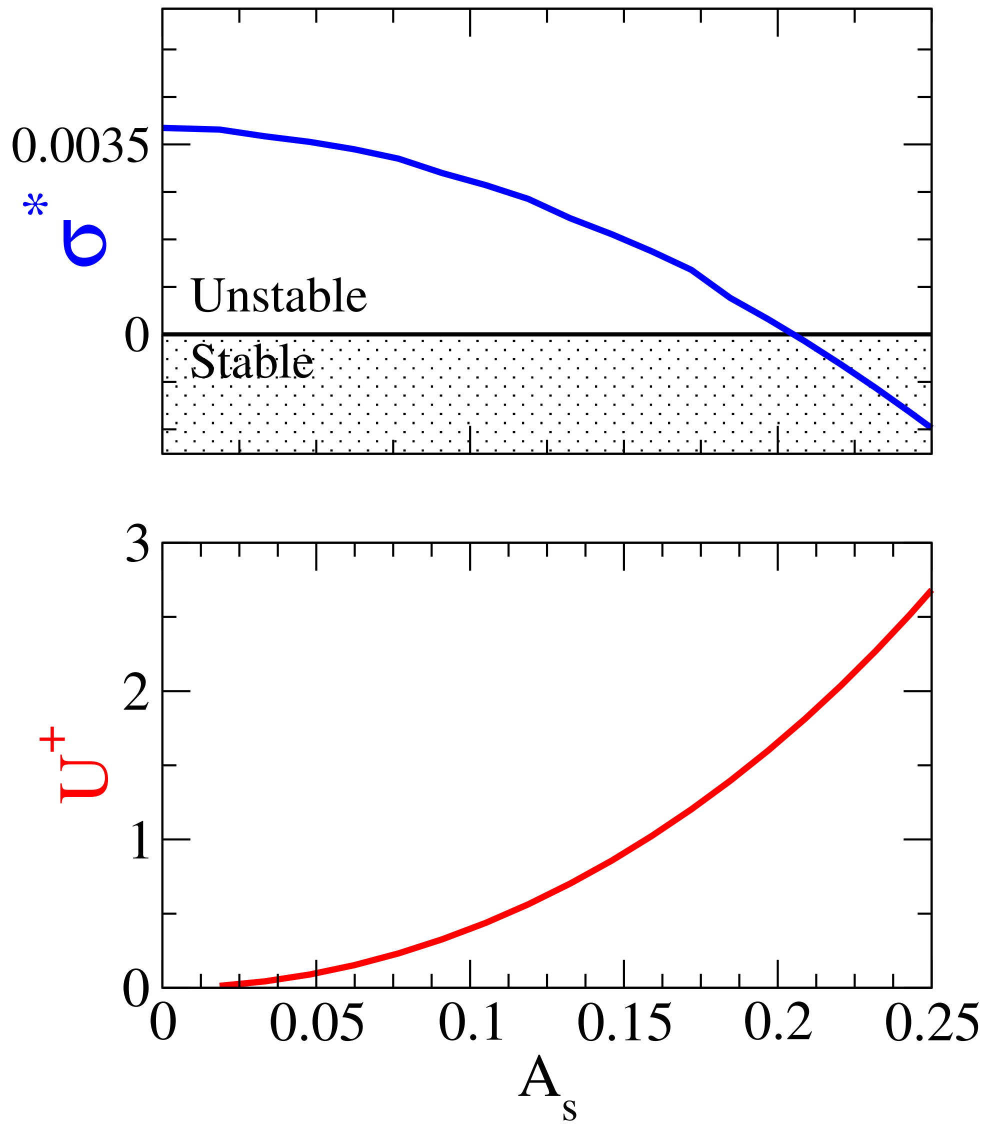
Compute the total sum of u^+ along the plate, i.e. the total mean flow excess,

$$U^+ = \int_{x_0}^{x_1} u^+ \, dx. \tag{1}$$

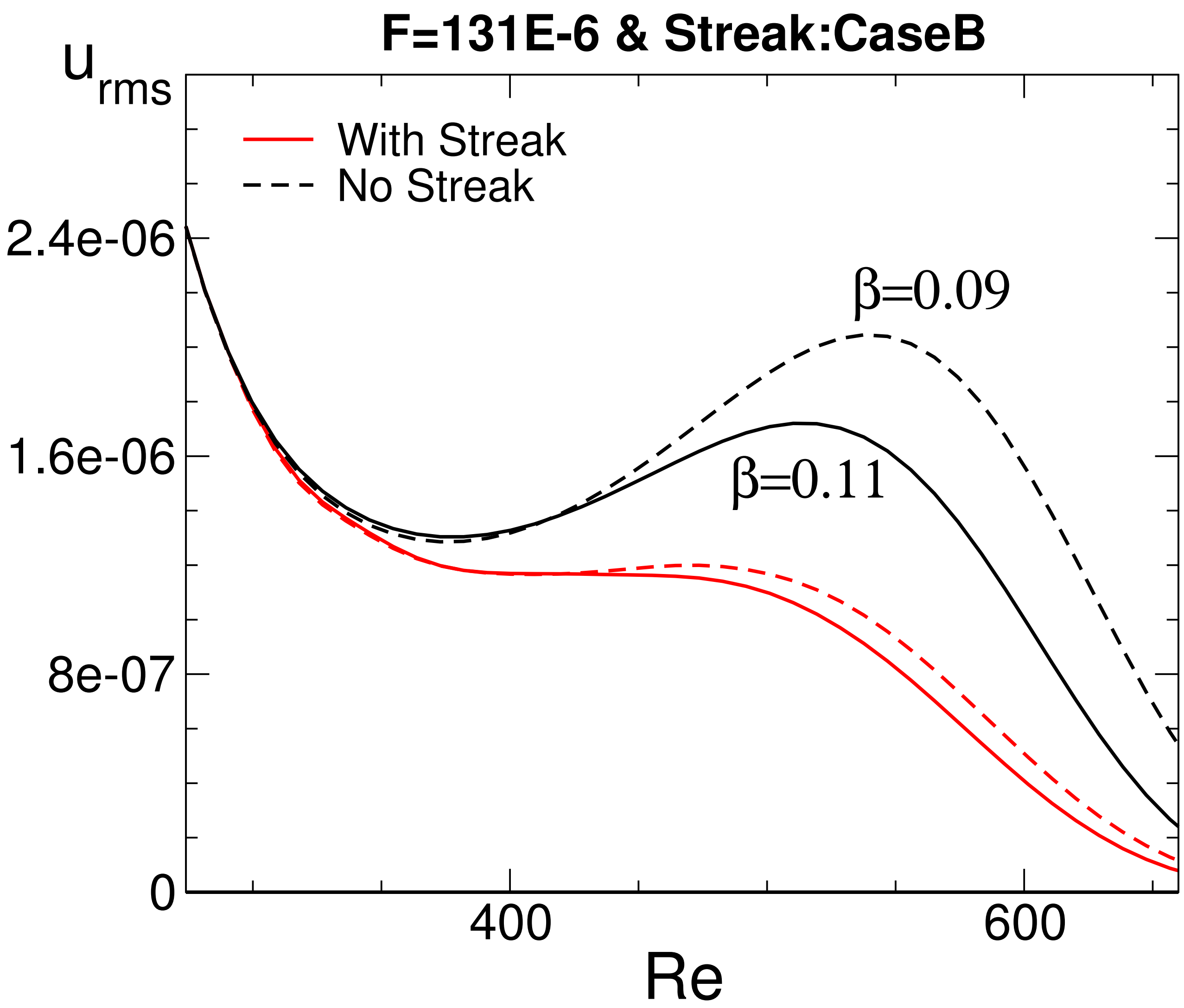


The streak that maximizes the U^+ gives the optimal stabilization effect.

Streak amplitude and spanwise wavelength

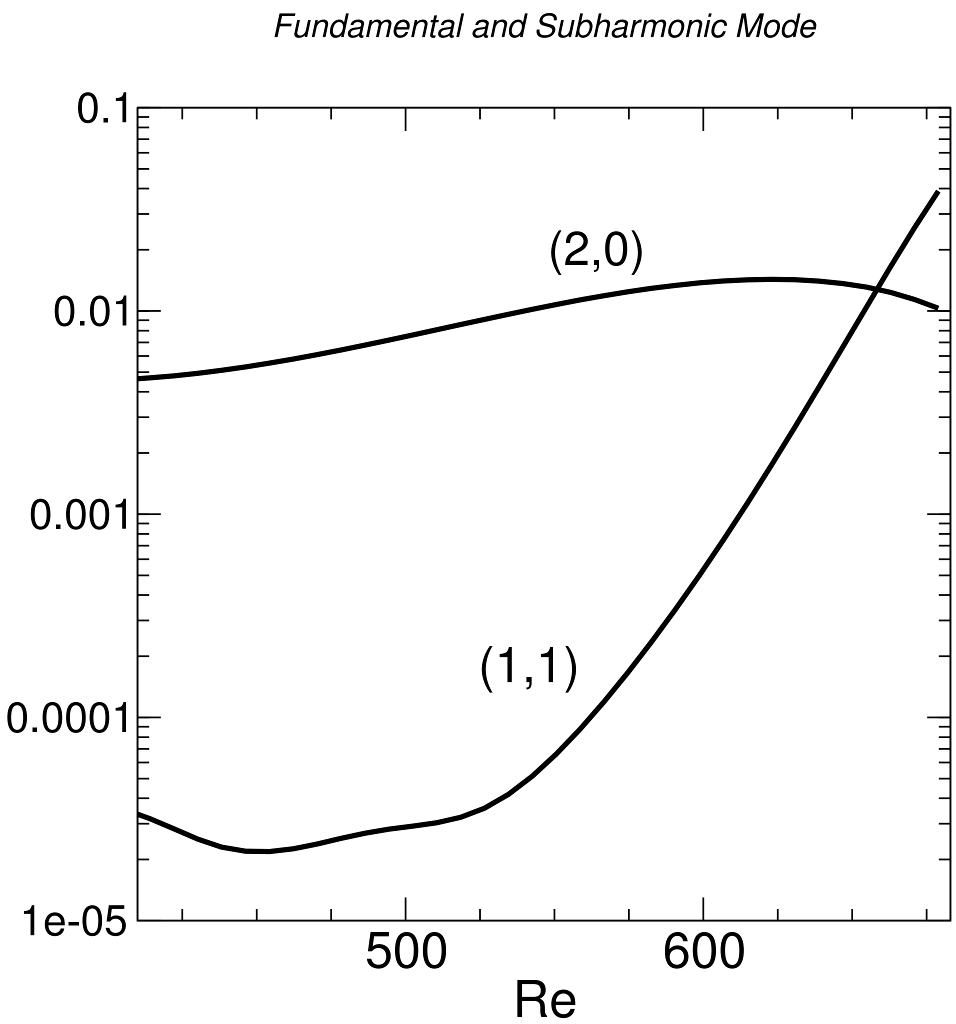


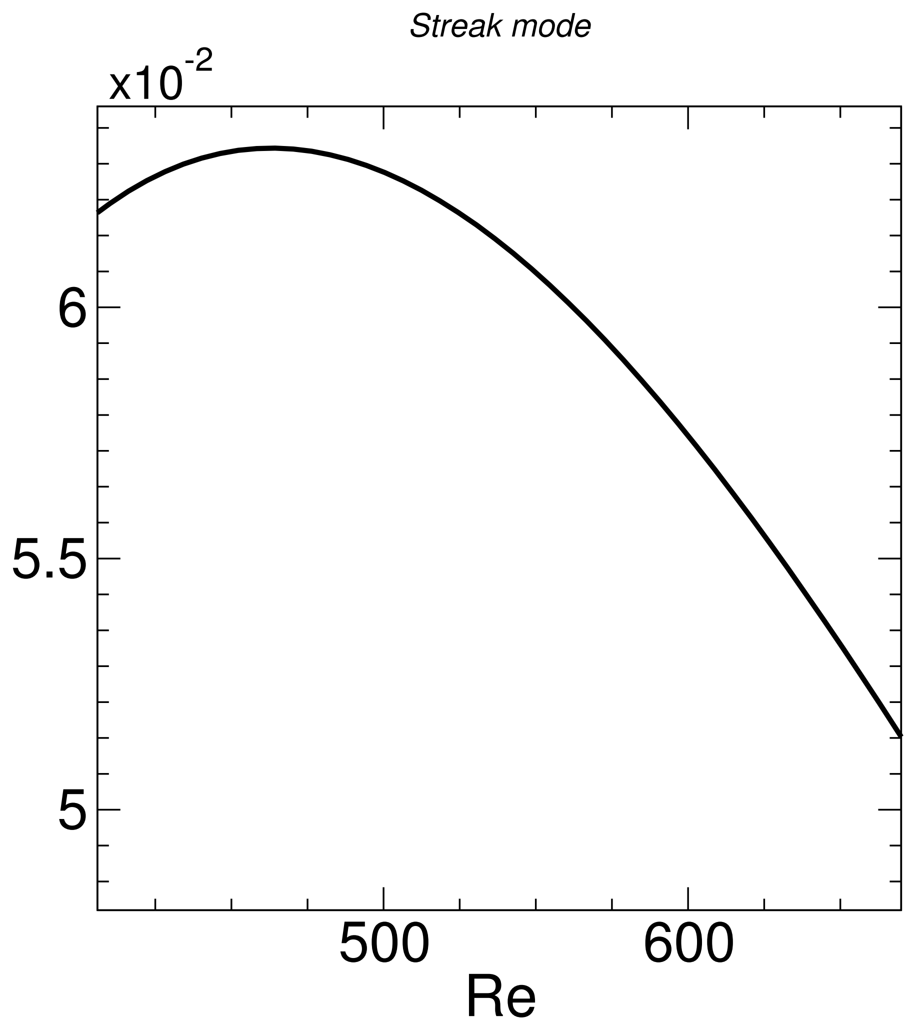
Oblique Waves



The stabilization effect is observed for 3D exponential disturbances.

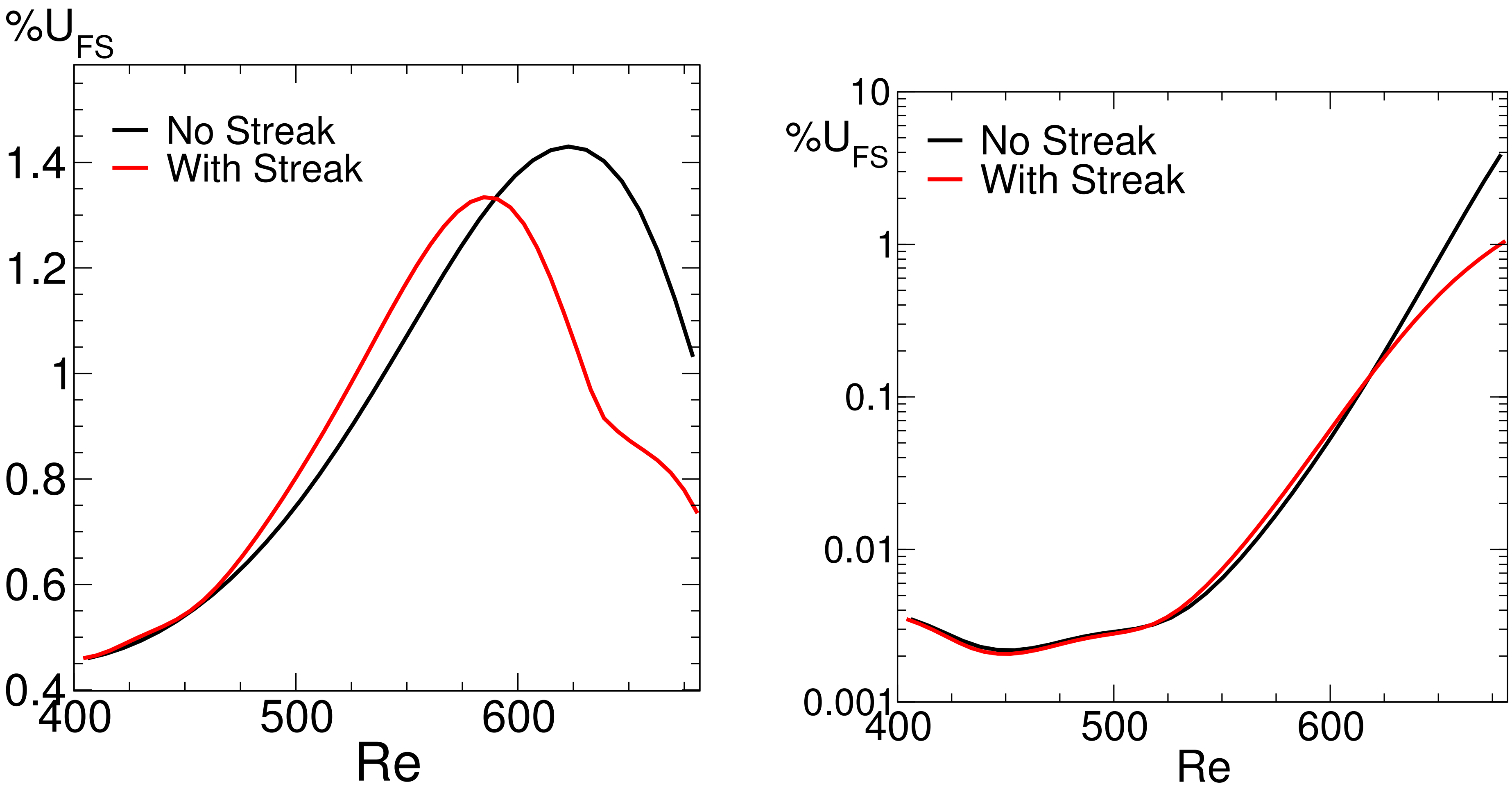
Subharmonic secondary instability.





Oblique waves $(1,1)$ and $(1,-1)$ with initial amplitude $A_{ob} = 0.0035\%\ U_\infty$ and $\beta = 0.14$.
TS wave with initial amplitude $A_{TS} = 0.46\%\ U_\infty$ at $Re = 406$.

Secondary instability with Streak



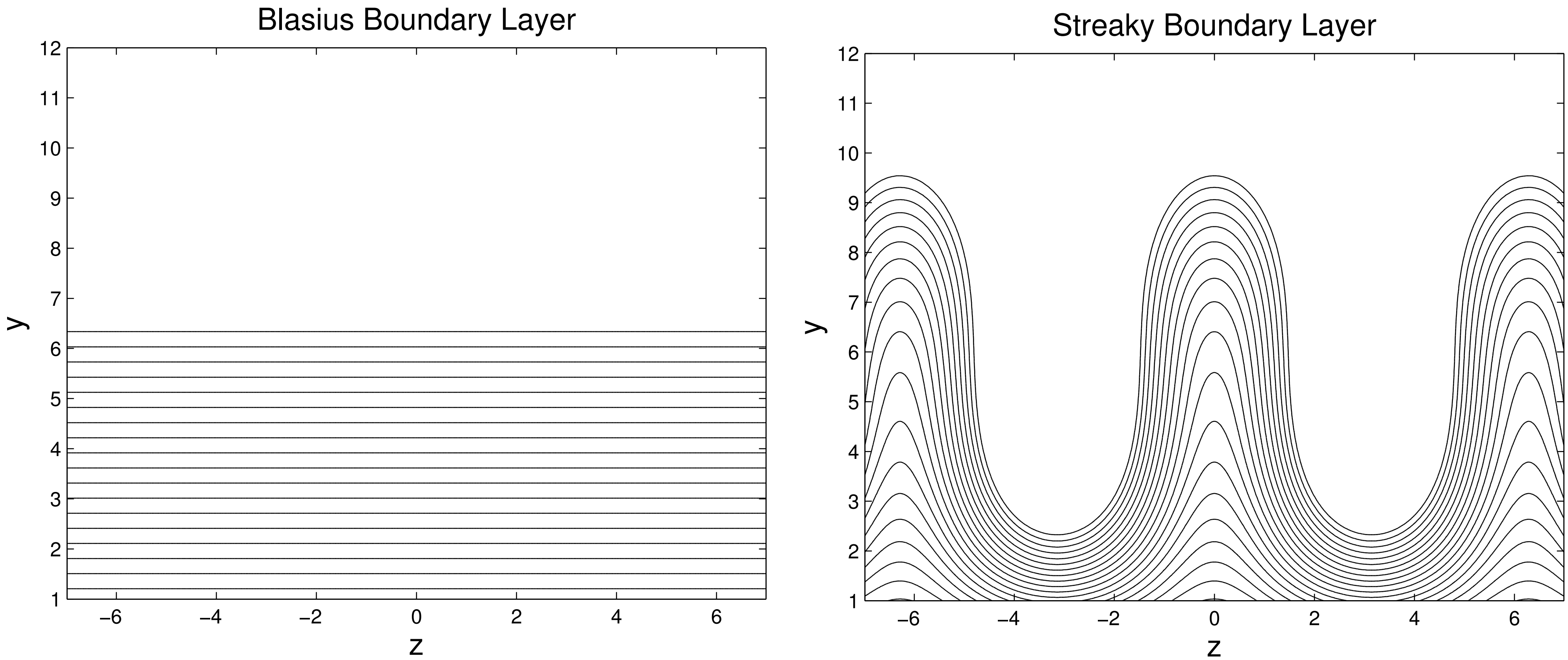
Subharmonic Wave: $3.89\%U_\infty$ at $Re = 680$ without streak, and $1.05\%U_\infty$ at $Re = 680$, only with a maximum streak amplitude of $A_s^* = 6.18\%U_\infty$.

Conclusions

- The optimal stabilization effect is obtained for streaks, which cause the largest distortion of flow between Branch I & II of the TS wave.
- These streaks attain the maximum amplitude close to Branch I of the TS wave.
- Finite amplitude TS waves are damped in the presence of streaks, and it seems to be no destabilizing nonlinear interaction between finite amplitude TS waves and streaks.

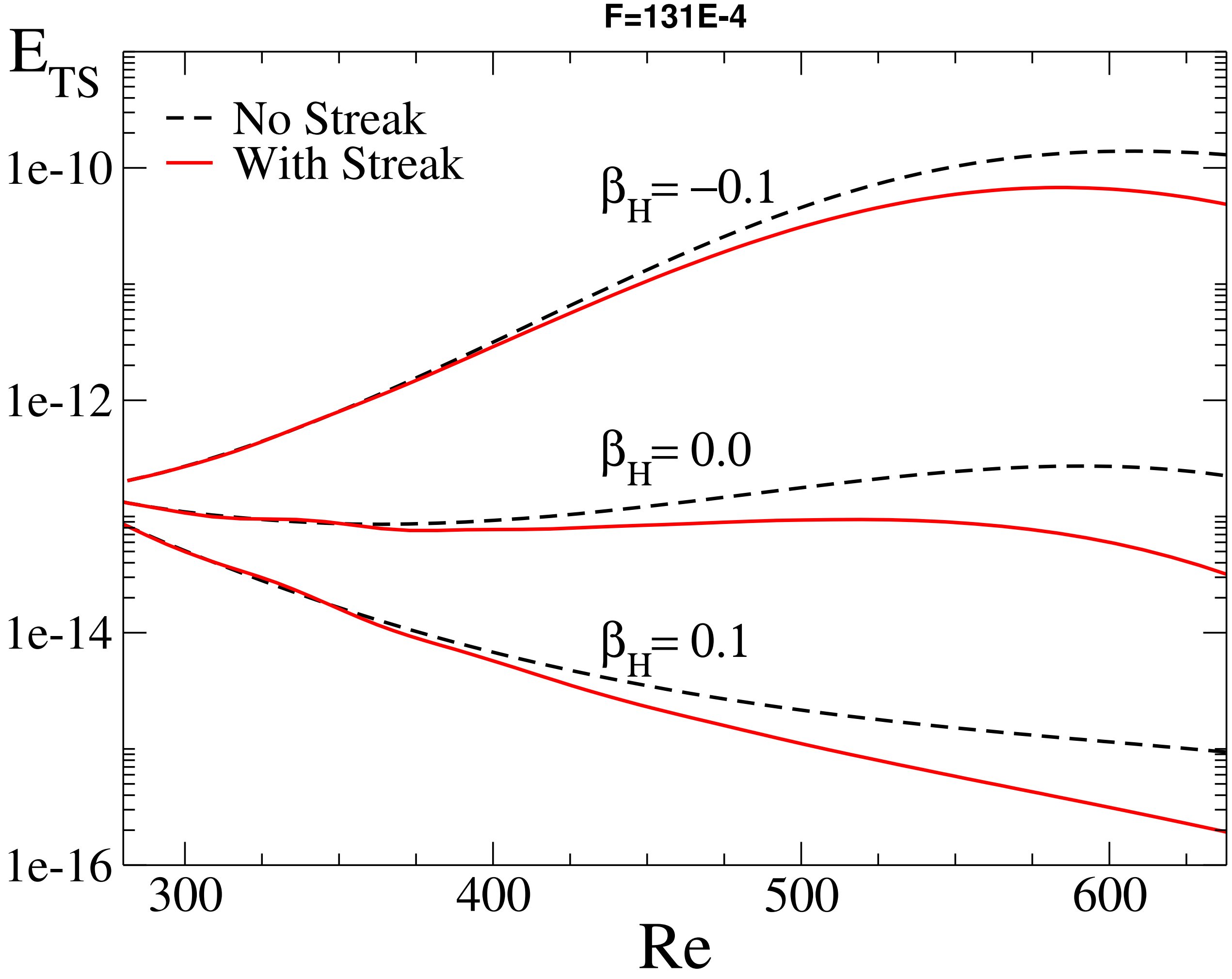
Extra Slides

Streaky Boundary Layer

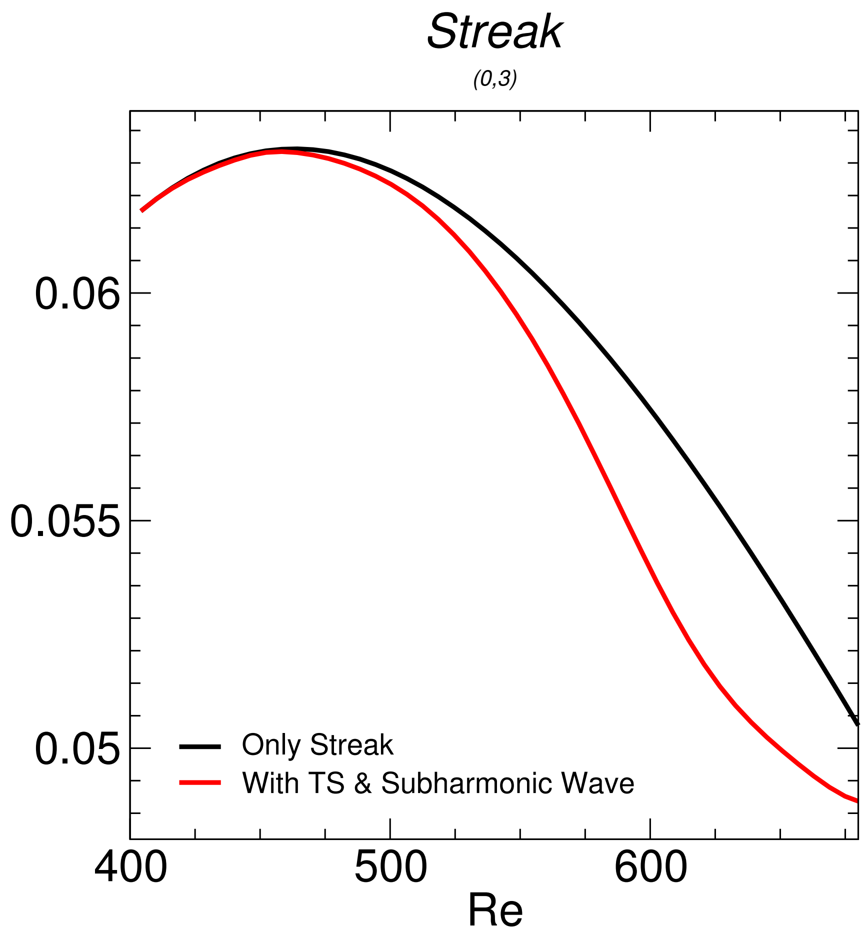


Spanwise modulation of the Boundary layer thickness.

The Effect of Pressure Gradients on Streaks



The action on the Streak



Streak with maximum amplitude $A^* = 6\%\ U_\infty$ and spanwise wavelength $\beta = 0.42$.