ASSESSMENT AND DEVELOPMENT OF SECOND ORDER TURBULENCE MODELS

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Presented by

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MOTIVATION

- these models describe the effect of mean flow and external agencies (such as buoyancy) on the evolution of turbulence
- therefore, in principle, these models give a more accurate description of complicated flow fields than the two equation models
  - e.g flows with large anisotropy in turbulence (such as near the leading edge of a turbine blade)

OBJECTIVE

- assess the performance of the various second order turbulence models in benchmark flows
- seek improvements where necessary
  - model for the pressure correlation term in the scalar flux equation
  - model for the scalar dissipation equation

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Transport Equations for Second Moments

$$
\begin{aligned}
\frac{D\overline{u_i u_j}}{Dt} &= P_{ij} + \Pi_{ij} + T_{ij} - D_{ij} \\
\frac{D\overline{u_i \theta}}{Dt} &= P_i + \Pi_i + T_i \\
\frac{D\overline{\theta^2}}{Dt} &= P + T - D
\end{aligned}
$$

These equations have to be closed by providing models for:

- Pressure correlation terms (Π_{ij}, Π_i)
- Transport (Diffusion) terms (T_{ij}, T_i)
- Dissipation terms (D_{ij}, D)

HOW TO ASSESS MODELS ?

Global computation

- Mean and turbulence equations are numerically solved

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$$\frac{D\overline{u_i u_j}}{Dt} = P_{ij} + \ldots\ldots$$

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- Results (e.g. Reynolds stresses) are then compared with experiments or DNS data

Direct comparison

Individual terms in the turbulence equations (such as pressure correlation terms) are directly compared with experiment or DNS data

Note that:

- In experiments pressure correlation terms can not be measured but can only be obtained indirectly through balance of second moment equations
- DNS allows direct computation of these correlations but is limited to low Reynolds number

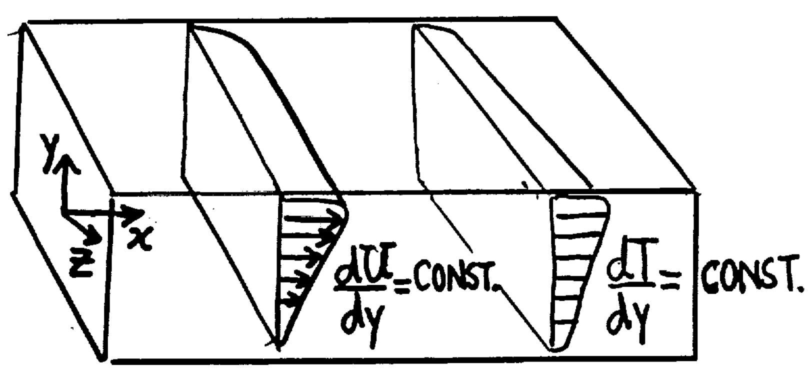
Most of the results to be shown in this presentation are direct comparisons

Models for pressure correlation term in the scalar flux equation

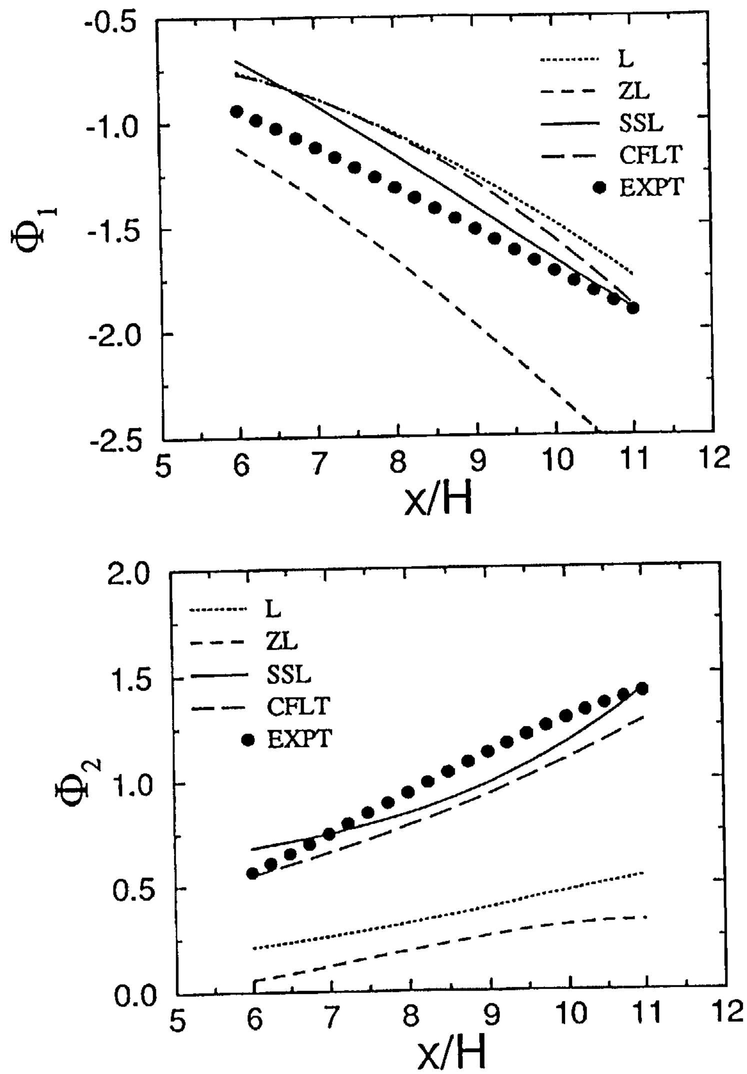
- a. Launder model (1975)
- b. Zeman and Lumley model (1976)
  - linear in scalar flux
  - do not satisfy realizability
- c. Shih, Shabbir and Lumley model (1985,1991)
- d. Craft, Fu, Launder, Tselepidakis model (1989)
  - linear in scalar flux and Reynolds stress
  - satisfy realizability

Application to Homogeneous Shear Flow

(Experiment as well as DNS data)



Tavoularis & Corrsin Expt (1981)



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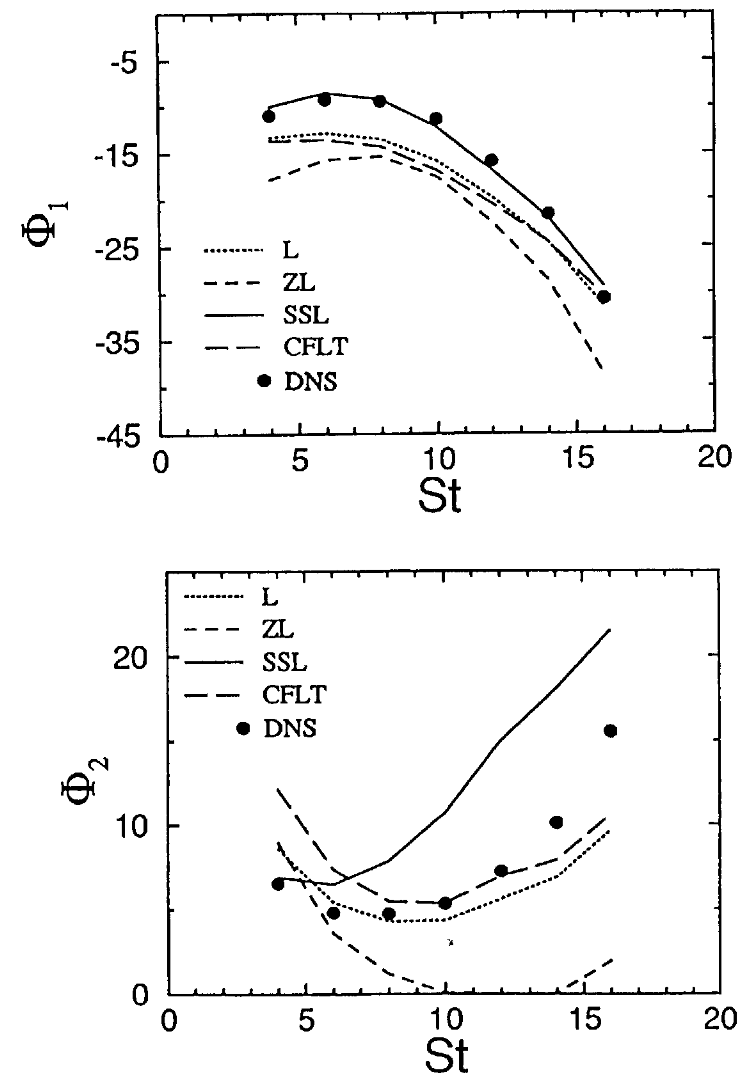
DNS Data of Rogers et al. (1986)



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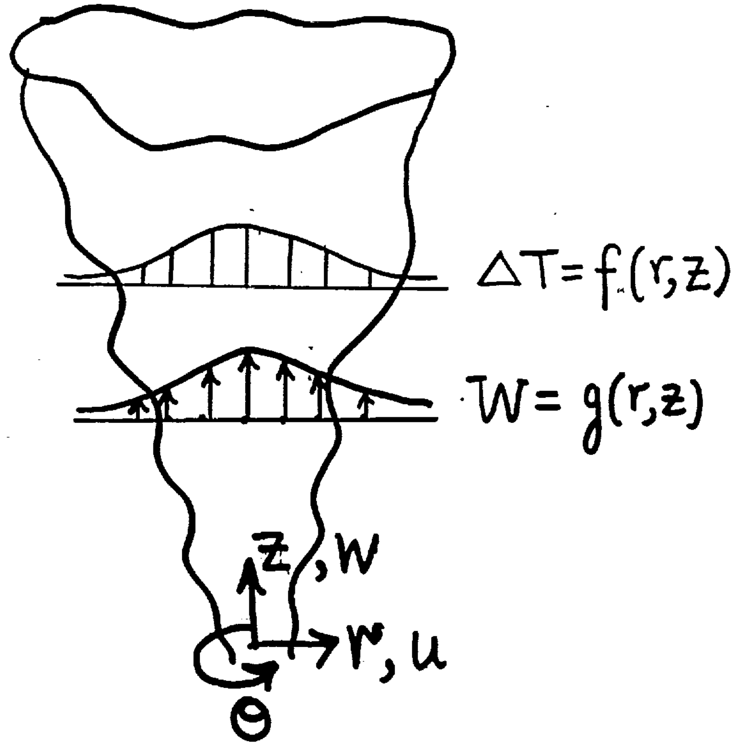
Application to Round Buoyant Plume Flow Experiment



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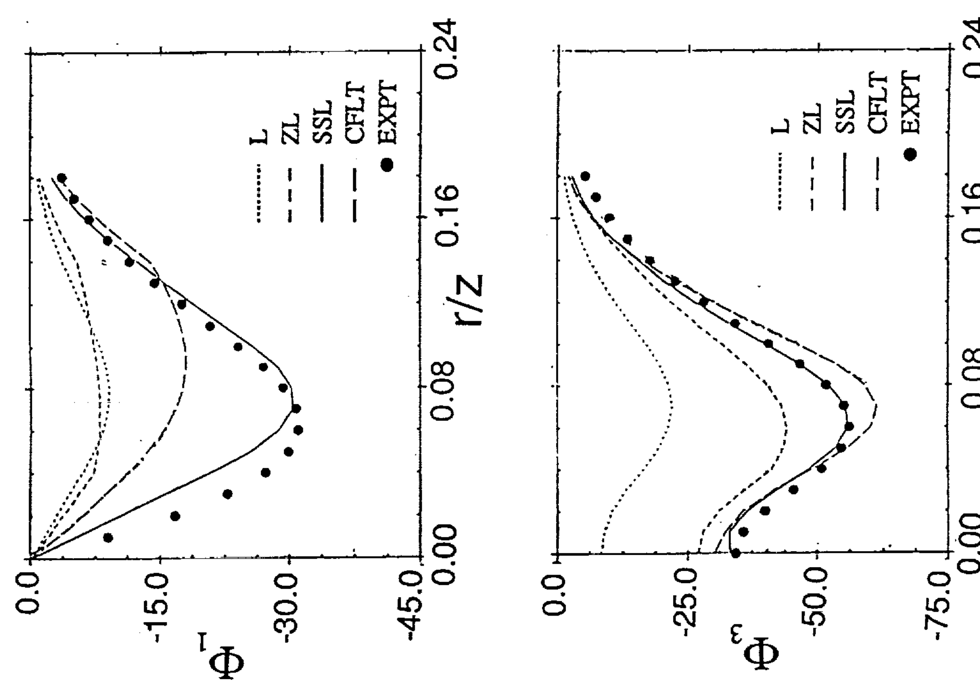
Shabbir and George Expt. (1990)



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CONCLUSION

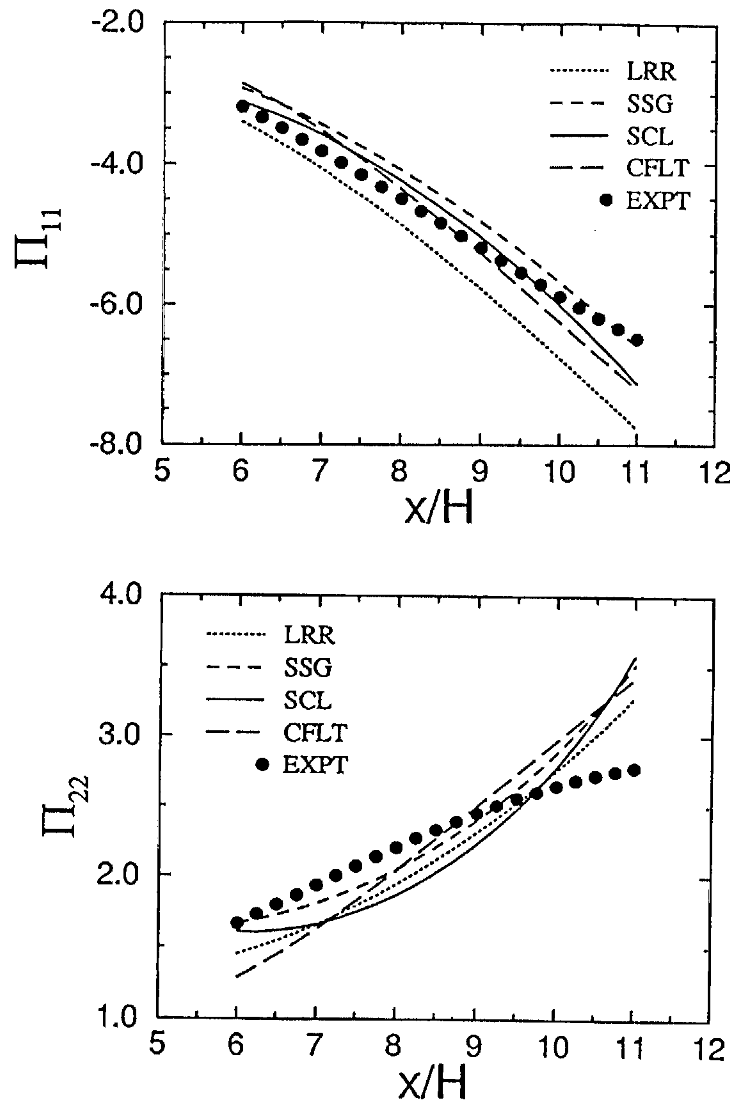
Models for pressure correlation term in scalar flux equation

- Models involving both scalar flux and Reynolds stress give better performance than the models which involve only scalar flux.

Models for pressure correlation term in the Reynolds stress equation

- a. Launder, Reece, Rodi model (1975)
- b. Speziale, Sarkar and Gatski model (1991)
  - linear or quasi-linear in Reynolds stress
  - do not satisfy realizability
- c. Shih and Lumley model (1985)
- d. Craft, Fu, Launder, Tselepidakis model (1989)
  - nonlinear in Reynolds stress
  - satisfy realizability

Tavoularis & Corrsin Expt (1981)



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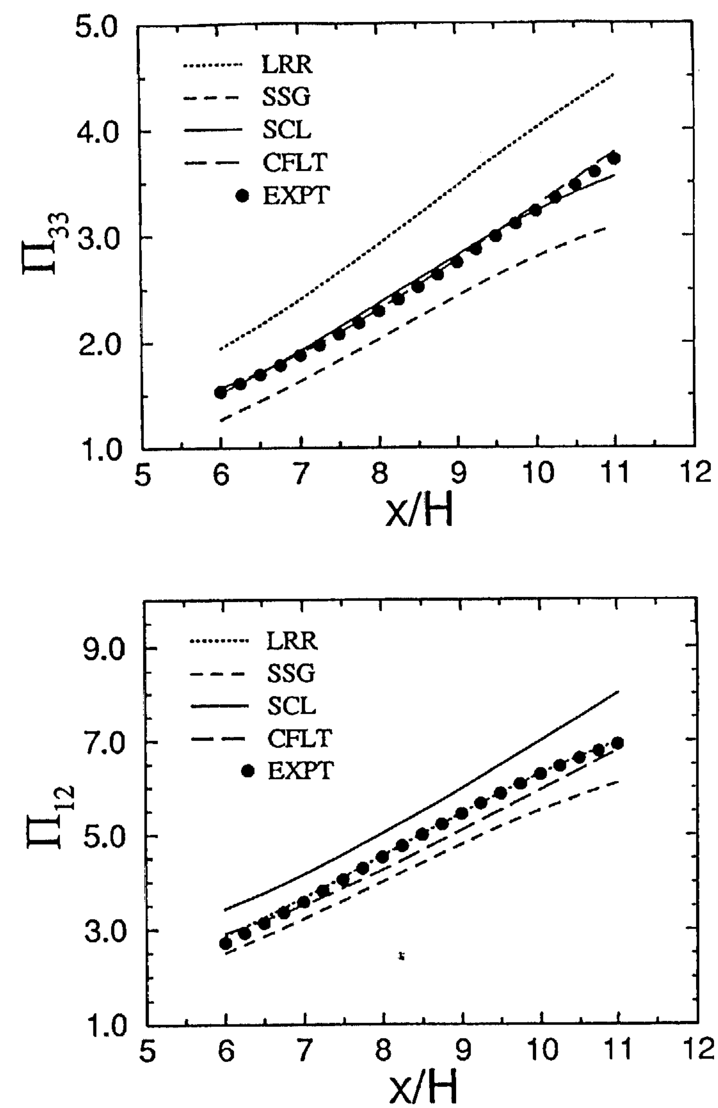
Tavoularis & Corrsin Expt (1981)



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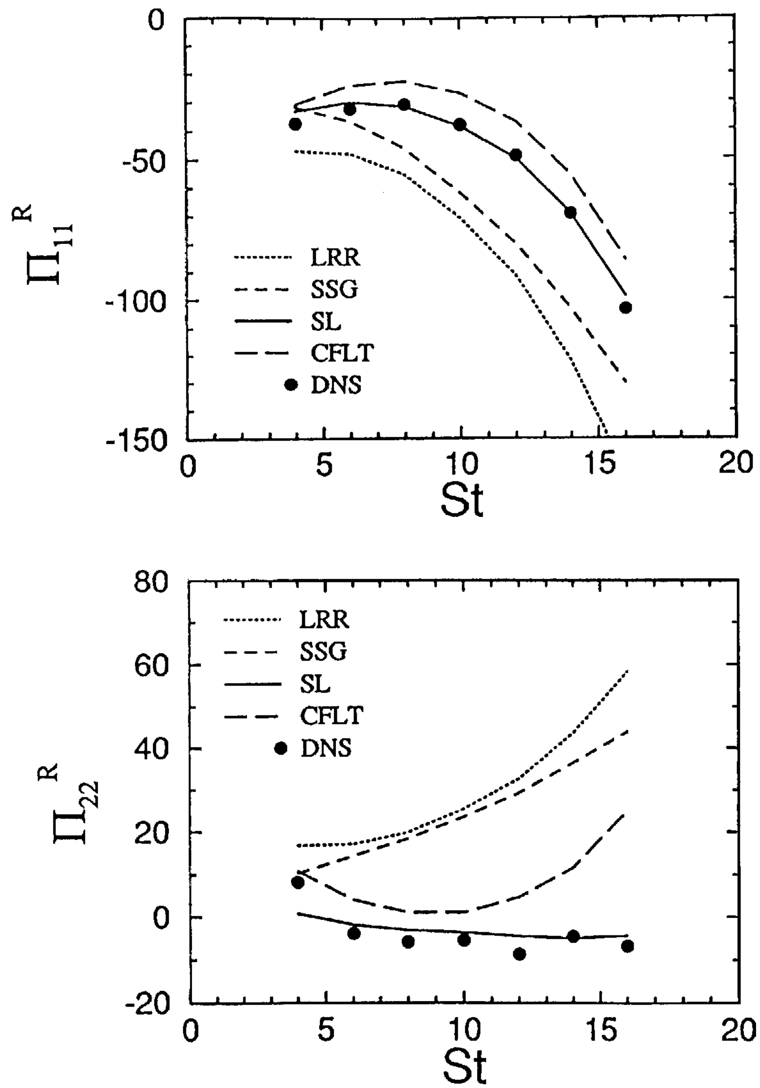
DNS Data of Rogers et al. (1986)



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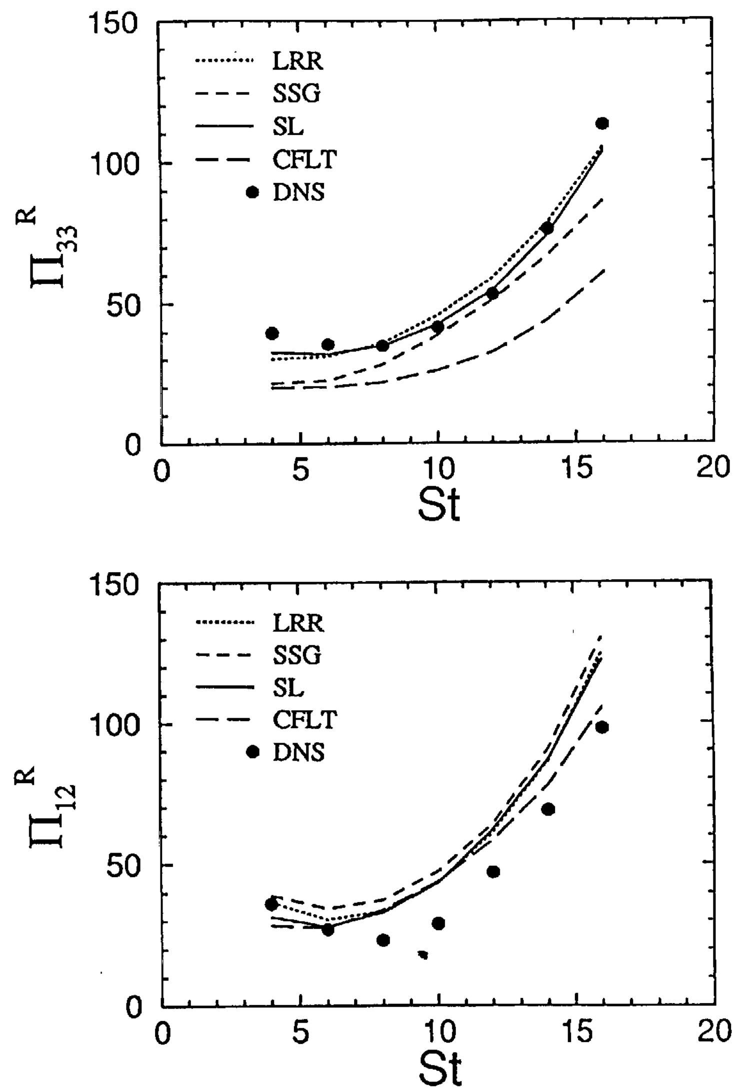
DNS Data of Rogers et al. (1986)



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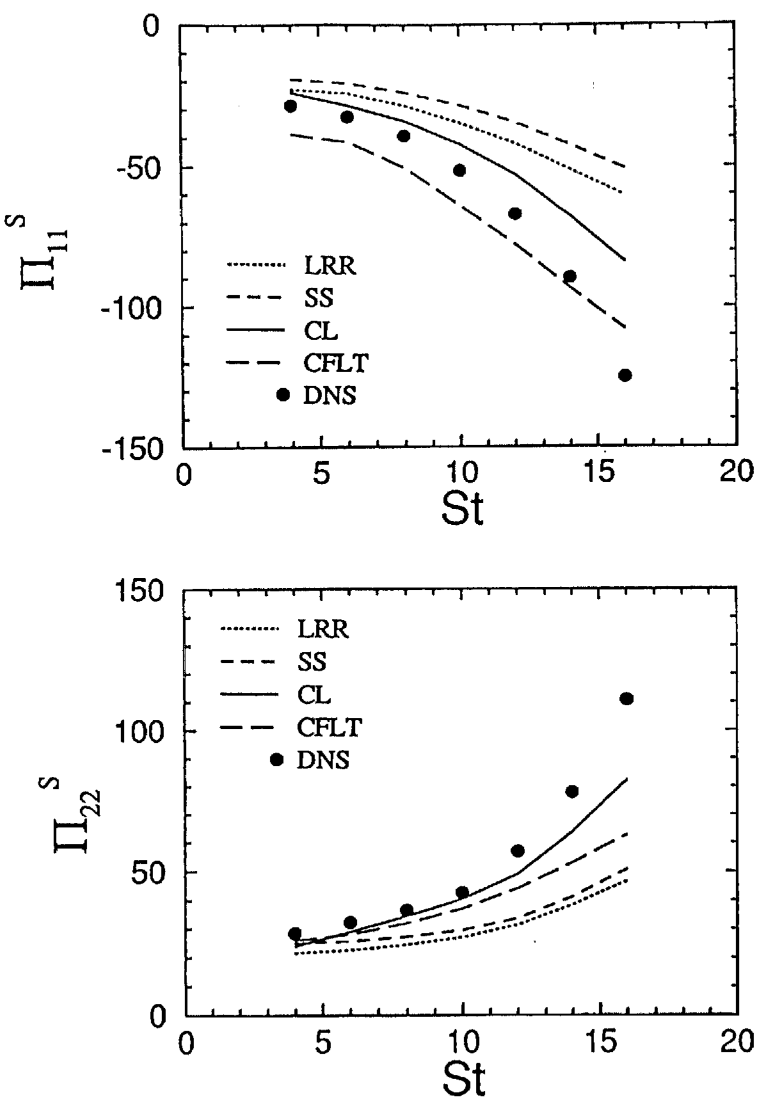
DNS Data of Rogers et al. (1986)



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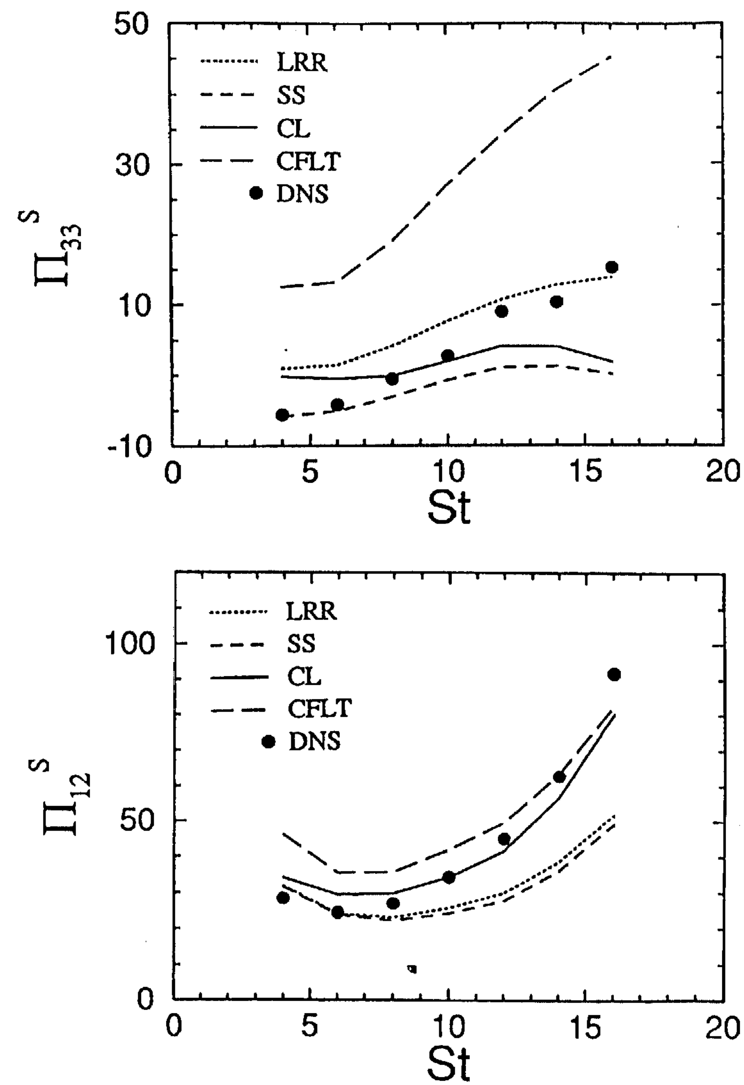
DNS Data of Rogers et al. (1986)



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CONCLUSION

Models for pressure correlation term in Reynolds stress equation

- For the DNS data non-linear models give better performance than linear models. However, for the experiment no single model performs better for all the components
- For the rapid part of the pressure correlation the relation $\Pi_{ij}^{R} = F(\overline{u_i u_j}, U_{i,j})$ is found to be adequate

CONCLUSION (contd.)

- Performance of all the slow pressure correlatiion models varies from one flow to another.
- Furthermore, the relation $\Pi_{ij}^{S} = F(\overline{u_i u_j}, k, \epsilon)$, is inadequuate in certain situations
  - DNS shows that Π_{ij}^{S} is dependent not only on the present time value of Reynolds stress but also on its past history
  - Definition of Π_{ij}^{S} implies that it is also a funciton of triple velocity moment $\overline{u_i u_j u_k}$
- Therefore, more research is needed before any model for Π_{ij}^{S} can be recommended for use.

A New Model Equation for Scalar Dissipation

- Traditional scalar dissipation rate equation is modeled in an analogue fashion to the mechanical dissipation equation
- Equation proposed here is modeled after the exact equation for scalar dissipation
- Its production/destruction mechanisms are different than the traditional model quation

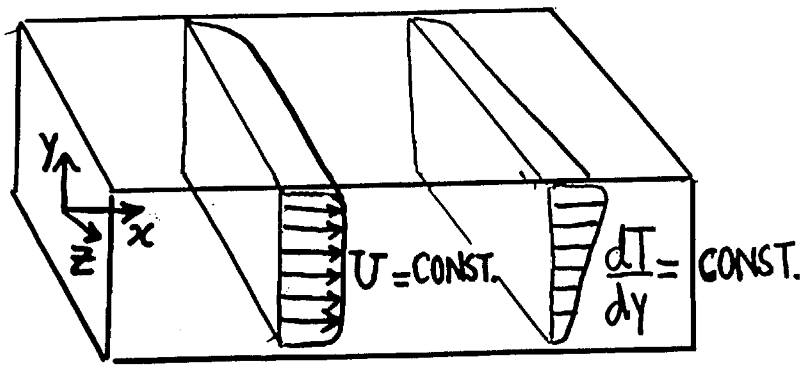
Application to Homogeneous Benchmark Flows

1. Homogeneous turbulence subjected to constant scalar gradient
2. Homogeneous turbulence subjected to constant scalar gradient and constant shear

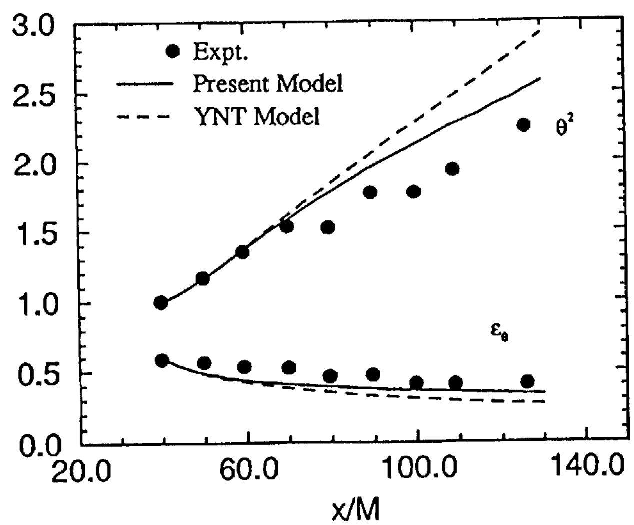
Global computation of the following two equations

$$
\begin{aligned}
U_j \frac{\partial \overline{\theta^2}}{\partial x_j} &= -\,2\overline{u_i\theta}\frac{\partial T}{\partial x_i} - 2\epsilon_\theta \\
U_j \frac{\partial \epsilon_\theta}{\partial x_j} &= C_{\theta 1}\epsilon_\theta S + C_{\theta 2}\frac{\sqrt{\epsilon_\theta \epsilon}\Phi}{\sqrt{Pr}} - C_{\theta 3}\frac{\epsilon_\theta \epsilon}{k}
\end{aligned}
$$

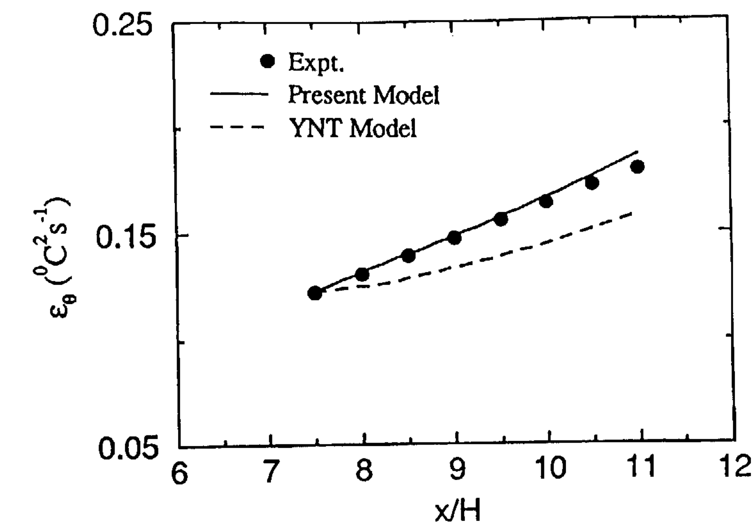
Mechanical field (i.e. k, ϵ, etc.) and scalar flux, $\overline{u_i\theta}$, are taken as known. This way performance of the scalar dissipation equation is isolated.

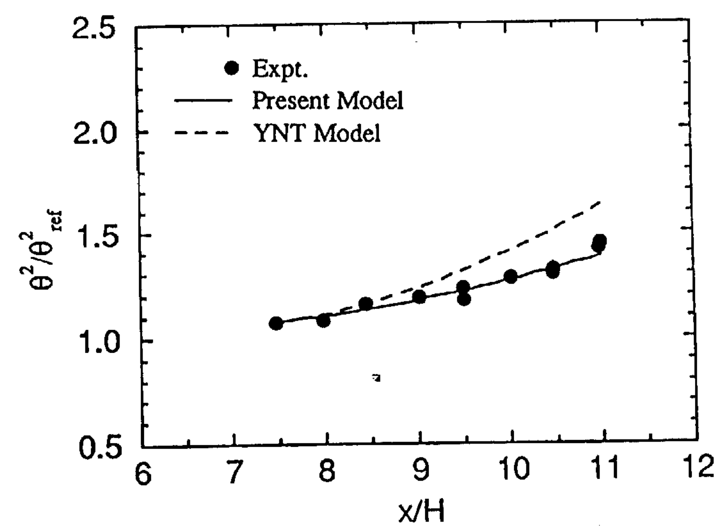


Sirivat & Warhaft Expt (1983)



Tavoularis & Corrsin Expt (1981)





CONCLUSION

- The transport equation for thermal dissipation rate proposed here gives improvement over the standard equation in at-least all the simpler benchmark flows. Its performance in the wall bounded flows is being assessed