TIME-DEPENDENT GRID ADAPTATION FOR MESHES OF TRIANGLES AND TETRAHEDRA

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MOTIVATION

- Unsteady CFD flow calculations are computationally expensive when compared to steady flow calculations
- Conflicting interests: We want adequate spatial & temporal accuracy but we don't want to pay the price (Excessive CPU time)
- The computational mesh drives the cost of CFD calculations and should be optimized for each flow condition. This suggests that solution algorithms should be closely tied with grid generation
- How do we optimize the mesh? Distribute the numerical error evenly throughout the mesh
- Use adaptive meshing to evenly distribute the spatial discretization errors
  - locally enrich in regions of relatively large errors
  - locally coarsen in regions of relatively small errors

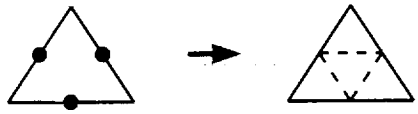
ENRICHMENT INDICATOR FOR THE SPATIAL ADAPTATION PROCEDURES

- Discretization errors generally occur where flow gradients are relatively large
  - shock waves
  - stagnation points
  - slip lines
  - expansion fans
- Magnitude of the gradient of density was used to detect relatively large flow gradients in 2D & 3D

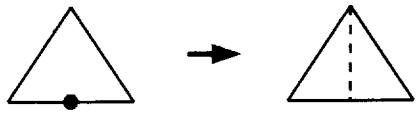
$$|\nabla \rho|$$

OVERVIEW OF 2D MESH ENRICHMENT STRATEGIES

- Type-4 enrichment element

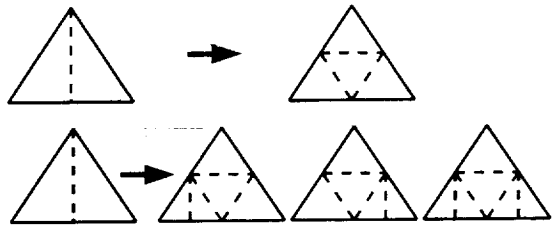


- Type-2 enrichment element

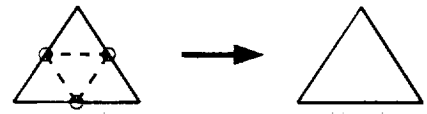


OVERVIEW OF 2D MESH ENRICHMENT STRATEGIES

- Further enrichment of a type-2 enrichment element

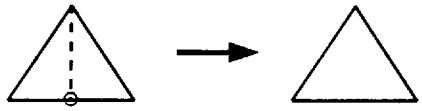


OVERVIEW OF 2D MESH COARSENING STRATEGIES



three nodes removed from a type-4 element

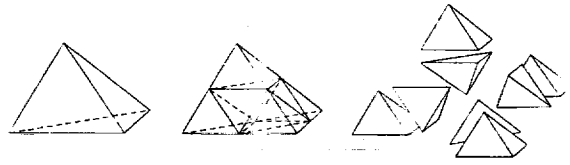
two nodes removed from a type-4 element



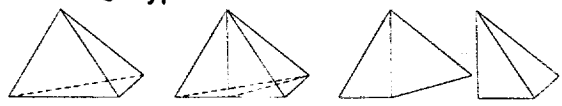
one node removed from a type-2 element

OVERVIEW OF 3D MESH ENRICHMENT STRATEGIES

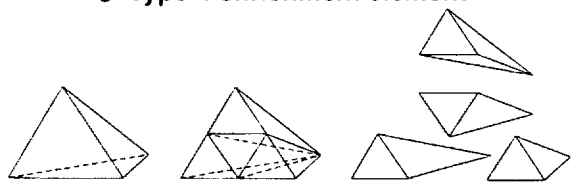
- Type-8 enrichment element



- Type-2 enrichment element

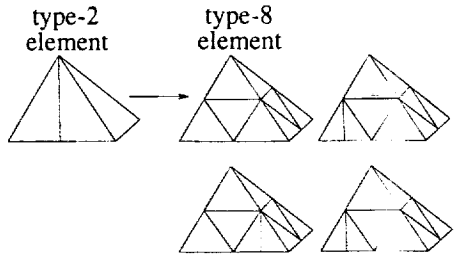


- Type-4 enrichment element



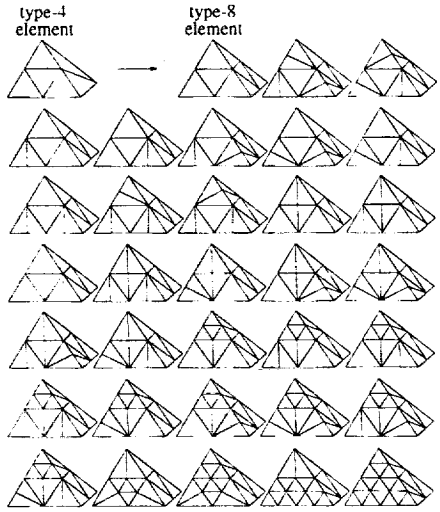
OVERVIEW OF 3D MESH ENRICHMENT STRATEGIES

- Further enrichment of a type-2 enrichment element



OVERVIEW OF 3D MESH ENRICHMENT STRATEGIES

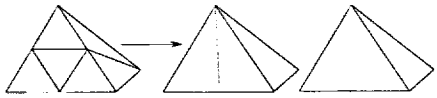
- Further enrichment of a type-4 enrichment element



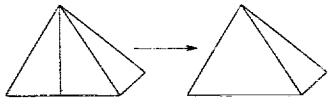
OVERVIEW OF 3D MESH COARSENING STRATEGIES

- Type-8 element coarsening

- Type-4 element coarsening



- Type-2 element coarsening



DESCRIPTION OF 2D & 3D UPWIND-TYPE EULER ALGORITHM OF BATINA

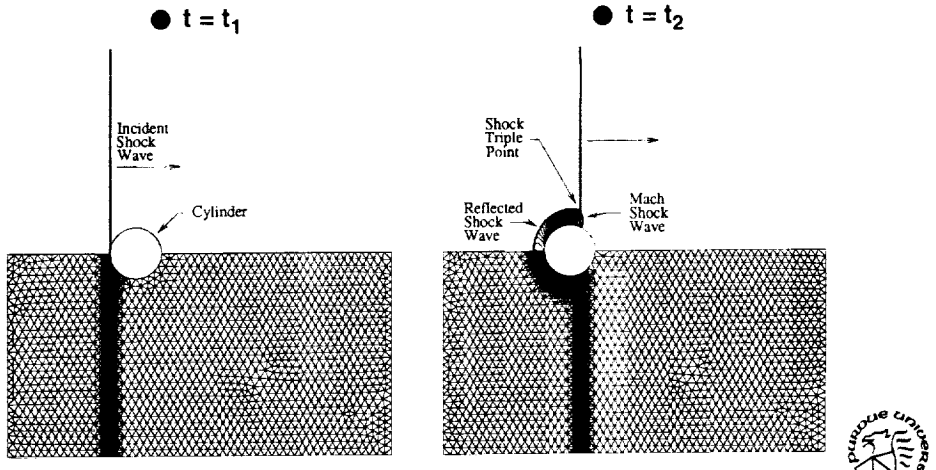
- Finite-volume spatial discretization on unstructured-grids
  - triangles in 2D
  - tetrahedra in 3D
- flux vector splitting of van Leer
- Flux limiting to suppress oscillations near shock waves
- Time integration may be either explicit Runge-Kutta scheme or implicit Gauss-Seidel relaxation scheme
- Implicit scheme allows very large CFL numbers for rapid convergence to steady state
- Choose time step for unsteady calculations based on physics of problem rather than numerical stability

OVERVIEW OF SPATIAL ADAPTATION RESULTS

- Two dimensional case
  - Shock diffraction problem
- Three dimensional cases
  - ONERA M6 wing
  - Shock-tube problem

INSTANTANEOUS MESH AND DENSITY CONTOUR LINES FOR THE SHOCK DIFFRACTION PROBLEM

- $M_s = 2.81$
- $\Delta\rho = 0.2$

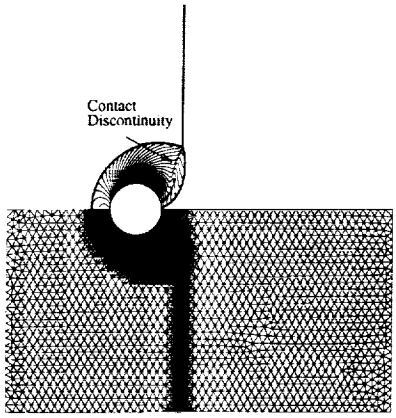


Rausch, 1992

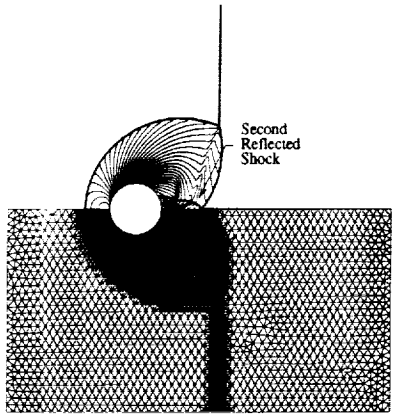
INSTANTANEOUS MESH AND DENSITY CONTOUR LINES FOR THE SHOCK DIFFRACTION PROBLEM

- $M_s = 2.81$
- $\Delta\rho = 0.2$

- $t = t_3$



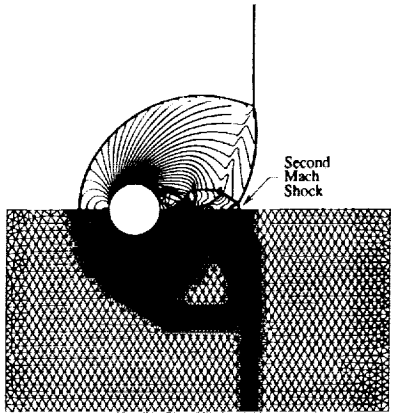
- $t = t_4$



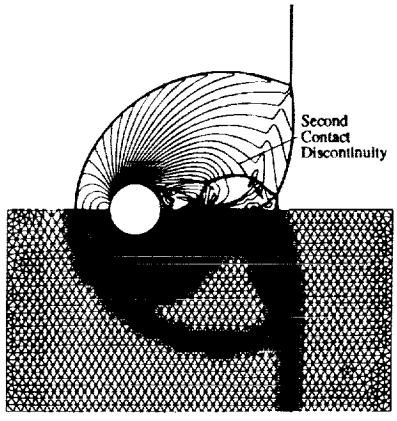
INSTANTANEOUS MESH AND DENSITY CONTOUR LINES FOR THE SHOCK DIFFRACTION PROBLEM

- $M_s = 2.81$
- $\Delta\rho = 0.2$

- $t = t_5$



- $t = t_6$



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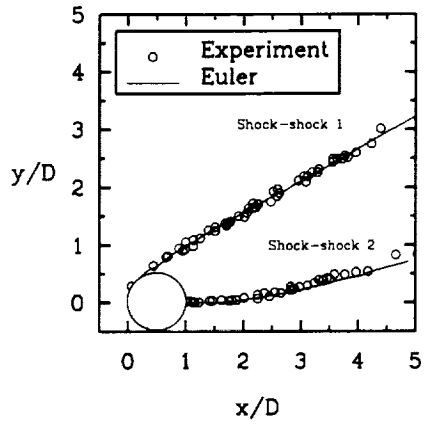
COMPARISON OF SHOCK TRIPLE POINT LOCATIONS WITH EXPERIMENTAL DATA

- Experimental data by Bryson and Gross, *Journal of Fluid Mechanics*, vol. 10, pp. 1-16, 1961



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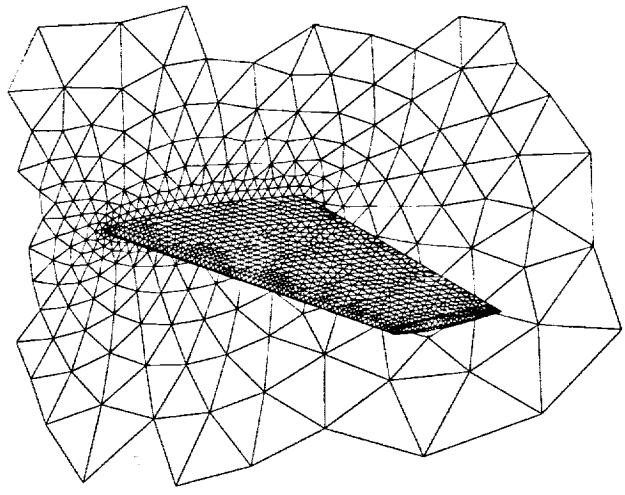
PARTIAL VIEW OF THE SURFACE MESHE FOR THE SYMMETRY PLANE AND THE ONERA M6 WING

- Total mesh has 46,516 tetrahedra and 8,824 nodes



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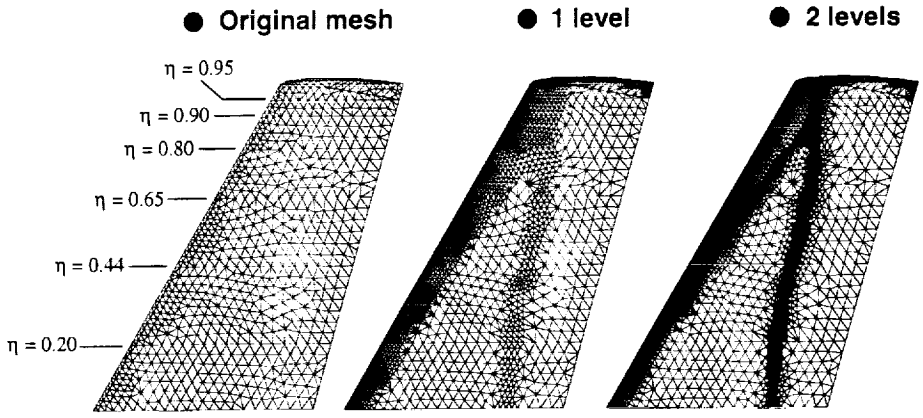
COMPARISON OF UPPER SURFACE MESHES FOR THE ONERA M6 WING

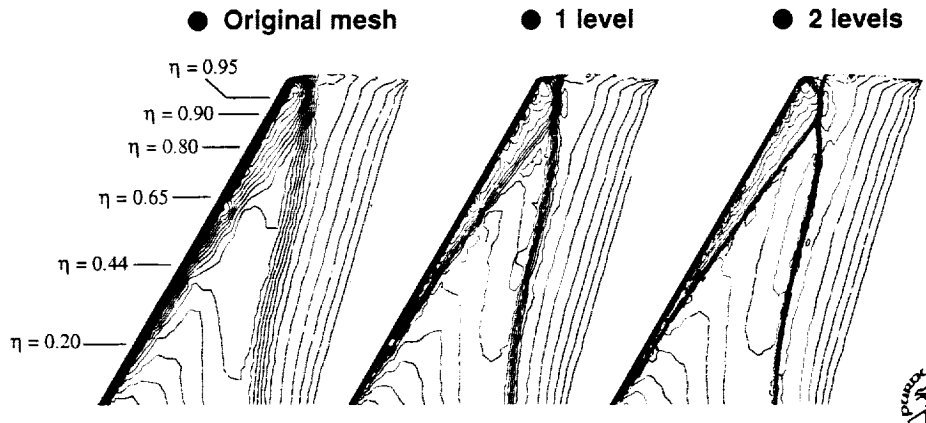
- $M_\infty = 0.84$, $\alpha_o = 3.06^o$



Rausch, 1992

COMPARISON OF UPPER SURFACE DENSITY CONTOUR LINES FOR THE ONERA M6 WING

- $M_\infty = 0.84$, $\alpha_o = 3.06^o$
- $\Delta\rho = 0.025$



Rausch, 1992

COMPARISON OF COEFFICIENT OF SURFACE PRESSURE FOR THE ONERA M6 WING

- $M_\infty = 0.84$, $\alpha_o = 3.06^o$
- $\eta = 0.80$

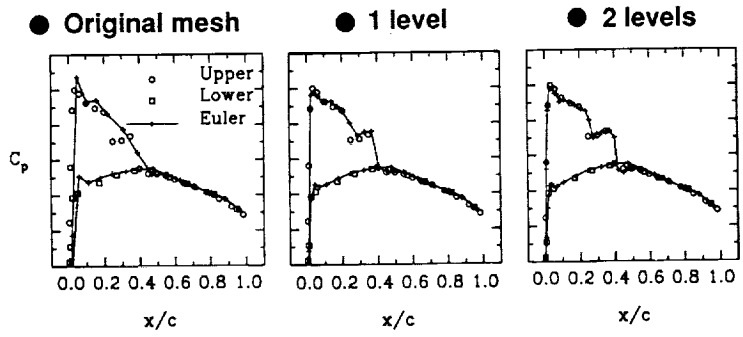


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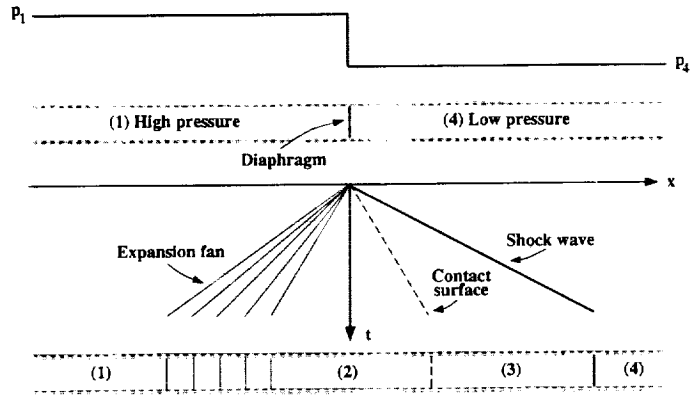
ILLUSTRATION OF THE SHOCK-TUBE PROBLEM



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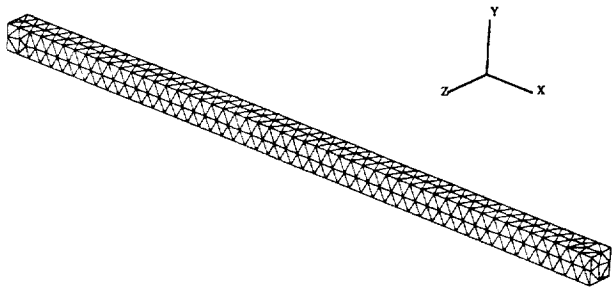
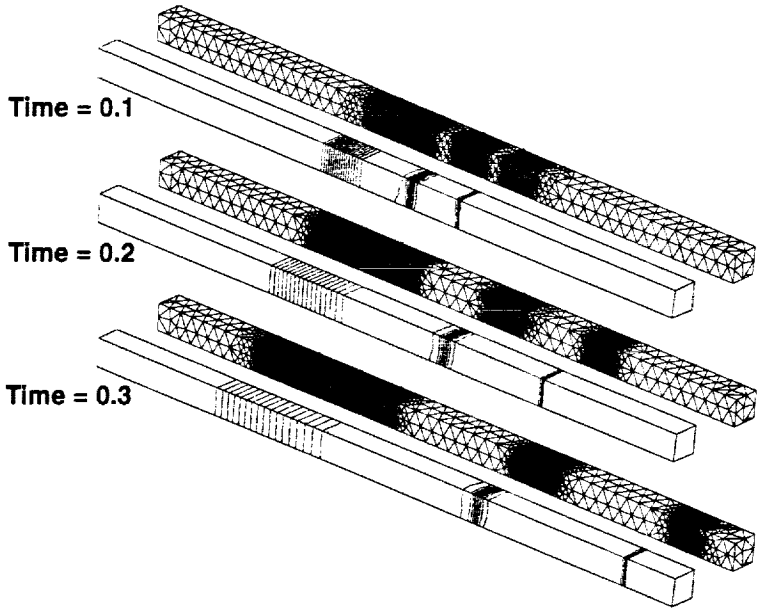
SURFACE MESH FOR THE SHOCK-TUBE PROBLEM

- Total mesh contains 562 nodes and 1,800 tetrahedra



Rausch, 1992

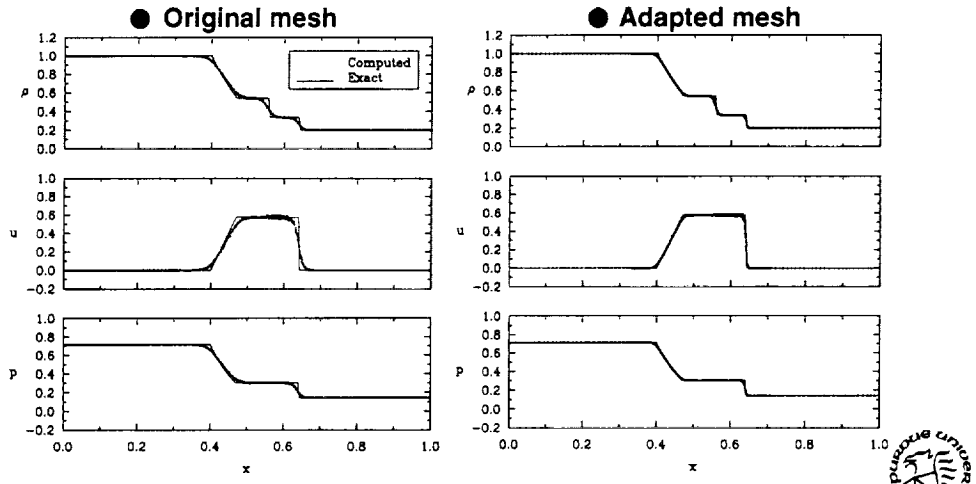
INSTANTANEOUS SURFACE MESH AND DENSITY CONTOUR LINES FOR THE SHOCK-TUBE PROBLEM



Rausch, 1992

COMPARISON OF THE VARIATION OF DENSITY, VELOCITY, AND PRESSURE THROUGHOUT THE SHOCK-TUBE

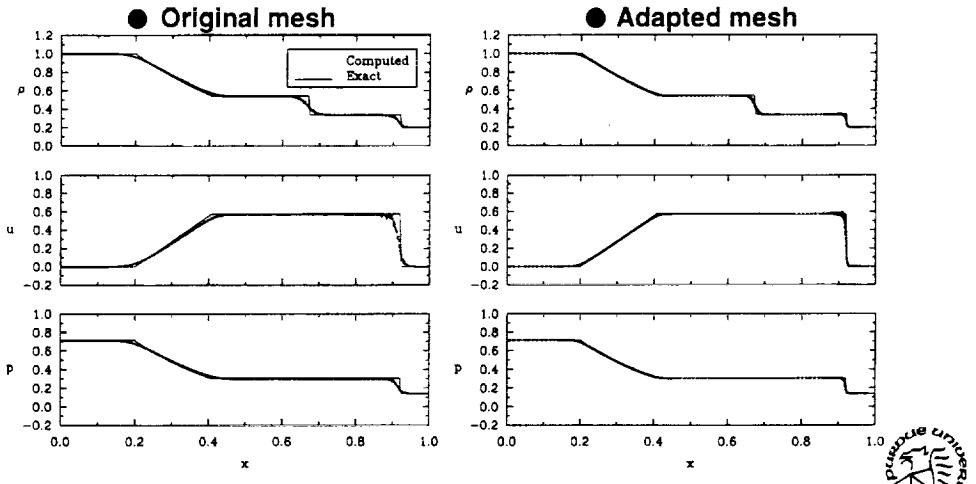
- Solution at time t = 0.1



Rausch, 1992

COMPARISON OF THE VARIATION OF DENSITY, VELOCITY, AND PRESSURE THROUGHOUT THE SHOCK-TUBE

- Solution at time t = 0.3



Rausch, 1992

SUMMARY

- Final solution adapted mesh depends on the original mesh
  - adapted mesh cannot be coarser than the original mesh
- Enrichment/Coarsening procedures are robust for isotropic cells; however, enrichment of high aspect ratio cells may fail near boundary surfaces with relatively large curvature
- Enrichment indicator worked well for the cases shown, but in general requires user supervision for a more efficient solution