R&D Trends in Aerospace CFD

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A Short Course on HPC, BigData and AI
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What is CFD ?

- Computational Fluid Dynamics
- Solving numerically the Navier-Stokes equations (or its approximate forms) on a discrete space (and time) domain with the help of high speed computers
- Navier-Stokes equations: partial differential equations depicting the mass, momentum and energy conservation, governing the fluid flow

NS equations

Navier–Stokes equations

Equations governing Fluid Flow: Mass, Momentum and Energy conservation

N–S equations in vector notation

$$\frac{\partial \mathcal{W}}{\partial t} + \nabla \cdot \left(\vec{\mathcal{F}} + \vec{F} \right) = 0$$

where,

$$\mathcal{W} = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ \rho w \\ e \end{bmatrix}, \vec{\mathcal{F}} = \begin{bmatrix} \rho u \\ \rho u^2 + p \\ \rho u u \\ \rho u w \\ (e+p)\, u \end{bmatrix} \hat{i} + \begin{bmatrix} \rho v \\ \rho v u \\ \rho v^2 + p \\ \rho v w \\ (e+p)\, v \end{bmatrix} \hat{j} + \begin{bmatrix} \rho w \\ \rho w u \\ \rho w v \\ \rho w^2 + p \\ (e+p)\, w \end{bmatrix} \hat{k}$$

NS Equations .....

$$\vec{F} = \begin{bmatrix} 0 \\ -\tau_{xx} \\ -\tau_{xy} \\ -\tau_{xz} \\ -u\tau_{xx} - v\tau_{xy} - w\tau_{xz} + q_x \end{bmatrix} \hat{i} + \begin{bmatrix} 0 \\ -\tau_{yx} \\ -\tau_{yy} \\ -\tau_{yz} \\ -u\tau_{yx} - v\tau_{yy} - w\tau_{yz} + q_y \end{bmatrix} \hat{j} + \begin{bmatrix} 0 \\ -\tau_{zx} \\ -\tau_{zy} \\ -\tau_{zz} \\ -u\tau_{zx} - v\tau_{zy} - w\tau_{zz} + q_z \end{bmatrix} \hat{k}$$

- $\mathcal{W}$: Vector of conserved variables
- $\vec{\mathcal{F}}, \vec{F}$: Inviscid, viscous flux vectors

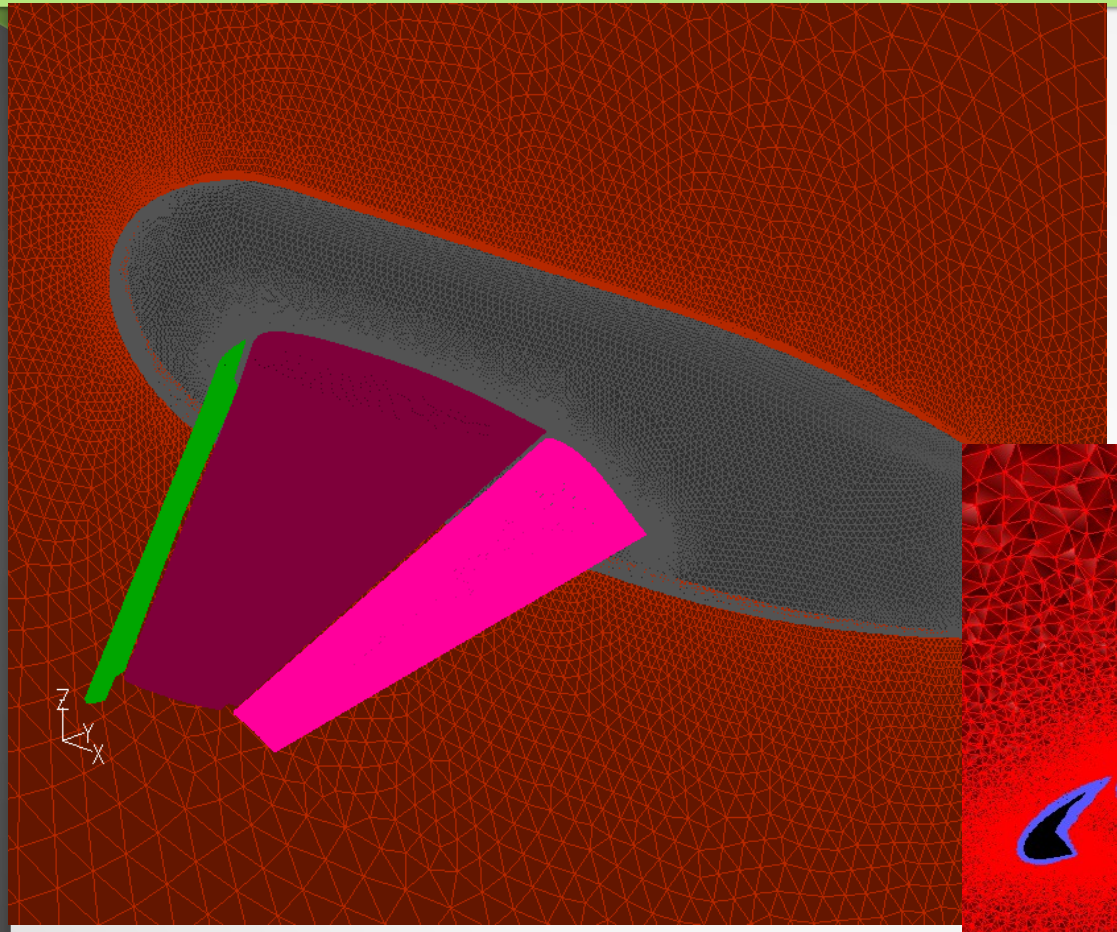
Solving the NS Equations

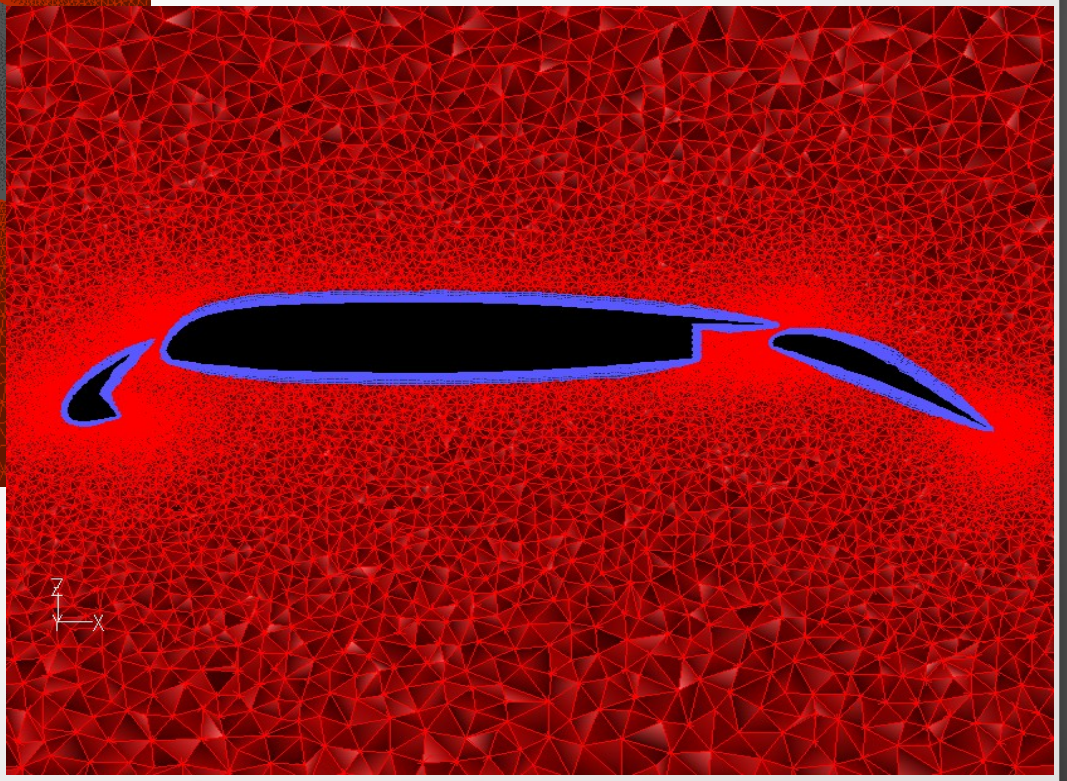
- Solution to NS equations subject to appropriate initial and boundary conditions
- Existence and Smoothness of NS solutions: Millennium prize problem of clay institute of mathematics
- Wind tunnels Vs Numerical solutions
- von Neumann: *..... purpose of experiment is to ..... replace a computation from an unquestioned theroy by direct measurements..... wind tunnels are computing devices for integrating pde governing fluid flow*

Solving the NS equations: CFD process

- Grid generation: Discretize the computational domain
- Discretize the equations: Finite difference/Finite volume/Finite element
- PDE ==> Algebraic equations
- Solve the resulting system of Algebraic equations
- General inputs from CFD: Forces & moments

Grids: High Lift flows

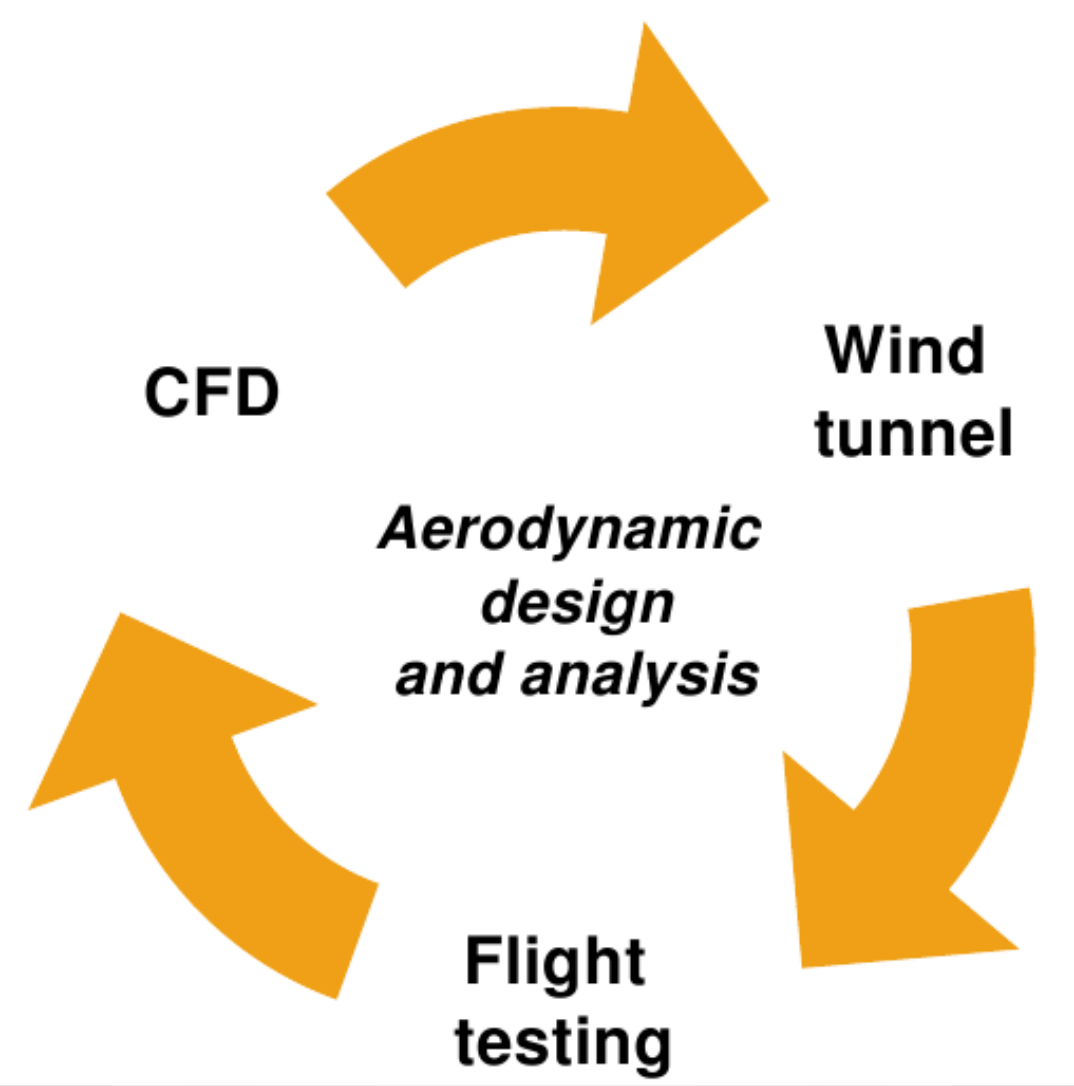




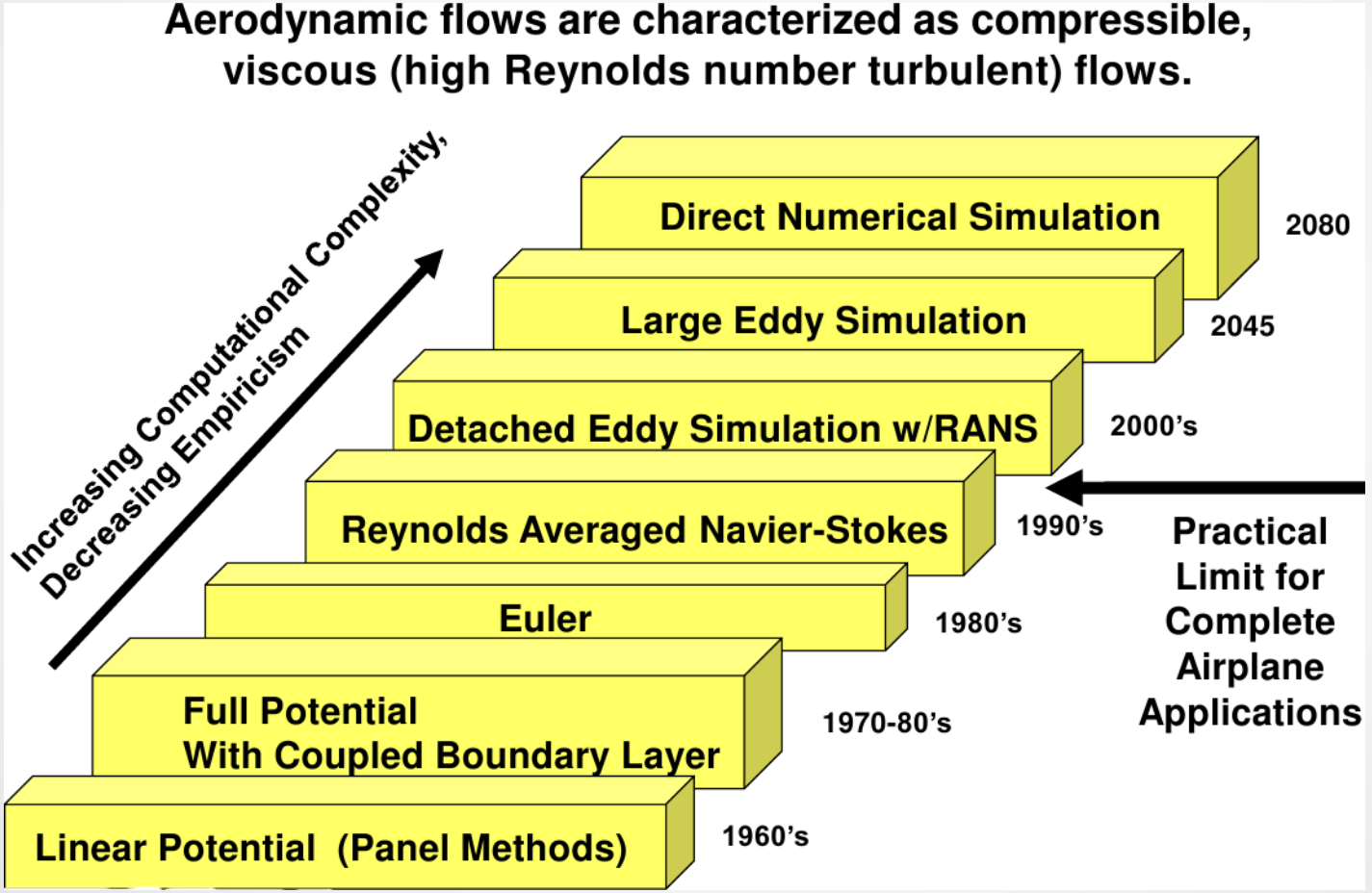
Solving NS equations

- Non-linearities
- Disparate length/time scales
- For a real case grids involve several million volumes
- HPC a must for computing the NS equations in realistic time frames
- Need: Accurate/robust algorithms exploiting the massive parallelism offered by the computing platforms

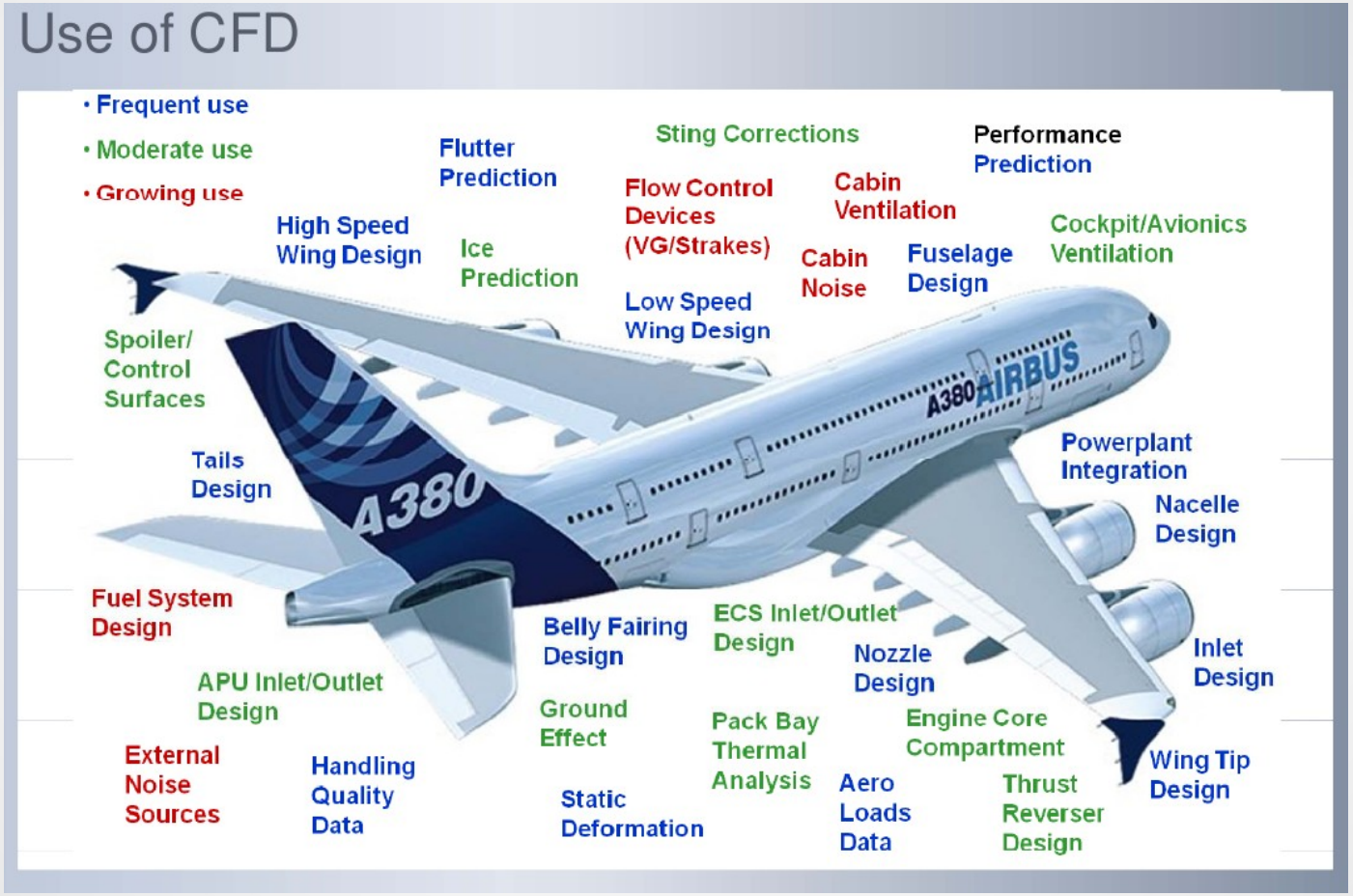
Aerodynamic Design



Computational Needs: Today & Tomorrow?



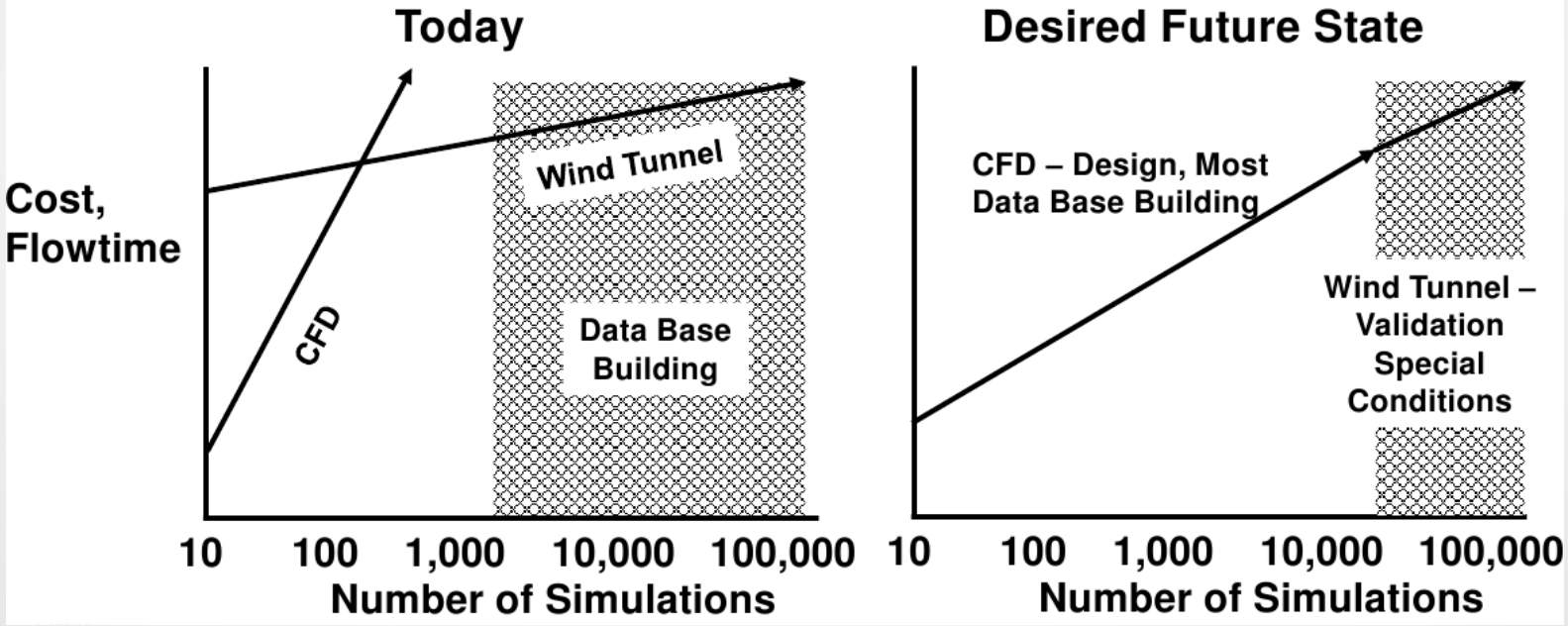
Use of CFD in Civil Aircraft



CFD Vs Wind Tunnels

The use of new CFD is driven by desperation.
Desperation to remain competitive!

One complete airplane development requires about 50,000 to 100,000 aerodynamic simulations



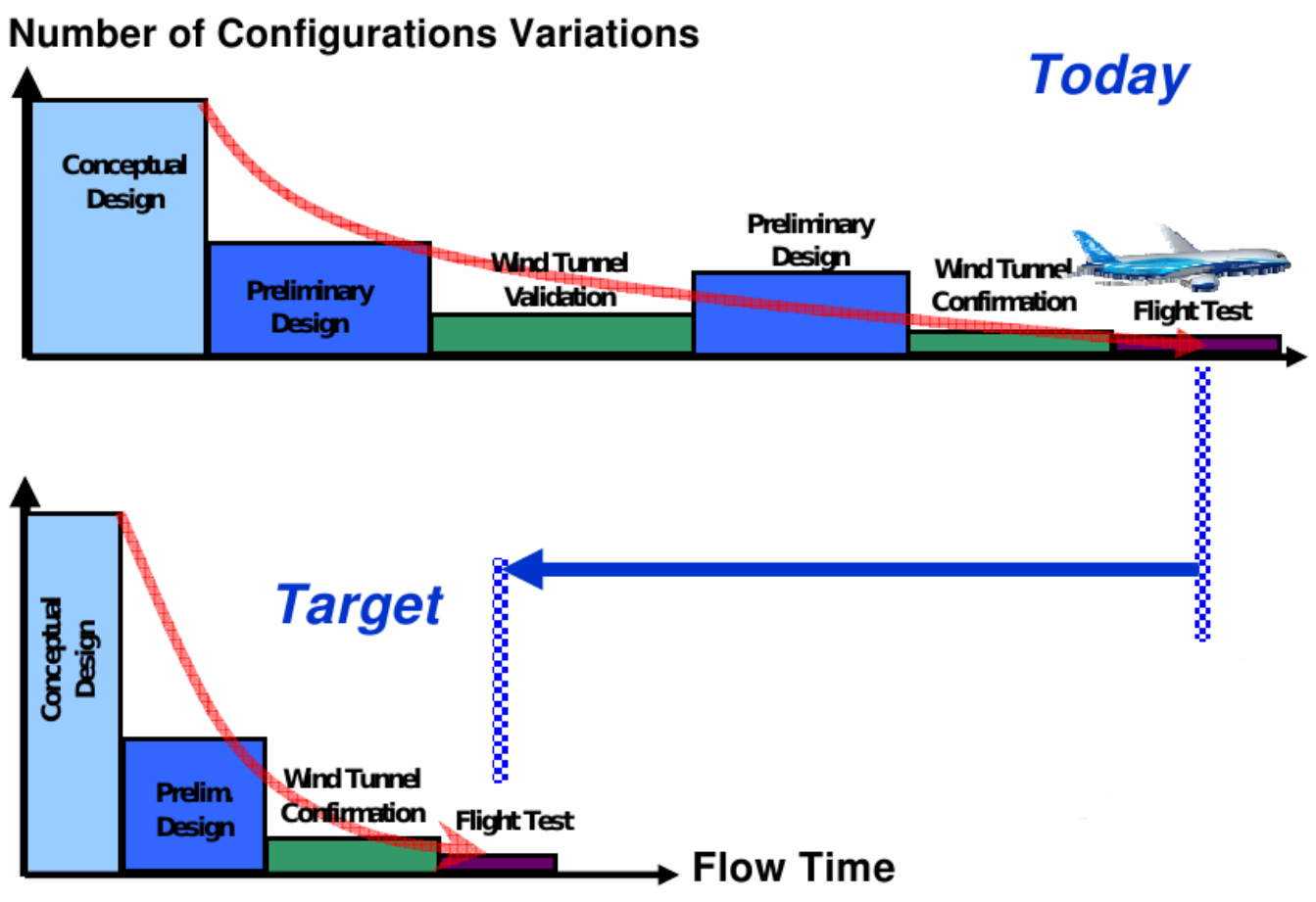
Design drivers

- Concept to flight test
- Environment: emission & noise
- Emission: Drag reduction,

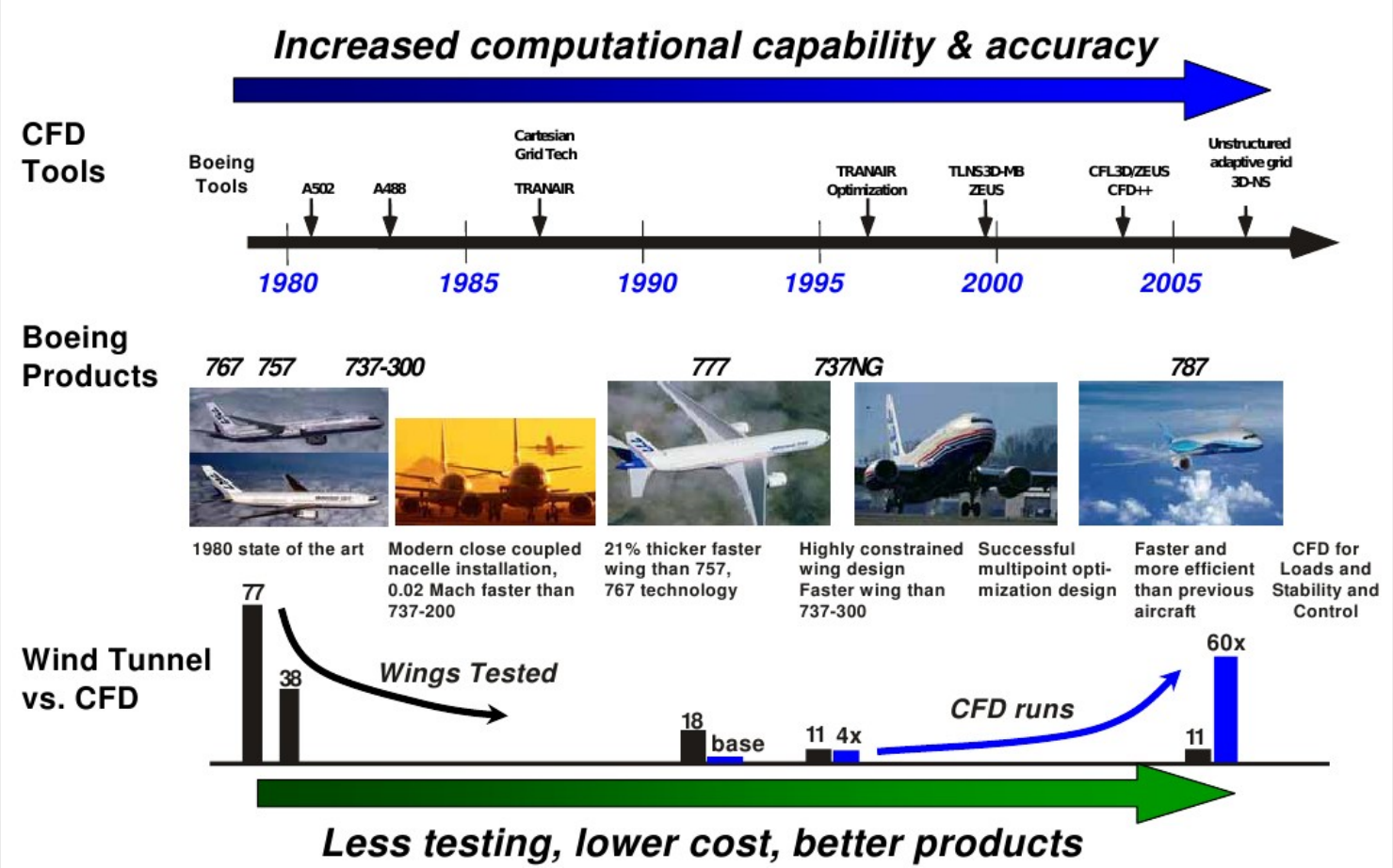
  Weight reduction,

  Efficient propulsion
- Combat Aircraft: RCS, Serpentine intake, weapon bay, store separation....

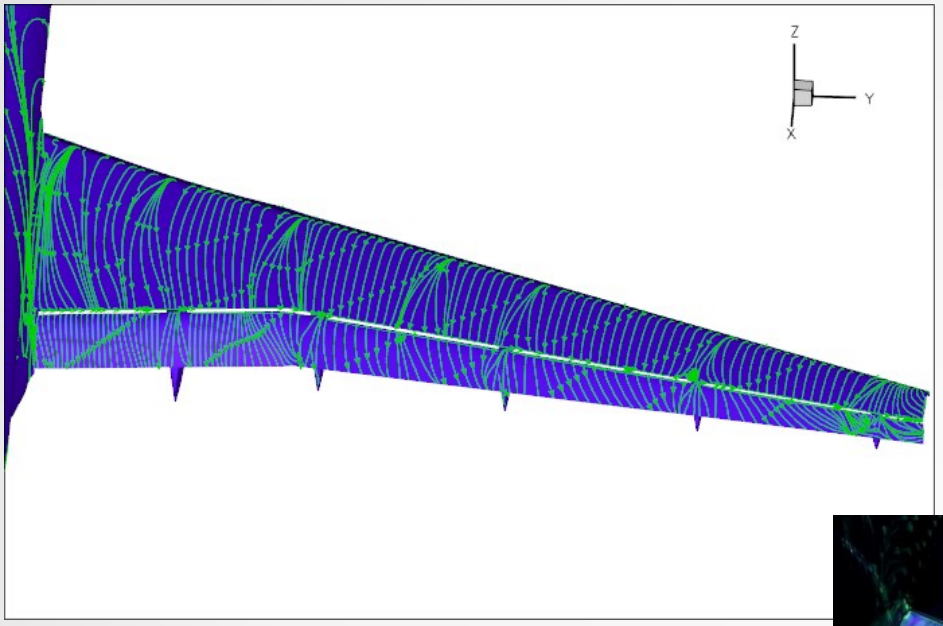
Concept to flight?

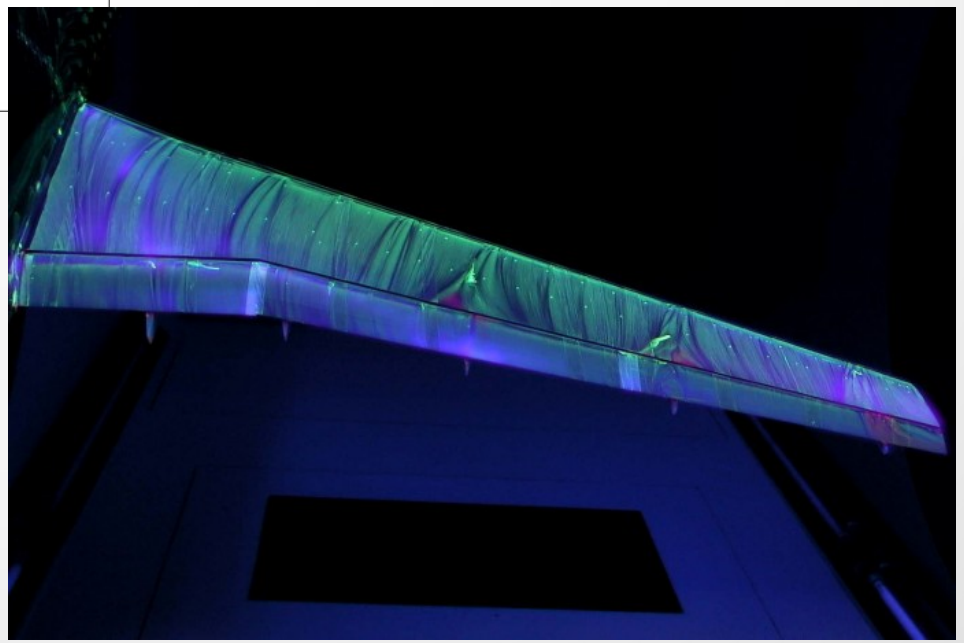


Boeing 787 Experience

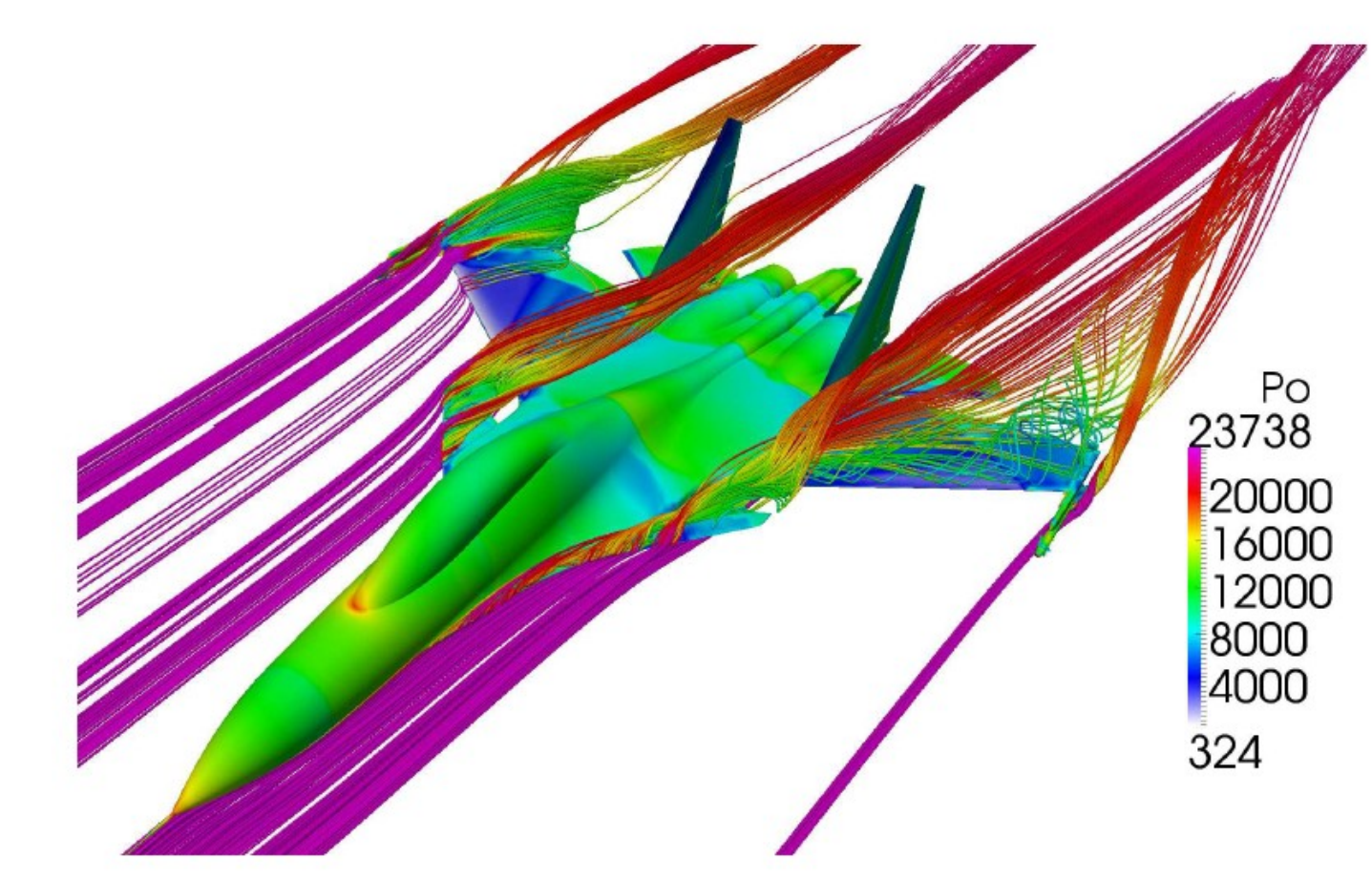


High Lift Design

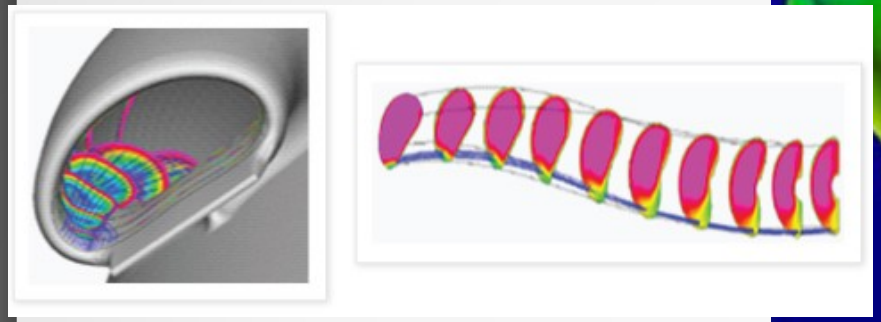


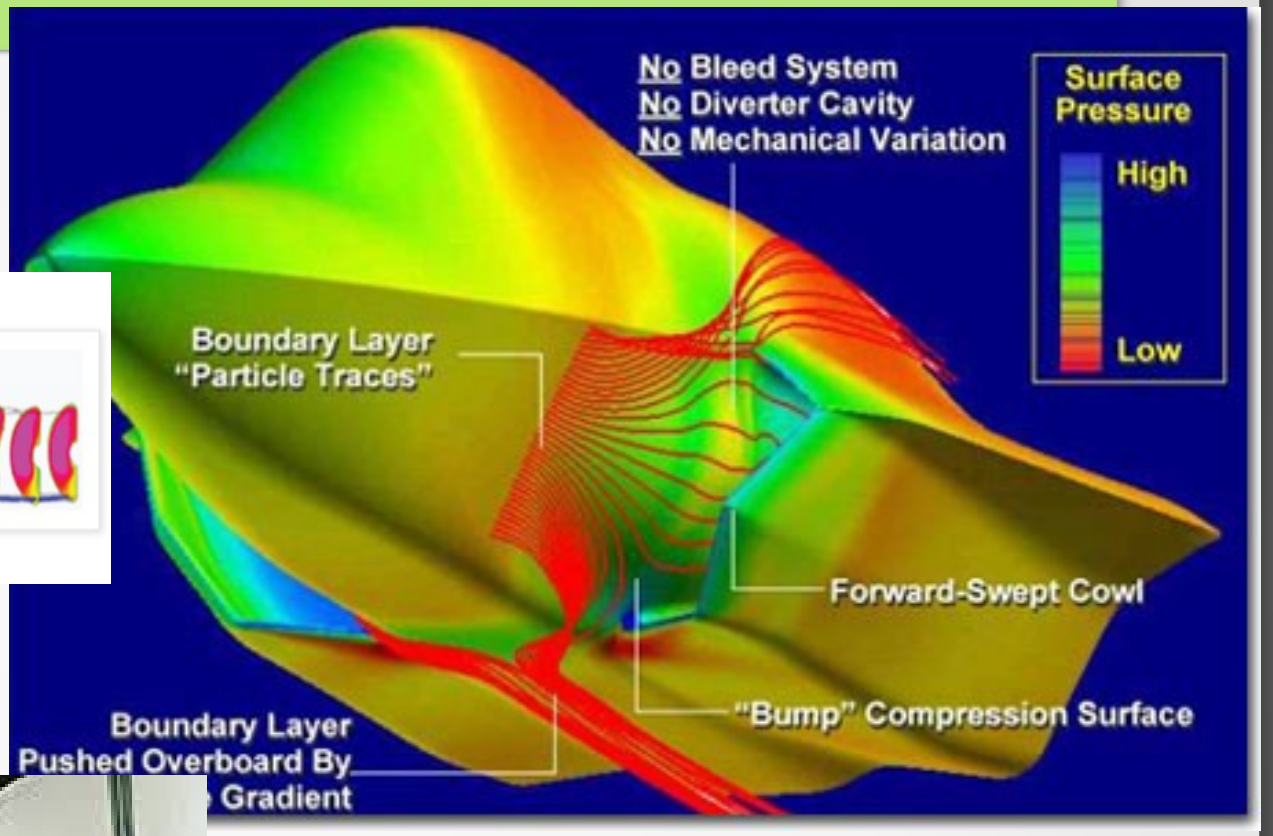


Configuration Design



Intake Design

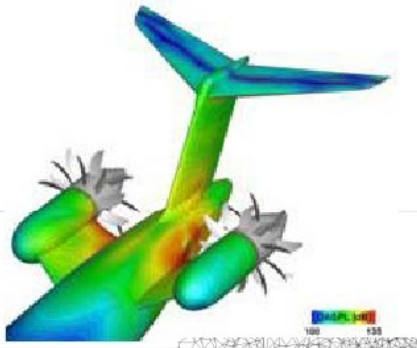


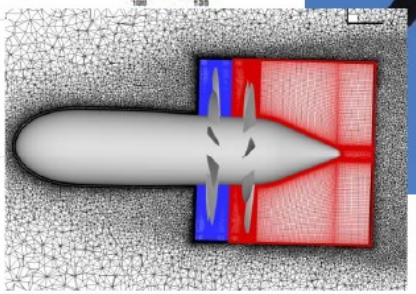


Unsteady Design

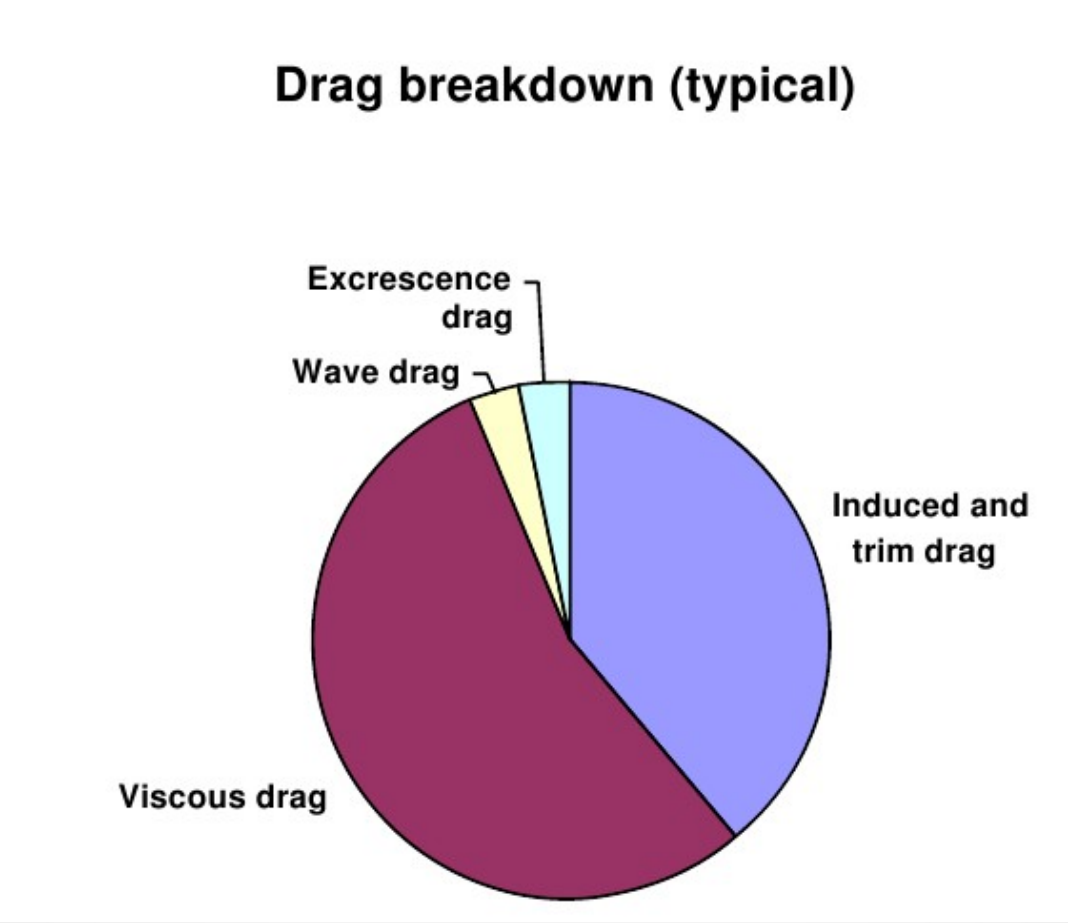
CFD Purpose: Predict Unsteady Aerodynamic Effects

- Unsteady simulation on installed rotor configuration
  - Validation investigation on A400M and IPEKA test models
  - Chimera mesh technique with combined structured & unstructured meshes





Drag Reduction



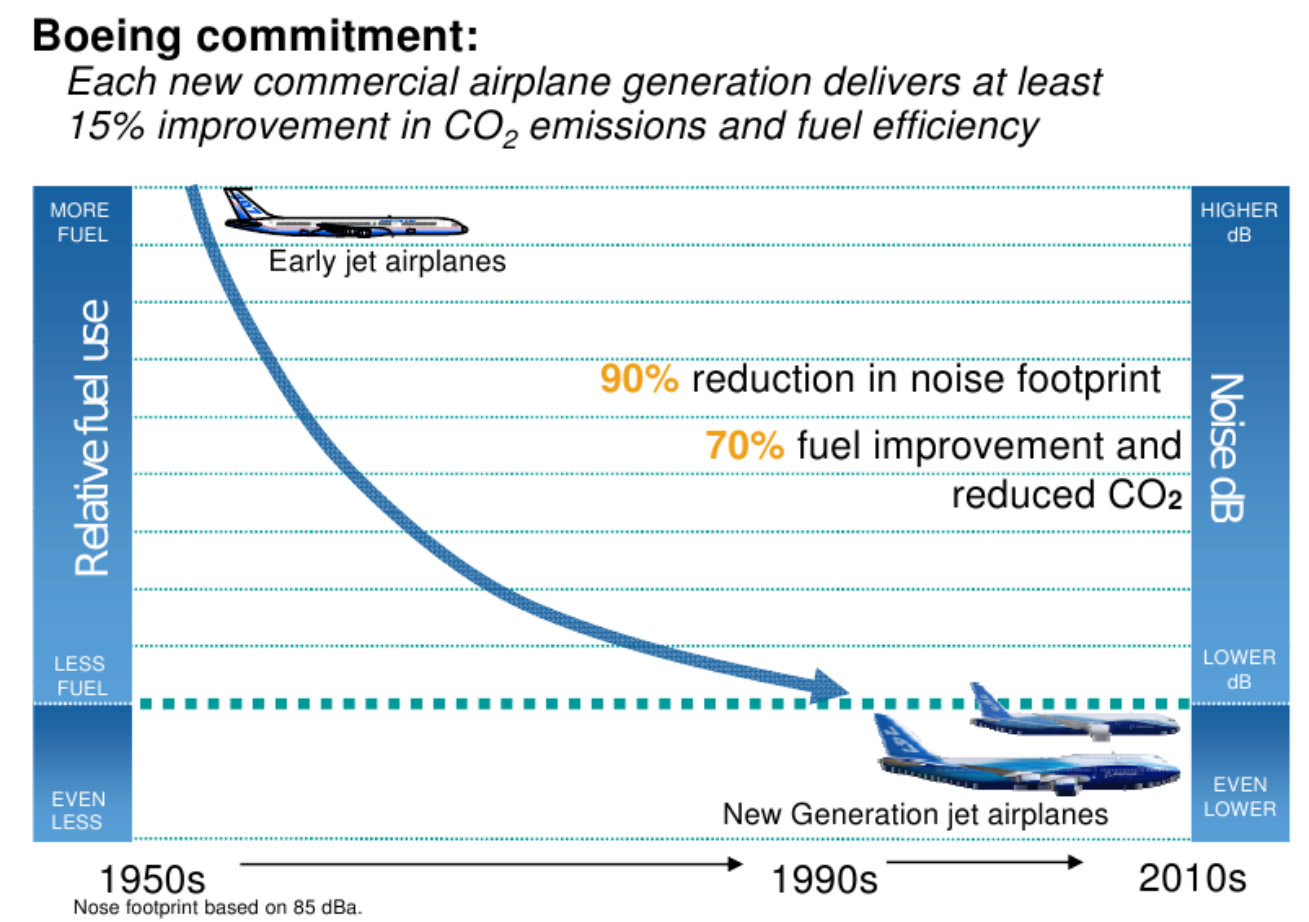
Use of Laminar Flow Sections

- Nacelle contours optimized with laminar transition location as additional design parameter
- Structural design and manufacturing methods tailored for NLF benefit

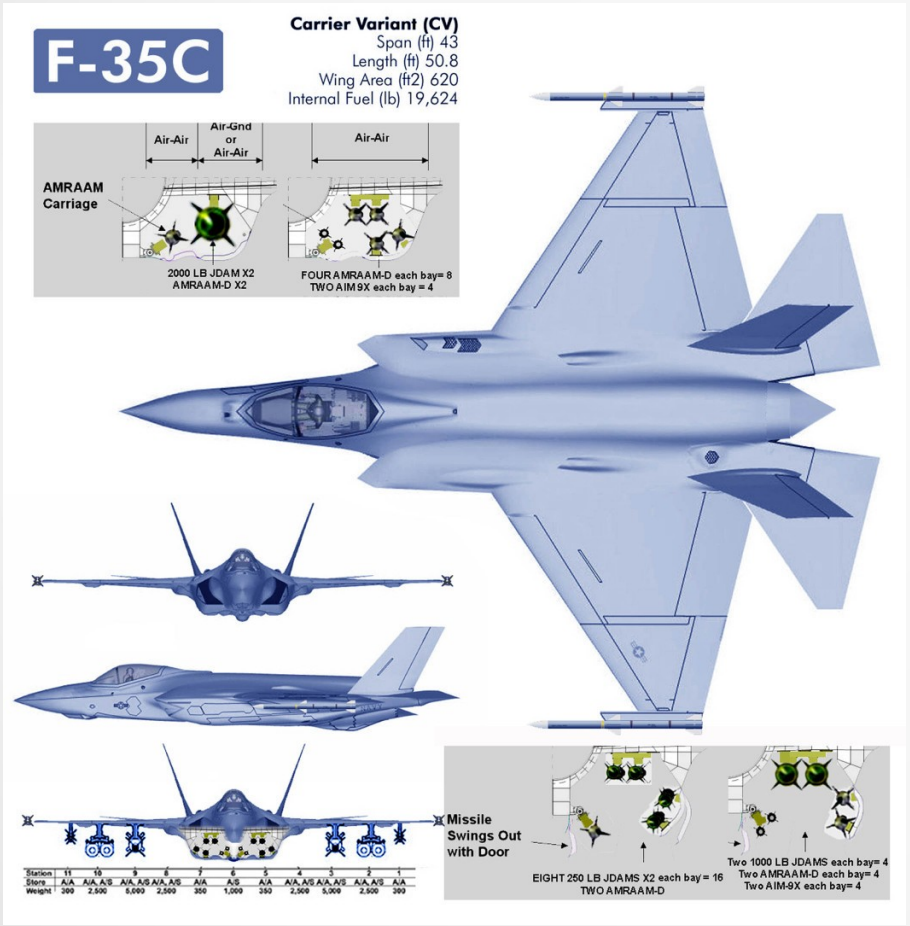
Noise Reduction

Landing Gear Noise Prediction

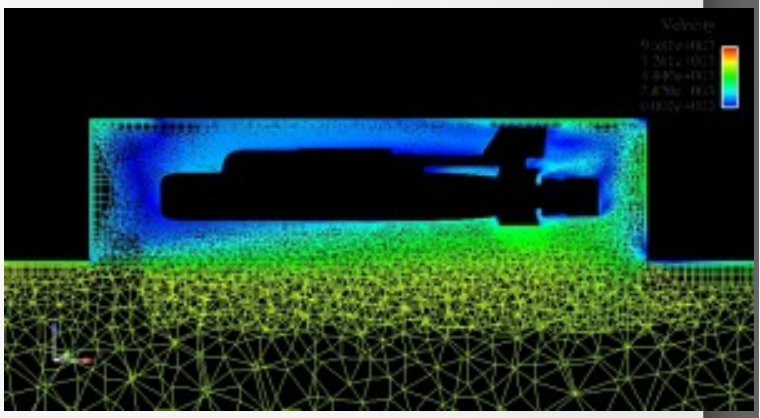
Noise/Fuel Use: Present Status



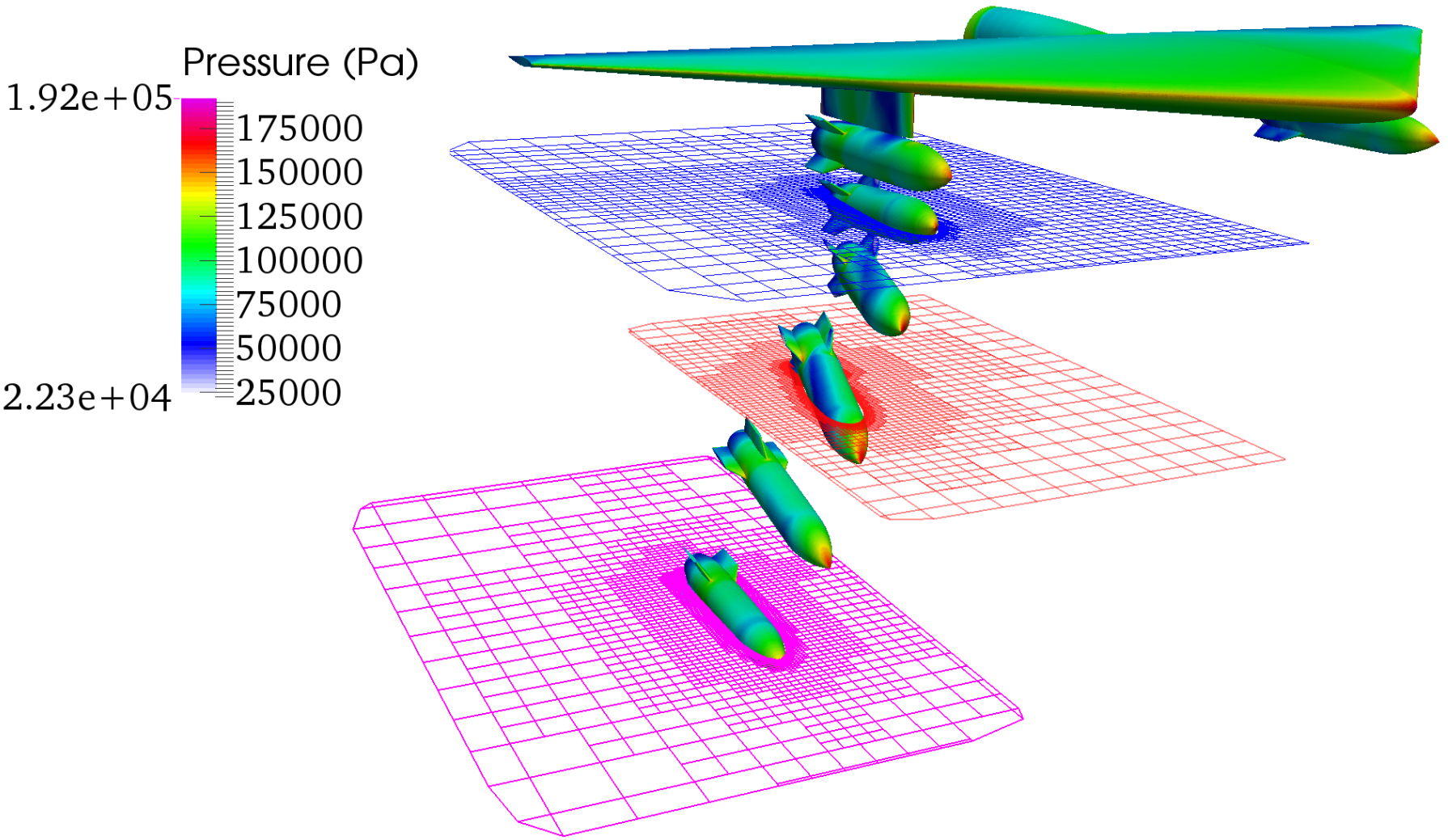
Weapon Bay


F-35C
Carrier Variant (CV)
Span (ft) 43
Length (ft) 50.8
Wing Area (ft2) 620
Internal Fuel (lb) 19,624
Air-Air
Air-Gnd or Air-Air
Air-Air
AMRAAM Carriage
2000 LB JDAM X2
AMRAAM-D X2
FOUR AMRAAM-D each bay= 8
TWO AIM 9X each bay = 4
Missile Swings Out with Door
EIGHT 250 LB JDAMS X2 each bay = 16
TWO AMRAAM-D
Two 1000 LB JDAMS each bay= 4
Two AMRAAM-D each bay= 4
Two AIM-9X each bay= 4

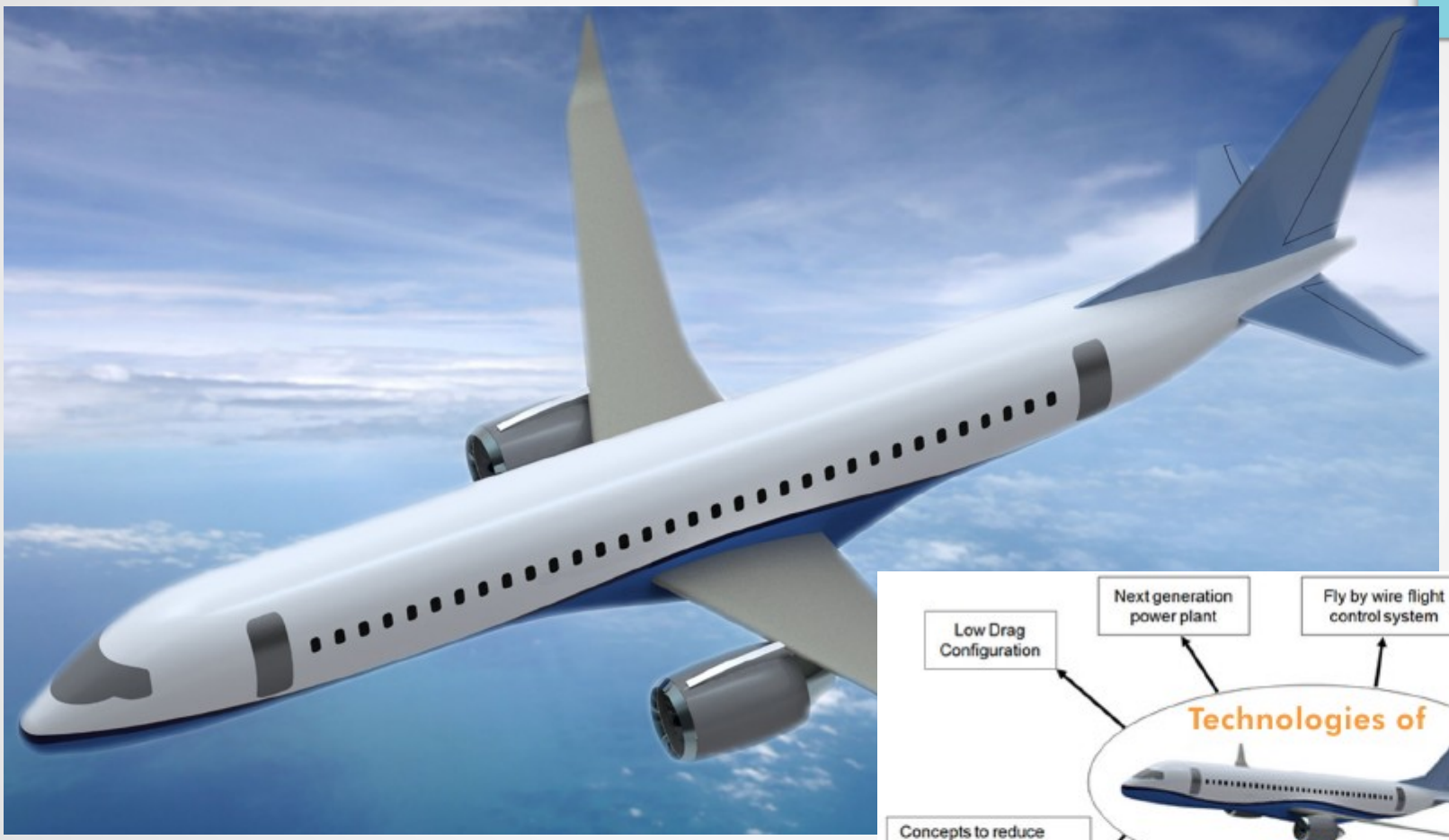

5

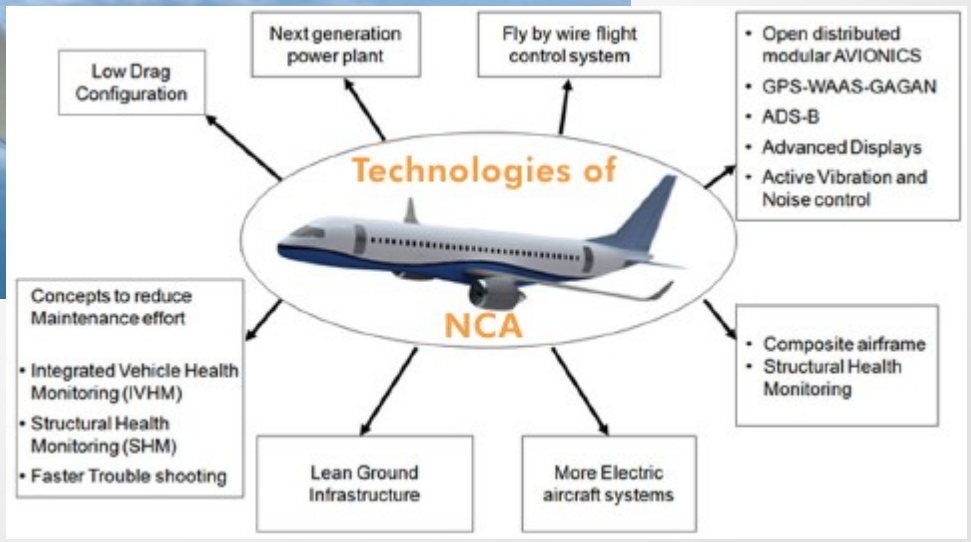


Store Separation

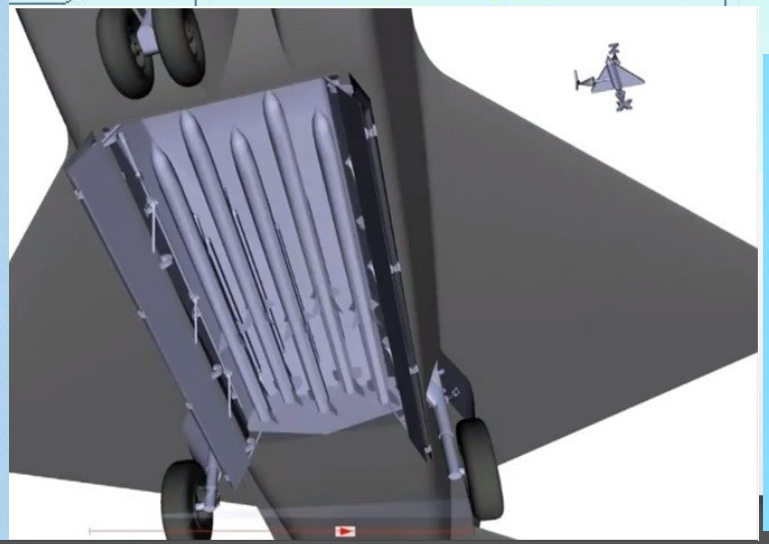


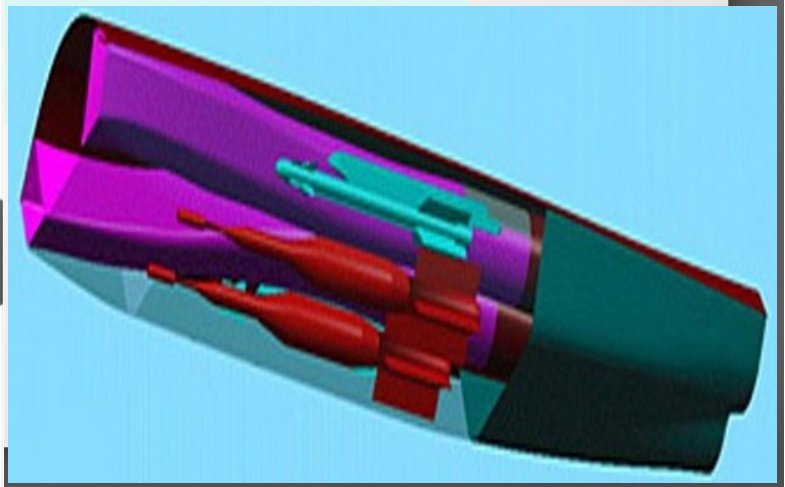
National Civil Aircraft (NCA)



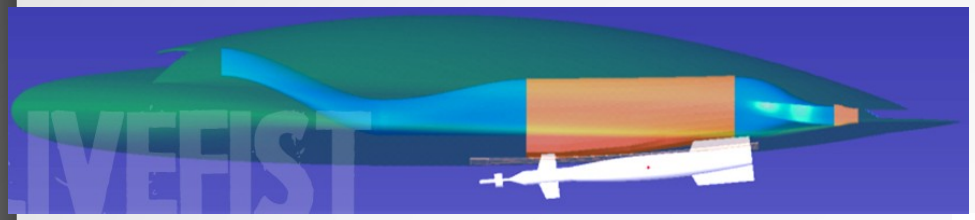


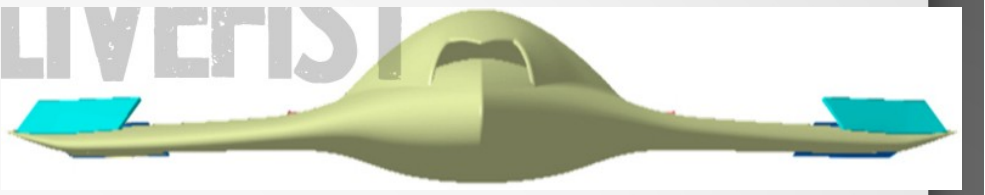
Advanced Medium Combat A/C

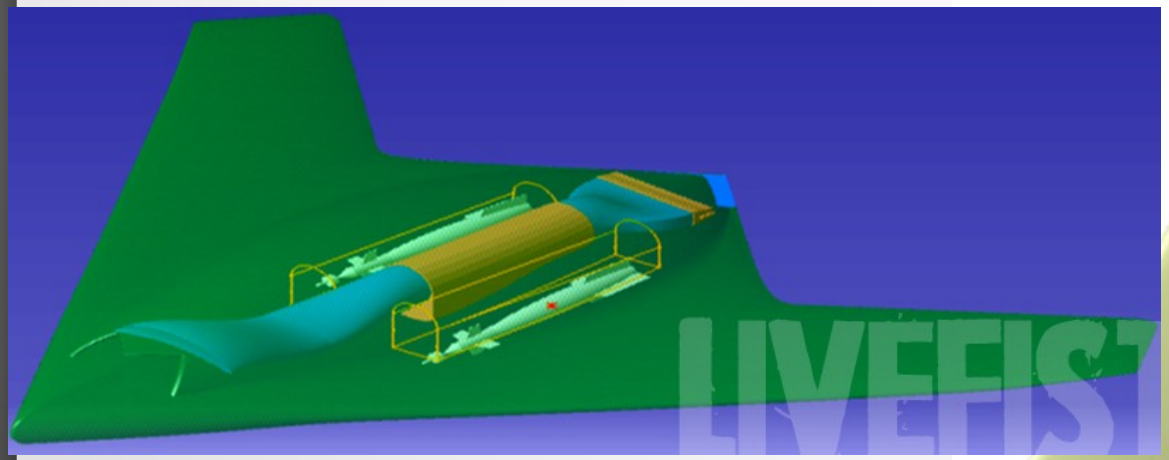




Unmanned Combat Vehicle







Needs & challenges.....

- Accurate Algorithms
- Robust Algorithms for automated CFD process
- Highly scalable codes
- HPC: Accelerators... GPU/Xeon-Phi
- Flying the NS equations? .....

Questions?

THANK YOU