TetrUSS Capabilities for S&C Applications

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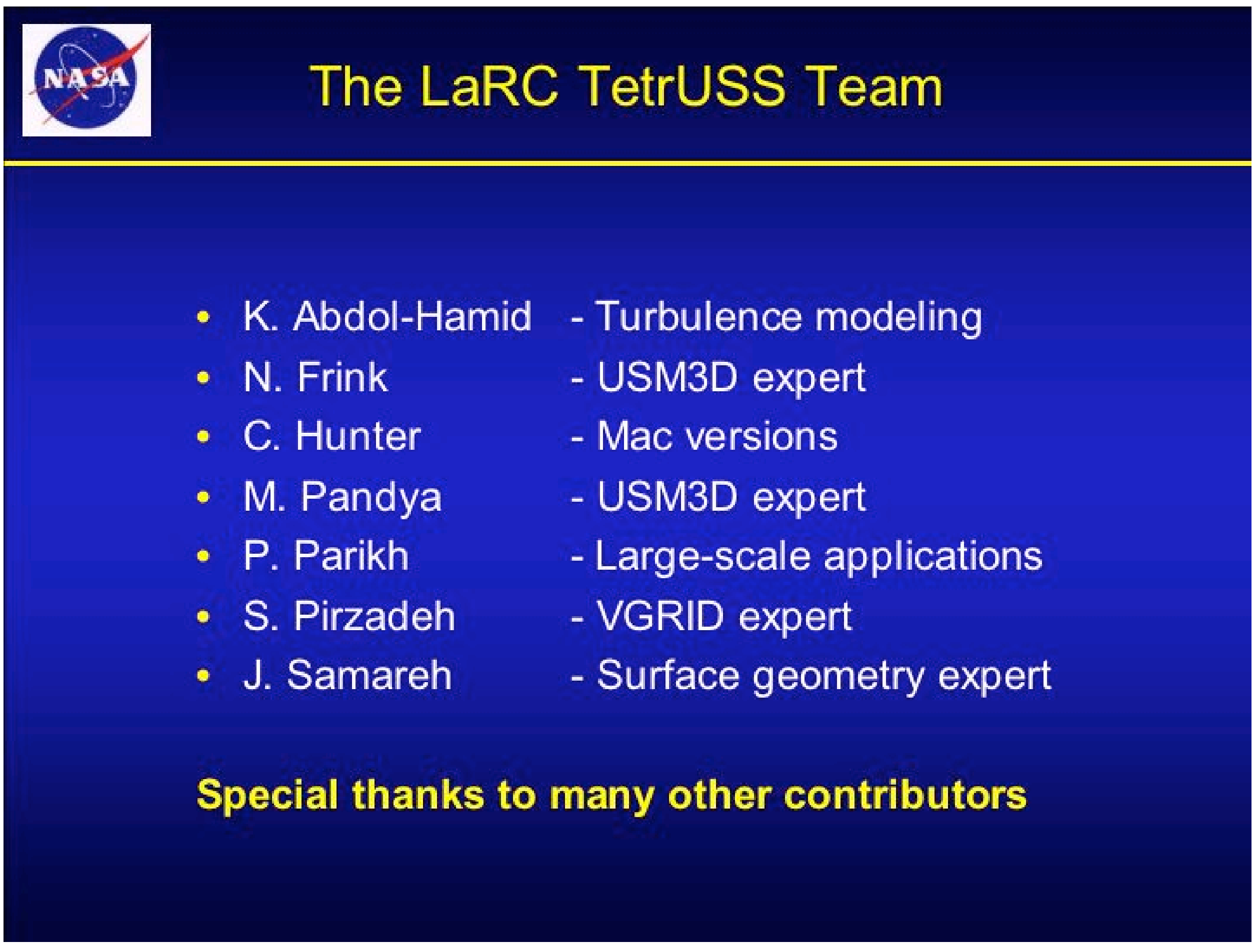
TetrUSS is very much a team effort. This slide lists the current LaRC team members, but many have contributed in various capacities as well. We will soon launch a new and updated web site that lists many of the contributors.

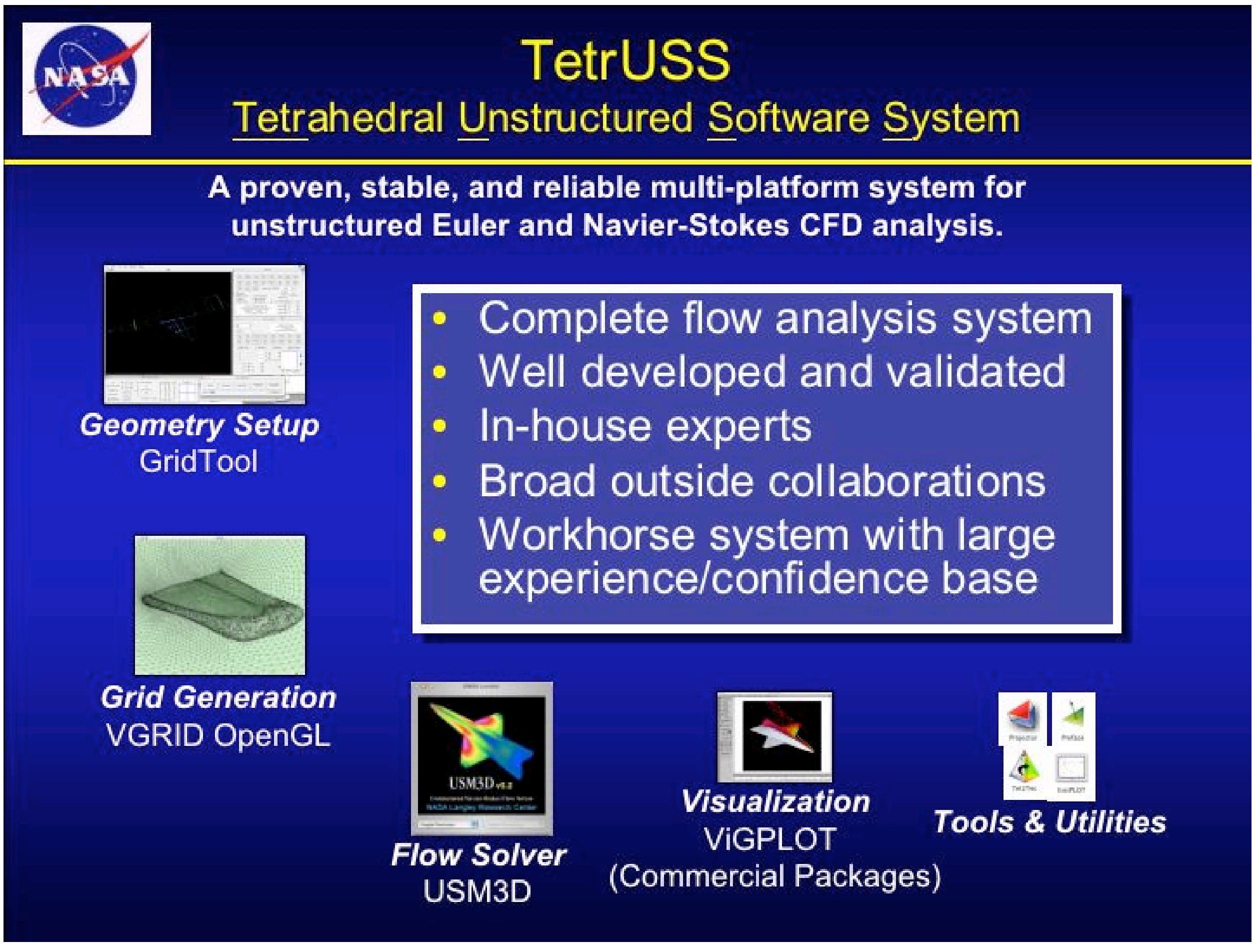


Briefing Outline

- Overview of TetrUSS
- Typical applications
- S&C related applications
- Next steps toward S&C
- Emerging capabilities
- Summary

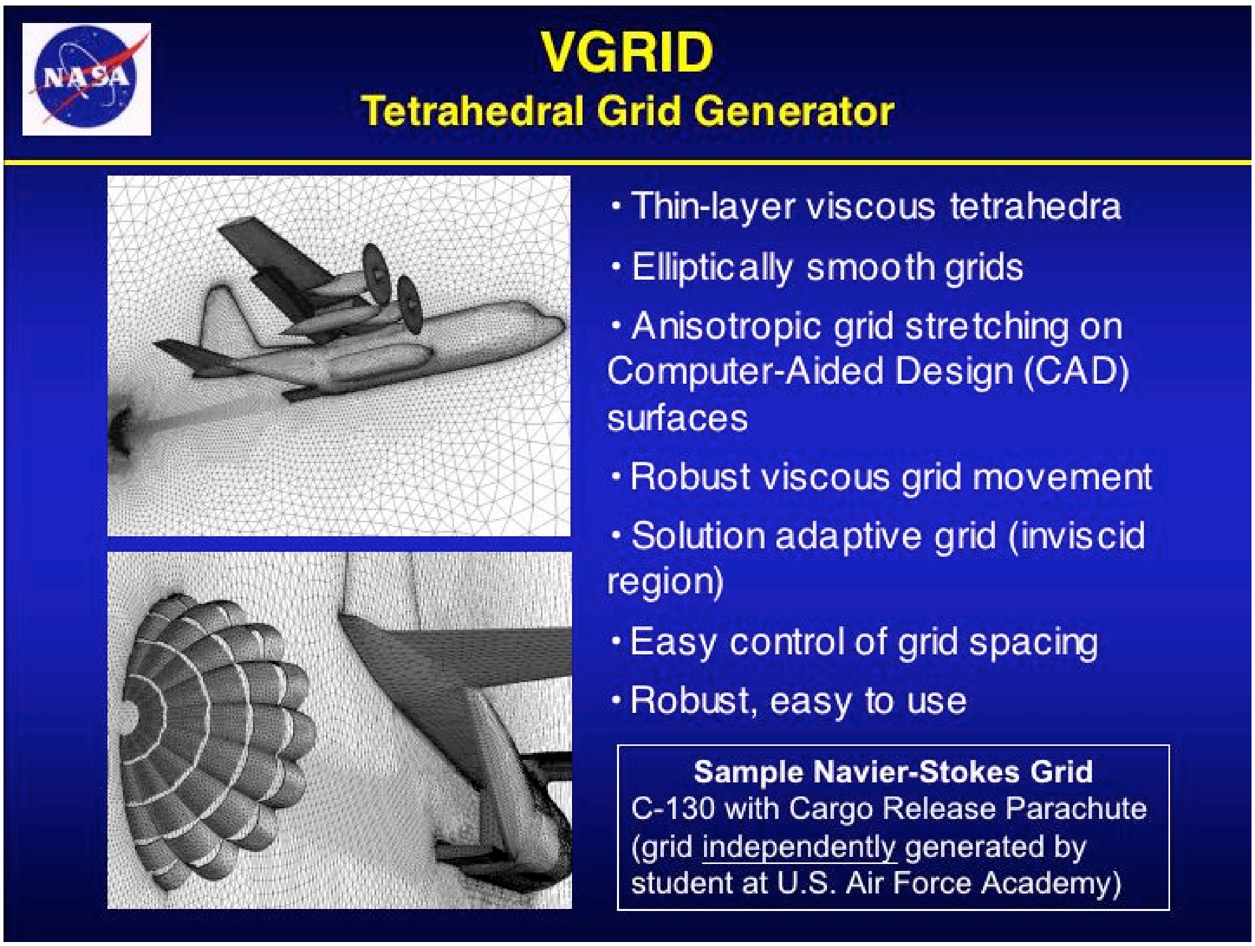
TetrUSS is a suite of loosely coupled computational fluid dynamics software that is packaged into a complete flow analysis system. The system components consist of tools for geometry setup, grid generation, flow solution, visualization, and various utilities tools. Development began in 1990 and it has evolved into a proven and stable system for Euler and Navier-Stokes analysis and design of unconventional configurations.

It is 1) well developed and validated, 2) has a broad base of support, and 3) is presently is a workhorse code because of the level of confidence that has been established through wide use. The entire system can now run on linux or mac architectures. In the following slides, I will highlight more of the features of the VGRID and USM3D codes.



The primary features of the VGRID code are listed here. This list will mean more to the CFD savvy individuals in the audience, but the bottom line is that it will generate high-quality Navier-Stokes grids on complex geometries with a nominal amount of training. It is now quite robust and fairly easy to use.

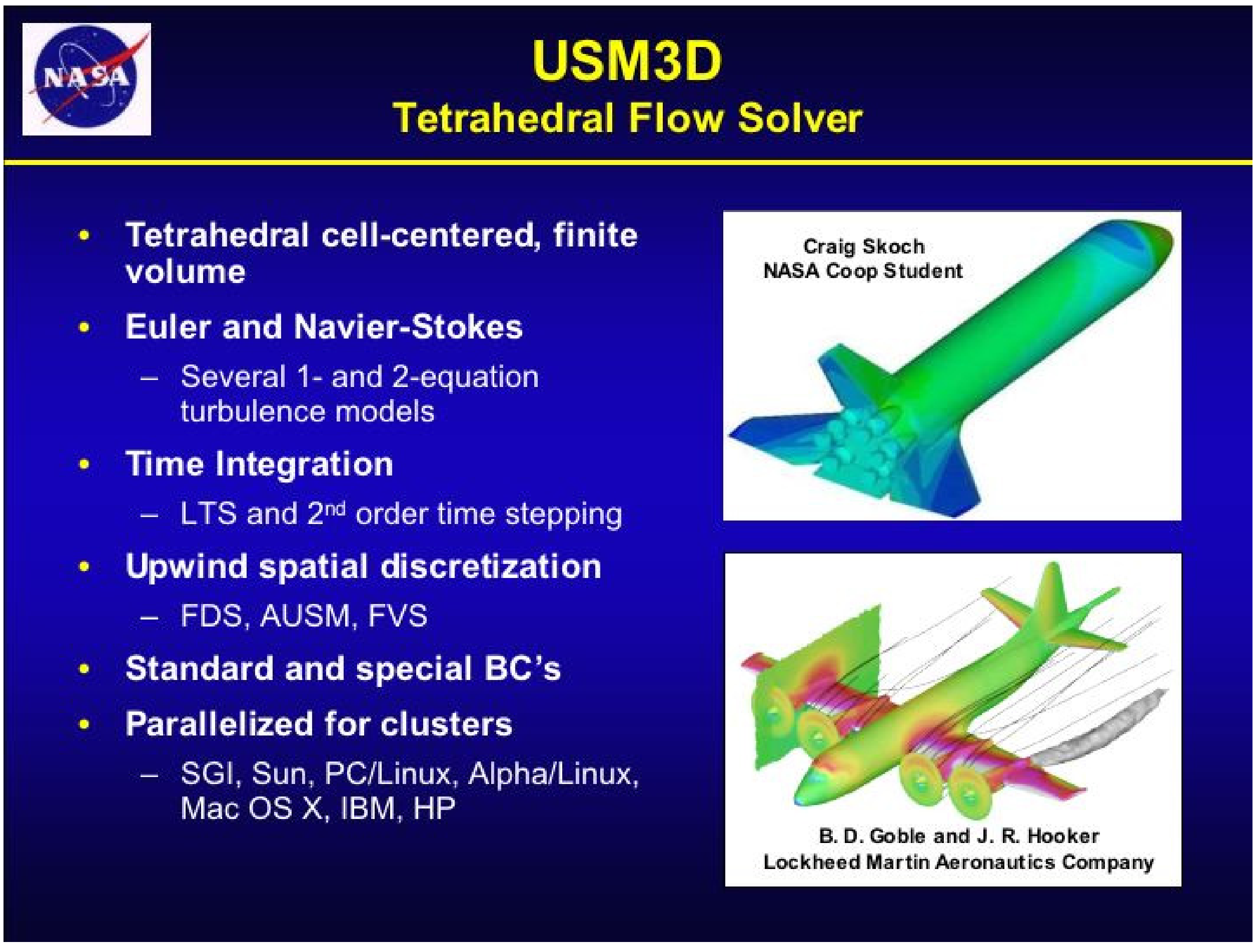
Here is an example of a full Navier-Stokes grid generated by a U.S. Air Force Academy student (albeit a sharp student). It is a C-130 with propellers with a slotted cargo release parachute.



The USM3D code is a cell-centered tetrahedral flow solver, in contrast to a "node-centered" solver for the CFD audience. It produces very accurate Navier-Stokes solutions on relatively coarse grids.

Turbulence is modeled by several models, i.e. the Spalart-Allmaras 1-eqn model, and the k-epsilon, Menter SST, and Algebraic Reynolds Stress Model (ARSM) 2-eqn models.

We can run both steady state with Local Time Stepping convergence acceleration, as well as unsteady flows with 2nd order time accuracy.



We have a range of established upwind schemes, but have some very useful and heavily used special boundary conditions, such as propeller model, engine intakes and jet exhausts, porous surfaces, and wall functions.

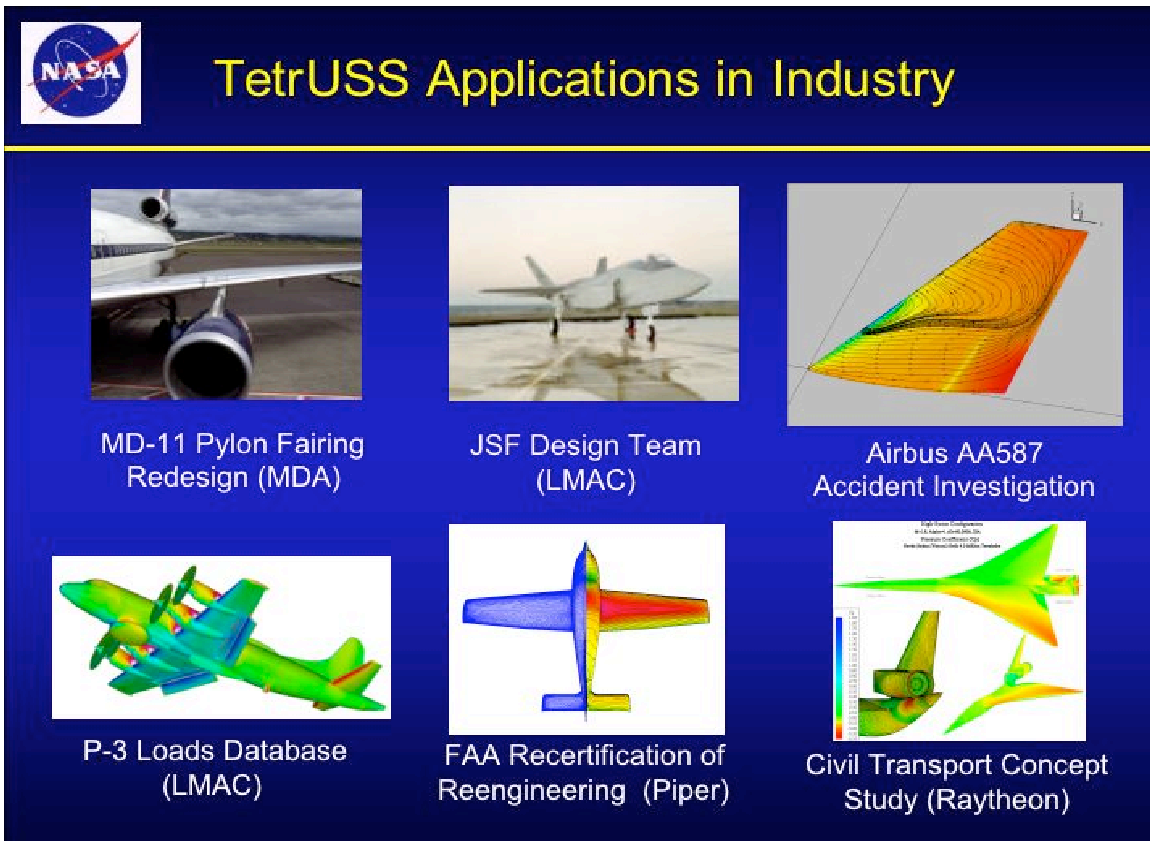
The code is very fast by current standards and runs on multiple types of parallel machine clusters.

I'll just highlight a few sample applications in industry and NASA in the next couple of slides.

Here we see a range of applications ranging from civil aircraft to fighter jets.

Back in 1992, MDA was unable to get FAA certification on the MD-11 due to a range shortfall traced to a higher than expected drag. We were requested by MDA to help eliminate an outboard pylon separation that was identified during a flight test with the expectation that it would eliminate enough drag to meet range requirements. We had a 3-month window to resolve the problem, have hardware built and flight tested. MDA sent an engineer here and we formed a tiger-team to accomplish this. The 3-month target was met and the drag was successfully reduced to permit FAA certification for range.

The JSF Design Team was another "Tiger Team" exercise with a short time scale. Several key LaRC code experts worked together to develop a new Passive Porosity BC for two structured and two



unstructured flow solvers. While I cannot show any details, the this new PassPort BC was used as an S&C tool to reduce a high-alpha pitch-up problem encountered during landing.

We were recently involved in providing some computational support to the Airbus accident investigation.

LMAC is a heavy user with many large-scale applications. Here is a sample of generating a loads database for the P-3 Orion, which required over 250 Navier-Stokes solutions on the full configuration with four co-rotating propellers.

Here is an example where Piper Aircraft has used TetrUSS to certify a reengineering of one of its aircraft.

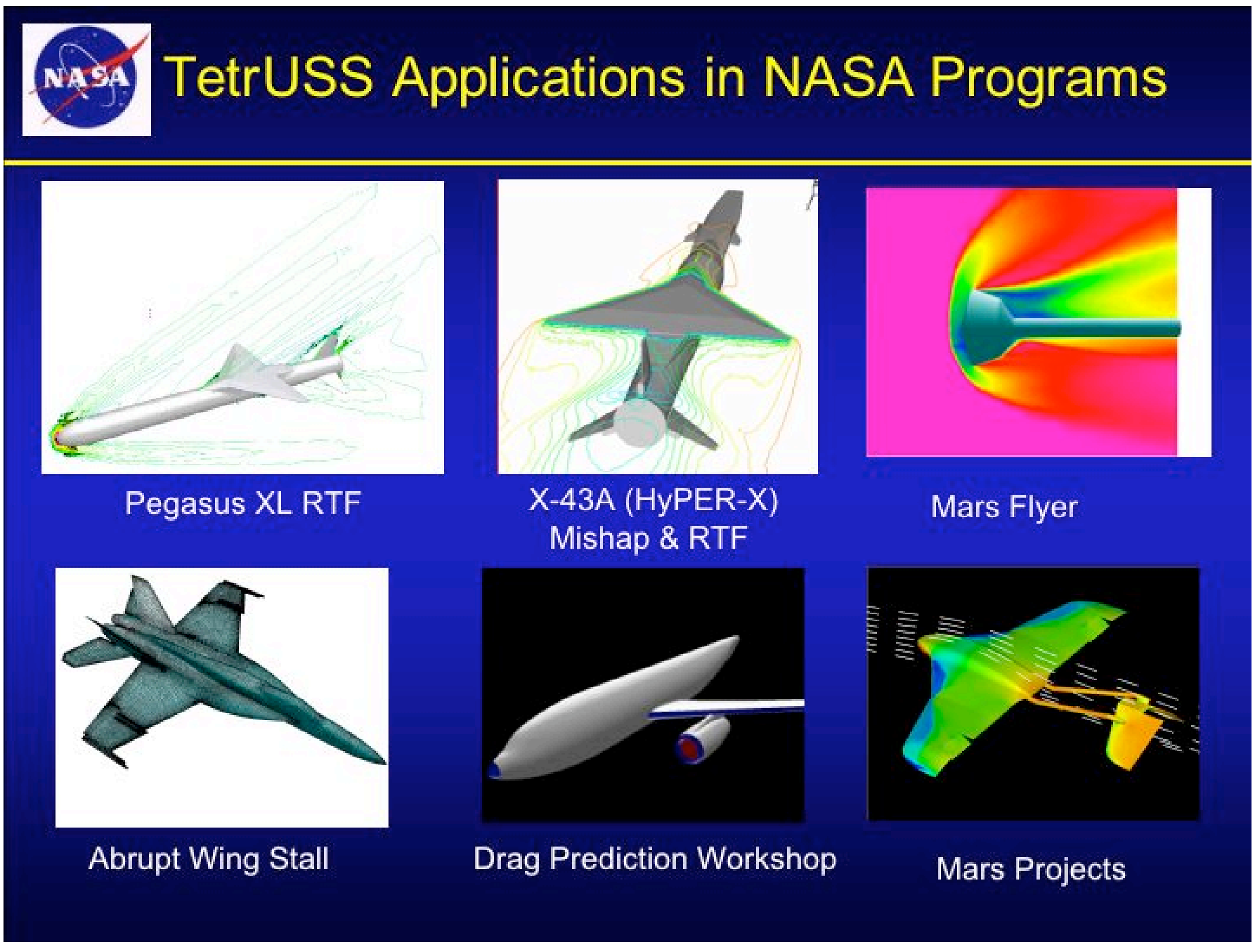
And more recently, Raytheon is using it to perform concept studies of a supersonic civil transport.

This just highlights a few of the NASA program applications.

TetrUSS was used in the mid-90's in the Pegasus Return-to-Flight effort to assess the effect of some geometry modifications on the lateral-directional stability of the new flight vehicle.

It is heavily used in the HyPER-X mishap investigation and Return-to-Flight effort. I'll show more on this in the next two slides.

TetrUSS was used in some Mars activities shown on the right.



It was heavily used in the Abrupt Wing Stall program investing the "wing drop" phenomenon encountered on the F/A-18EF. Here massively separated flows were routinely computed and accurate results obtained.

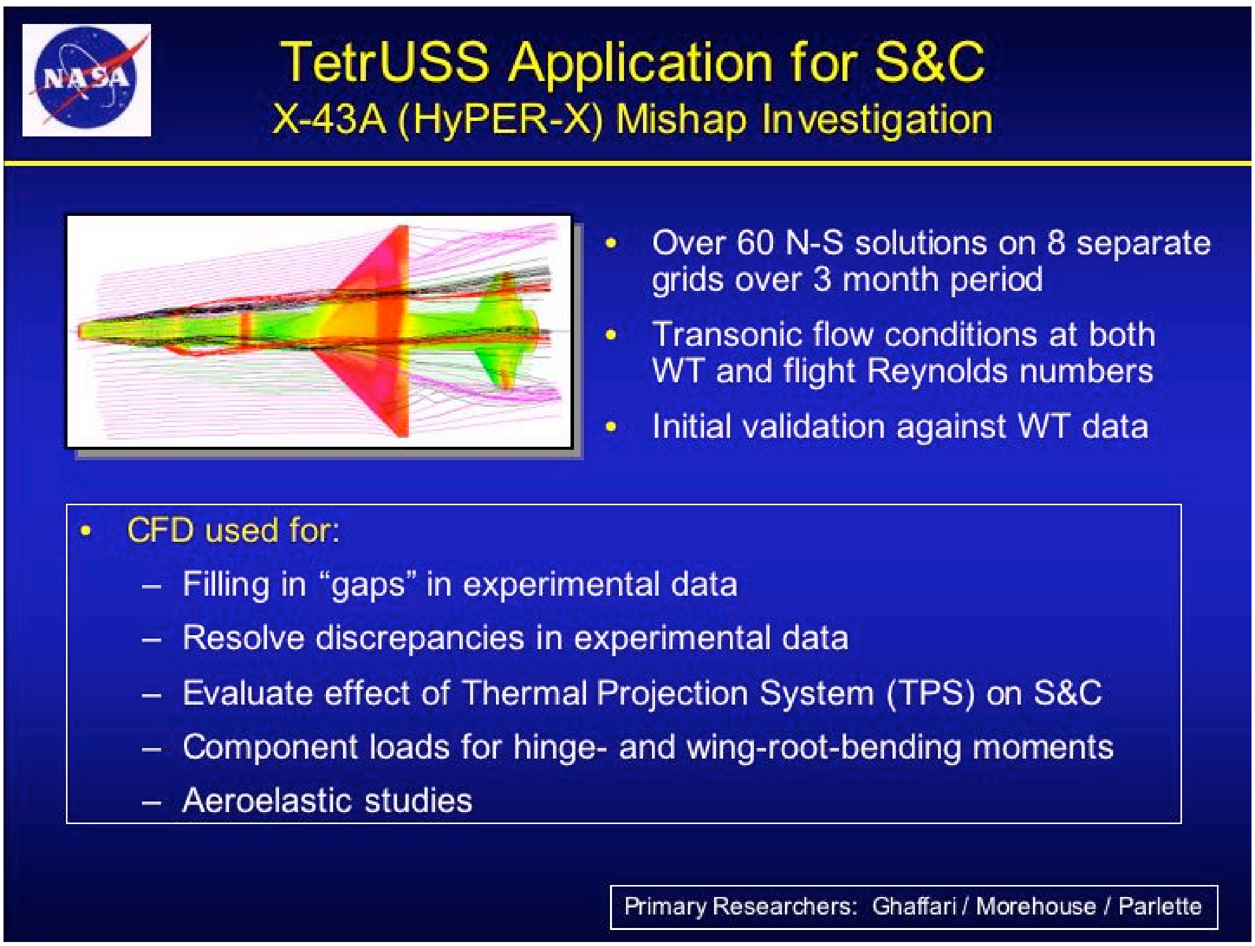
The VGRID code was used to generate some of the unstructured grids used in the AIAA 1st and 2nd Drag Prediction Workshops, the latter held this past summer just before the Orlando Applied Aero conference. These workshops drew many participants from many countries around the world.

Overall TetrUSS Characteristics

- **Ease of Grid Generation on Complex Configurations**
  - Less than one week for Euler
  - About 2 weeks for Navier-Stokes
- **Quick turn-around**
  - Navier-Stokes solution on 10-million cell grid in about 40 wall-clock hours on 48 Pentium-4 processors
- **Training class 1st week of each month includes**
  - Onsite instruction at LaRC
  - Hands-on practice
  - Free to U.S. entities

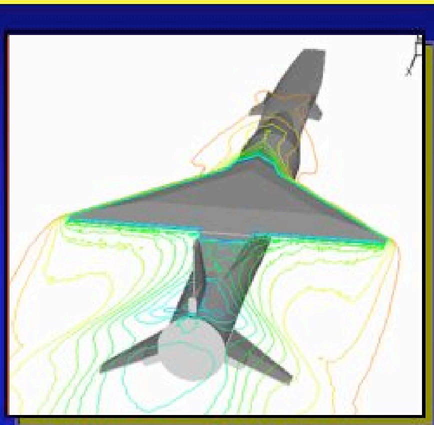
This illustrates a large-scale application of TetrUSS in response to an urgent problem. TetrUSS was the primary CFD code used in the HyPER-X Mishap Investigation and for Return-to-Flight support.

All related date is proprietary and the details cannot be discussed here, but this slide summarizes the investigation.



TetrUSS Application for S&C

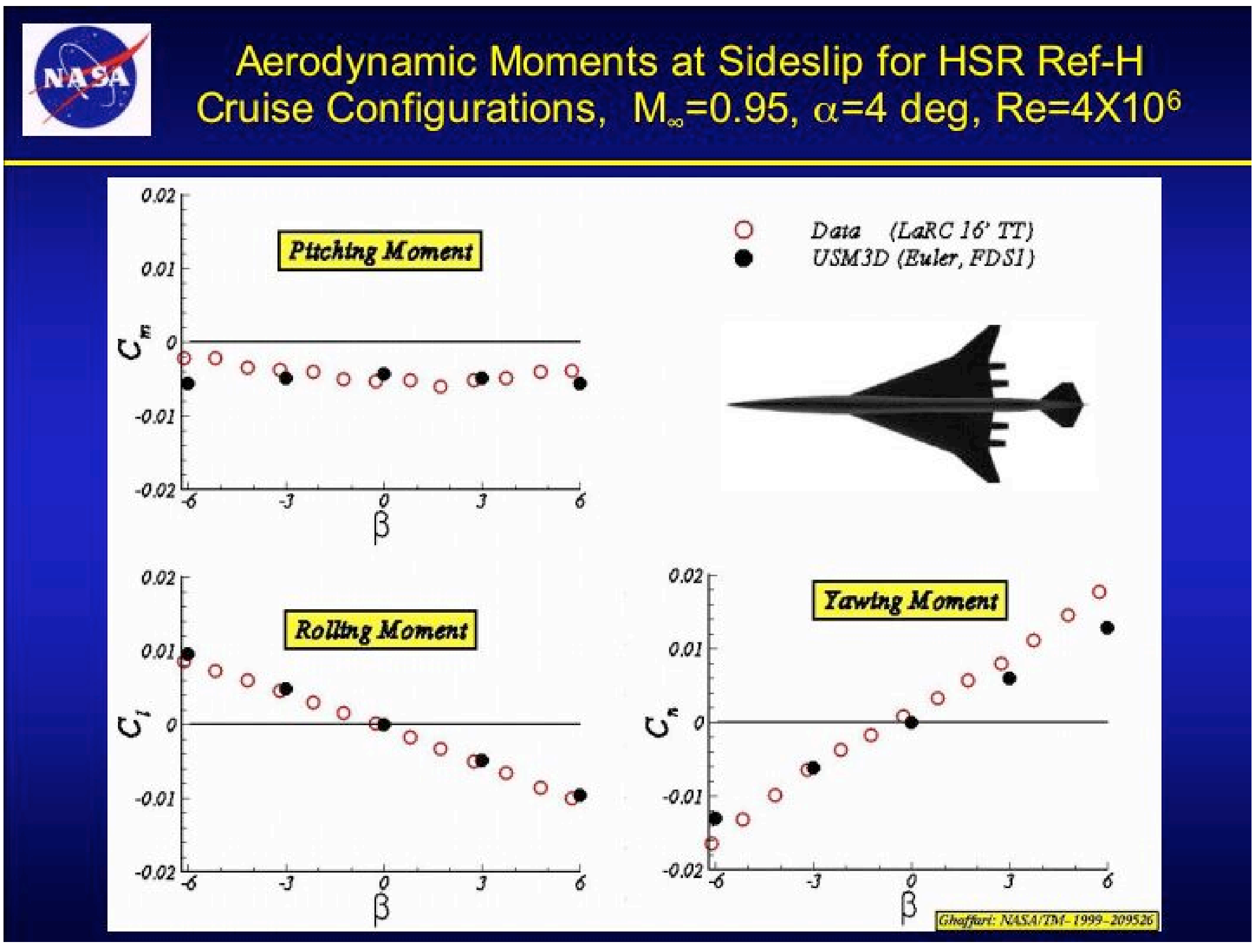
X-43A (HyPER-X) Return to Flight (RTF)

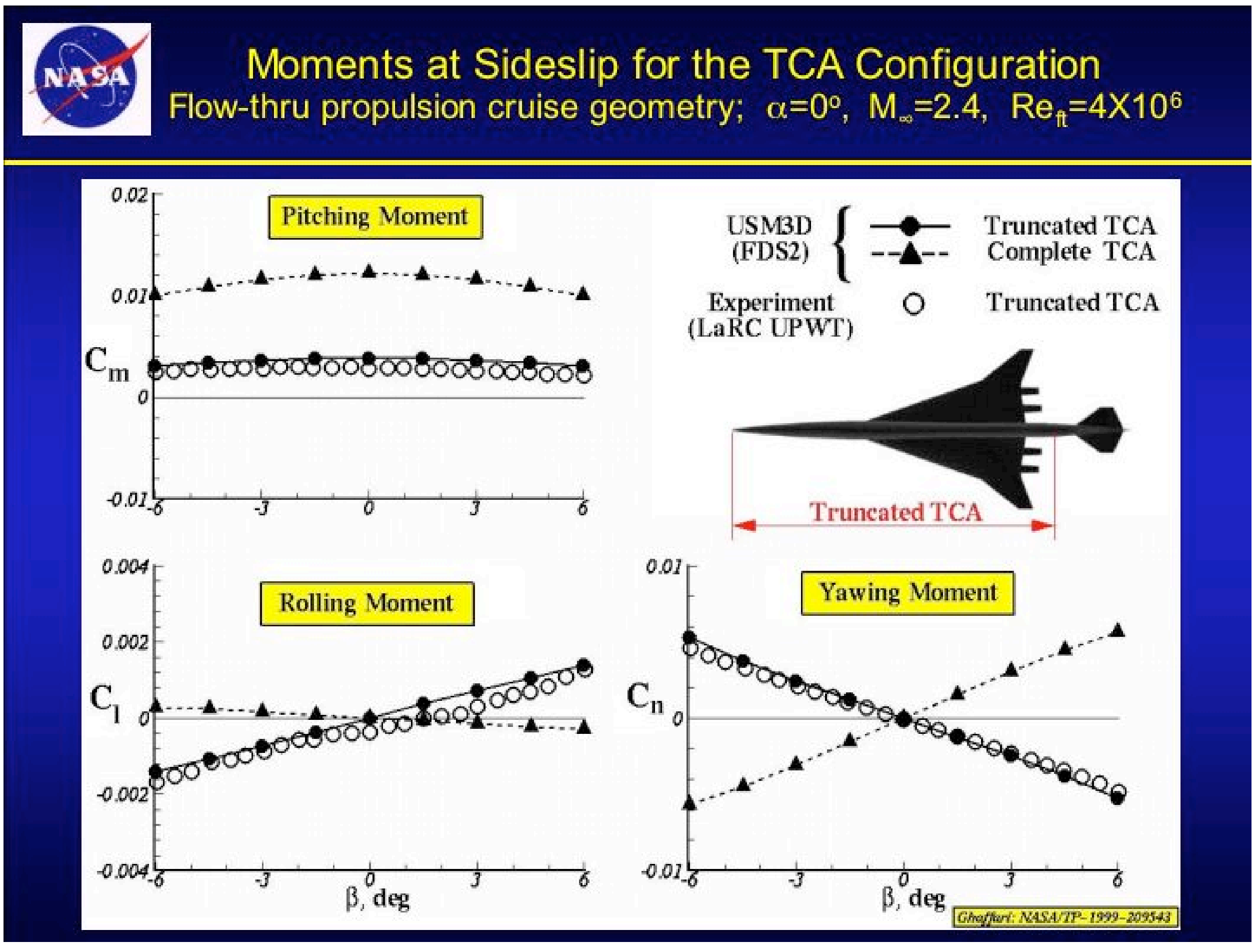


- Effort similar to the mishap investigation
- Over 60 N-S solutions on 16 different grids of full stack configuration with TPS in 3-months
- Mach range from 1.4 to 7.0
- Mostly at WT Reynolds number, some at Flight scaling

- In addition to the uses in the Mishap Investigation, CFD was used for:
  - Trajectory design
  - Loads and hinge moments for mechanical design of spindle & gears for the control surfaces

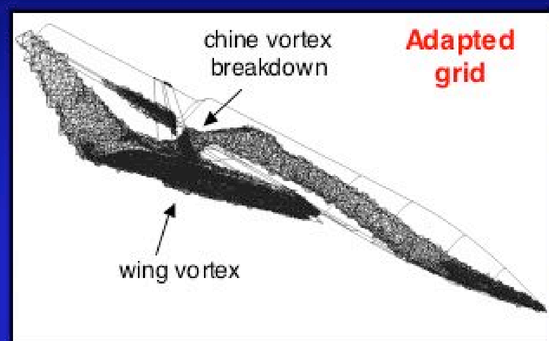
Primary Researchers: Armand / Tyler / Parlette / Parikh

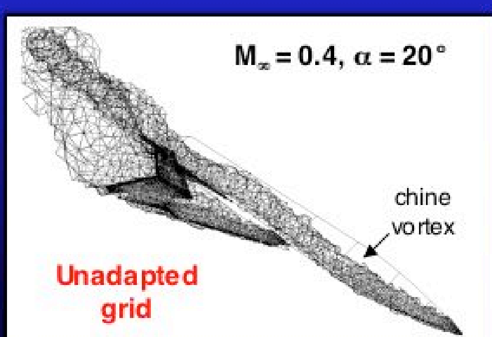

Aerodynamic Moments at Sideslip for HSR Ref-H Cruise Configurations, M_∞=0.95, α=4 deg, Re=4X10^6
Pitching Moment
Data (LaRC 16' TT)
USM3D (Euler, FDS1)
C_m
β
Rolling Moment
C_l
Yawing Moment
C_n
Ghaffari: NASA/TM-1999-209526

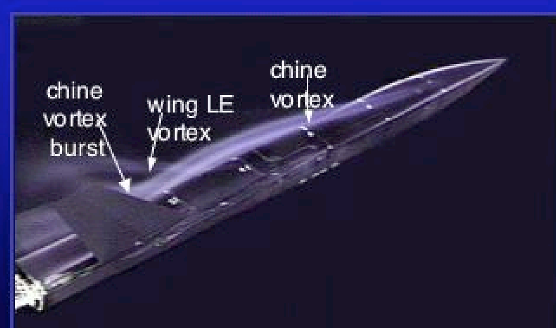

Moments at Sideslip for the TCA Configuration
Flow-thru propulsion cruise geometry; α=0°, M∞=2.4, Re_ft=4X10^6
Pitching Moment
USM3D (FDS2)
Truncated TCA
Complete TCA
Experiment (LaRC UPWT)
Truncated TCA
Truncated TCA
Rolling Moment
Yawing Moment
β, deg
β, deg
Ghaffari: NASA/TP-1999-209543

Solution Adaptive Grid for Vortex Breakdown

- Hybrid grid adaption thru local surface refinement and volume remeshing
- Critical for correctly resolving vortex breakdown and predicting pitchup





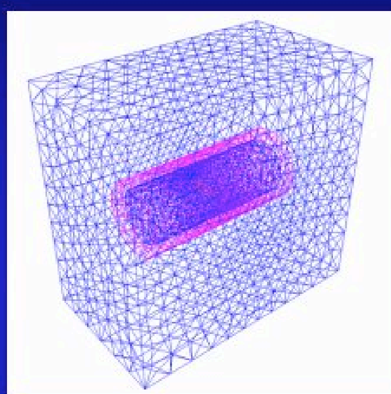


Next Steps Toward S&C

- **What we can do now**
  - Rapid grid generation
  - Large-scale computational studies
  - Solution-adaptive grid for inviscid, steady flows
  - Static longitudinal and lateral/directional derivatives
  - Massively separated flows

- **What is needed for S&C problems**
  - Dynamic longitudinal and lateral/directional derivatives
  - Dynamic grid adaption
  - Unsteady flows on moving components
  - Unsteady flow control effectors

Work in Progress: Forced Oscillation



- An overset grid approach
- Inner grid(red) contains body and moves (oscillates)
- Outer grid (blue) is fixed
- Overlapped cylindrical regions

- Series of steady state solutions - one for each roll angle (φ)
- Each steady solution obtained by solving outer and inner grids alternatively, with solution interpolated in the overlapped region, until converged to SS

Future Focus toward S&C

- **Large-Scale Aero-Database Generation**
  - USM3D to be added to the NASA Ames AeroDB system in Fall '03
  - Enables generation of hundreds of N-S and thousands of Euler solutions per week
  - Goal is to extract simulation database and S&C derivatives
- **Chimera Overset Grid**
  - R. Noack's DirtLib libraries installed into USM3D in early Sept. 03 (presently under verification testing)
  - Goal to facilitate dynamic "Free-to-Roll", 6-DOF simulation capabili and movable control surfaces
- **Detached Eddy Simulation**
  - Installed into USM3D – verification testing underway
  - Goal to include massively separated unsteady flow effects into "edge of the envelope" flight conditions

Summary

- **TetrUSS is a workhorse flow analysis system for large-scale aerodynamic problems**
  - Complete flow analysis system designed for broad application
  - Extensive validation with large user/experience base
  - Readily usable with nominal amount of training
- **Demonstrated applicability to S&C**
  - Lateral/Directional stability
  - Hinge moment estimates
- **New significant capabilities coming in near future**
  - Large-scale aero database generation
  - Chimera overset grids
  - Detached Eddy Simulation
- **We solicit your feedback on future S&C requirements**