Antony Jameson's Contributions and Lasting Impact on Computational Aerodynamics

Dimitri Mavriplis
University of Wyoming (Emeritus)
University of Washington Affiliate
Scientific Simulations LLC

Happy Birthdays

- Great accomplishments
- Great opportunity for a symposium
  - Thanks to the organizers

Pictures at 60 years of age

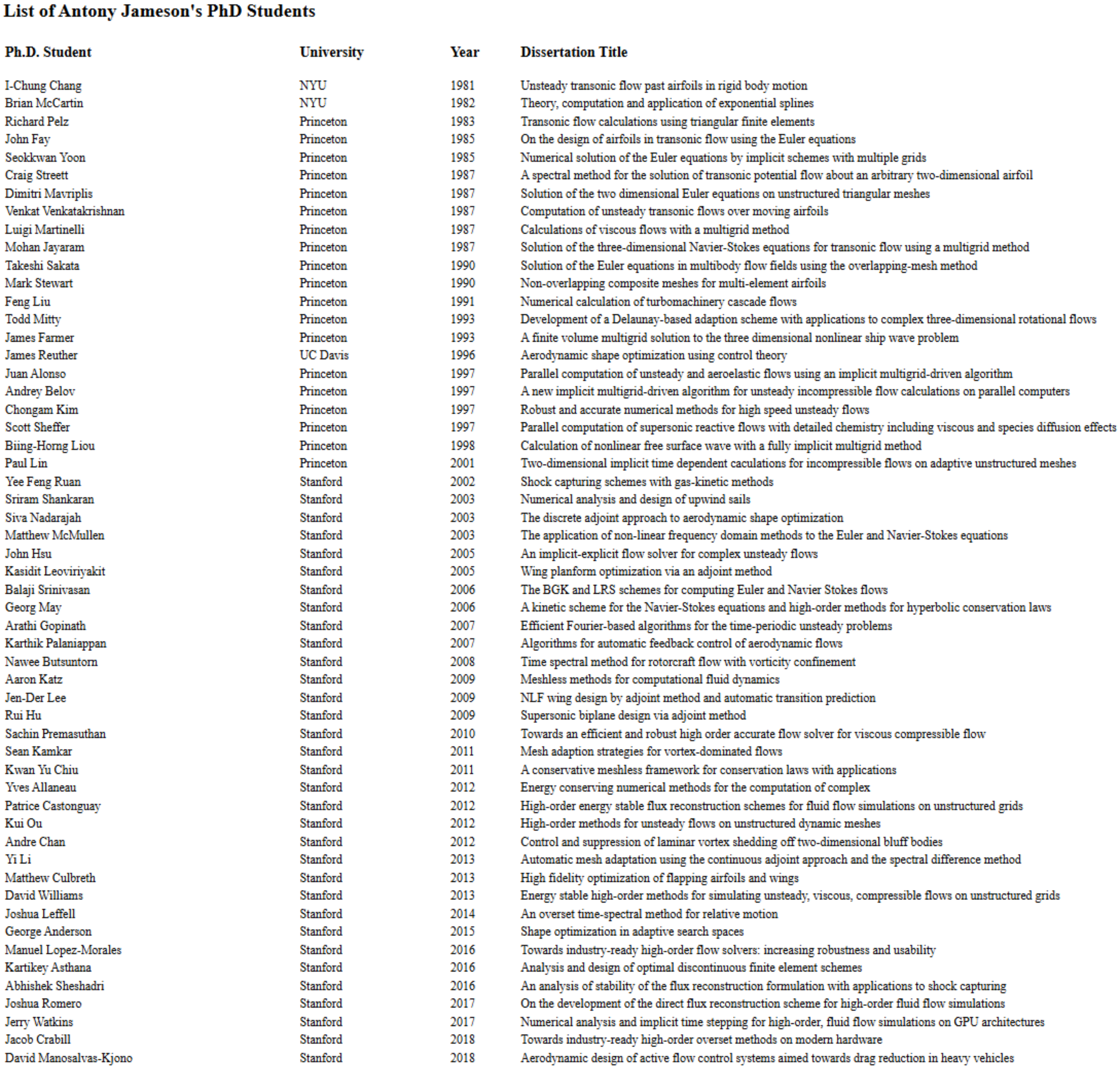
Overview of my Talk

- Focus on Antony Jameson’s contributions and impact
- Not too technical
  - Challenge 1: No equations
  - Challenge 2: No results from me
    - Use as much as possible Jameson material
- Personal experience
- Thoughts about future directions/opportunities

Antony Jameson's Contributions

- > 500 papers on Stanford site
  - ☐ Discretization schemes
    - ❖ JST, but many others
  - ☐ Convergence acceleration/Solvers
    - ❖ Enthalpy damping, Residual smoothing, Multigrid, etc.
  - ☐ Adjoint methods/Design Optimization
  - ☐ Implicit Time Stepping
    - ❖ Dual Time stepping, Time Spectral, Implicit RK
  - ☐ High Order Methods (DG, FR ...)
  - ☐ FLO, SYN and AIRPLANE codes

Antony Jameson's Impact



List of Antony Jameson's PhD Students

Ph.D. Student	University	Year	Dissertation Title
I-Chung Chang	NYU	1981	Unsteady transonic flow past airfoils in rigid body motion
Brian McCartin	NYU	1982	Theory, computation and application of exponential splines
Richard Pelz	Princeton	1983	Transonic flow calculations using triangular finite elements
John Fay	Princeton	1985	On the design of airfoils in transonic flow using the Euler equations
Seokkwan Yoon	Princeton	1985	Numerical solution of the Euler equations by implicit schemes with multiple grids
Craig Streett	Princeton	1987	A spectral method for the solution of transonic potential flow about an arbitrary two-dimensional airfoil
Dimitri Mavriplis	Princeton	1987	Solution of the two dimensional Euler equations on unstructured triangular meshes
Venkat Venkatakrishnan	Princeton	1987	Computation of unsteady transonic flows over moving airfoils
Luigi Martinelli	Princeton	1987	Calculations of viscous flows with a multigrid method
Mohan Jayaram	Princeton	1987	Solution of the three-dimensional Navier-Stokes equations for transonic flow using a multigrid method
Takeshi Sakata	Princeton	1990	Solution of the Euler equations in multibody flow fields using the overlapping-mesh method
Mark Stewart	Princeton	1990	Non-overlapping composite meshes for multi-element airfoils
Feng Liu	Princeton	1991	Numerical calculation of turbomachinery cascade flows
Todd Mitty	Princeton	1993	Development of a Delaunay-based adaption scheme with applications to complex three-dimensional rotational flows
James Farmer	Princeton	1993	A finite volume multigrid solution to the three dimensional nonlinear ship wave problem
James Reuther	UC Davis	1996	Aerodynamic shape optimization using control theory
Juan Alonso	Princeton	1997	Parallel computation of unsteady and aeroelastic flows using an implicit multigrid-driven algorithm
Andrey Belov	Princeton	1997	A new implicit multigrid-driven algorithm for unsteady incompressible flow calculations on parallel computers
Chongam Kim	Princeton	1997	Robust and accurate numerical methods for high speed unsteady flows
Scott Sheffer	Princeton	1997	Parallel computation of supersonic reactive flows with detailed chemistry including viscous and species diffusion effects
Biing-Horng Liou	Princeton	1998	Calculation of nonlinear free surface wave with a fully implicit multigrid method
Paul Lin	Princeton	2001	Two-dimensional implicit time dependent caculations for incompressible flows on adaptive unstructured meshes
Yee Feng Ruan	Stanford	2002	Shock capturing schemes with gas-kinetic methods
Sriram Shankaran	Stanford	2003	Numerical analysis and design of upwind sails
Siva Nadarajah	Stanford	2003	The discrete adjoint approach to aerodynamic shape optimization
Matthew McMullen	Stanford	2003	The application of non-linear frequency domain methods to the Euler and Navier-Stokes equations
John Hsu	Stanford	2005	An implicit-explicit flow solver for complex unsteady flows
Kasidit Leoviriyakit	Stanford	2005	Wing planform optimization via an adjoint method
Balaji Srinivasan	Stanford	2006	The BGK and LRS schemes for computing Euler and Navier Stokes flows
Georg May	Stanford	2006	A kinetic scheme for the Navier-Stokes equations and high-order methods for hyperbolic conservation laws
Arathi Gopinath	Stanford	2007	Efficient Fourier-based algorithms for the time-periodic unsteady problems
Karthik Palaniappan	Stanford	2007	Algorithms for automatic feedback control of aerodynamic flows
Nawee Butsuntorn	Stanford	2008	Time spectral method for rotorcraft flow with vorticity confinement
Aaron Katz	Stanford	2009	Meshless methods for computational fluid dynamics
Jen-Der Lee	Stanford	2009	NLF wing design by adjoint method and automatic transition prediction
Rui Hu	Stanford	2009	Supersonic biplane design via adjoint method
Sachin Premasuthan	Stanford	2010	Towards an efficient and robust high order accurate flow solver for viscous compressible flow
Sean Kamkar	Stanford	2011	Mesh adaption strategies for vortex-dominated flows
Kwan Yu Chiu	Stanford	2011	A conservative meshless framework for conservation laws with applications
Yves Allaneau	Stanford	2012	Energy conserving numerical methods for the computation of complex
Patrice Castonguay	Stanford	2012	High-order energy stable flux reconstruction schemes for fluid flow simulations on unstructured grids
Kui Ou	Stanford	2012	High-order methods for unsteady flows on unstructured dynamic meshes
Andre Chan	Stanford	2012	Control and suppression of laminar vortex shedding off two-dimensional bluff bodies
Yi Li	Stanford	2013	Automatic mesh adaptation using the continuous adjoint approach and the spectral difference method
Matthew Culbreth	Stanford	2013	High fidelity optimization of flapping airfoils and wings
David Williams	Stanford	2013	Energy stable high-order methods for simulating unsteady, viscous, compressible flows on unstructured grids
Joshua Leffell	Stanford	2014	An overset time-spectral method for relative motion
George Anderson	Stanford	2015	Shape optimization in adaptive search spaces
Manuel Lopez-Morales	Stanford	2016	Towards industry-ready high-order flow solvers: increasing robustness and usability
Kartikey Asthana	Stanford	2016	Analysis and design of optimal discontinuous finite element schemes
Abhishek Sheshadri	Stanford	2016	An analysis of stability of the flux reconstruction formulation with applications to shock capturing
Joshua Romero	Stanford	2017	On the development of the direct flux reconstruction scheme for high-order fluid flow simulations
Jerry Watkins	Stanford	2017	Numerical analysis and implicit time stepping for high-order, fluid flow simulations on GPU architectures
Jacob Crabill	Stanford	2018	Towards industry-ready high-order overset methods on modern hardware
David Manosalvas-Kjono	Stanford	2018	Aerodynamic design of active flow control systems aimed towards drag reduction in heavy vehicles

How I came to study under Antony Jameson

How I came to study under Antony Jameson

How I came to study under Antony Jameson

LEAR FAN

Moya Olsen Lear
Chairman of the Board

LearAvia Corp.
Box 60000
Reno, Nevada 89506
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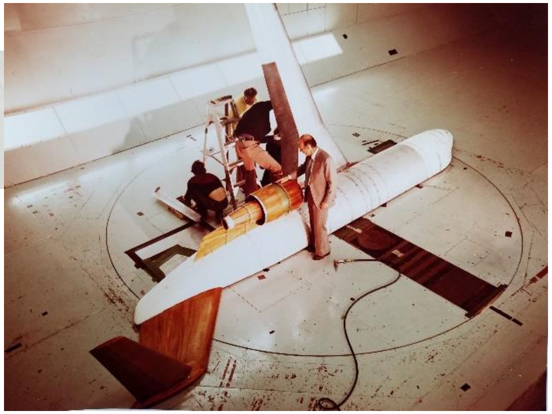
July 19, 1978



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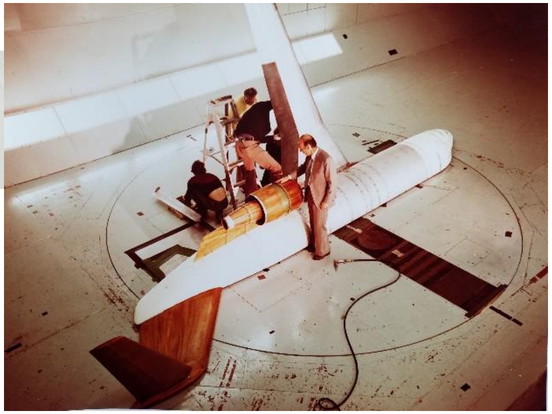

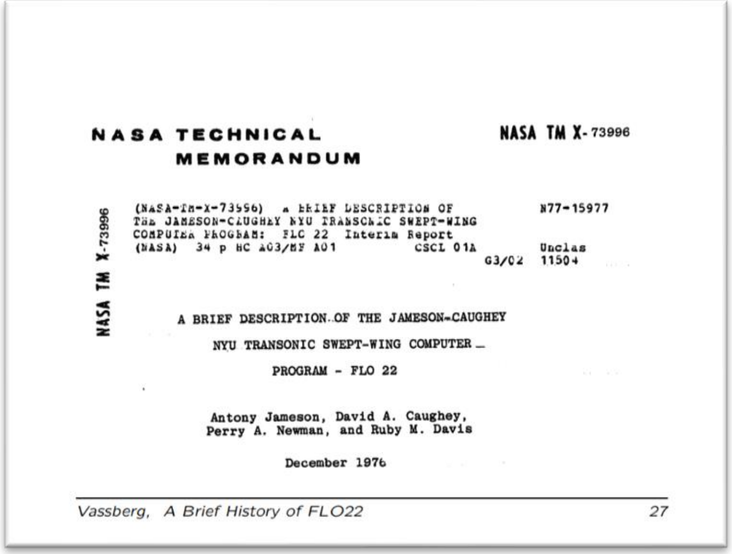

NASA TECHNICAL MEMORANDUM

NASA TM X-73996

NASA TM X-73996

(NASA-TM-X-73996) A BRIEF DESCRIPTION OF THE JAMESON-CAUGHEY NYU TRANSONIC SWEPT-WING COMPUTER PROGRAM: FLO 22 Interim Report (NASA) 34 p HC A03/MF A01 CSCL 01A

N77-15977

Unclas
G3/02 11504

A BRIEF DESCRIPTION OF THE JAMESON-CAUGHEY
NYU TRANSONIC SWEPT-WING COMPUTER
PROGRAM - FLO 22

Antony Jameson, David A. Caughey,
Perry A. Newman, and Ruby M. Davis

December 1976

Vassberg, A Brief History of FLO22 27

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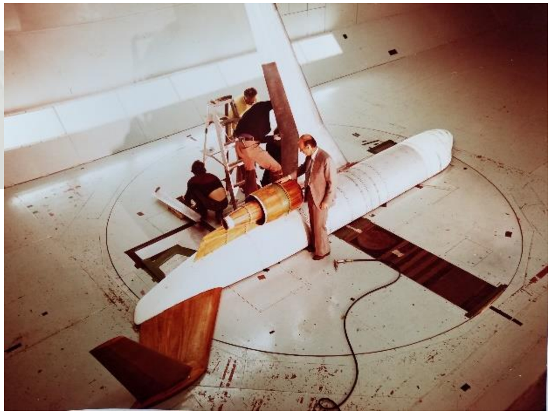
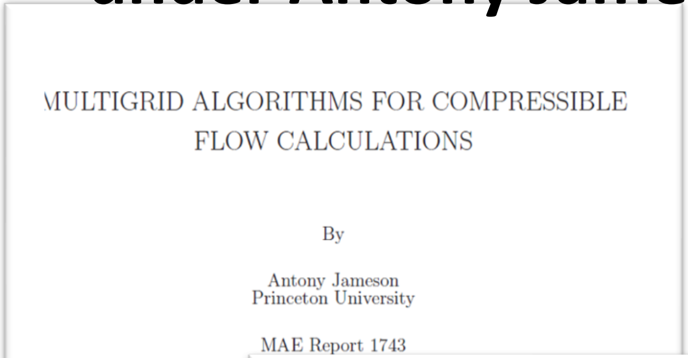


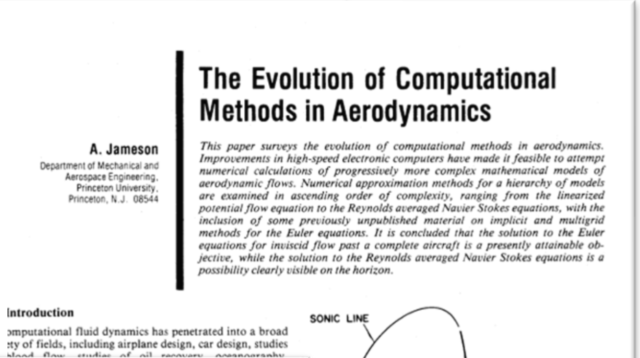


MULTIGRID ALGORITHMS FOR COMPRESSIBLE FLOW CALCULATIONS

By

Antony Jameson
Princeton University

MAE Report 1743



The Evolution of Computational Methods in Aerodynamics

A. Jameson
Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, N.J. 08544

This paper surveys the evolution of computational methods in aerodynamics. Improvements in high-speed electronic computers have made it feasible to attempt numerical calculations of progressively more complex mathematical models of aerodynamic flows. Numerical approximation methods for a hierarchy of models are examined in ascending order of complexity, ranging from the linearized potential flow equation to the Reynolds averaged Navier Stokes equations, with the inclusion of some previously unpublished material on implicit and multigrid methods for the Euler equations. It is concluded that the solution to the Euler equations for inviscid flow past a complete aircraft is a presently attainable objective, while the solution to the Reynolds averaged Navier Stokes equations is a possibility clearly visible on the horizon.

Introduction

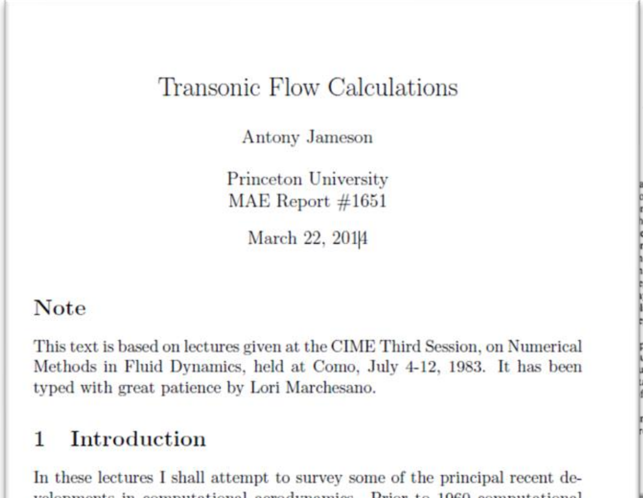
omputational fluid dynamics has penetrated into a broad ety of fields, including airplane design, car design, studies

TRANSONIC FLOW PAST AN AIRFOIL
Fig. 1.1

alculations of aerodynamic properties of least isolated omponents of an airplane. Efficient flight can be achieved nly by establishing highly coherent flows. Consequently here are many important applications where it is not ecessary to solve the full Navier Stokes equations, and useful redictions can be made with simplified mathematical odels. Since the work of Prandtl, it has been recognized that flows at the large Reynolds numbers typical in most flight egimes, viscous effects are important chiefly in thin shear yers adjacent to the surface. While these boundary layers lay a critical role in determining whether the flow will eparate, and how much circulation will be generated around lifting surface, the equations of inviscid flow are a good pproximation in the bulk of the flow field. The Reynolds umbers for a large airplane (of the order of 30 million) are uch that laminar flow in the boundary layer becomes unstable, with the result that the flow will be turbulent over most f the surface of the airplane.

On the other hand, many useful predictions can be made nder the assumption that the flow is inviscid. It then follows rom Kelvin's Theorem that in the absence of discontinuities

Transactions of the ASME



Transonic Flow Calculations

Antony Jameson

Princeton University
MAE Report #1651

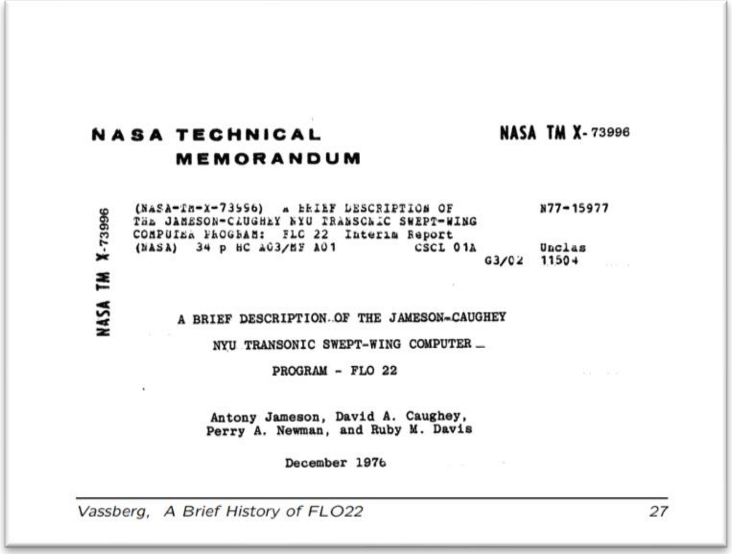
March 22, 2014

Note

This text is based on lectures given at the CIME Third Session, on Numerical Methods in Fluid Dynamics, held at Como, July 4-12, 1983. It has been typed with great patience by Lori Marchesano.

1 Introduction

In these lectures I shall attempt to survey some of the principal recent de-



NASA TECHNICAL MEMORANDUM NASA TM X-73996

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(NASA-TM-X-73996)  A BRIEF DESCRIPTION OF            N77-15977
THE JAMESON-CAUGHEY NYU TRANSONIC SWEPT-WING
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                                              G3/02  11504
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Antony Jameson, David A. Caughey,
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December 1976

The Laundry List (circa 1983)

- Unsteady Flows
- Multiblock Meshes
- Overset Meshes
- Navier-Stokes methods
- Complex geometries (unstructured meshes)
- Convergence acceleration (multigrid)
- Others, I can’t remember…

The Laundry List (circa 1983)

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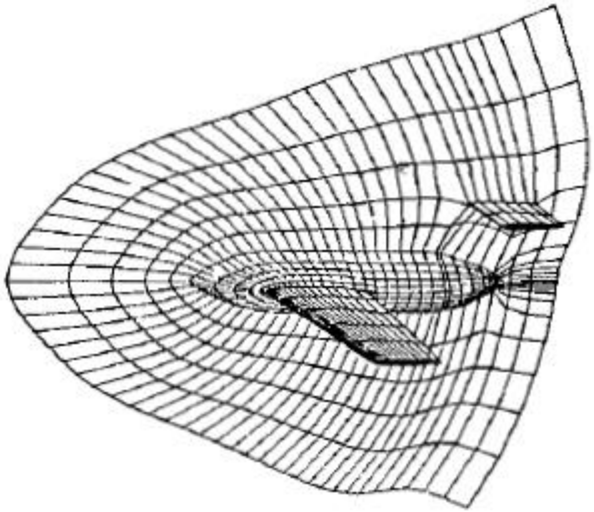
Complex Geometries

- Goal: Full Aircraft Code
  - Initial work focused on block structured grids
  - Rich Pelz had shown full potential equation on 2D triangular meshes



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  - I was tasked with solving Euler equations on 2D triangular meshes
    - Initial results looked promising

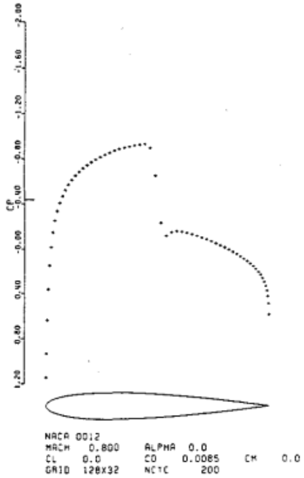

Figure 6

Calculated Pressure Distribution
Using Triangle Code

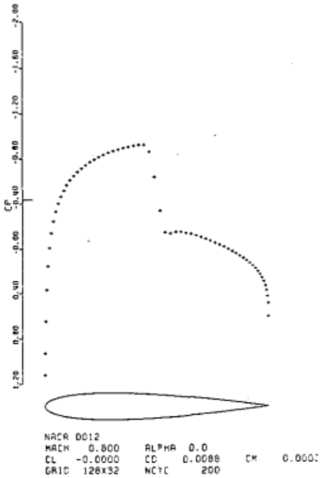

Figure 7

Calculated Pressure Distribution Using FLO52

Complex Geometries

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    - Initial Airplane code paper in 1986

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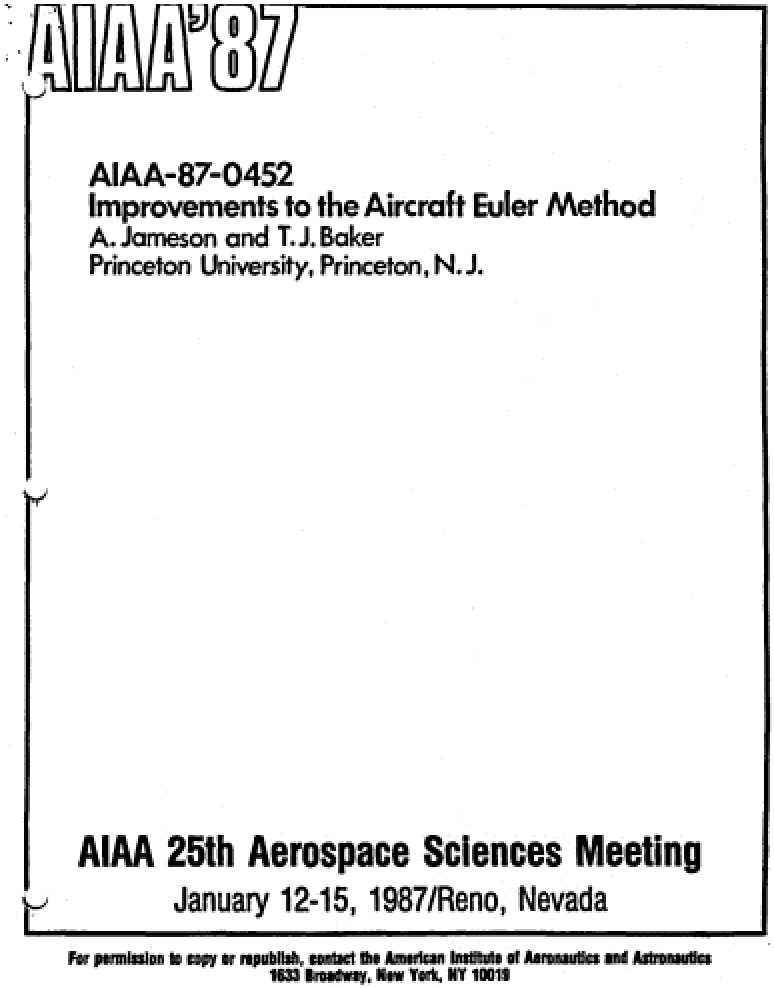
  - Jameson/Baker start focusing on solution of Euler equations on 3D tetrahedral meshes
    - Initial Airplane code paper in 1986
    - I begin to wonder what my thesis contribution will be…

Circa 1987



AIAA'87

AIAA-87-0452
Improvements to the Aircraft Euler Method
A. Jameson and T. J. Baker
Princeton University, Princeton, N.J.

AIAA 25th Aerospace Sciences Meeting
January 12-15, 1987/Reno, Nevada

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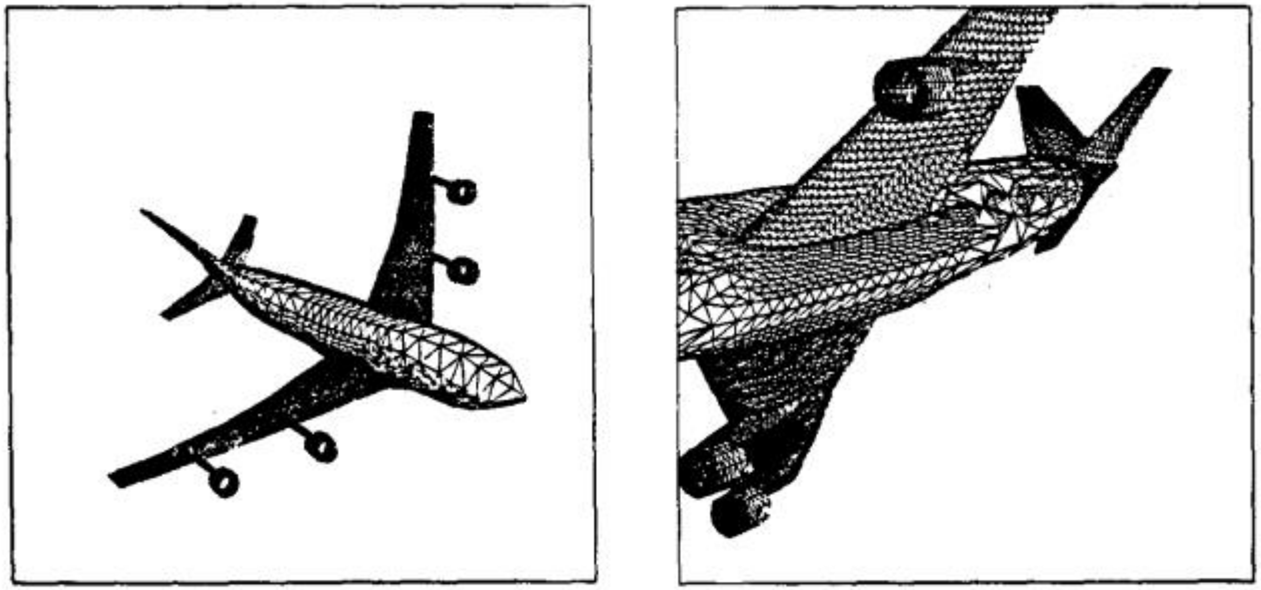
1633 Broadway, New York, NY 10019

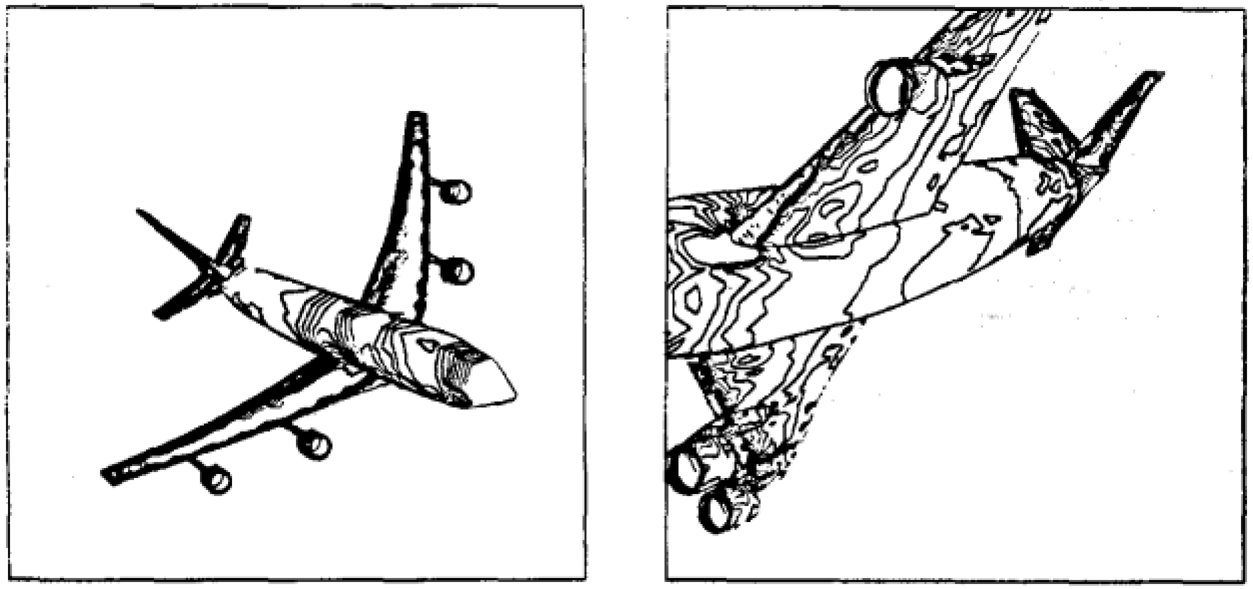
- 2nd "Airplane" Paper
- Delaunay triangulation
- Unstructured mesh Euler solver
  - JST Sheme
  - Explicit Runge-Kutta
  - Implicit residual smoothing
  - Enthalpy damping

1987 Jameson Airplane Paper



- Unstructured tetrahedral mesh
  - **35,370 points, 181,959 tetrahedra**
  - Mesh generation: 15 minutes
    - No mention of geometry issues
  - Flow solver : 1 hour on 1 processor of CRAY-XMP
    - Vectorized, later parallelized for CRAY-XMP/YMP

1987 Jameson Airplane Paper



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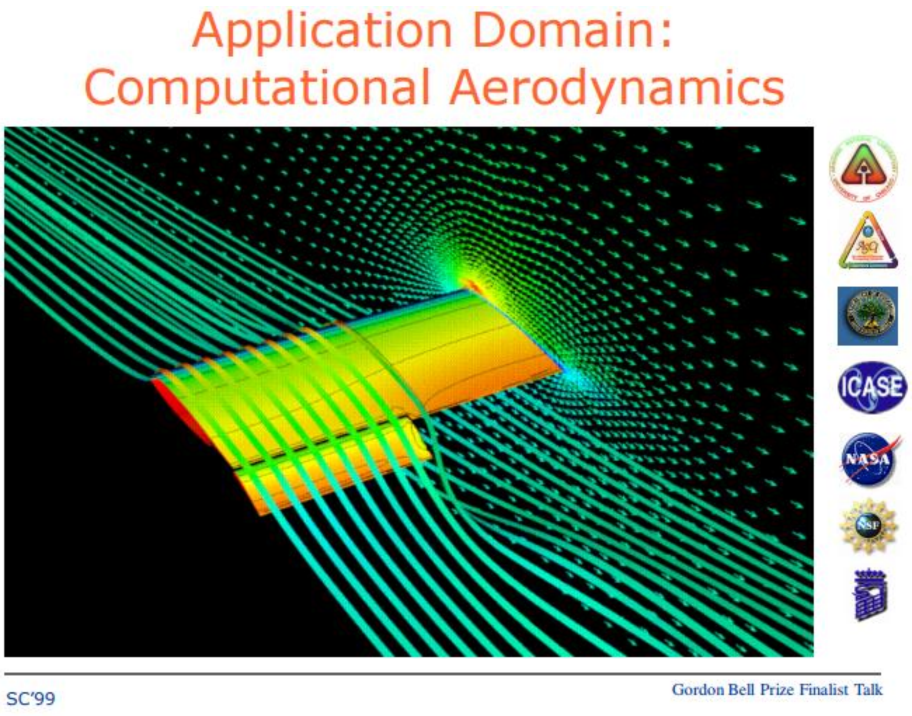
Circa 1999 (12 Years later)

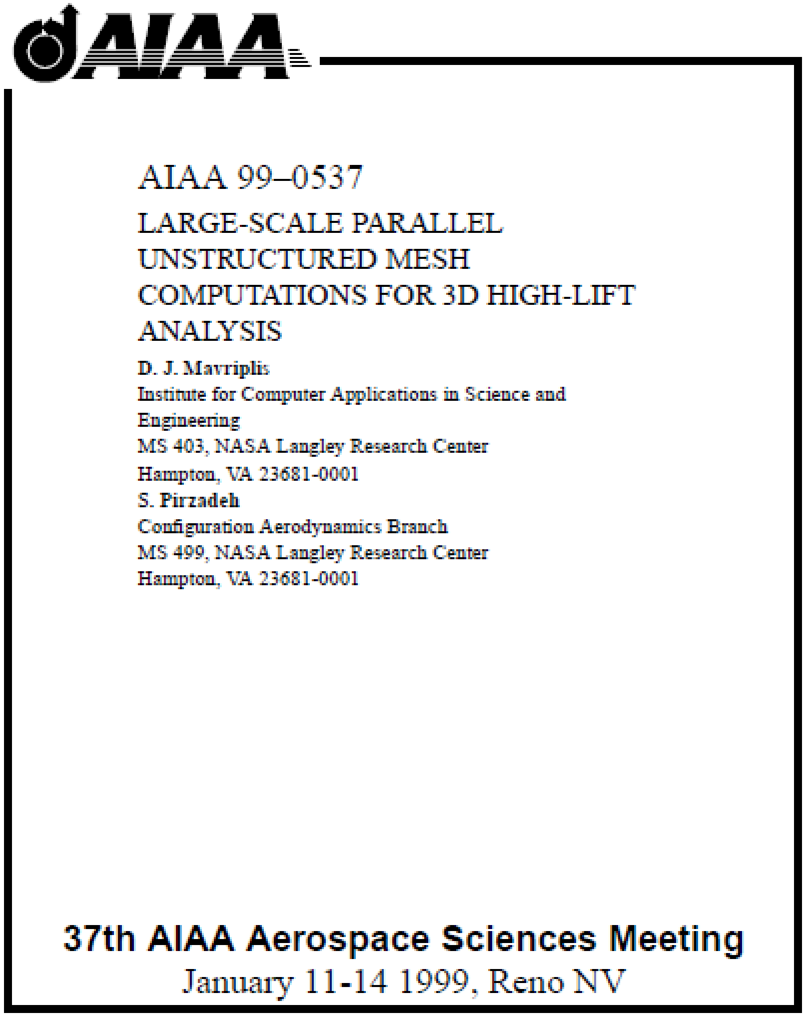


Application Domain:
Computational Aerodynamics

SC'99

Gordon Bell Prize Finalist Talk

- **PETSc-FUN3D wins 1999 Gordon Bell prize**



AIAA

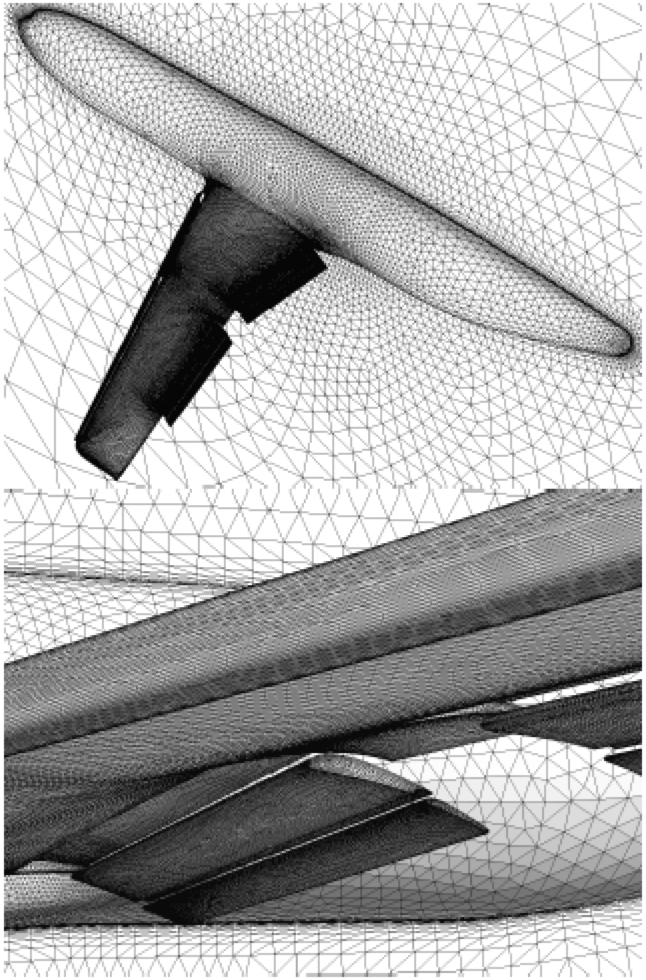
AIAA 99–0537

LARGE-SCALE PARALLEL UNSTRUCTURED MESH COMPUTATIONS FOR 3D HIGH-LIFT ANALYSIS

D. J. Mavriplis
Institute for Computer Applications in Science and Engineering
MS 403, NASA Langley Research Center
Hampton, VA 23681-0001
S. Pirzadeh
Configuration Aerodynamics Branch
MS 499, NASA Langley Research Center
Hampton, VA 23681-0001

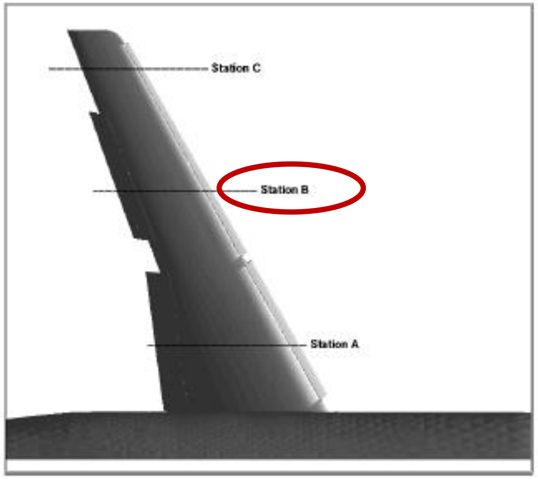
37th AIAA Aerospace Sciences Meeting
January 11-14 1999, Reno NV

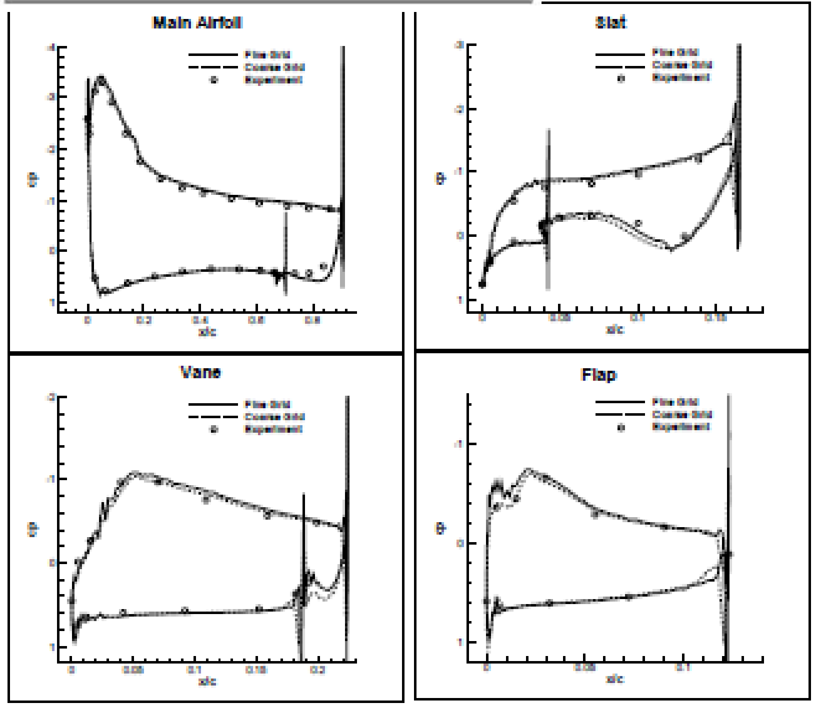
1999 High Lift Paper



- Coarse Mesh: 3 million points
- Fine mesh: 25 million points
- RANS simulation on up to 1500 CRAY-T3E processors
  - c/o Rob Vermeland

1999 High Lift Paper





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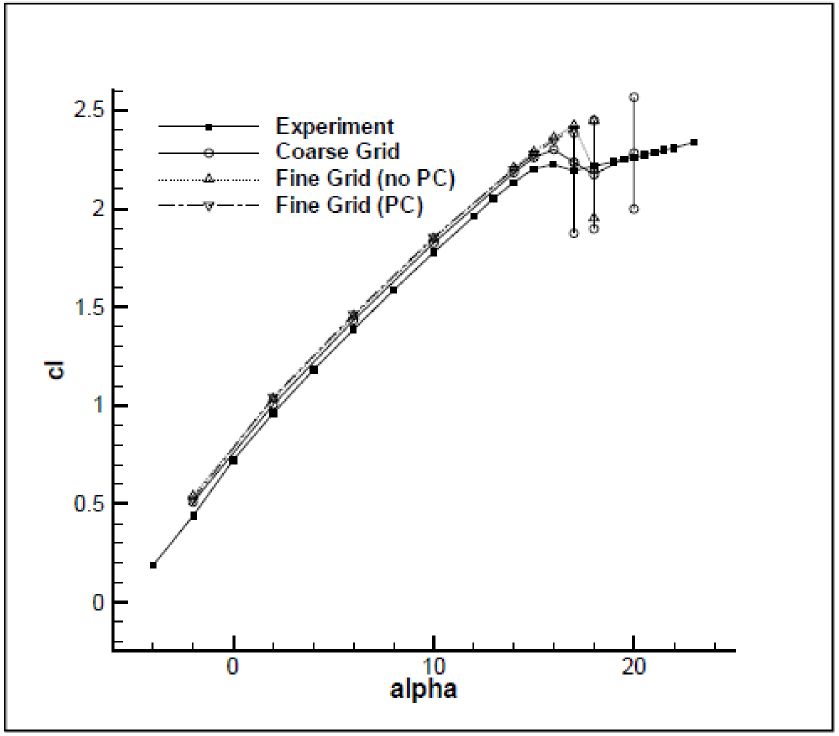
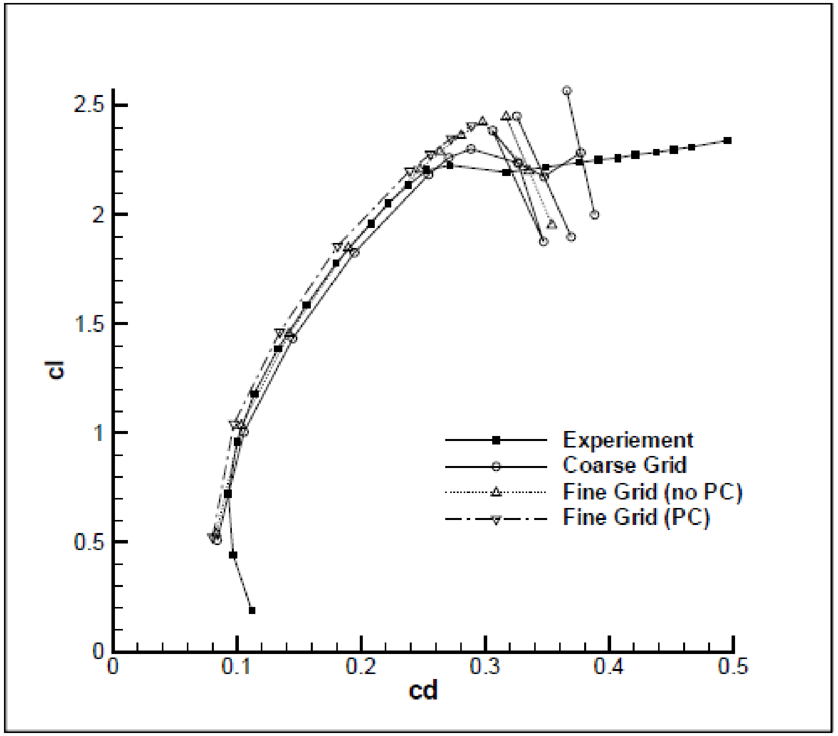
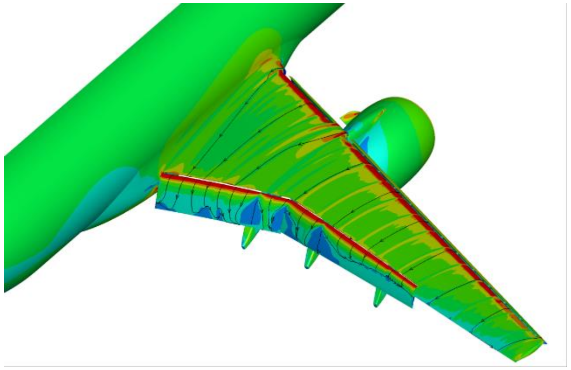




- Reasonable agreement with experimental force data
- Easier take-off configuration

37 Years Later
HLPW5 Fixed Grid RANS TFG

Reproduced from HLPW5 Fixed Grid RANS TFG Presentation



Discretization Approaches

- Node-centered, finite-volume, 2nd order : 6 solvers, 69 sets
- Cell-centered, finite-volume, 2nd order : 16 solvers, 141 sets
- Node-centered, continuous finite-element : 2 solvers, 14 sets

RANS Models

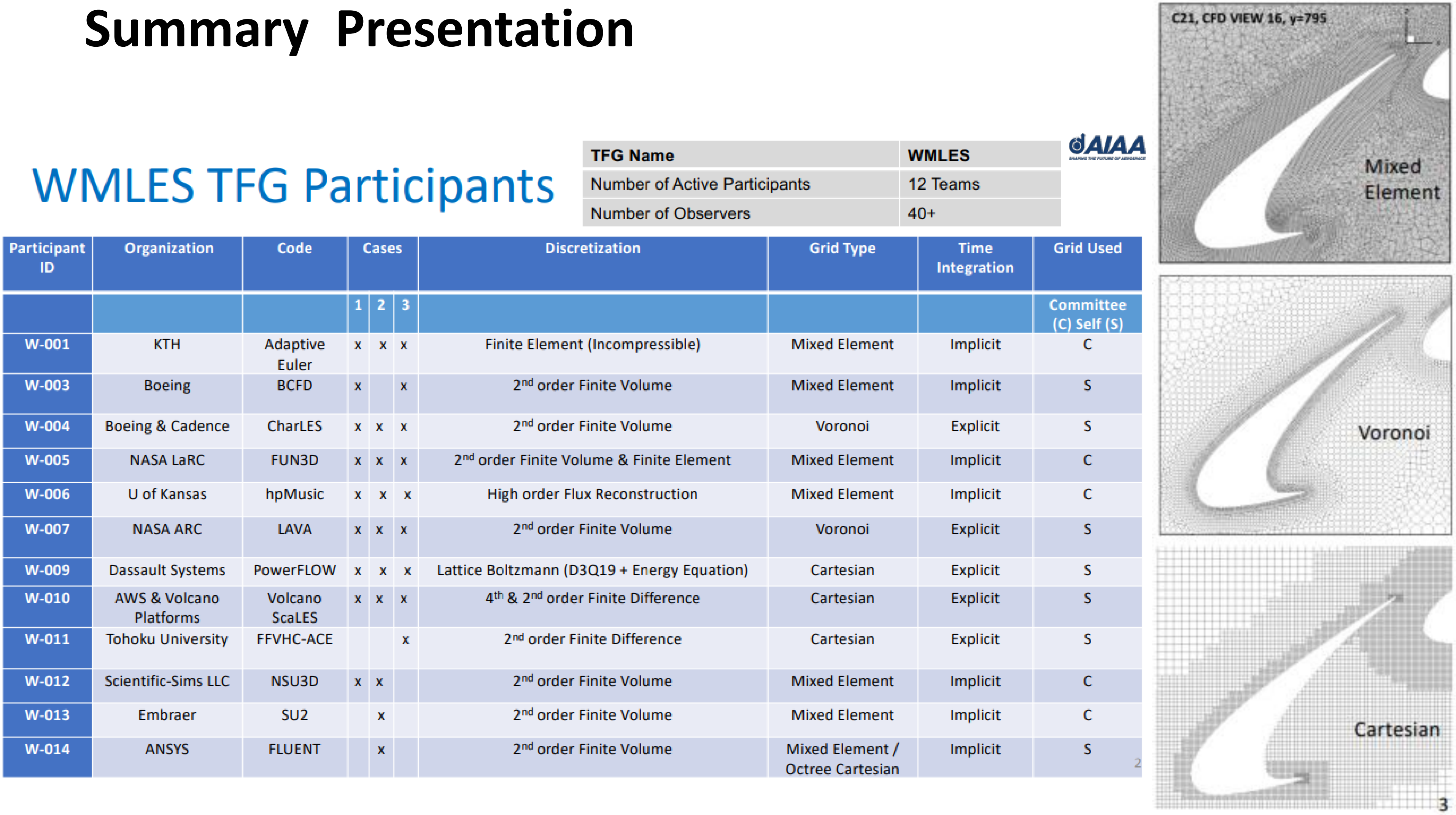
- Spalart-Allmaras (SA) equations, including SA-neg and SA-noft2 variants : 22 solvers, 150 sets
- SA-R(C_{rot}=1)-QCR2000 equations : 13 solvers, 32 sets
- Other models : 9 solvers, 42 sets

Fixed-Grid Families

- POINTWISE, mixed-element (1.R.01, 1.R.09, 2.R.03, 3.R.01) : 18 solvers, 83 sets
- HELDENMESH, mixed-element (1.R.03, 1.R.05, 1.R.07, 2.R.01, 3.R.02) : 11 solvers, 76 sets
- ANSYS ICEM CFD, hex-dominant (1.R.04, 1.L.01, 1.H.04, 2.L.01) : 10 solvers, 31 sets
- STAR-CCM+, mixed-element (2.R.04) : 2 solvers, 9 sets
- Custom grids : 6 solvers, 18 sets

Exclusively Unstructured Meshes

HLPW5 WMLES TFG Results and Summary Presentation



WMLES TFG Participants

TFG Name	WMLES
Number of Active Participants	12 Teams
Number of Observers	40+

Participant ID	Organization	Code	Cases			Discretization	Grid Type	Time Integration	Grid Used
			1	2	3				Committee (C) Self (S)
W-001	KTH	Adaptive Euler	x	x	x	Finite Element (Incompressible)	Mixed Element	Implicit	C
W-003	Boeing	BCFD	x		x	2nd order Finite Volume	Mixed Element	Implicit	S
W-004	Boeing & Cadence	CharLES	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-005	NASA LaRC	FUN3D	x	x	x	2nd order Finite Volume & Finite Element	Mixed Element	Implicit	C
W-006	U of Kansas	hpMusic	x	x	x	High order Flux Reconstruction	Mixed Element	Implicit	C
W-007	NASA ARC	LAVA	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-009	Dassault Systems	PowerFLOW	x	x	x	Lattice Boltzmann (D3Q19 + Energy Equation)	Cartesian	Explicit	S
W-010	AWS & Volcano Platforms	Volcano ScaLES	x	x	x	4th & 2nd order Finite Difference	Cartesian	Explicit	S
W-011	Tohoku University	FFVHC-ACE			x	2nd order Finite Difference	Cartesian	Explicit	S
W-012	Scientific-Sims LLC	NSU3D	x	x		2nd order Finite Volume	Mixed Element	Implicit	C
W-013	Embraer	SU2		x		2nd order Finite Volume	Mixed Element	Implicit	C
W-014	ANSYS	FLUENT		x		2nd order Finite Volume	Mixed Element / Octree Cartesian	Implicit	S

HLPW5 WMLES TFG Results and Summary Presentation

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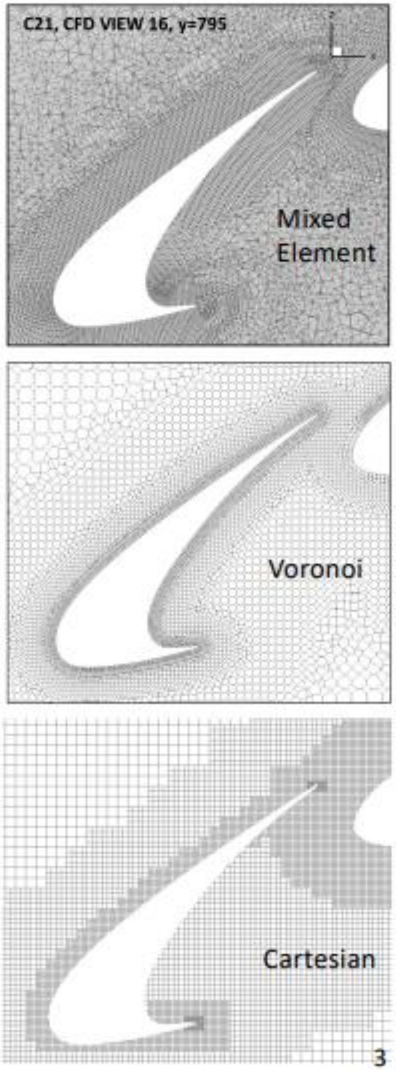
W-004	Boeing & Cadence	CharLES	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-005	NASA LaRC	FUN3D	x	x	x	2nd order Finite Volume & Finite Element	Mixed Element	Implicit	C
W-006	U of Kansas	hpMusic	x	x	x	High order Flux Reconstruction	Mixed Element	Implicit	C
W-007	NASA ARC	LAVA	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-009	Dassault Systems	PowerFLOW	x	x	x	Lattice Boltzmann (D3Q19 + Energy Equation)	Cartesian	Explicit	S
W-010	AWS & Volcano Platforms	Volcano ScaLES	x	x	x	4th & 2nd order Finite Difference	Cartesian	Explicit	S
W-011	Tohoku University	FFVHC-ACE			x	2nd order Finite Difference	Cartesian	Explicit	S
W-012	Scientific-Sims LLC	NSU3D	x	x		2nd order Finite Volume	Mixed Element	Implicit	C
W-013	Embraer	SU2		x		2nd order Finite Volume	Mixed Element	Implicit	C
W-014	ANSYS	FLUENT		x		2nd order Finite Volume	Mixed Element / Octree Cartesian	Implicit	S



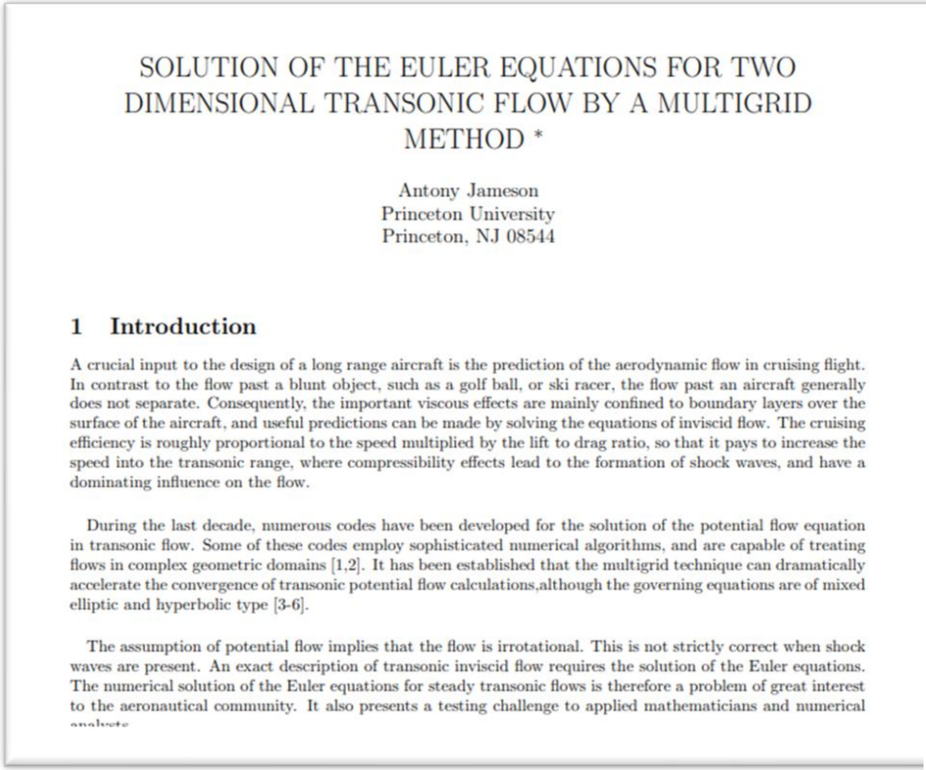
Another paradigm shift, ~40 years later?

The Laundry List (circa 1983)

- Unsteady Flows
- Multiblock Meshes
- Overset Meshes
- Navier-Stokes methods
- Complex geometries (unstructured meshes)
- Convergence acceleration (multigrid)
- Others, I can't remember…

Convergence Acceleration

- 1983 Copper Mountain MG Conference:



SOLUTION OF THE EULER EQUATIONS FOR TWO DIMENSIONAL TRANSONIC FLOW BY A MULTIGRID METHOD *

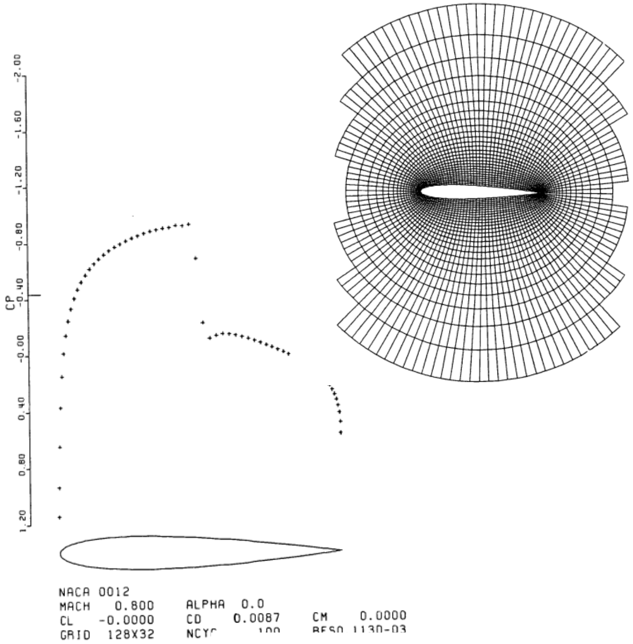
Antony Jameson
Princeton University
Princeton, NJ 08544

1 Introduction

A crucial input to the design of a long range aircraft is the prediction of the aerodynamic flow in cruising flight. In contrast to the flow past a blunt object, such as a golf ball, or ski racer, the flow past an aircraft generally does not separate. Consequently, the important viscous effects are mainly confined to boundary layers over the surface of the aircraft, and useful predictions can be made by solving the equations of inviscid flow. The cruising efficiency is roughly proportional to the speed multiplied by the lift to drag ratio, so that it pays to increase the speed into the transonic range, where compressibility effects lead to the formation of shock waves, and have a dominating influence on the flow.

During the last decade, numerous codes have been developed for the solution of the potential flow equation in transonic flow. Some of these codes employ sophisticated numerical algorithms, and are capable of treating flows in complex geometric domains [1,2]. It has been established that the multigrid technique can dramatically accelerate the convergence of transonic potential flow calculations,although the governing equations are of mixed elliptic and hyperbolic type [3-6].

The assumption of potential flow implies that the flow is irrotational. This is not strictly correct when shock waves are present. An exact description of transonic inviscid flow requires the solution of the Euler equations. The numerical solution of the Euler equations for steady transonic flows is therefore a problem of great interest to the aeronautical community. It also presents a testing challenge to applied mathematicians and numerical analysts



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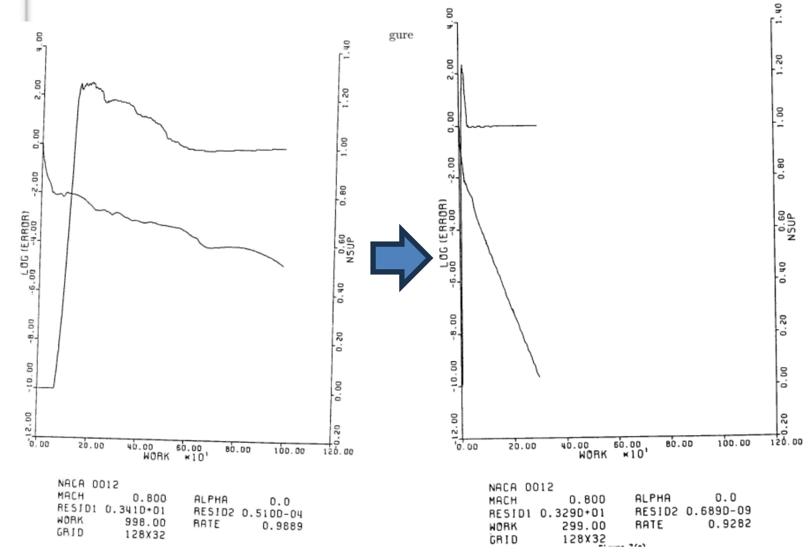

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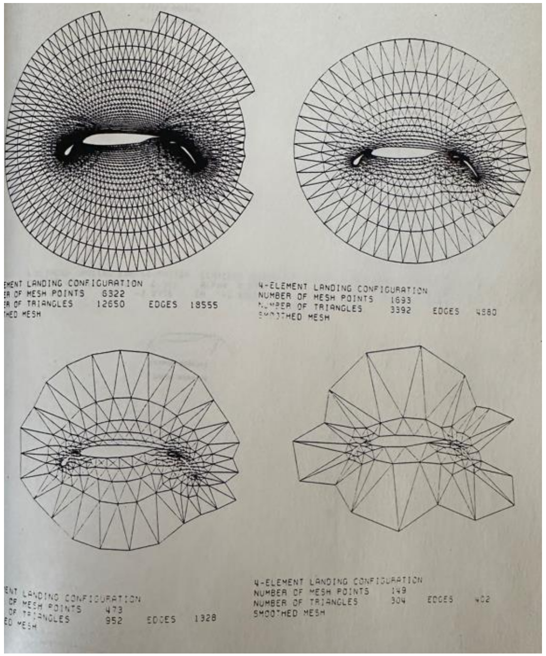
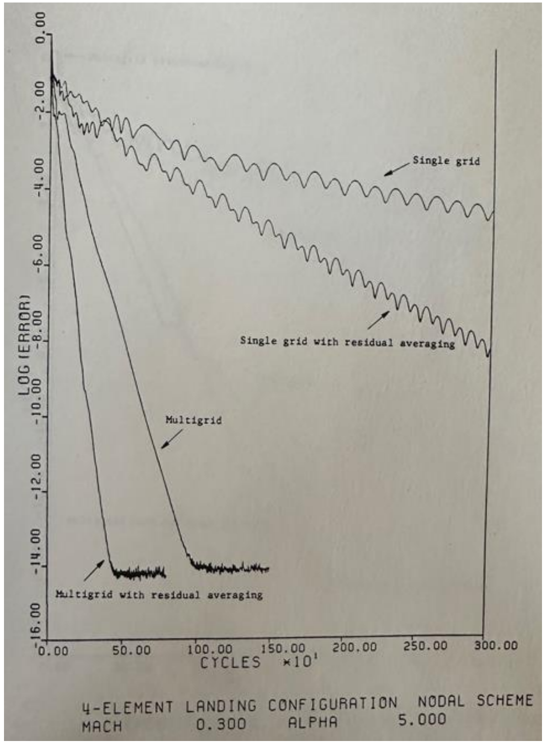
GRID 128X32

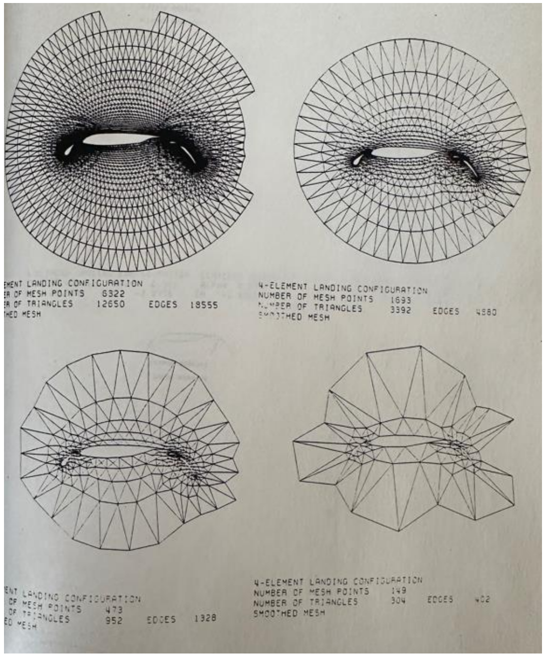
MG for 2D Euler on Unstructured Meshes

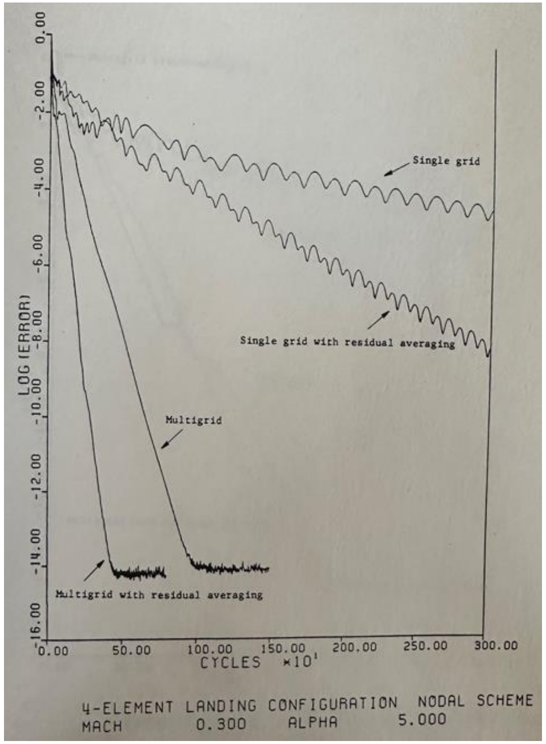




MG for 2D Euler on Unstructured Meshes

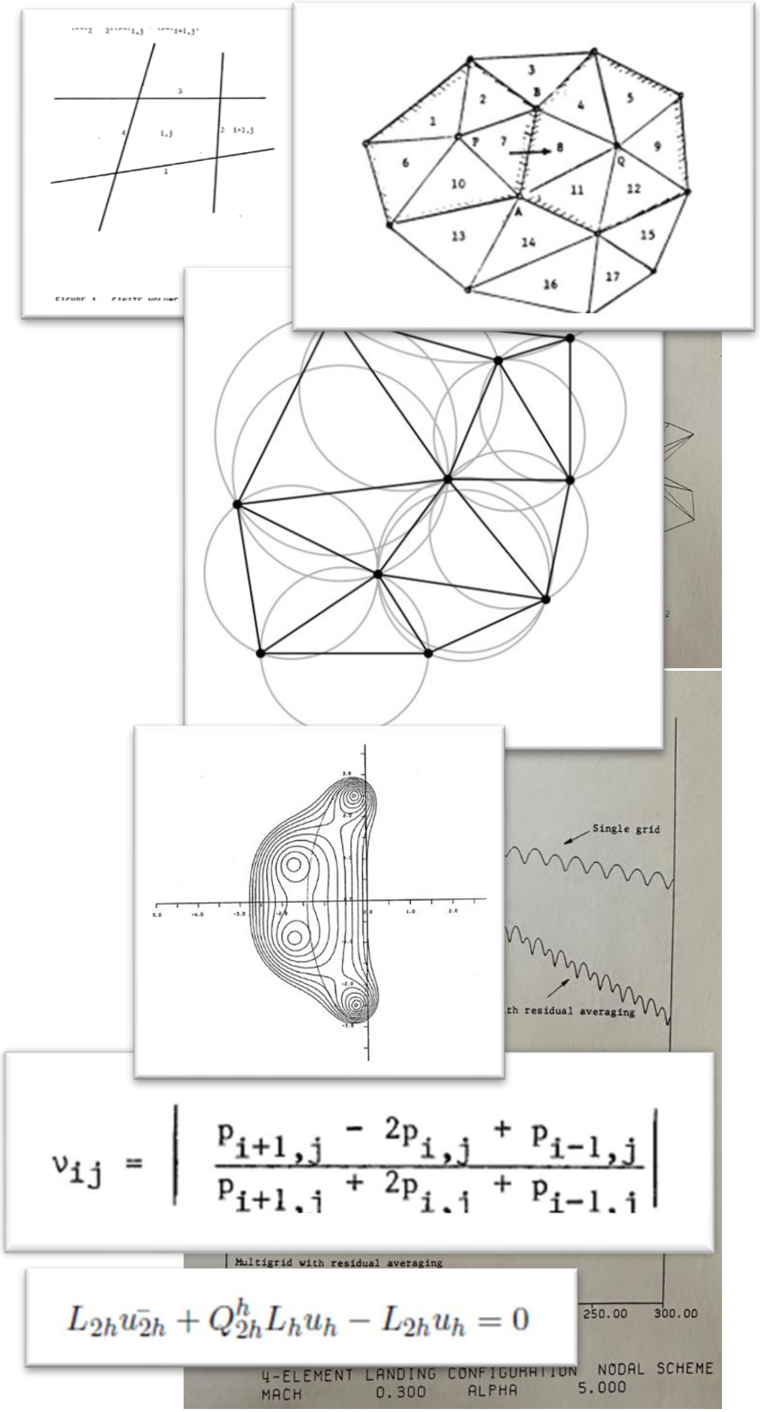
- Looks “quaint” today…





MG for 2D Euler on Unstructured Meshes

- Looks quaint today…
- But what I learned as a grad student:
    - Delaunay triangulation, Voronoi diagrams and mesh smoothing
    - Discretizations, FV and FEM
    - Residual smoothing
    - Multigrid methods
    - Fast search algorithms for mesh interpolation
    - Vectorization (Cyber 203, Convex)
    - Computer graphics (move/draw)
    - IBM, CDC, Unix OS
    - The CFD obsession…



$$\nu_{ij} = \left| \frac{p_{i+1,j} - 2p_{i,j} + p_{i-1,j}}{p_{i+1,j} + 2p_{i,j} + p_{i-1,j}} \right|$$

$$L_{2h}\bar{u}_{2h} + Q^{h}_{2h} L_h u_h - L_{2h} u_h = 0$$

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Thesis Acknowledgements:

"… the perfect balance between academic freedom and expert guidance which has been afforded to me"

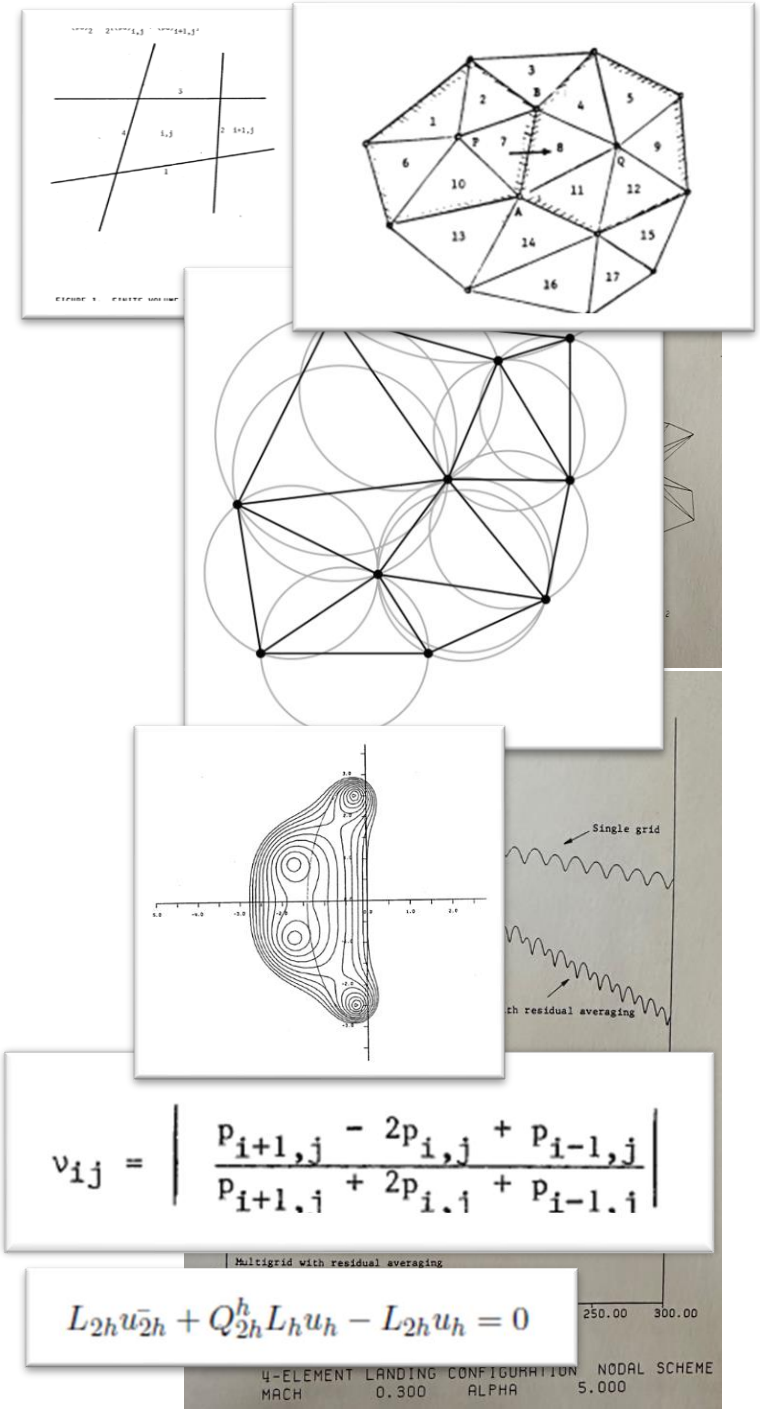

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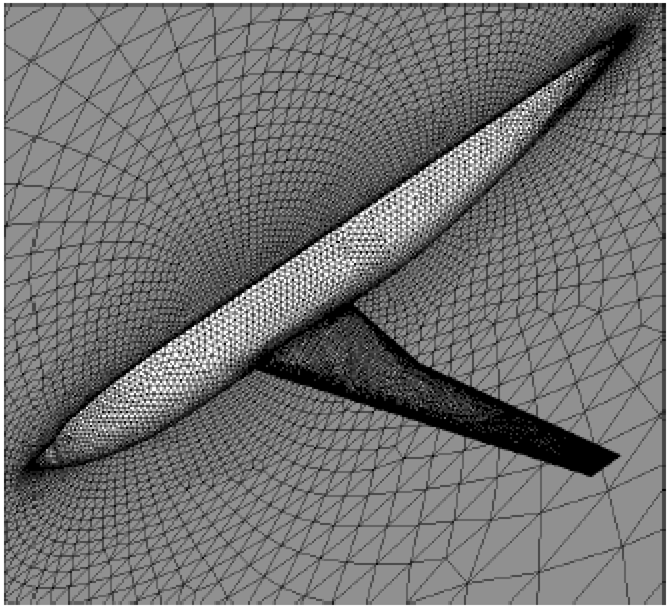
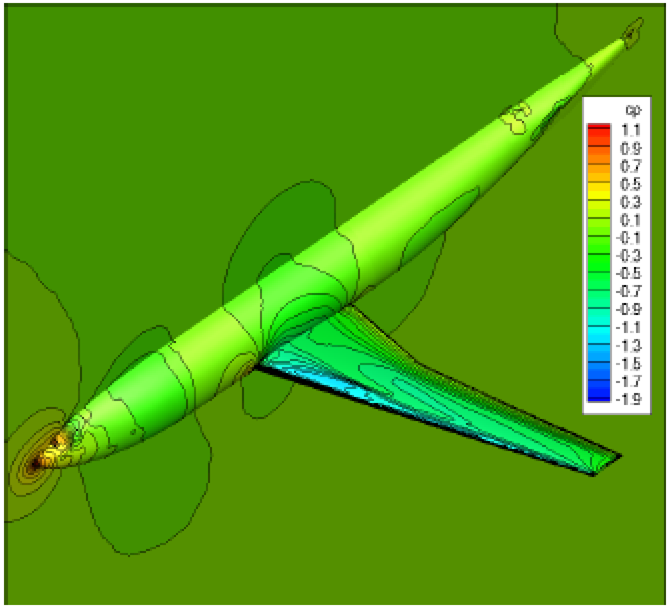
Illustration of Multigrid Efficiency

Easy test case

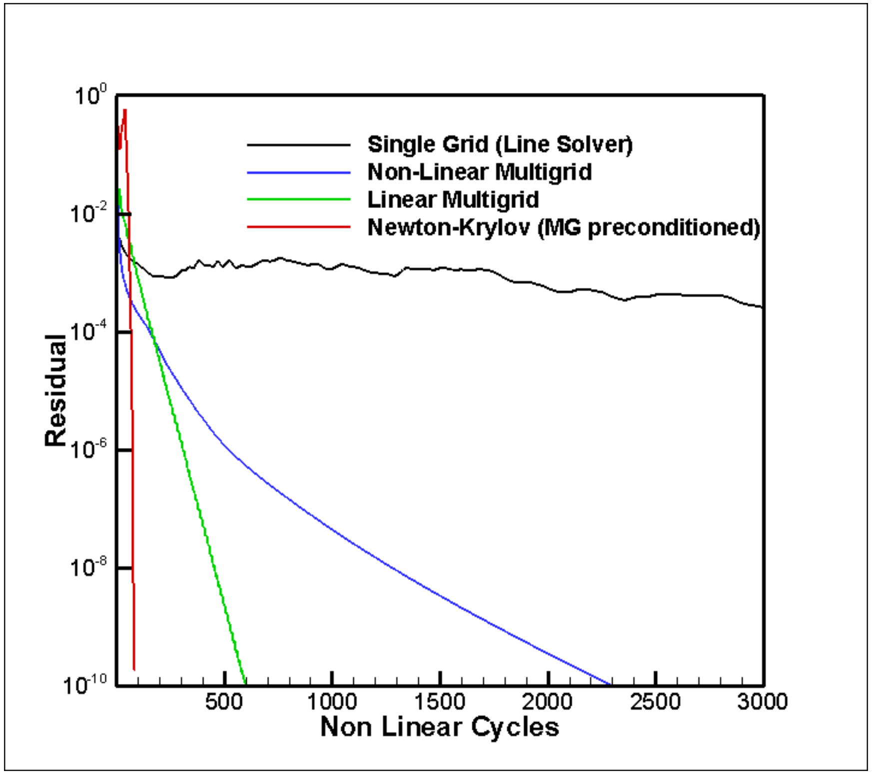




- F6 Wing-body (DPW3)
- Mach=0.75, Incidence=1deg, Re=3 million
- Prism-Tet Mesh: 1.2 million points (~3 million elements)

NSU3D Solutions for WB Test Case

1.2 million points on 128 cores



- Single grid solver is slow to converge
- FAS MG is much faster
- Linear MG is fastest
- Newton-Krylov takes only 88 nonlinear steps
  -

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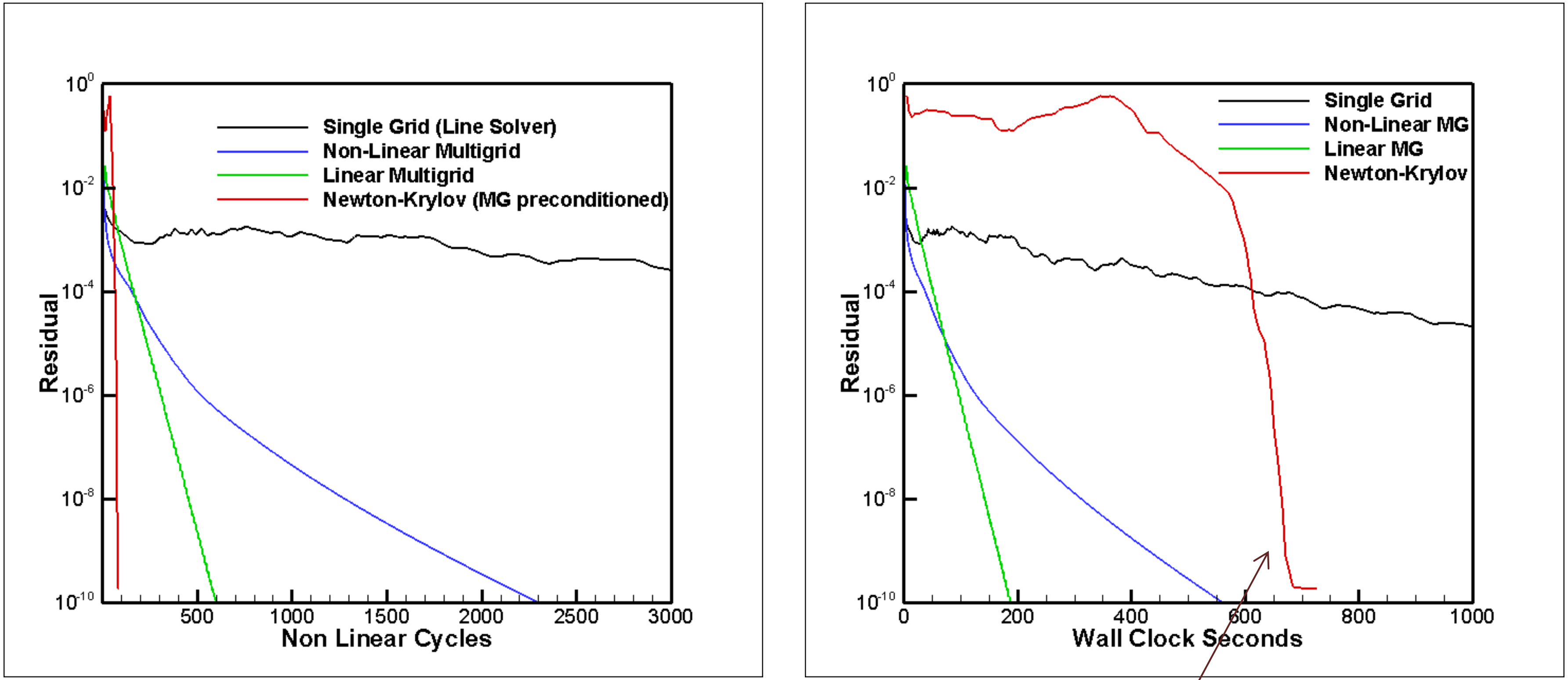
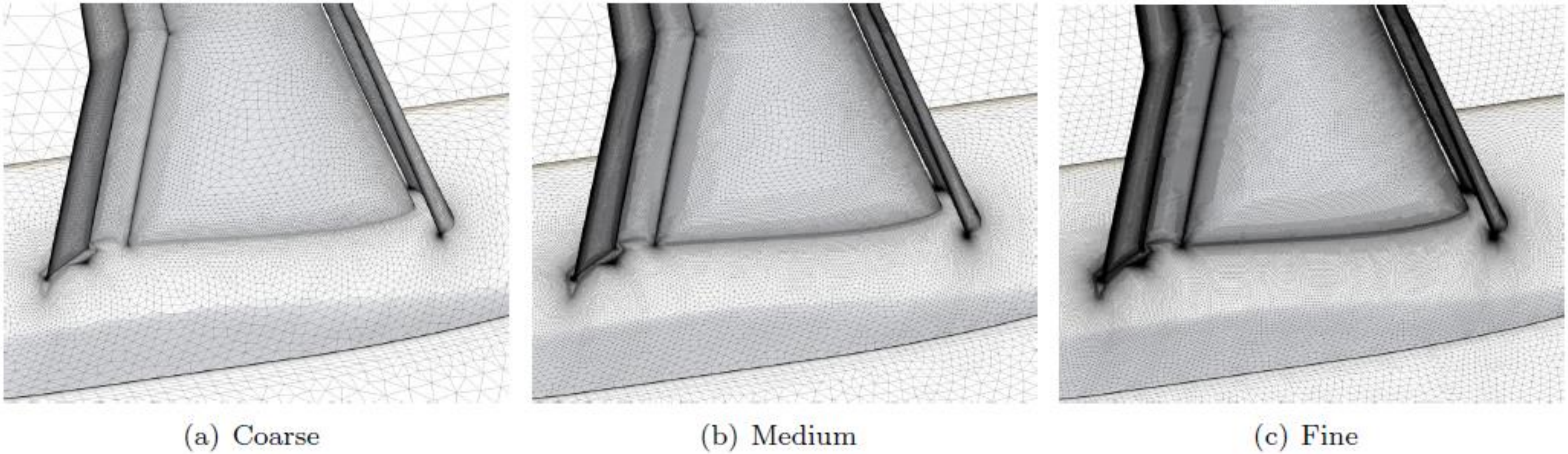


- Single grid solver is slow to converge
- FAS MG is much faster
- Linear MG is fastest
- Newton-Krylov takes only 88 nonlinear steps
  - But cost is higher due to slow initial convergence

NSU3D for HLPW2 Mesh Refinement Study

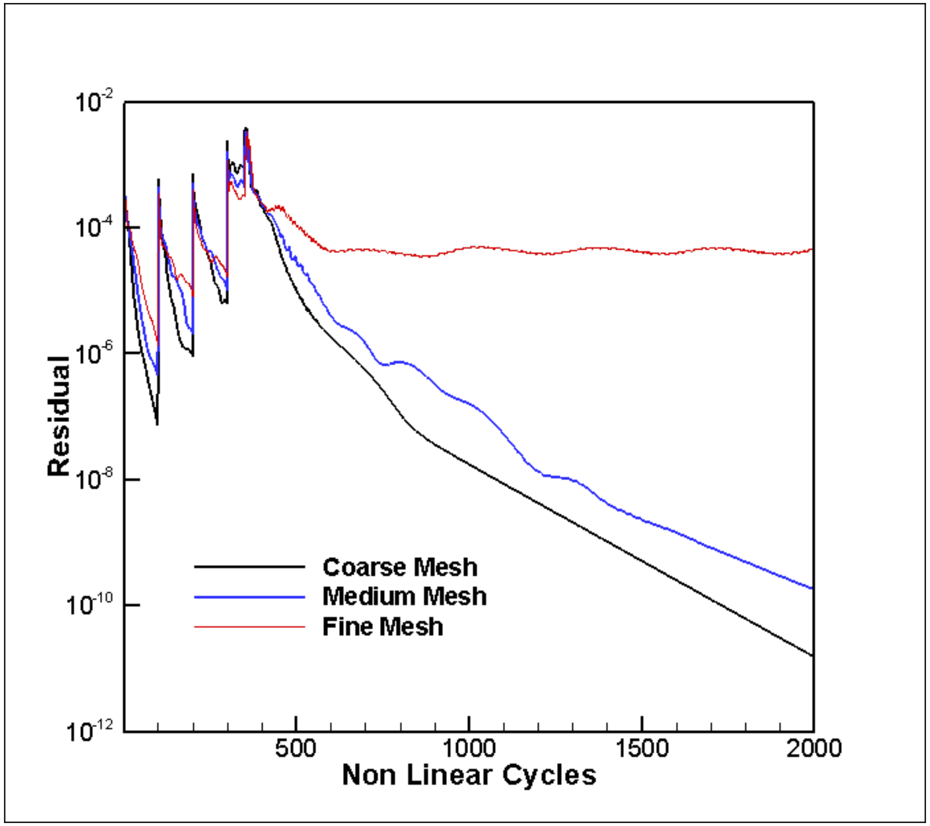
(More Difficult)



(a) Coarse (b) Medium (c) Fine

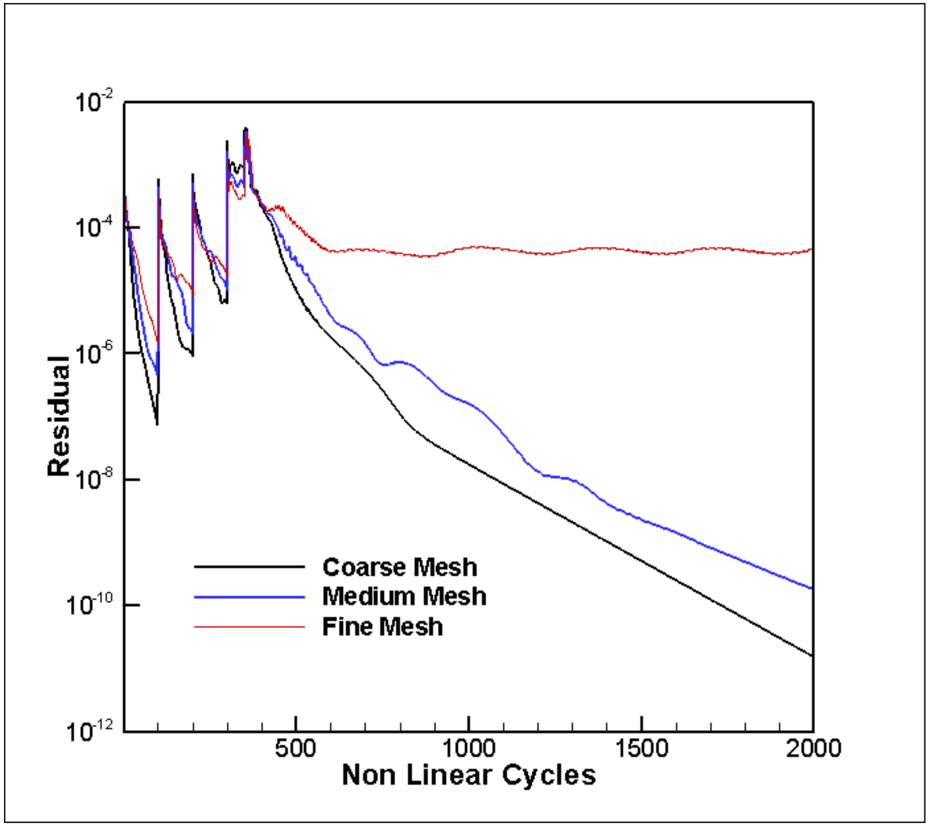
- Mach=0.175, Incidence=16deg, Re=15 million
  - Coarse Mesh: 10 million points
  - Medium Mesh: 30 million points
  - Fine Mesh: 75 million points

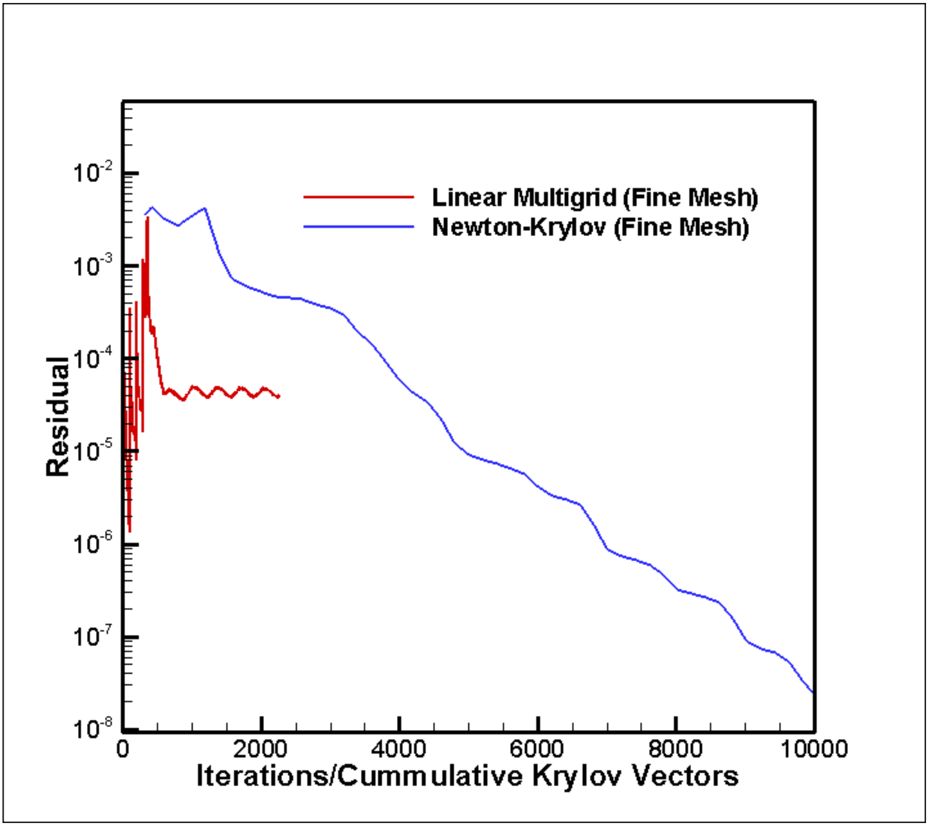
NSU3D for HLPW2 Mesh Refinement Study



- FAS MG converges fully only on coarsest mesh
- Linear MG converges on coarse/medium, stalls on fine mesh
- Newton-Krylov converges fine mesh at considerable extra cost
  - Time-averaged forces from Linear MG on fine mesh very close to Newton final values

NSU3D for HLPW2 Mesh Refinement Study





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Hierarchy of Solvers

- FAS Multigrid
  - Fast when works
  - No tuning parameters
- Linear Iterative Solver (MG, GS, Lines, etc)
  - Somewhat more robust
  - Some tuning parameters
    - linear tol. , inner cycles, CFL ramping
- Newton-Krylov
  - Most robust
  - Even more tuning parameters…
  - Considerably slower when other methods converge
  - Effective in final stages of convergence
  - Slow initial convergence
  - Forces/moments only converge at end !
- Importance of improved solver technology
  - For ALL CFD DISCRETIZATIONS
  - For MDA/MDAO

Future Potential of MG Solvers

- Non-linear (FAS) multigrid has fallen out of favor for stiff problems
- Concept of non-linear solvers with local linearization remains appealing
  - Well suited to new hardware characteristics
  - Multigrid/Multi-resolution concept remains very powerful
  - More work is needed in these areas

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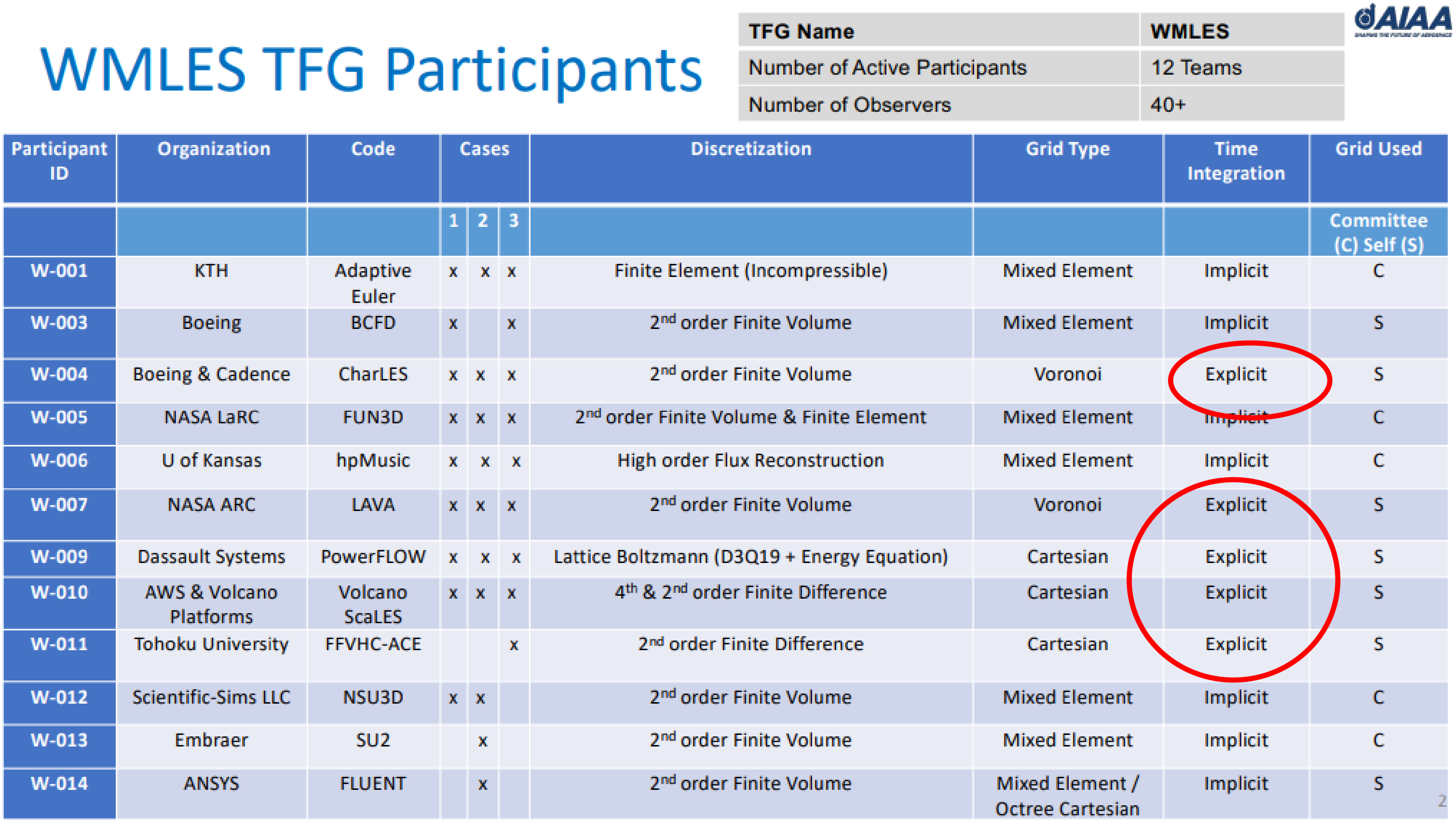
- Jameson et al. continued interest in these areas
  - Fast Preconditioned Multigrid Solution of the Euler and Navier-Stokes equations for Steady, Compressible Flows. David Caughey & Antony Jameson. International Journal for Numerical Methods in Fluids, Vol. 43, 2003. Pages 537-553.
  - Monotonicity Preserving Multigrid Time Stepping Schemes for Conservation Laws. Justin W. L. Wan & Antony Jameson. Computing and Visualization in Science, Vol. 10, 2007.
  - *p*-Multigrid Spectral Difference Method For Viscous Compressible Flow Using 2D Quadrilateral Meshes. Sachin Premasuthan, Chunlei Liang, Antony Jameson & Z. J. Wang. AIAA Paper 2009-950, 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 5-8, 2009.
  - Convergence Acceleration of High Order Numerical Simulations using a Hybrid Spectral Difference / Finite Volume Multigrid Method. Y. Allaneau, L. Y. Li & A. Jameson. ICCFD7-1606, 7th International Conference on Computational Fluid Dynamics (ICCFD7), Big Island, HI, July 9-13, 2012.
  - A study of multigrid smoothers used in compressible CFD based on the convection diffusion equation. Philipp Birken, Jonathan Bull & Antony Jameson. ECCOMAS Congress 2016, VII European Congress on Computational Methods in Applied Sciences and Engineering, M. Papadrakakis, V. Papadopoulos, G. Stefanou, V. Plevris (eds.), Crete island Greece, 5-10 June, 2016.
  - The Design of Steady State Schemes for Computational Aerodynamics. F. D. Witherden, A. Jameson and D. W. Zingg. Handbook of Numerical Analysis, Vol. 18, Chapter 11, pp. 303-349, Editors: Remi Abgrall, Chi-Wang Shu, Elsevier B.V., January 18, 2017. http://dx.doi.org/10.1016/bs.hna.2016.11.006.
  - Nonlinear *p*-Multigrid Preconditioner for Implicit Time Integration of Compressible Navier-Stokes Equations with *p*-Adaptive Flux Reconstruction. L. Wang, W. Trojak, F. D. Witherden and A. Jameson. Journal of Scientific Computing, doi: 10.1007/s10915-022-02037-w, 9 November, 2022.

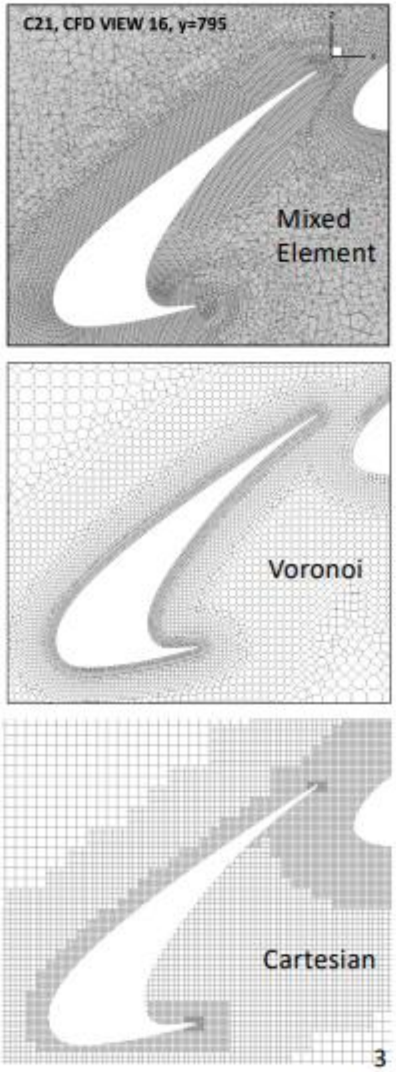
HLPW5 WMLES TFG Results and Summary Presentation



WMLES TFG Participants

TFG Name	WMLES
Number of Active Participants	12 Teams
Number of Observers	40+

Participant ID	Organization	Code	Cases			Discretization	Grid Type	Time Integration	Grid Used
			1	2	3				Committee (C) Self (S)
W-001	KTH	Adaptive Euler	x	x	x	Finite Element (Incompressible)	Mixed Element	Implicit	C
W-003	Boeing	BCFD	x		x	2nd order Finite Volume	Mixed Element	Implicit	S
W-004	Boeing & Cadence	CharLES	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-005	NASA LaRC	FUN3D	x	x	x	2nd order Finite Volume & Finite Element	Mixed Element	Implicit	C
W-006	U of Kansas	hpMusic	x	x	x	High order Flux Reconstruction	Mixed Element	Implicit	C
W-007	NASA ARC	LAVA	x	x	x	2nd order Finite Volume	Voronoi	Explicit	S
W-009	Dassault Systems	PowerFLOW	x	x	x	Lattice Boltzmann (D3Q19 + Energy Equation)	Cartesian	Explicit	S
W-010	AWS & Volcano Platforms	Volcano ScaLES	x	x	x	4th & 2nd order Finite Difference	Cartesian	Explicit	S
W-011	Tohoku University	FFVHC-ACE			x	2nd order Finite Difference	Cartesian	Explicit	S
W-012	Scientific-Sims LLC	NSU3D	x	x		2nd order Finite Volume	Mixed Element	Implicit	C
W-013	Embraer	SU2		x		2nd order Finite Volume	Mixed Element	Implicit	C
W-014	ANSYS	FLUENT		x		2nd order Finite Volume	Mixed Element / Octree Cartesian	Implicit	S



Another paradigm shift, ~40 years later?
Or an opportunity for MG for moderate CFL implicit systems?

List of Antony Jameson's PhD Students

Ph.D. Student	University	Year	Dissertation Title
I-Chung Chang	NYU	1981	Unsteady transonic flow past airfoils in rigid body motion
Brian McCartin	NYU	1982	Theory, computation and application of exponential splines
Richard Pelz	Princeton	1983	Transonic flow calculations using triangular finite elements
John Fay	Princeton	1985	On the design of airfoils in transonic flow using the Euler equations
Seokkwan Yoon	Princeton	1985	Numerical solution of the Euler equations by implicit schemes with multiple grids
Craig Streett	Princeton	1987	A spectral method for the solution of transonic potential flow about an arbitrary two-dimensional airfoil
Dimitri Mavriplis	Princeton	1987	Solution of the two dimensional Euler equations on unstructured triangular meshes
Venkat Venkatakrishnan	Princeton	1987	Computation of unsteady transonic flows over moving airfoils
Luigi Martinelli	Princeton	1987	Calculations of viscous flows with a multigrid method
Mohan Jayaram	Princeton	1987	Solution of the three-dimensional Navier-Stokes equations for transonic flow using a multigrid method
Takeshi Sakata	Princeton	1990	Solution of the Euler equations in multibody flow fields using the overlapping-mesh method
Mark Stewart	Princeton	1990	Non-overlapping composite meshes for multi-element airfoils
Feng Liu	Princeton	1991	Numerical calculation of turbomachinery cascade flows
Todd Mitty	Princeton	1993	Development of a Delaunay-based adaption scheme with applications to complex three-dimensional rotational flows
James Farmer	Princeton	1993	A finite volume multigrid solution to the three dimensional nonlinear ship wave problem
James Reuther	UC Davis	1996	Aerodynamic shape optimization using control theory
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Chongam Kim	Princeton	1997	Robust and accurate numerical methods for high speed unsteady flows
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Yee Feng Ruan	Stanford	2002	Shock capturing schemes with gas-kinetic methods
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Matthew McMullen	Stanford	2003	The application of non-linear frequency domain methods to the Euler and Navier-Stokes equations
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Georg May	Stanford	2006	A kinetic scheme for the Navier-Stokes equations and high-order methods for hyperbolic conservation laws
Arathi Gopinath	Stanford	2007	Efficient Fourier-based algorithms for the time-periodic unsteady problems
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Nawee Butsuntorn	Stanford	2008	Time spectral method for rotorcraft flow with vorticity confinement
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George Anderson	Stanford	2015	Shape optimization in adaptive search spaces
Manuel Lopez-Morales	Stanford	2016	Towards industry-ready high-order flow solvers: increasing robustness and usability
Kartikey Asthana	Stanford	2016	Analysis and design of optimal discontinuous finite element schemes
Abhishek Sheshadri	Stanford	2016	An analysis of stability of the flux reconstruction formulation with applications to shock capturing
Joshua Romero	Stanford	2017	On the development of the direct flux reconstruction scheme for high-order fluid flow simulations
Jerry Watkins	Stanford	2017	Numerical analysis and implicit time stepping for high-order, fluid flow simulations on GPU architectures
Jacob Crabill	Stanford	2018	Towards industry-ready high-order overset methods on modern hardware
David Manosalvas-Kjono	Stanford	2018	Aerodynamic design of active flow control systems aimed towards drag reduction in heavy vehicles

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Kartikey Asthana	Stanford	2016	Analysis and design of optimal discontinuous finite element schemes
Abhishek Sheshadri	Stanford	2016	An analysis of stability of the flux reconstruction formulation with applications to shock capturing
Joshua Romero	Stanford	2017	On the development of the direct flux reconstruction scheme for high-order fluid flow simulations
Jerry Watkins	Stanford	2017	Numerical analysis and implicit time stepping for high-order, fluid flow simulations on GPU architectures
Jacob Crabill	Stanford	2018	Towards industry-ready high-order overset methods on modern hardware
David Manosalvas-Kjono	Stanford	2018	Aerodynamic design of active flow control systems aimed towards drag reduction in heavy vehicles

Jameson 60th Symposium, Ithaca NY, November 1994

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The Jameson way

Rainald Löhner

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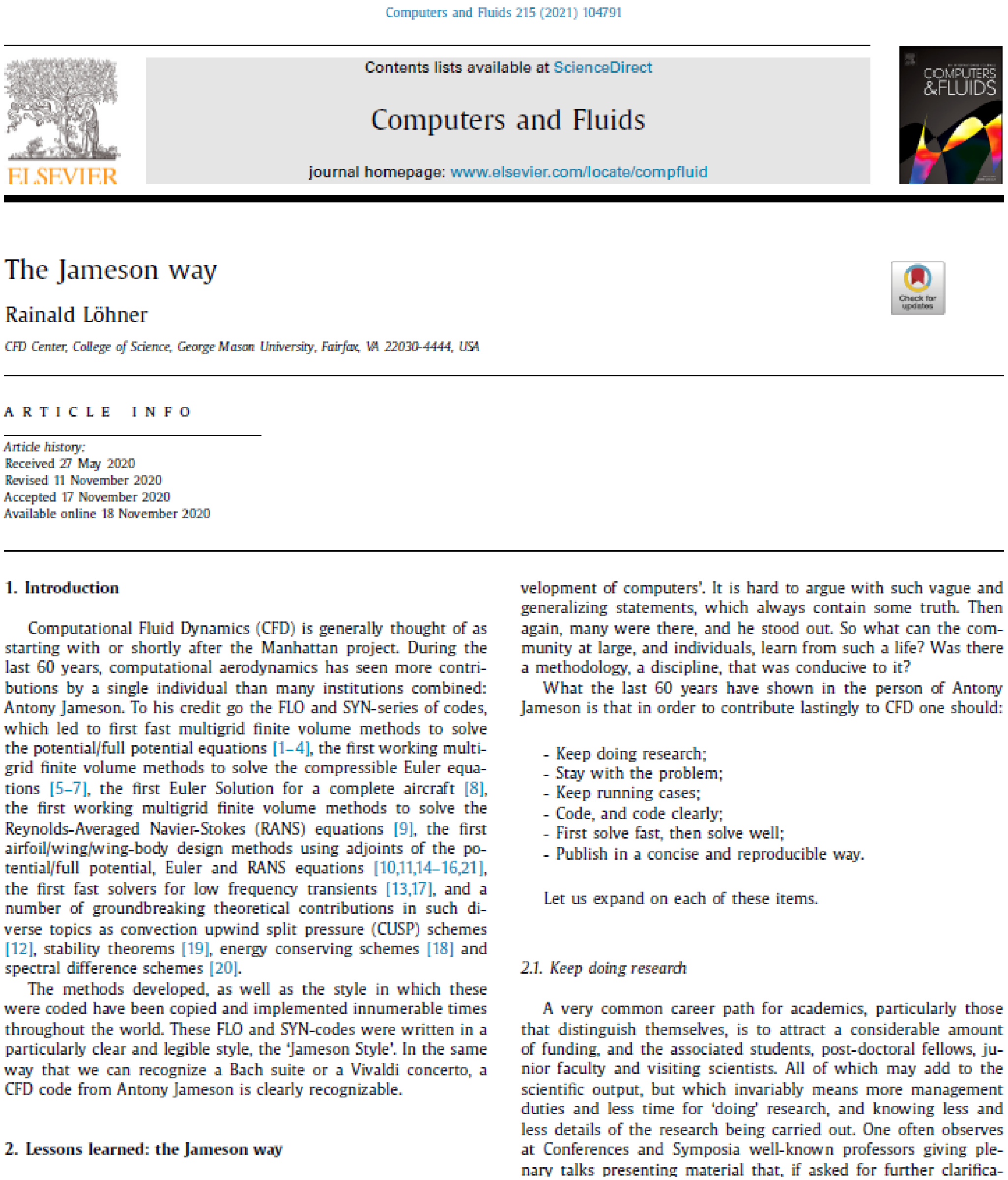
What the last 60 years have shown in the person of Antony Jameson is that in order to contribute lastingly to CFD one should:

- Keep doing research;
- Stay with the problem;
- Keep running cases;
- Code, and code clearly;
- First solve fast, then solve well;
- Publish in a concise and reproducible way.

Let us expand on each of these items.

2.1. *Keep doing research*

A very common career path for academics, particularly those that distinguish themselves, is to attract a considerable amount of funding, and the associated students, post-doctoral fellows, junior faculty and visiting scientists. All of which may add to the scientific output, but which invariably means more management duties and less time for 'doing' research, and knowing less and less details of the research being carried out. One often observes at Conferences and Symposia well-known professors giving plenary talks presenting material that, if asked for further clarifica-



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Contributions and Lasting Impact

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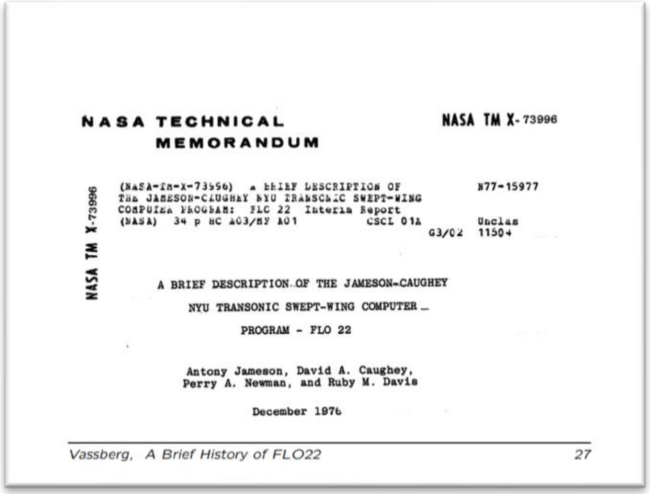

NASA TECHNICAL MEMORANDUM

NASA TM X-73996

(NASA-TM-X-73996) A BRIEF DESCRIPTION OF THE JAMESON-CAUGHEY NYU TRANSONIC SWEPT-WING COMPUTER PROGRAM: FLO 22 Interim Report (NASA) 34 p HC A03/MF A01 CSCL 01A G3/02

N77-15977

Unclas 11504

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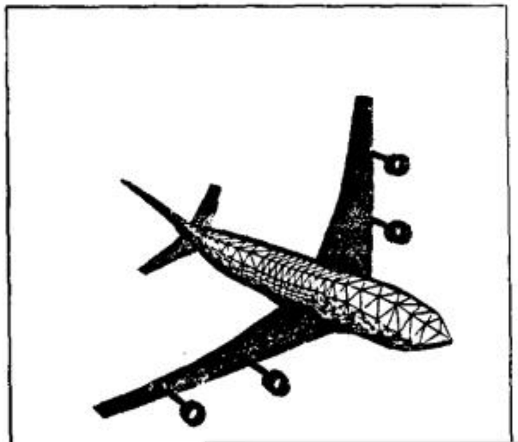
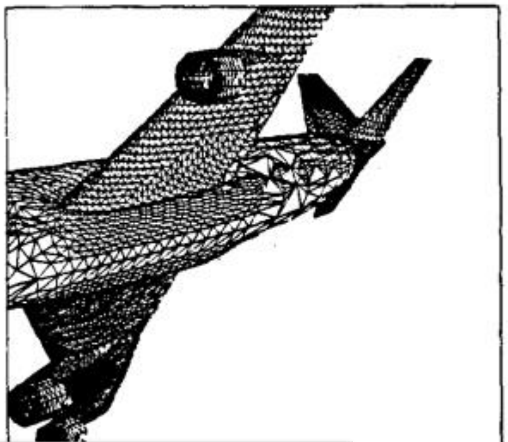
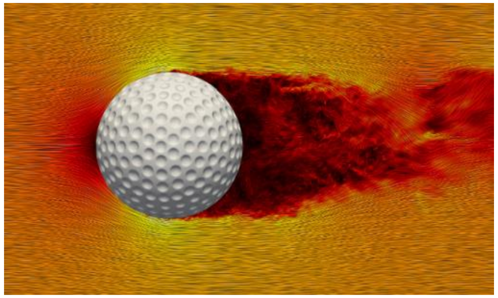
Antony Jameson, David A. Caughey,
Perry A. Newman, and Ruby M. Davis

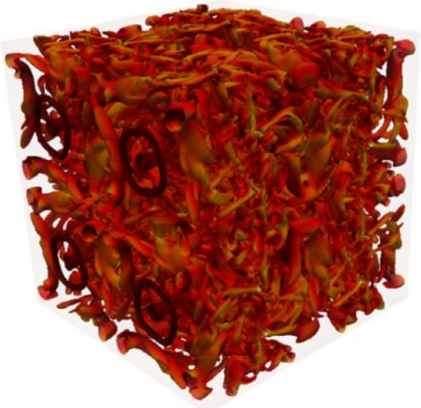
December 1976

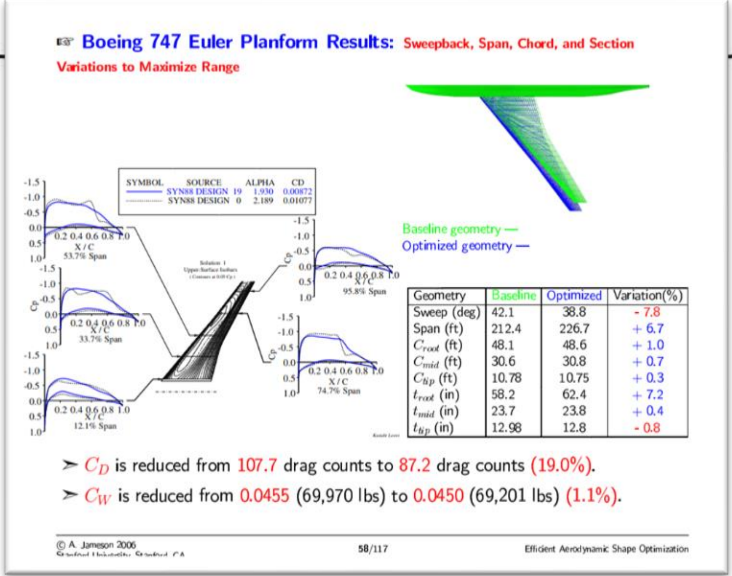
Vassberg, A Brief History of FLO22 27











☞ **Boeing 747 Euler Planform Results:** Sweepback, Span, Chord, and Section Variations to Maximize Range

Geometry	Baseline	Optimized	Variation(%)
Sweep (deg)	42.1	38.8	- 7.8
Span (ft)	212.4	226.7	+ 6.7
C_{root} (ft)	48.1	48.6	+ 1.0
C_{mid} (ft)	30.6	30.8	+ 0.7
C_{tip} (ft)	10.78	10.75	+ 0.3
t_{root} (in)	58.2	62.4	+ 7.2
t_{mid} (in)	23.7	23.8	+ 0.4
t_{tip} (in)	12.98	12.8	- 0.8

- ➢ C_D is reduced from 107.7 drag counts to 87.2 drag counts (19.0%).
- ➢ C_W is reduced from 0.0455 (69,970 lbs) to 0.0450 (69,201 lbs) (1.1%).

© A. Jameson 2006 58/117 Efficient Aerodynamic Shape Optimization

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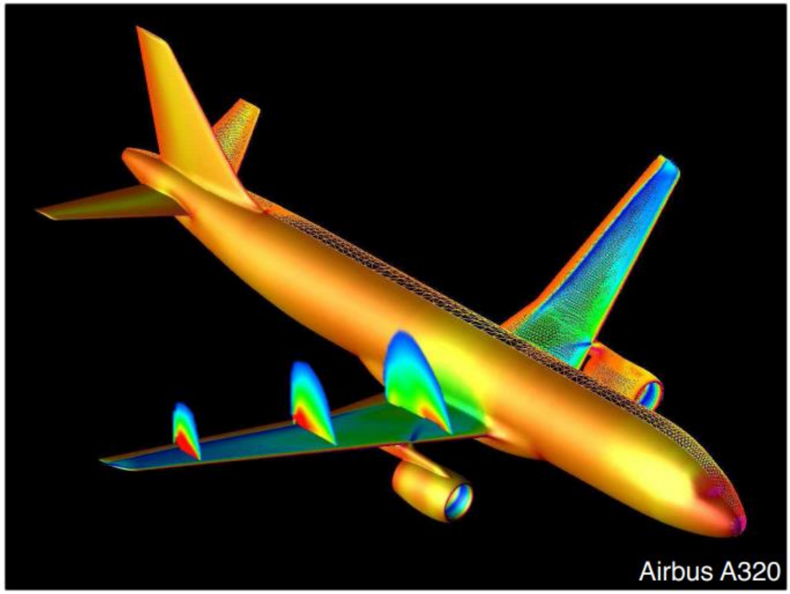

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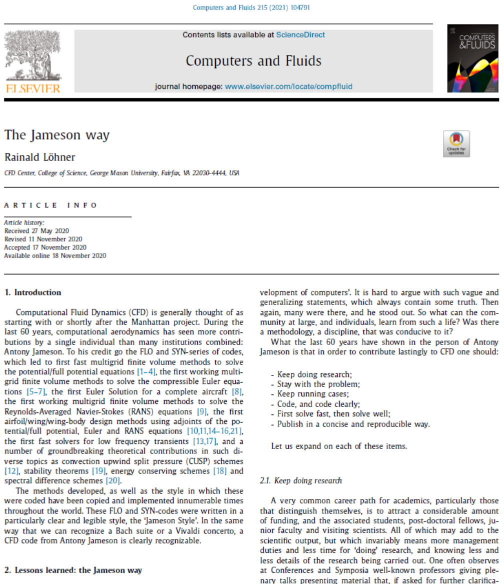

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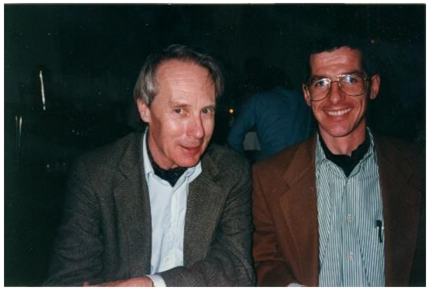

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  - John C. Maxwell is the person who famously said, "The true measure of leadership is influence - nothing more, nothing less," essentially stating that success should be measured by how many people you influence.

Thank you