Industrialization of turbulence-resolving CFD methods

Aerospace Technology Congress 2019

S. Arvidson, PhD | Propulsion, Saab Aeronautics |
Visiting researcher, Chalmers

sebastian.arvidson@saabgroup.com

Acknowledgement

- This work has been funded by the Swedish Governmental Agency for Innovation Systems (VINNOVA), the Swedish Defence Materiel Administration (FMV) and the Swedish Armed Forces within the National Aviation Research Programme (NFFP, Contract No. 2013-01209 and 2017–04887) and Saab Aeronautics.
- Part of the work is also connected to the GARTEUR AG54 project, in which Saab Aeronautics is an AG member.
- Simulations were partly performed on resources provided by the Swedish National Infrastructure for Computing (SNIC) at the National Supercomputer Centre (NSC).

FÖRSVARSMAKTEN

C3SE Chalmers Centre for Computational Science and Engineering

Chalmers University of Technology Göteborg University

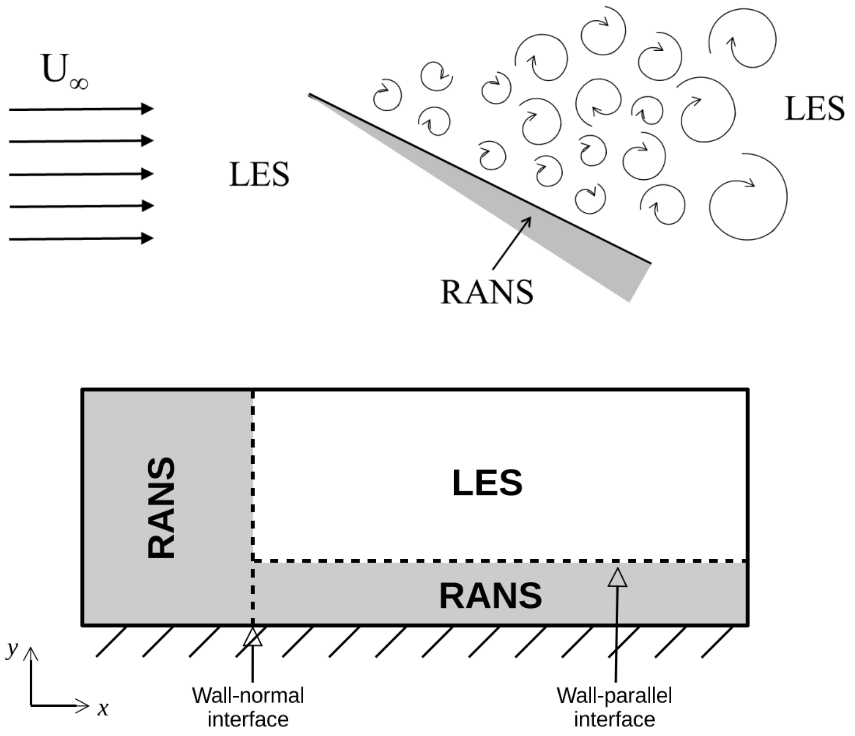
Outline

- Background and motivation
- Status on turbulence-resolving methods: an industiral perspective
- NFFP7 related projects and results
- Challenges and outlook

Background and motivation

- Accurate Computational Fluid Dynamics (CFD) is vital for predicting aircraft operability and engine/inlet function
- Turbulence-resolving methods needed to accurately predict flows where a wide range of spatial and temporal scales are present
- High Reynolds number flows in aeronautical applications
- Reynolds-Average Navier-Stokes (RANS) for attached flows; inaccurate for separated flow
- Large-Eddy Simulations (LES) for separated flow; prohibitively expensive for attached boundary layers at high Reynolds numbers

Hybrid RANS-LES methods (HRLM)



Schematics of hybrid RANS-LES modeling

Turbulence modeling approaches and related computational cost*

Modeling type	Unsteady	Empiricism	Grid	Steps
RANS	No	Strong	10^7	10^3
URANS	Yes	Strong	10^7	$10^{3.5}$
HRLM (DES)	Yes	Strong	10^8	10^4
LES	Yes	Weak	$10^{11.5}$	$10^{6.7}$
DNS	Yes	Weak	10^{16}	$10^{7.7}$

*Spalart, IJHFF 21 (2000)

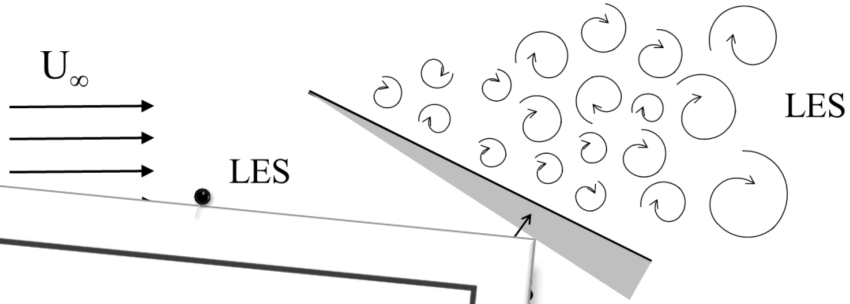
Background and motivation

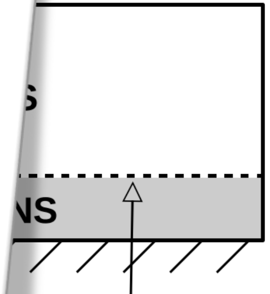
- Accurate Computational Fluid D… predicting aircraf…
- Turbulence-resol… predict flows whe… scales are presen…
- High Reynolds nu…
- Reynolds-Average… flows; inaccurate fo…
- Large-Eddy Simula… prohibitively expens… high Reynolds numb…

Separated flow over the canards and main wings.

This figure has intentionally been removed

…ind tunnel test. Visulaization of …let flow at static condition.





…NS-LES modeling

Hybrid RANS-LES methods (HRLM)

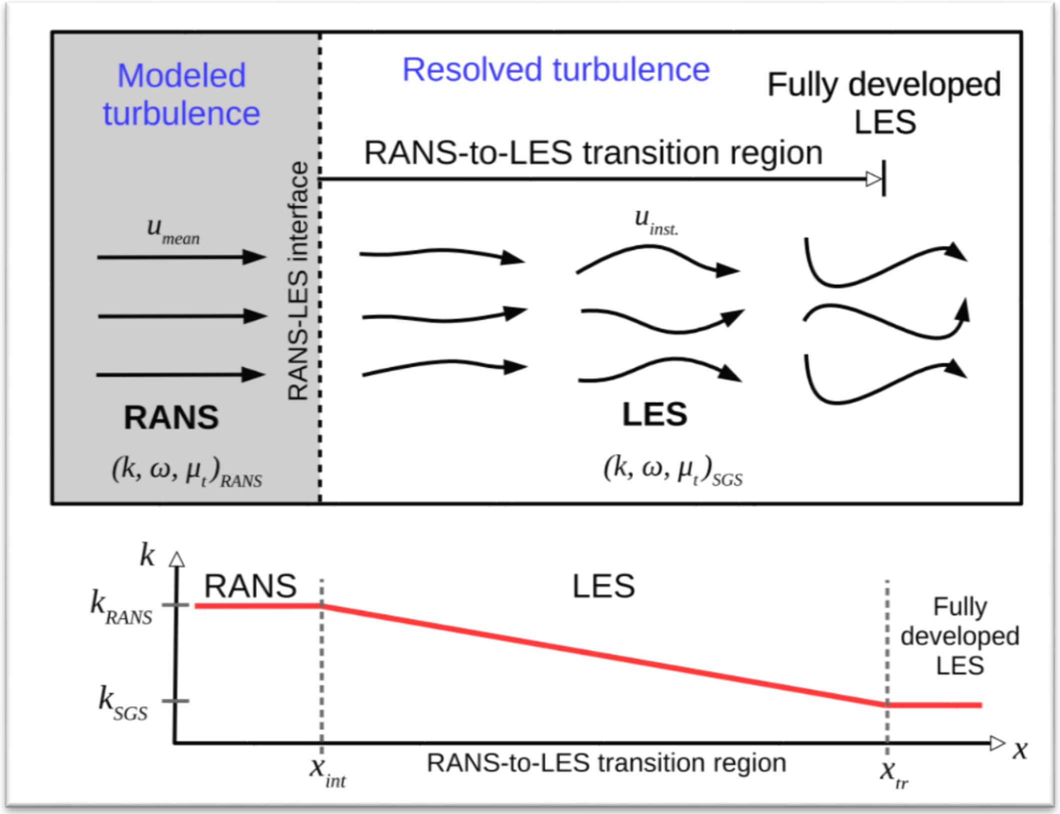
Turbulence … related computational cost*

Modeling type	Unsteady	Empiricism	Grid	Steps
RANS	No	Strong	10^{7}	10^{3}
URANS	Yes	Strong	10^{7}	$10^{3.5}$
HRLM (DES)	Yes	Strong	10^{8}	10^{4}
LES	Yes	Weak	$10^{11.5}$	$10^{6.7}$
DNS	Yes	Weak	10^{16}	$10^{7.7}$

*Spalart, IJHFF 21 (2000)

Transition from RANS to LES

- **Grey area:** transition region from RANS to fully developed LES



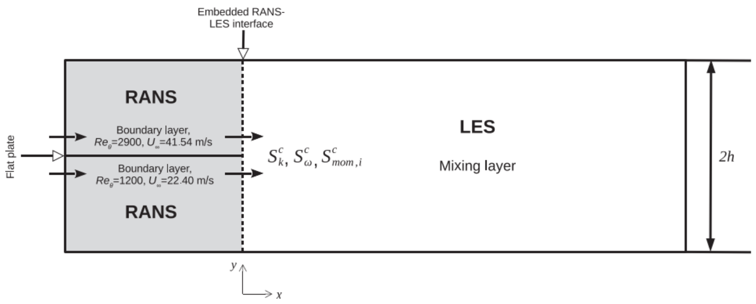
Schematic of RANS-to-LES transition.

From: Arvidson, Methodologies for RANS-LES interfaces in turbulence-resolving simulations, PhD thesis, Chalmers 2017

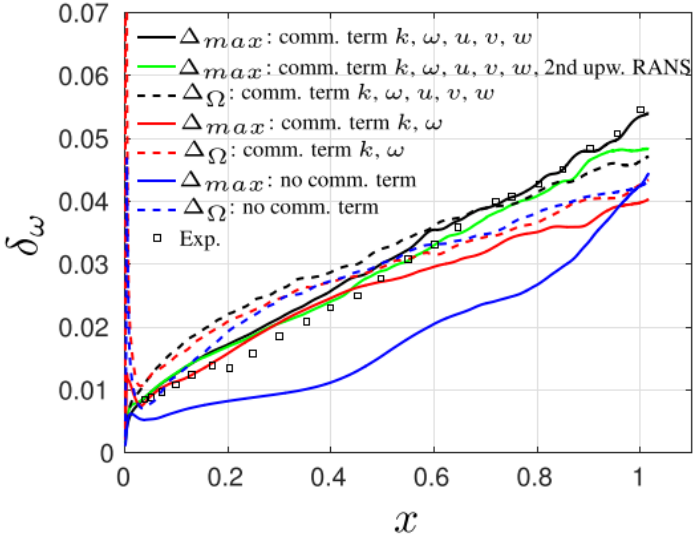
Transition from RANS to LES

Examples of Grey Area Mitigation (GAM) methods

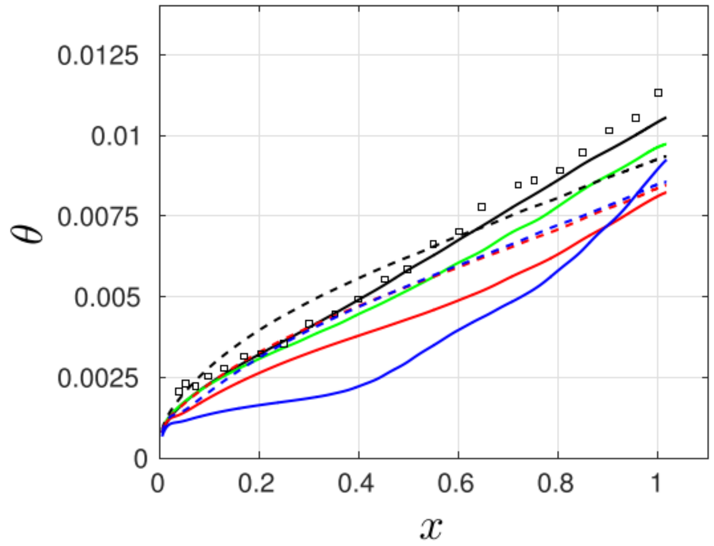
- RANS-LES interface methods
  - Synthetic turbulent fluctuations
  - Commutation terms
- LES length scale adaption
- High-pass filtering methods
- Turbulence models with back-scatter



Computational setup for mixing layer simulation



(a) Vorticity thickness



(b) Momentum thickness

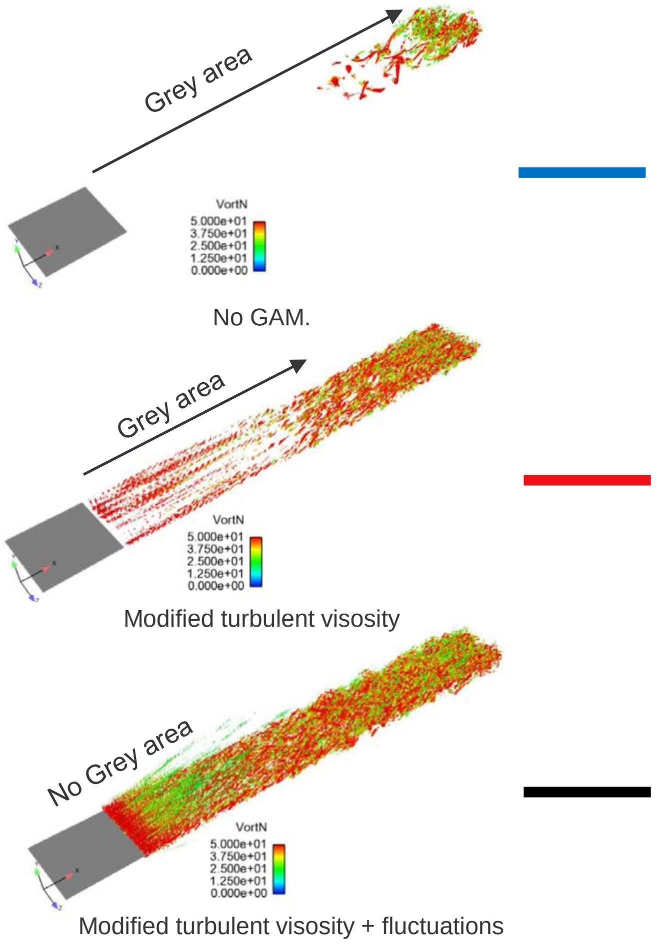


Illustration of GAM using commutation terms at the RANS-LES interface in mixing layer flow.

Mixing layer. Growth of vorticity thickness and momentum thickness.

From: Arvidson et al., Interface methods for grey-area mitigation in turbulence-resolving hybrid RANS-LES, International Journal of Heat and Fluid Flow, 73 (2018)

Hybrid RANS-LES on the Gripen inlet

- Large-scale separation inlet flow with strong total pressure fluctuations where a wide range of spatial and temporal scales are present
- Improved predictions with HRLM compared to RANS

- Status of today's hybrid RANS-LES methods
  - Large-scale separation flow: ok
  - Complex attached flows and shallow separation flow: improvements needed

This figure has intentionally been removed

Time-averaged total pressure contours at the engine face (AIP)

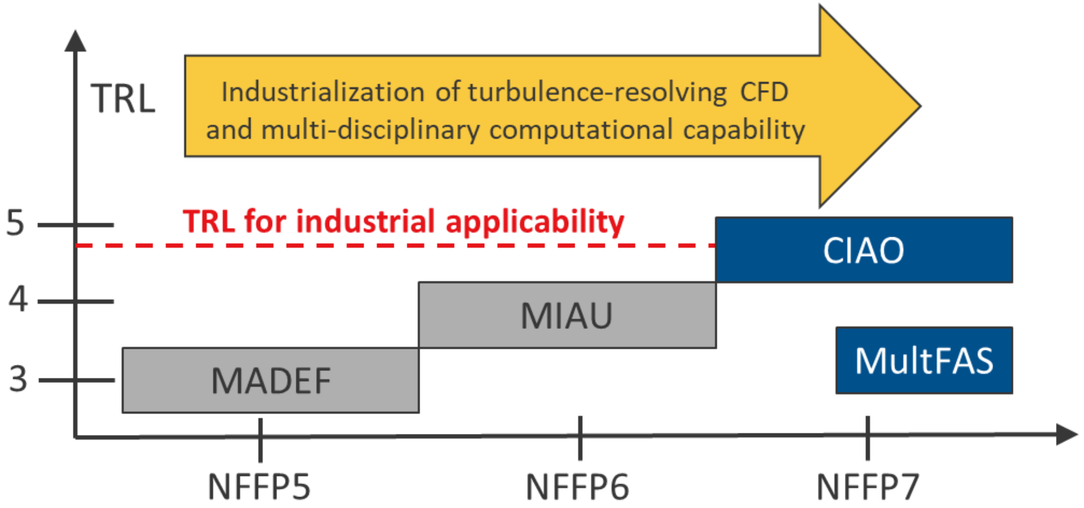
- Low speed
- High AoA
- High mass flow ratio

This movie has intentionally been removed

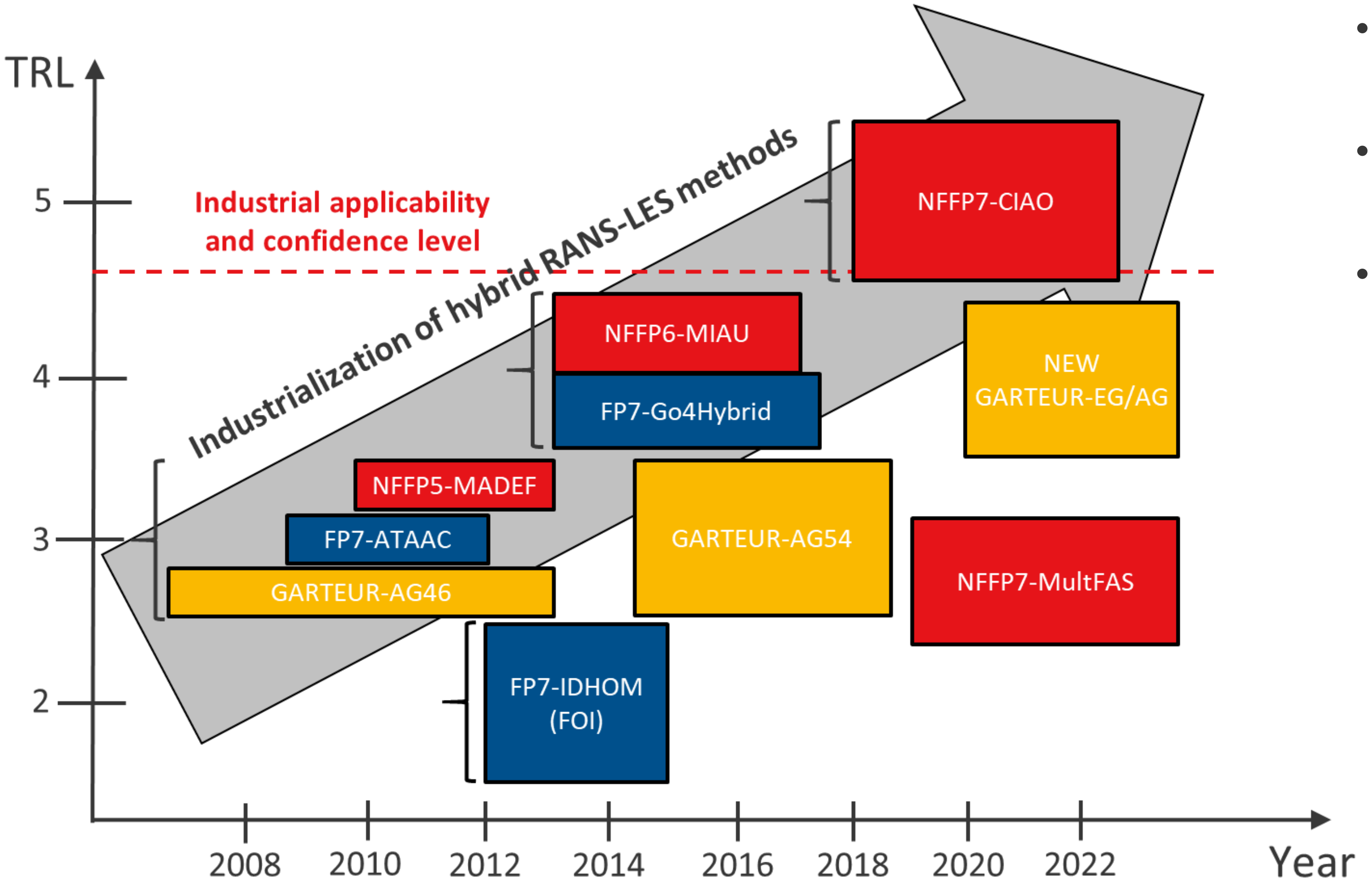
Resolved turbulent structures in the Gripen inlet

A serie of CFD projects – one vision…

- NFFP7 – CIAO (on-going, 2018-2022)
  - *Industrialization of CFD methods for improved predictions of complex aeronautical flows*
- NFFP7 - MultFAS (starts in November, 2019-2022)
  - *Multidisciplinary advanced computations: Fluid dynamics – Aeroacoustics – Structural dynamics*



NFFP7 in an international context



- Research projects with Saab participation
- NFFP projects coordinated by Saab
- A mix of national and international research projects to achieve international novelty and fulfill national (industry) needs

: **NFFP/Vinnova**

: **EU**

: **Garteur**

NFFP7-CIAO

"Industrialization of CFD methods for improved predictions of complex aeronautical flows"

- CFD where the large-scale turbulence is resolved in time and space using hybrid RANS-LES modeling (HRLM)
- Main purpose: industrialization of HRLM
  - Descritization schemes adapted for HRLM
  - Advanced RANS modeling for improved HRLM
  - Improved RANS-LES coupling and grey area mitigation
- Main tool: Saab's flow solver M-Edge
- Motivation: to strengthen Saab's and Sweden's CFD capability in the aeronautical field to meet future challenges and needs

This movie has intentionally been removed

Resolved turbulence downstream of landing gear using HRLM

NFFP7-CIAO

2018-2022

NFFP7-CIAO: Strategy, approach and methodology

- To use outcomes from NFFP5-MADEF, NFFP6-MIAU and other relevant state-of-the-art national and international R&D projects as starting point
- Assessment and improvement of numerical methods, such as low-dissipation and low-dispersion (LD2) schemes, for improved accuracy in turbulence-resolving simulations
- Introduction of Explicit Algebraic Reynolds Stress Modeling (EARSM) for improved predictions of complex attached flows such as corner flow separations
- Development and demonstration of RANS-LES interface methodology for geometrically arbitrary interfaces
- Development and demonstration of a synthetic turbulence generator (STG) adapted for Embedded LES (ELES) of compressible flow.
- Industrial assessment of the developed methodologies on aeronautical test cases

NFFP7-MultFAS

"Multidisciplinary advanced computations: Fluid dynamics – Aeroacoustics – Structural dynamics"

- Computational Fluid-Structure Interaction (FSI) and Aero Acoustics (CAA)
- Main purpose: to establish a robust computational FSI and CAA process for complex aeronatical applications
  - FSI and CAA on cavities
  - Transonic flow around non-aerodynamic objects to study aero acoustic mechanisms
- Main tool: Saab's flow solver M-Edge
- Motivation: to strengthen multidisciplinary computations within FSI and CAA for aeronautical applications

This movie has intentionally been removed

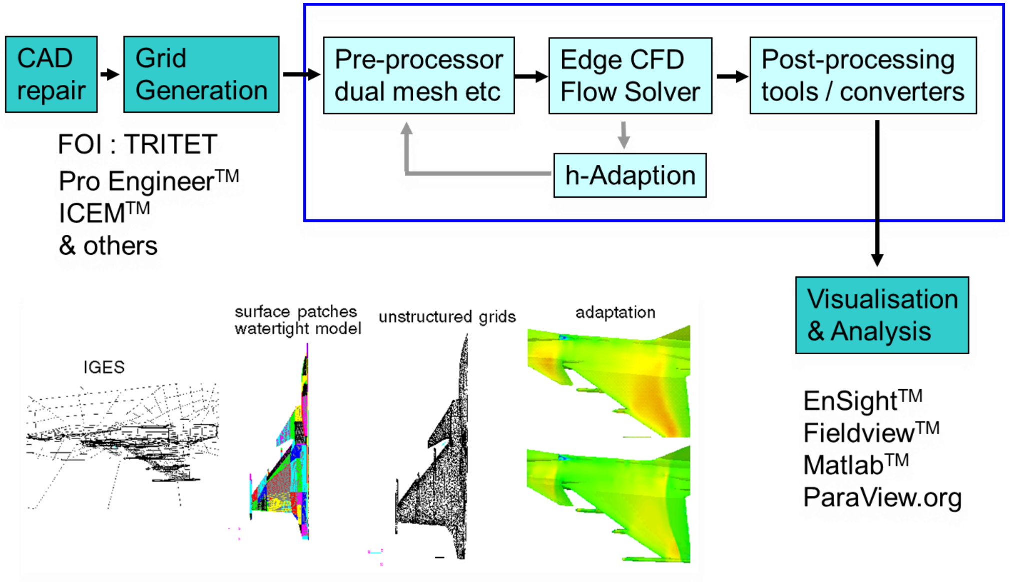
Cavity flow

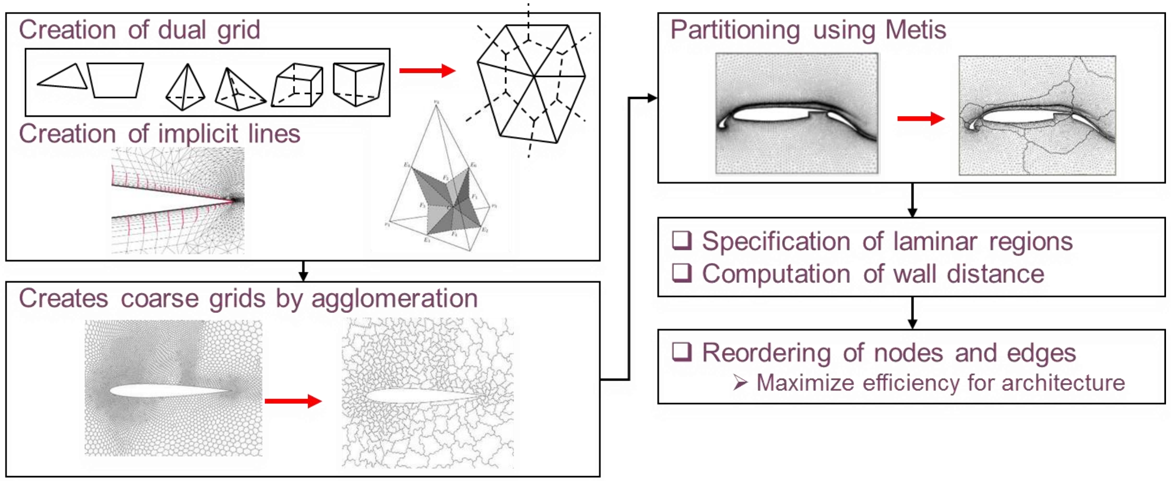
NFFP7-MultFAS

2019-2022

M-Edge

- M-Edge (Modularized Edge) is Edge with some functionalities in modules
- M-Edge property of Saab
  - Development in collaboration with FOI and national/international academia and institutions
- M-Edge main components
  - Flow solver, preprocessor, mesh adaptation, …
  - Stand alone programs
- Finite-Volume flow solver
  - Steady/unsteady, inviscid/viscous computations
  - Edge and dual grid based, unstructured grids
  - Solves the compressible N-S equations
  - Aeroelastics, mesh deformation
  - Models for flow control, adjoint solver …
  - High temperature extensions
  - GUI, documentation



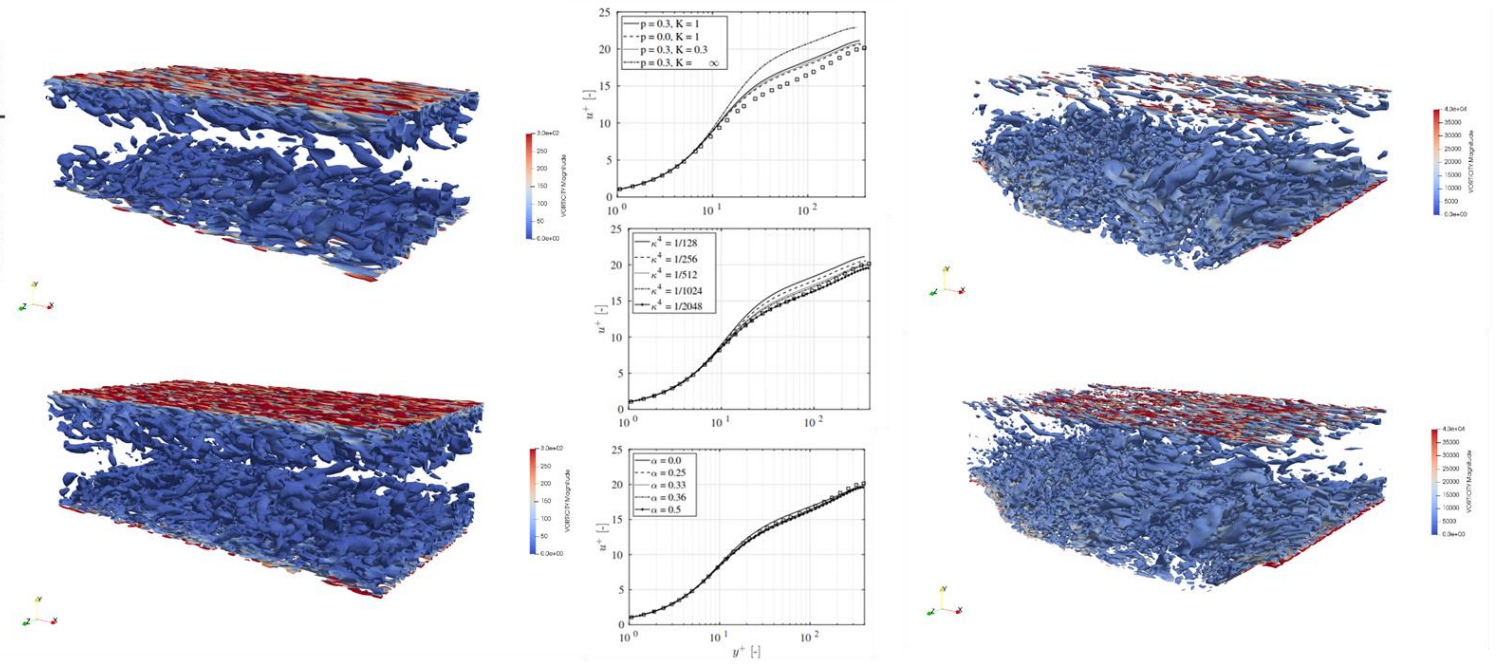


Results - effect of disretization scheme

Results from NFFP7-CIAO: effect of low dissipation and low dispertion discretization schemes

Reference scheme
Matrix dissipation

LD2 scheme



Resolved turbulent srtuctures | Mean velocity profiles | Resolved turbulent srtuctures

Channel flow | Periodic hill flow

Improved accuracy

Next steps

- Assessment of LD2 on industry relevant applications
- Assessment of EARSM based HRLM in M-Edge on aeronautical applications
- Synthetic turbulence at RANS-LES interfaces
- Improved RANS-LES coupling for hybrid and embedded approaches

Credits: Magnus Carlsson | magnus.carlssno@chalmers.se

Challenges and outlook

Challenges

- To achieve accuracy and efficiency with HRLM needed for industrial applicability
- Robust and efficient low dissipation and low dispertion schemes
- Geometrically arbitrary RANS-LES interfaces for embedded LES
  - Efficient grey-area mitigation methods
- Efficient and robust grey-area mitigation methods for seamless HRLM
- User independent seamless HRLM methods for industrial complex applications
- Efficient and robust industry applicable mesh generation strategies for accurate HRLM

Outlook

- HRLM needed to meet industrial requirements on
  - more cost effective products,
  - enhanced aircraft capabilities,
  - reduced environmental footprint
    - emissions
    - noise
- Improved CFD accuracy ➔ less testing and more simulations
  - Wind tunnel tests and flight tests can be traded for CFD
- An extensive increase in use of HRLM in the aeronautical industry

Thank you!

S. Arvidson | sebastian.arvidson@saabgroup.com

Gripen E at take-off