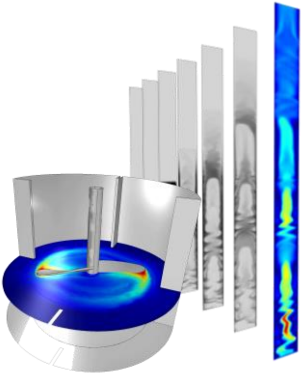
6th OKUCC

압력 기반의 압축성 유동 해석자



2017. 09. 21
㈜네오플럭스 김태우

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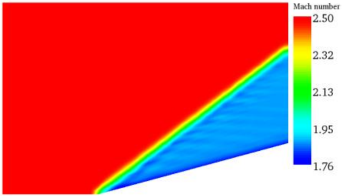
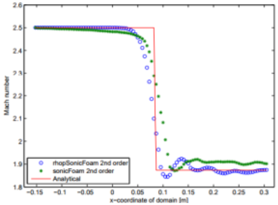
연구 필요성

- New algorithm for high speed flow for pressure based solver
  - 필요성
    - 충격파나 압축성 효과가 두드러지는 고속 유동 해석에서의 압력 기반 해석자의 불안정성
    - 밀도 기반의 segregated solver 의 경우, 높은 정확도에 비해 낮은 CFL 수를 요구하며 기존의 OpenFOAM 라이브러리와 결합이 어려움
    - **압력 기반의 고속 유동 해석자 개발 필요**





연구 필요성

- **New algorithm for high speed flow for pressure based solver**
  - pressure based flux splitting central scheme
    - 격자 면에서의 flux 계산에 적용
    - Kurganov-Tadmor flux splitting scheme
    - Low Mach number correction

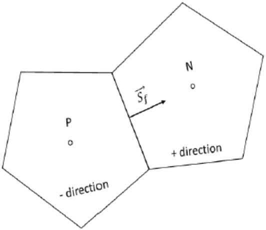
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

$$\frac{\partial \rho \vec{u}}{\partial t} + \nabla \cdot (\rho \vec{u} \cdot \vec{u})$$
$$= \nabla \cdot \mu \left[(\nabla \vec{u} + (\nabla \vec{u})^T) - \frac{2}{3} (\nabla \cdot \vec{u}) I \right] - \nabla p$$

$$\frac{\partial \rho h}{\partial t} + \nabla \cdot (\rho \vec{u} h) - \nabla \cdot (\alpha_{eff} \nabla h) = \frac{\partial p}{\partial t} + \vec{u} \cdot \nabla p$$

$$\frac{\partial \psi p_{ref}}{\partial t} + \nabla \cdot (\psi p_{ref} \vec{u}) + \frac{\partial \psi p_d}{\partial t} + \nabla \cdot (\psi p_d \vec{u}) = 0$$

$$\Psi_f \phi_f = \Psi_f^P (\alpha_f^P \phi_f^P + \alpha_f^P \alpha_f^{\min}) + \Psi_f^N (\alpha_f^N \phi_f^N - \alpha_f^P \alpha_f^{\min})$$



* M.Kraposhin(ISP RAS), S. Strizhak(HP) and A. Bovtrikova(ISP RAS), "*Adaptation of Kurganov-Tadmor's numerical scheme for applying in combination with the PISO method in numerical simulation of flows in a wide range of Mach numbers* ", Procedia Computer Science, Vol. 66, 2015, pp43-52

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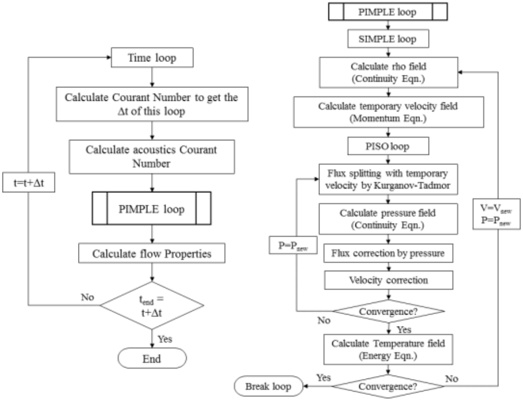
Pressure Based Segregated Solver

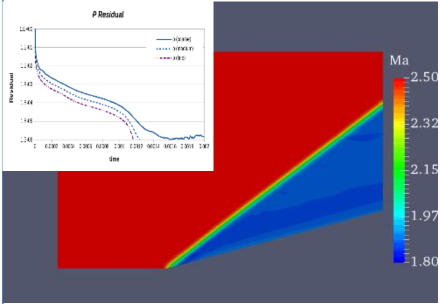
- 해석자 개발
  - buoyantPCNFoam
    - 넥스트폼에서 개선한 simple 알고리즘과 KT-scheme 을 적용하여 개발한 all mach number 해석자
    - unsteady/steady 해석 수행 가능
    - steady 해석의 경우, local time step을 사용
    - 해석 절차는 우측의 절차로 진행

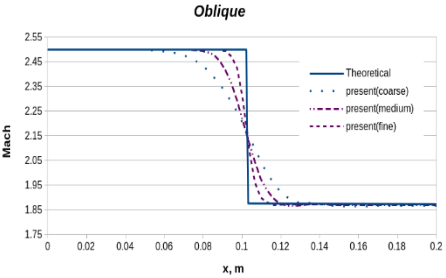


Pressure Based Segregated Solver

- 해석자 결과
  - Oblique shock

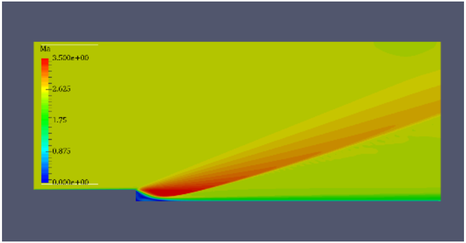
Mach	Pressure (psia)	Temperature (R)	Wedge half-angle (°)
2.5	14.7	520	15

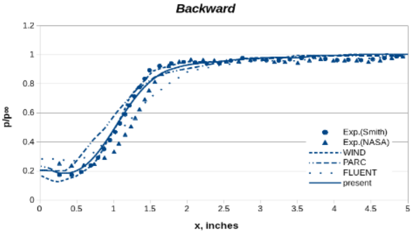




Pressure Based Segregated Solver

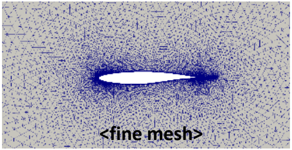
- 해석자 결과
  - Backward-facing step
    - $M_\infty = 2.5$, $P_\infty = 13316.6$ Pa, $T_\infty = 344$K
    - 48000 cells
    - κ-ω SST turbulence model

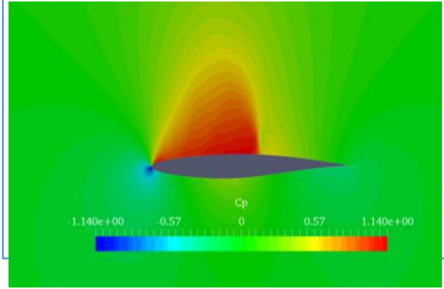


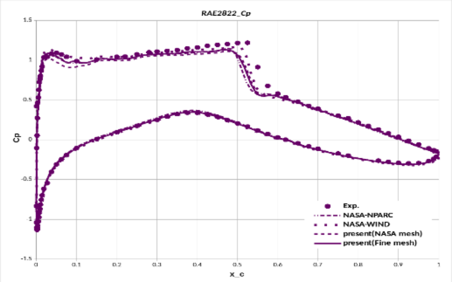


Pressure Based Segregated Solver

- 해석자 결과
  - RAE 2822 2D Airfoil
    - M_{∞}= 0.729 (NASA NPARC)
    - NASA mesh : 23552 cells(plot3D type), Fine mesh : 35892 cells(hybrid type)
    - Spalart-Allmaras turbulence model
    - Characteristic farfield boundary condition

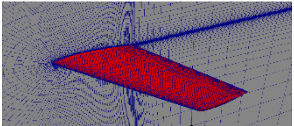




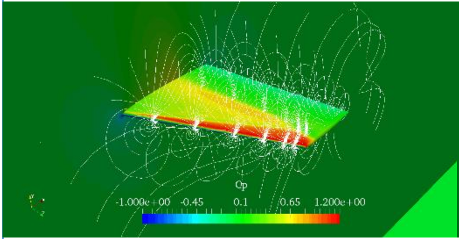


Pressure Based Segregated Solver

- 해석자 결과
  - Onera M6 wing
    - NASA NPARC Condtions
    - NASA mesh : 800,000 cells (plot3D type), fine mesh : 2,400,000 cells
    - Spalart-Allmaras turbulence model
    - Characteristic farfield boundary condition



<NASA mesh>



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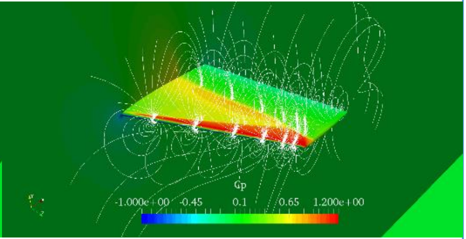

<Fine mesh>

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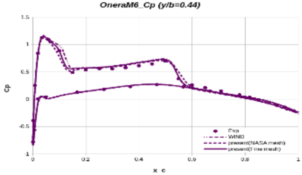
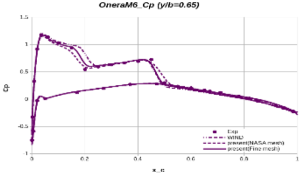
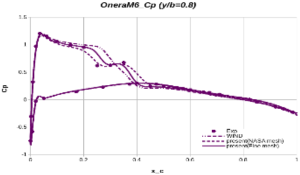
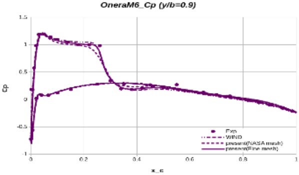
Pressure Based Segregated Solver

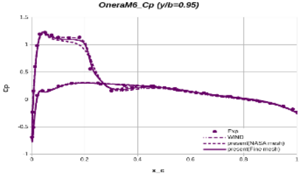
- 해석자 결과
  - Onera M6 wing





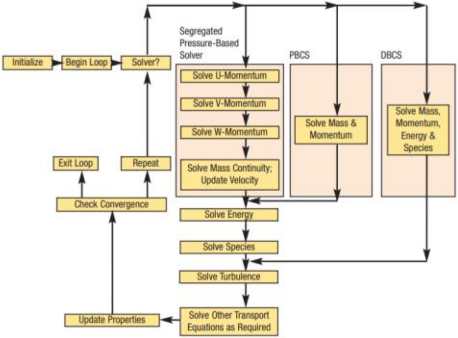






Pressure Based Coupled Solver

- 해석자 개발
  - pUCoupledNFoam, pUhCoupledNFoam
    - Pressure Based Coupled Solver 는 운동량 방정식의 ∇p 항의 압력값과 압력에 관한 식으로 변형된 연속방정식의 $\nabla \phi$ 항의 속도값을 현재의 반복 시점에서 계산되는 값들을 사용하는 방법
    - 기존의 segregated solver에 비해 보다 강건하게 계산을 수행할 수 있는 장점이 있으나, 메모리 용량 및 한번의 반복 계산당 요구되는 계산 시간이 증가하는 단점이 존재
    - 현재 기존의 압력-속도 coupled solver 이외에 엔탈피 에너지 식과 연속 방정식을 연결한 coupled solver을 수식적으로 도출하여 개발 중



Pressure Based Coupled Solver

- **해석자 개발**
  - pUCoupledNFoam

$$\begin{bmatrix} a_C^{uu} & a_C^{uv} & a_C^{uw} & a_C^{up} \\ a_C^{vu} & a_C^{vv} & a_C^{vw} & a_C^{vp} \\ a_C^{wu} & a_C^{wv} & a_C^{ww} & a_C^{wp} \\ a_C^{pu} & a_C^{pv} & a_C^{pw} & a_C^{pp} \end{bmatrix} \begin{bmatrix} u_C \\ v_C \\ w_C \\ p_C \end{bmatrix} + \sum_{F=NB(C)} \begin{bmatrix} a_F^{uu} & a_F^{uv} & a_F^{uw} & a_F^{up} \\ a_F^{vu} & a_F^{vv} & a_F^{vw} & a_F^{vp} \\ a_F^{wu} & a_F^{wv} & a_F^{ww} & a_F^{wp} \\ a_F^{pu} & a_F^{pv} & a_F^{pw} & a_F^{pp} \end{bmatrix} \begin{bmatrix} u_F \\ v_F \\ w_F \\ p_F \end{bmatrix} = \begin{bmatrix} b_C^u \\ b_C^v \\ b_C^w \\ b_C^p \end{bmatrix}$$

  - pUhCoupledNFoam

$$\begin{pmatrix} G & -[\vec{o}] \\ C_c[\hat{\vec{u}}^*]S[\vec{r}][\vec{k}] + [\vec{o}][\vec{r}][\vec{k}] & C_c\left([\hat{\vec{\varrho}}^{(m-1)}](-\hat{A}_M\hat{M}) + [\hat{\vec{u}}^*]S[\vec{r}]\right) + [\vec{o}][\vec{r}] \end{pmatrix} \begin{pmatrix} \vec{h}' \\ \vec{p}' \end{pmatrix}$$

$$= \begin{pmatrix} \vec{g} + [\vec{o}](\vec{p}^{(m-1)} - \vec{p}_0) \\ -[\vec{o}](\vec{\varrho}^{(m-1)} - \vec{\varrho}_0) - C_c[\hat{\vec{\varrho}}^{(m-1)}]\hat{\vec{u}}^* \end{pmatrix}.$$

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Pressure Based Coupled Solver

- 해석자 결과
  - Unsteady shock tube

Table 1. Initial conditions.

Region	Pressure (psia)	Temperature (R)	Density
1	1.0	416.0	0.125
4	10.0	520.0	1.0

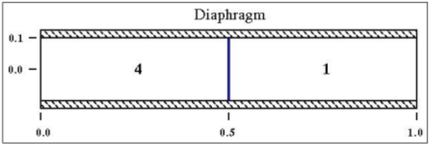


Figure 1. Shock tube at initial state.

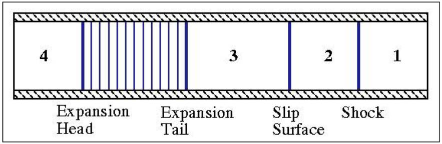
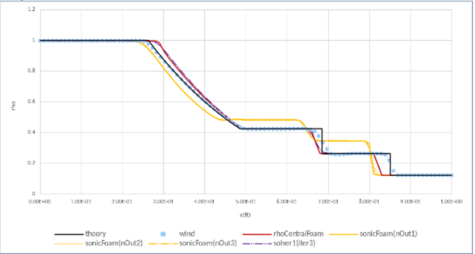
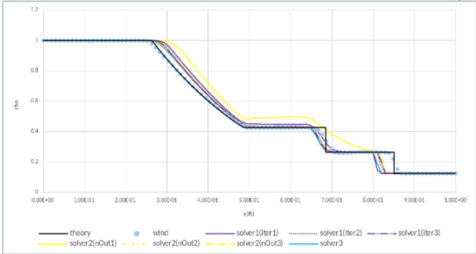


Figure 2. Shock tube shortly after diaphragm has burst.

Pressure Based Coupled Solver

- 해석자 결과
  - Unsteady shock tube
    - Analytic solution and Density based solvers(WIND, rhoCentralFoam)
    - Pressure based segregated solvers(sonicFoam, buoyantPCNFoam(solver1)) and coupled solvers(pUCoupledCNFoam(solver2), pUhCoupledCNFoam(solver3))





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Pressure Based Coupled Solver

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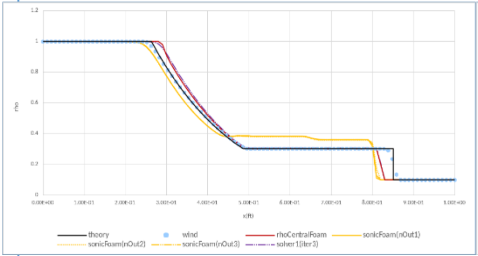

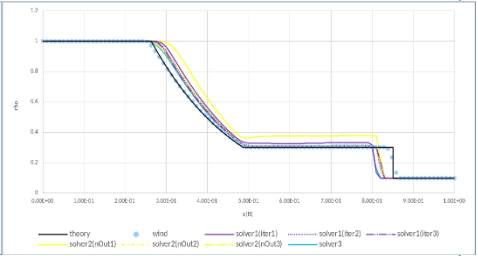

Pressure Based Coupled Solver

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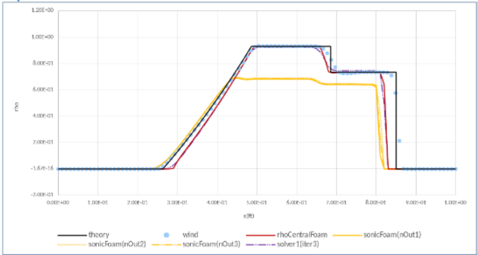

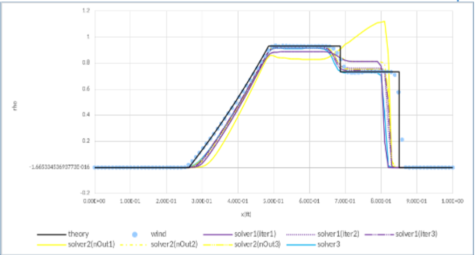

결론

감사합니다