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# SELECTED TOPICS IN OVERSET TECHNOLOGY DEVELOPMENT AND APPLICATIONS AT NASA AMES RESEARCH CENTER


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Invited presentation at the 6th Symposium on Overset Composite Grids & Solution Technology, Ft. Walton Beach, FL, October 8-10, 2002


Ames Research Center

## OUTLINE

- Overview of overset activities at NASA Ames
- Recent developments in Chimera Grid Tools
- A general framework for multiple component dynamics
- A general script module for automating liquid rocket sub-systems simulations
- Critical future work

# OVERSET ACTIVITIES AT NASA AMES

## Development

- Chimera Grid Tools (Chan, Rogers)
- PEGASUS 5 (Rogers)
- OVERFLOW chemistry (Olsen, et al.)
- INS3D multi-level parallelizm (Kiris)
- XML4CFD (Murman, Chan, Aftosmis, Meakin)
- AeroDB (Rogers, Aftosmis, Tejnil, Ahmad, Pandya, ... )
- ASG auto surface gridding (Klopfer, Onufer) [restart FY03?]

I

- OVERFLOW-D (Meakin, Potsdam)

A

## Applications

- Liquid rocket engine subsystems (Kiris, Chan, Kwak)
- Liquid Glide Back Booster under AeroDB (Chaderjian)
- Cardiovascular system - assist devices, arteries (Kiris, Kwak)
- Harrier in ground effect (Chaderjian, et al.) [not active]

I

- Rotorcraft (Meakin, Potsdam, Strawn, Dimanlig, ...)
- Missiles (Meakin, Nygaard)

A

# IMPLEMENTATION OF CHEMISTRY IN OVERFLOW

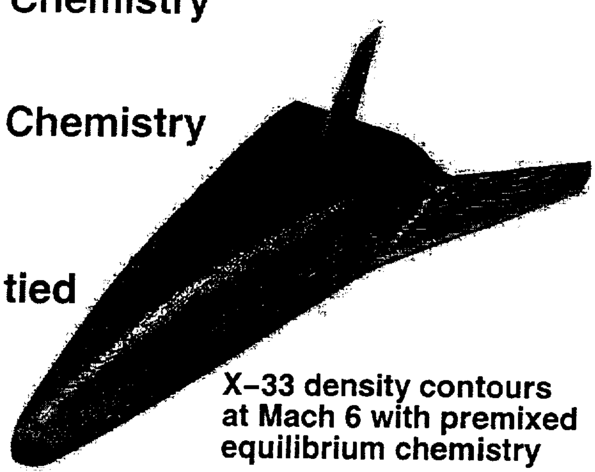
Collaborators: M. Olsen, S. Venkateswaran, D. Prabhu, T. Olsen, Y. Liu, M. Vinokur

**Premixed Equilibrium Chemistry**
- computation speed comparable with perfect gas

**General (Non-Premixed) Equilibrium Chemistry**
- robust reacting capability

**Computationally Efficient Finite Rate Chemistry**
- general reacting flow capability

**Features**
- general thermodynamic model (not tied to a particular functional form)
- computational efficiency
- general mixtures of perfect gases



X-33 density contours at Mach 6 with premixed equilibrium chemistry

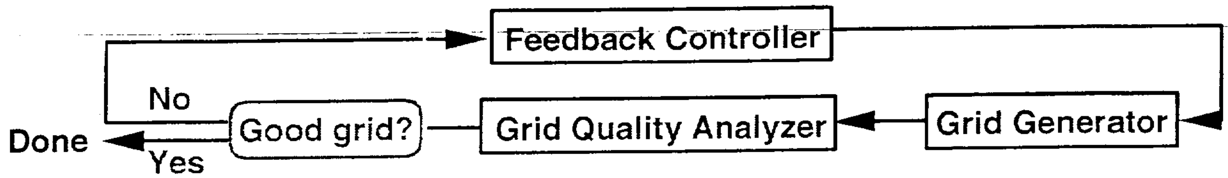
Papers submitted to 41st AIAA Aerospace Sciences Meeting & Exhibit, Jan., 2003.

Olsen, M. E., Venkateswaran, S., Prabhu, D. K. and Olsen, T., Implementation of Finite Rate Chemistry Capability in OVERFLOW.

Olsen, M. E., Liu, Y., Vinokur, M. and Olsen, T., Implementation of Premixed Equilibrium Chemistry Capability in OVERFLOW.

## ASG AUTOMATIC SURFACE GRIDDING

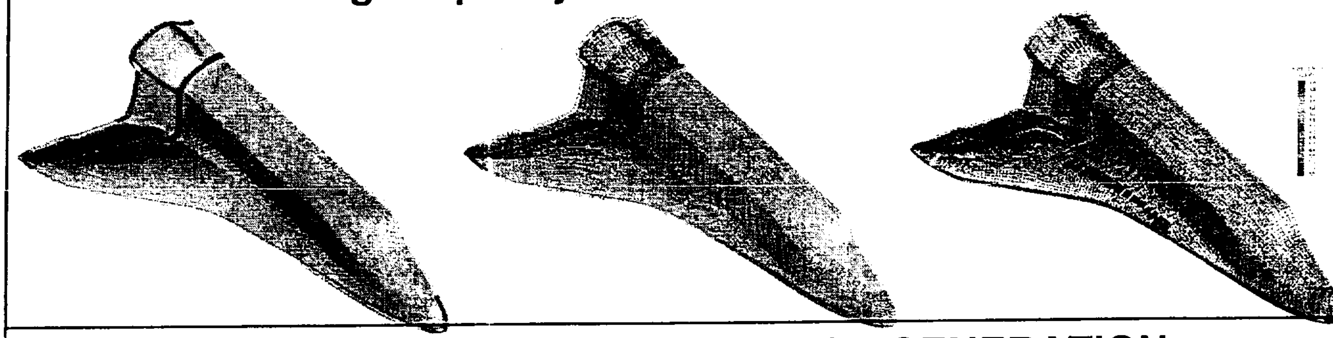
Collaborators: Goetz Klopfer, Jeff Onufer (restart FY 03 ?)




**Grid Generator**
- SURGRD hyperbolic/algebraic surface grid generator

**Grid Quality Analyzer**
- single grid (grid–induced truncation error)
- overlap grid (relative volume, cell–difference, stencil quality)

**Feedback Controller**
- re–adjusts grid generator inputs based on grid quality
- iterate until grid quality criteria are satisfied



## HARRIER UNSTEADY DATABASE GENERATION

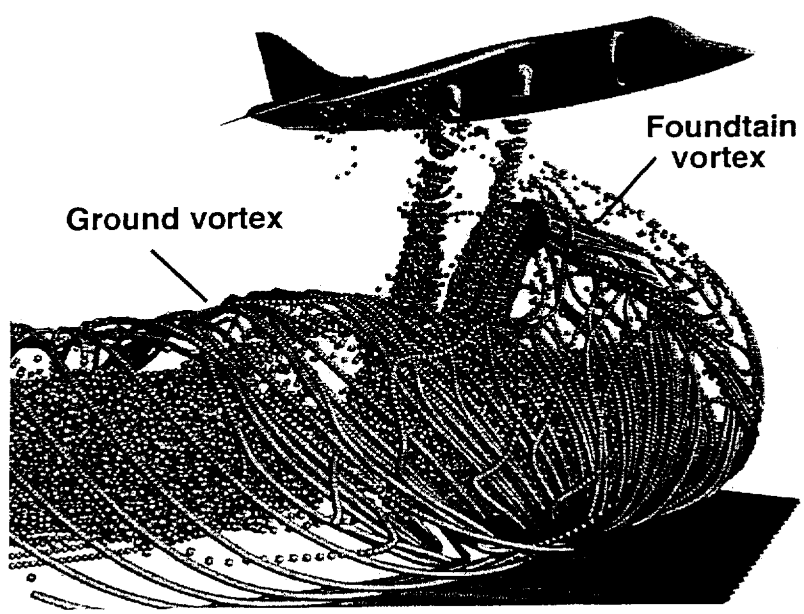
Collaborators: N. Chaderjian, J. Ahmad, S. Pandya, S. Murman

Motivation: Safety

-hot gas ingestion
-suck–down effect
-ground personnel

Objectives

- reduce process time to generate database
- demonstrate ability to capture unsteady flow structures & frequency



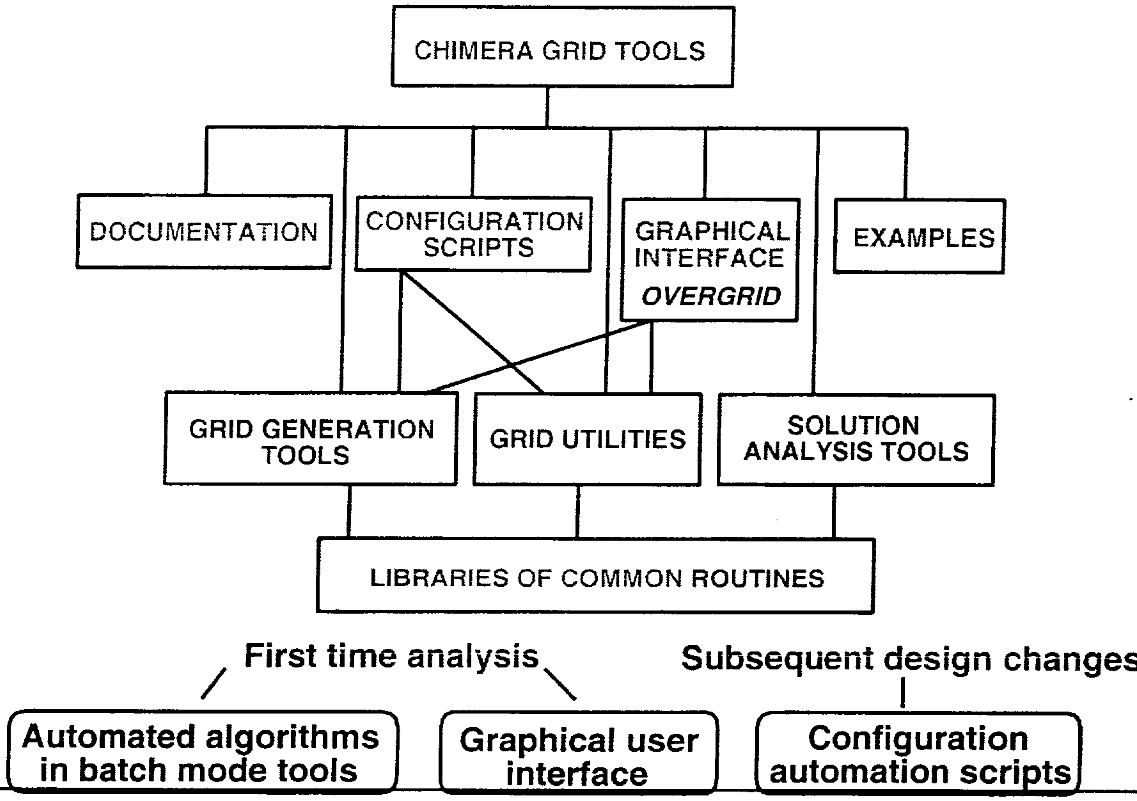

Results

- 35 time accurate RANS solutions (4 million pts) in 1 week using OVERFLOW (952 dedicated Origin processors, AIAA 2002–3056)
- captured low frequency oscillations (0.5 Hz)
- captured unsteady flow structures
- developed Dbview GUI for local/remote access of database

# CHIMERA GRID TOOLS (CGT)

Collaborators: William Chan, Stuart Rogers,
Steve Nash, Pieter Buning, Bob Meakin

**Objective – reduce overall Chimera CFD analysis time**




# RECENT DEVELOPMENTS IN CGT

**Version 1.7 released in July, 2002**

**Main new features in OVERGRID**

- Advanced diagnostics
- Auto boundary conditions selection and display
- OVERFLOW–D function calls
- Component hierarchy and dynamics module
- Faster I/O and reduction on peak memory requirement

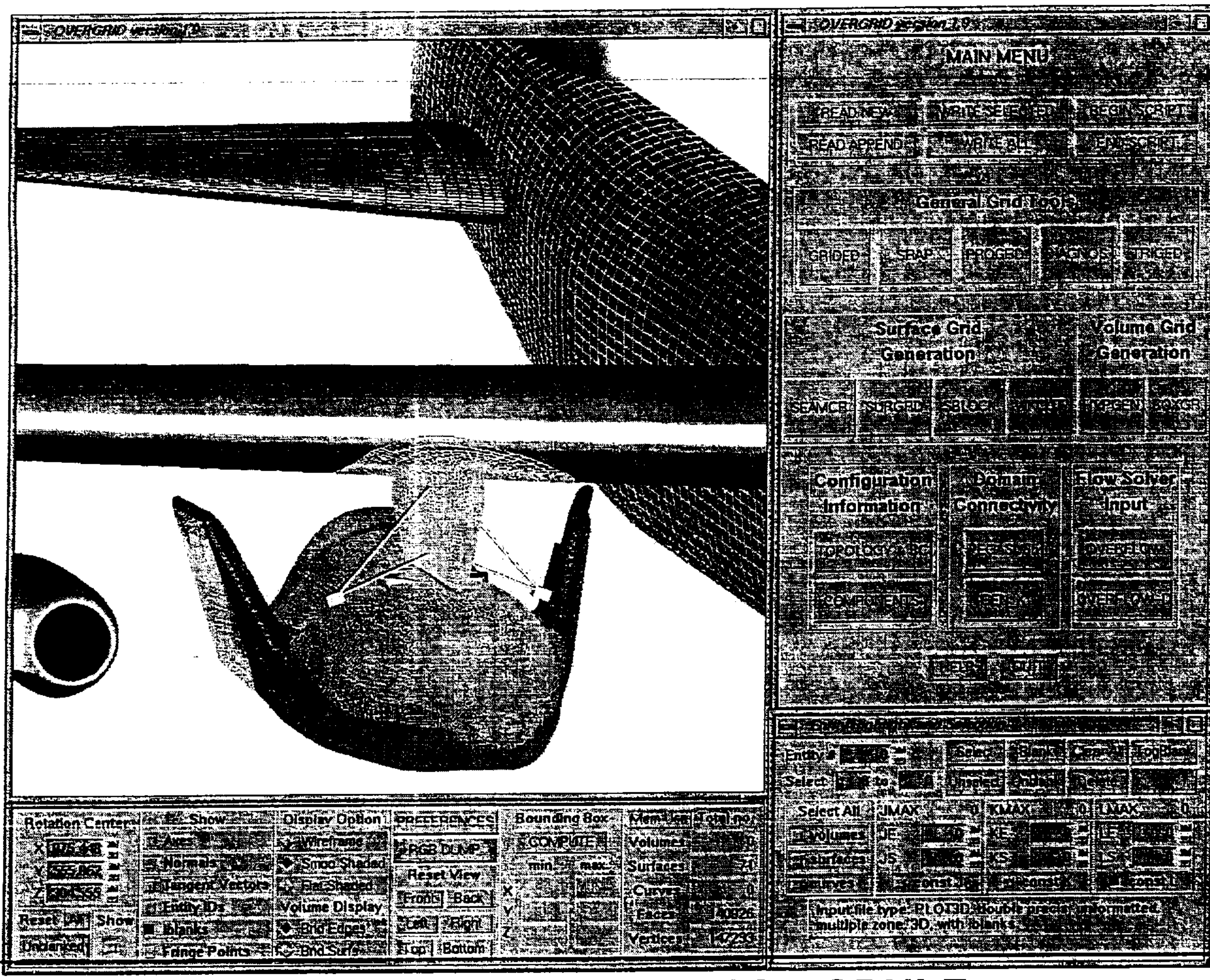
**Recent publications at 32nd AIAA Fluid Dynamics Conference, St. Louis, Missouri, June, 2002**

Chan, W. M., The OVERGRID Interface for Computational Simulations on Overset Grids, AIAA Paper 2002–3188.

Chan, W. M., Gomez, R. J., Rogers, S. E. and Buning, P. G., Best Practices in Overset Grid Generation, AIAA Paper 2002–3191.

Suhs, N. E., Rogers, S. E. and Dietz, W. E., PEGASUS 5: An Automated Pre–processor for Overset–Grid CFD, AIAA Paper 2002–3186

# OVERGRID'S MAIN WINDOWS (version 1.9)




# ADVANCED DIAGNOSTICS MODULE

Grid wireframe colored by
- structured grid quality
- surface triangulation quality
- scalar function on triangulation

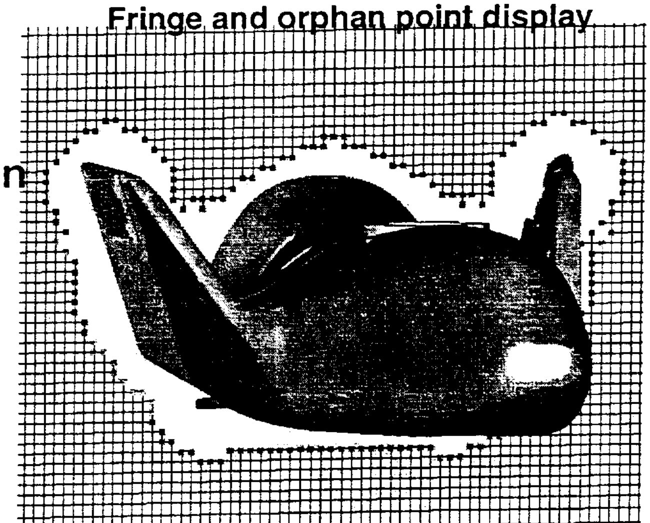
Orphan points
- display all or by grid

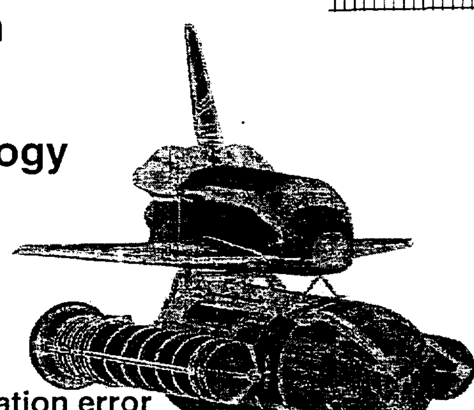
Iblank statistics
- % blanked
- % fringe

Negative Jacobian
- report by grid

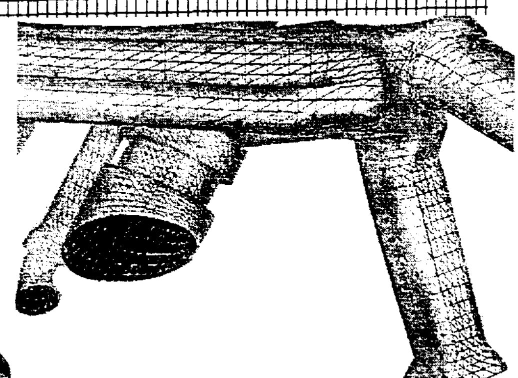
Surface grid topology
- check
- reset

Fringe and orphan point display





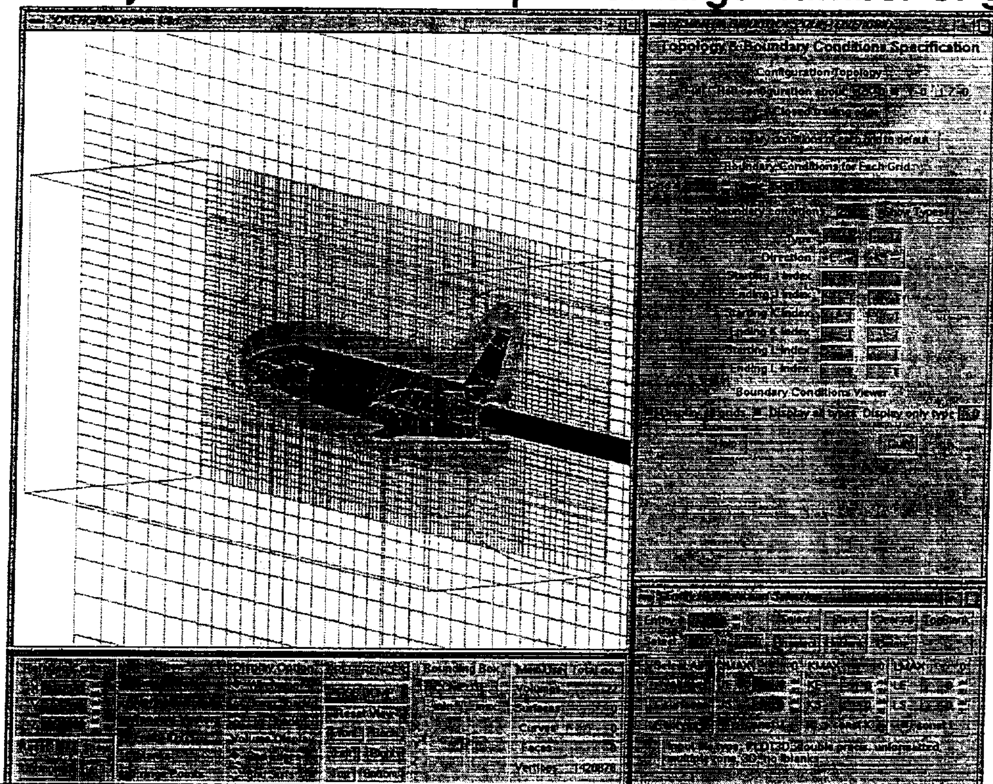
Grid induced truncation error



Scalar function on surface

## AUTO BOUNDARY CONDITIONS SELECTION AND DISPLAY

- Auto selection of topological and wall boundary conditions
- Widgets for fast manual override if needed
- Surfaces colored by b.c. type for quick visual check
- Very fast flow solver input for large number of grids

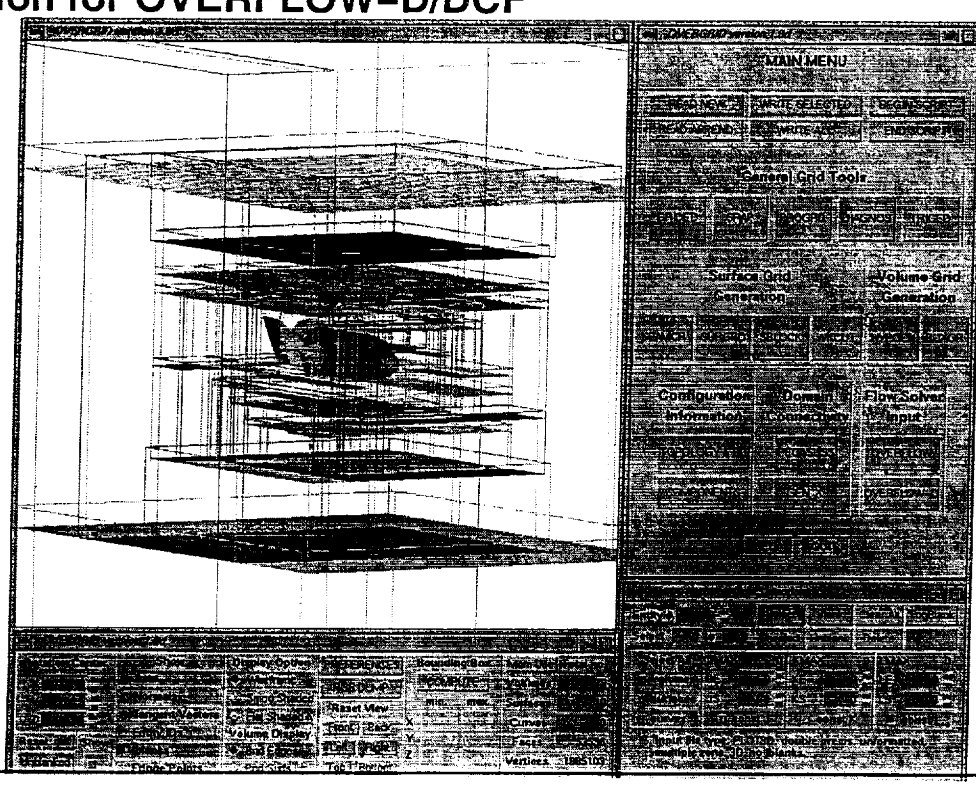



Orange = symmetry plane
Dark blue = viscous wall
Green = periodic
Magenta = wake cut

Total of 48 b.c. types supported

## OFF-BODY CARTESIAN GRID GENERATION AND DOMAIN CONNECTIVITY USING OVERFLOW-D

- Module for auto multi-level off-body Cartesian grid generation
- Module for creating object X-rays for hole cutting
- Module for specifying hole cutting information and input creation for OVERFLOW-D/DCF



## TO-DO LIST FOR CHIMERA GRID TOOLS

- More robust hybrid/triangulation grid generation tool for forces and moments computation

- Surface grid generation time reduction

  > More automatic surface curve creation
  > More automatic domain decomposition
  > OVERGRID interface for ASG algorithm/software

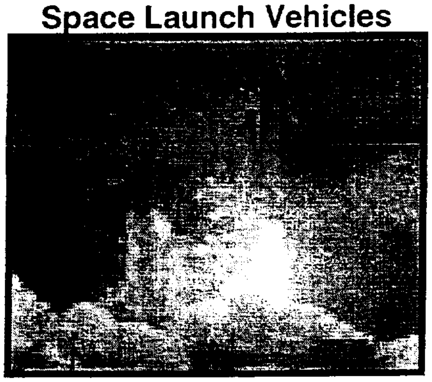
- Surface grid generation on CAD – investigate CAPRI interface

- More coordination between graphical interface and scripts

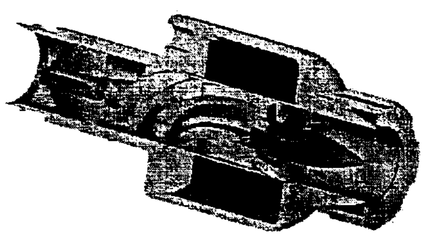
- Approx. 80 other items for improvements to CGT and overset technology

## A SAMPLE OF APPLICATIONS WITH MULTIPLE COMPONENTS IN RELATIVE MOTION

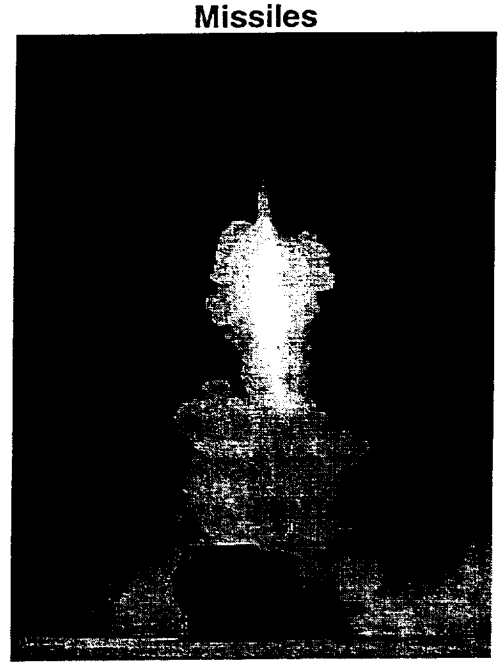
Space Launch Vehicles



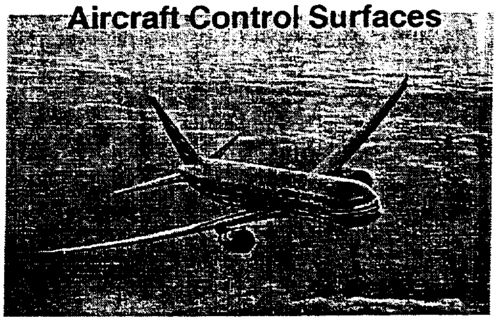
Heart Assist Devices



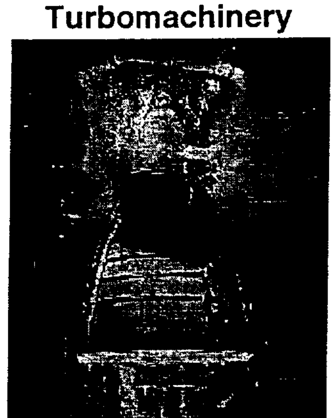
Missiles



Aircraft Control Surfaces



Turbomachinery



Paratroop/store Deployment

Rotorcraft

## A FRAMEWORK FOR MULTIPLE COMPONENT DYNAMICS

Collaborators: Scott Murman, William Chan,
Mike Aftosmis, Bob Meakin

### Motivation

- Computations involving multiple complex bodies in relative motion have been scarce mainly because
  > intensive CPU time required
  > problem definition is difficult and not standardized
- Potential benefit for a variety of NASA and DOD programs

### Objective

- Develop common framework that can be used by different kinds of flow solvers (structured or unstructured)
  OVERFLOW–D (structured overset)
  FLOWCART (unstructured Cartesian)

### Approach

- Use XML files as information exchange format between GUI (for problem setup) and flow solvers
- Develop API for reading/writing the XML files (XML4CFD) (C and f90 versions)

## FRAMEWORKS

### Configuration

- Components hierarchy and relationship to grids, geometry, virtual surfaces, etc.

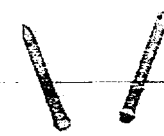
### Scenario

- Rigid–body dynamics of components
  > prescribed motion
  > motion under aerodynamic loads
    - unconstrained 6–dof
    - constrained
    - controlled

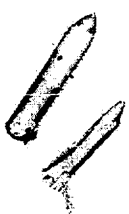
### Configuration Space

- A set of configurations defined by parameterizing certain attributes of a baseline configuration (e.g., a space launch vehicle with a sweep of elevon settings)

## CONFIGURATION FRAMEWORK



- A configuration is a collection of rigid components
- Each component is allowed one immediate parent and can move relative to its parent
- A root component has no parent and can move relative to other root components under an inertial coordinate system
- A component can be of type struc, tri or container
- Struc and tri components can have associated geometry/grids
- A component can be moved to its initial position via a set of transforms (a prescribed sequence of rotations, translations, and mirror commands)



```
<Component Name="Body flap" Parent="Orbiter" Type="struc">
   <Data> <Grid List="9, 11-13" /> </Data>
   <Transform>
      <Rotate Center="90.0,0.0,0.0" Axis="0.0,1.0,0.0" Angle="10"
   </Transform>
</Component>
```

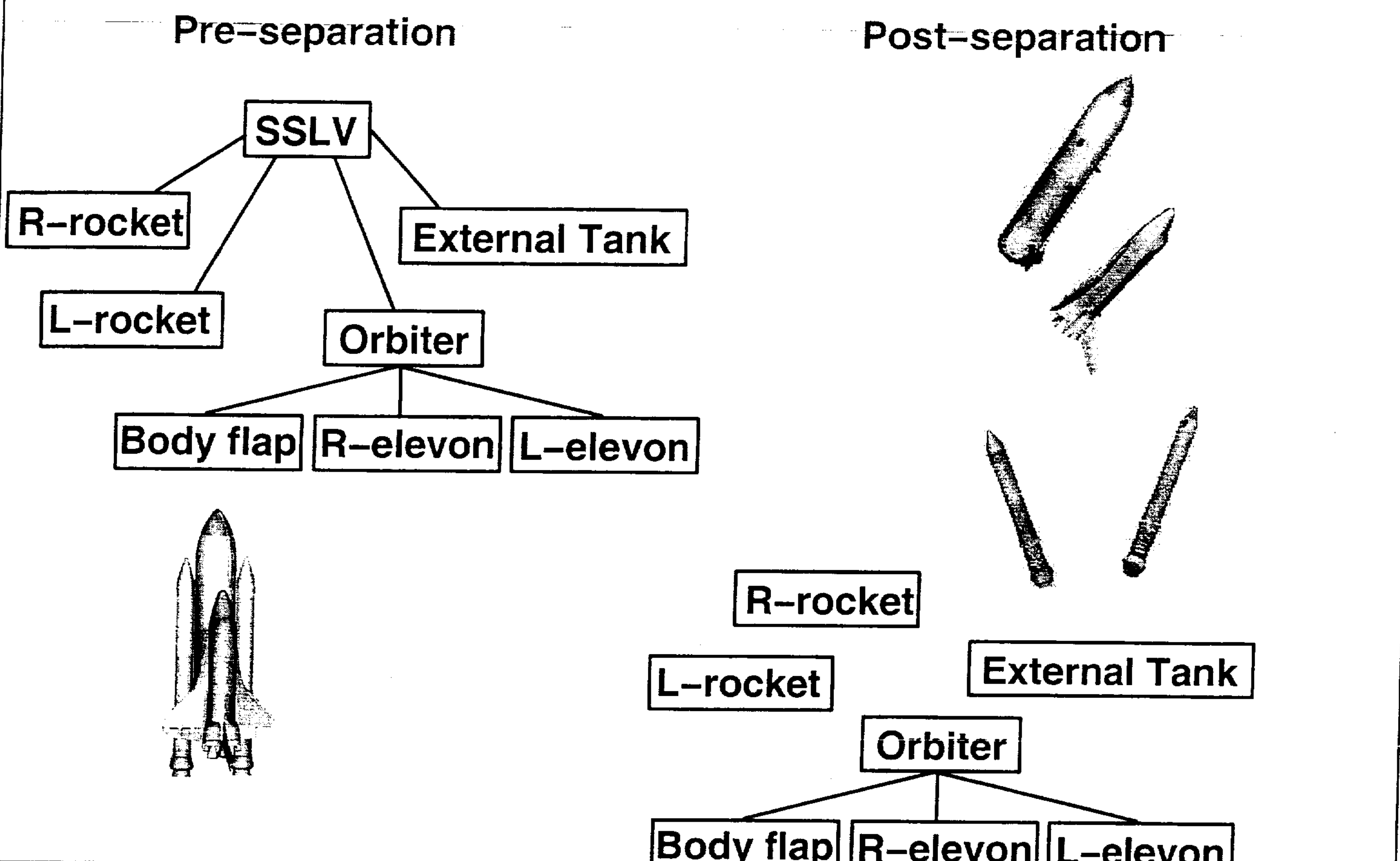
## SCENARIO FRAMEWORK

- A scenario is a collection of prescribed or aero6dof motions
- Each prescribed or aero6dof motion describes the dynamics of a component over a period of time
- Each component may have different motions during different periods of time
- Each prescribed motion is a sequence of rotations and translations over a time period where the velocity components and angular speeds can be arbitrary functions of time

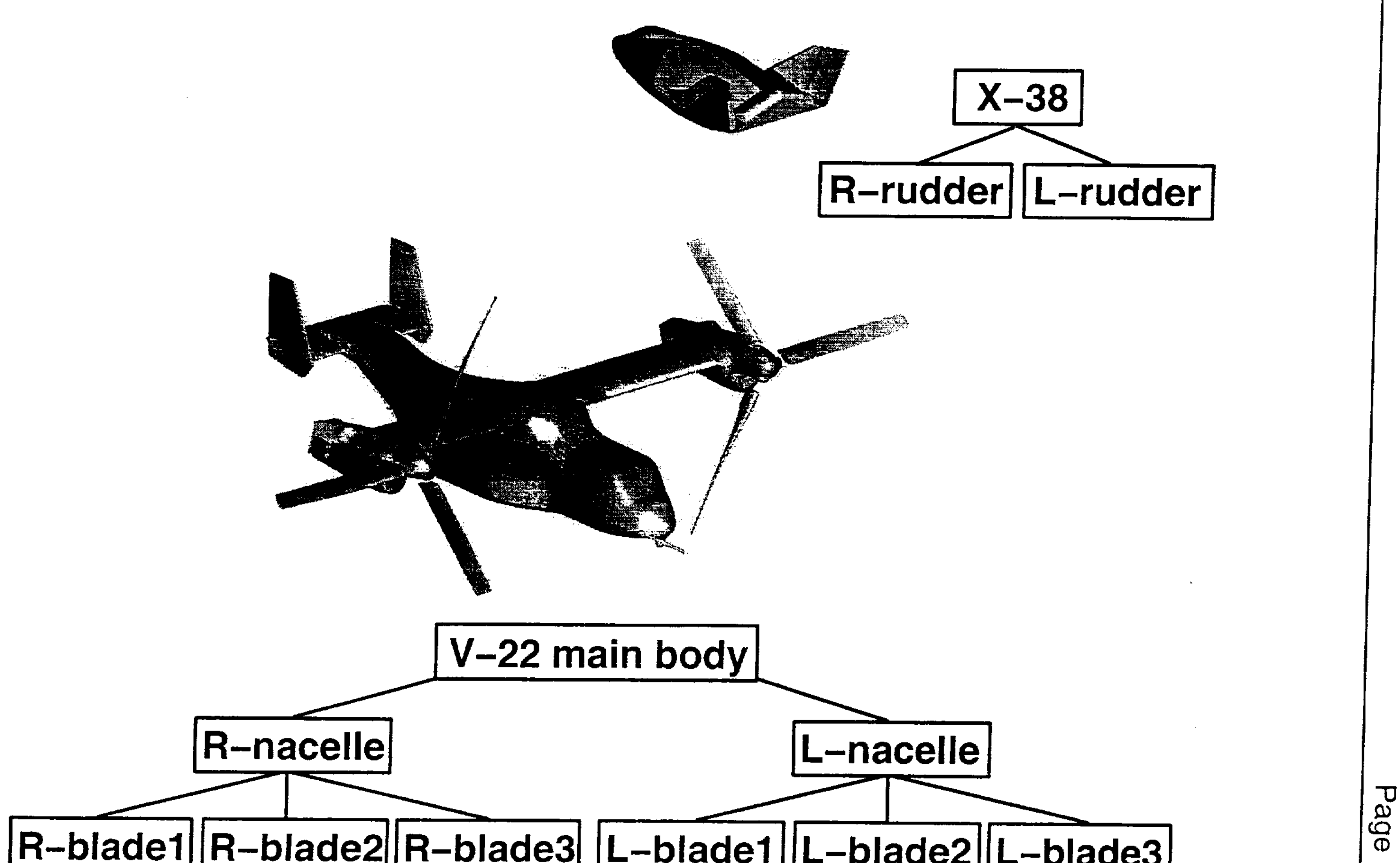
```
<Prescribed Component="Orbiter" Start="0.0" End="1.0">
 <Translate Velocity="0.0, 0.0, 3.0*t^2" />
 <Rotate Center="0.5,0.0,1.0" Axis="0.0,1.0,0.0" Speed="sin(0.5*pi*t)"/>
</Prescribed>
```

- Each aero6dof motion requires the input of the component's
  - > mass and center of mass
  - > moments of inertia and directions of principal axes
  - > external forces and moments (gravity, etc.)
  - > constraints

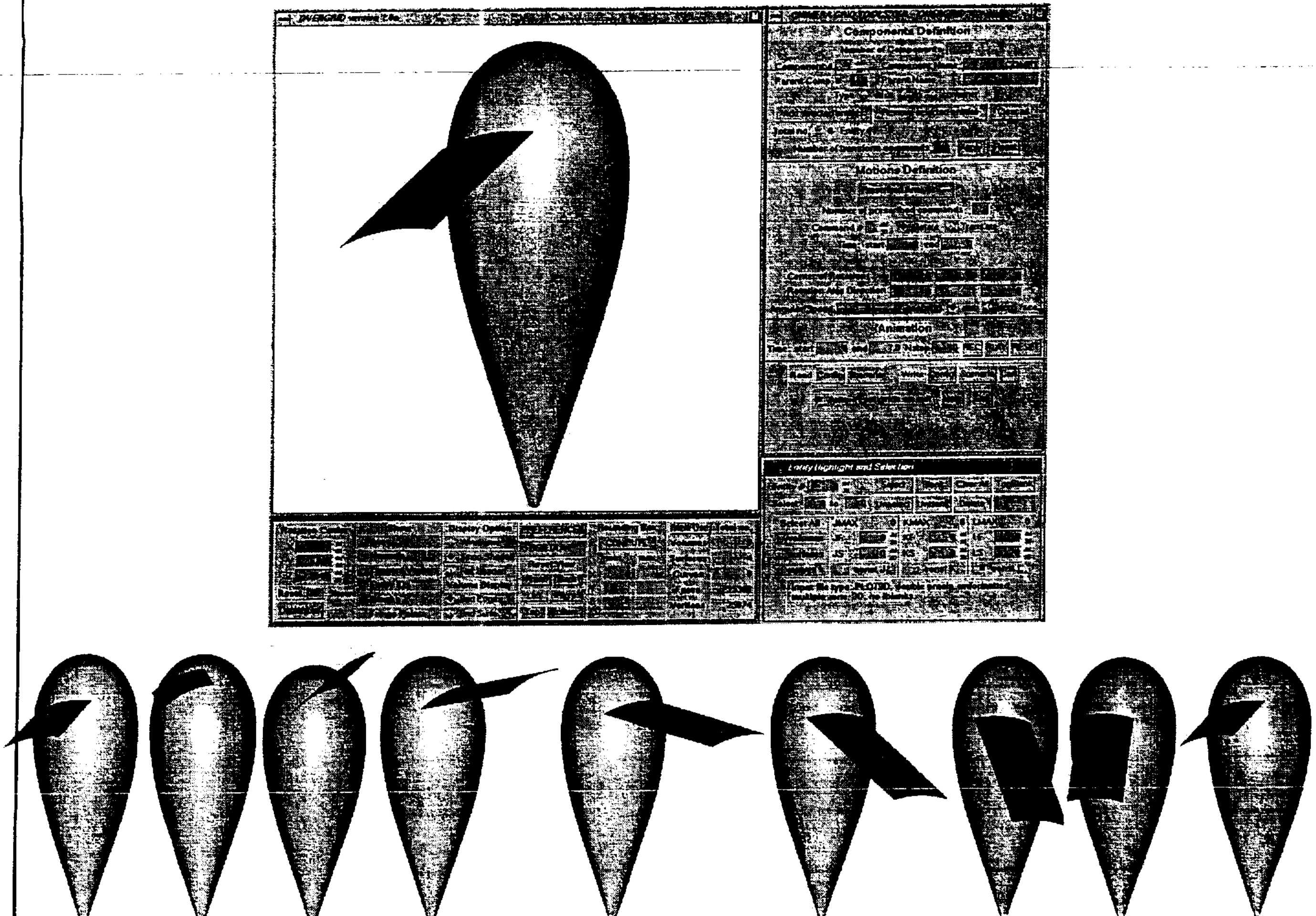
# SPACE SHUTTLE LAUNCH VEHICLE PARENT/CHILD COMPONENT HIERARCHY




# V-22 AND X-38 PARENT/CHILD COMPONENT HIERARCHY



# DEMONSTRATION OF FLAPPING WING IN SCOOPING MOTION



## CURRENT STATUS AND FUTURE PLANS

Current status

OVERGRID – specification and animation of components hierarchy and dynamics for prescribed motion, read/write XML files for interfacing with flow solvers

OVERFLOW–D (1.5e) and FLOWCART– read Config and Scenario XML files for driving prescribed motions

Future plans

Config – config. space, 'clone' component type

Scenario – prescribed motion with table lookup,
aero6dof motion, controlled motion, mixed motions

More details in paper:

Murman, S. M., Chan, W. M., Aftosmis, M. J., and Meakin, R. L., An Interface for Specifying Rigid–Body Motion for CFD Applications, submitted to 41st AIAA Aerosciences Meeting and Exhibit, January, 2003.

# SCRIPT DEVELOPMENT FOR TURBOPUMP SIMULATIONS

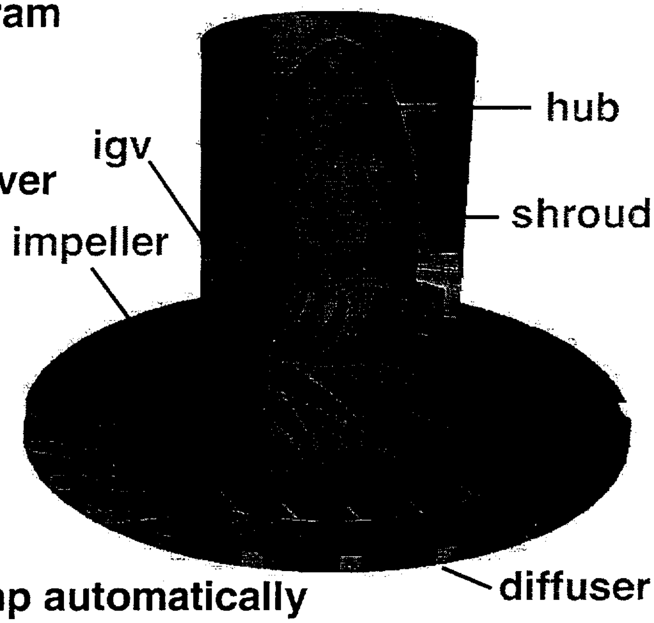
Collaborators: Cetin Kiris, William Chan, Dochan Kwak

## Motivation

Support 2nd generation RLV program with high fidelity viscous analysis

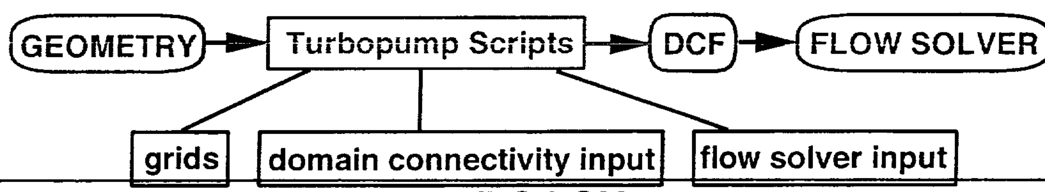
Significant user's effort needed in process from geometry to flow solver

How coarse can a grid system be and still provide accurate results?




## Objective

Develop script system to generate grids, create domain connectivity and flow solver inputs for different components of complete turbopump automatically




## APPROACH

### General Gridding Strategy

- Create grid system for each component independently and use ring grids for communication between components

### First Generation Scripts

- One specialized script for each component with optional rings at inflow and outflow boundaries
- Manual assembly of grids/inputs from different components

### Second Generation Scripts

- Single master script that allows the user to specify any combination of components and rings

- Master script calls generic component and ring scripts

- Generic component script can handle geometry for inducer, inlet guide vanes, impeller and diffuser

- Generic ring script can handle ring grid topology for inflow, outflow, and between components

## SCRIPT GENERATION

Disadvantages

- Require expertise to build scripts the first time

Advantages

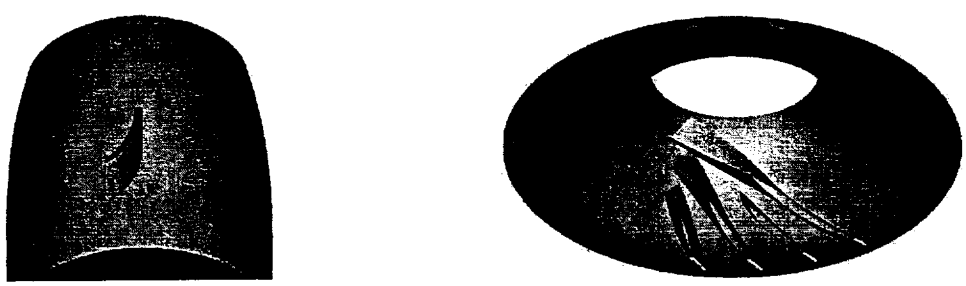
- Allow rapid re–run of entire process
- Easy to do grid refinement and parameter studies
- Easy to try different gridding strategies
- Documentation of gridding procedure

Tcl scripting language

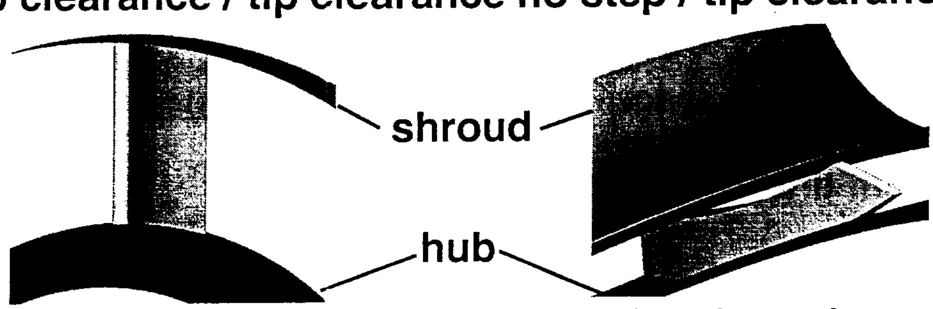
- Works on UNIX, LINUX and WINDOWS
- Integer and floating point arithmetic capability
- Modular procedure calls
- Easy to add GUI later if needed

## COMPONENT GEOMETRY PARAMETERS

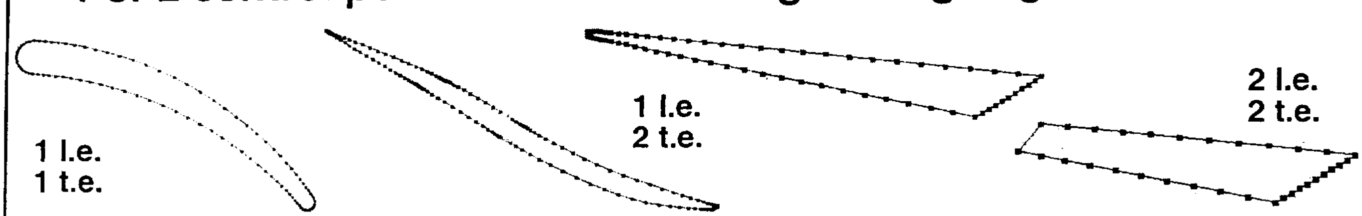
- number of sections and number of distinct blades per section



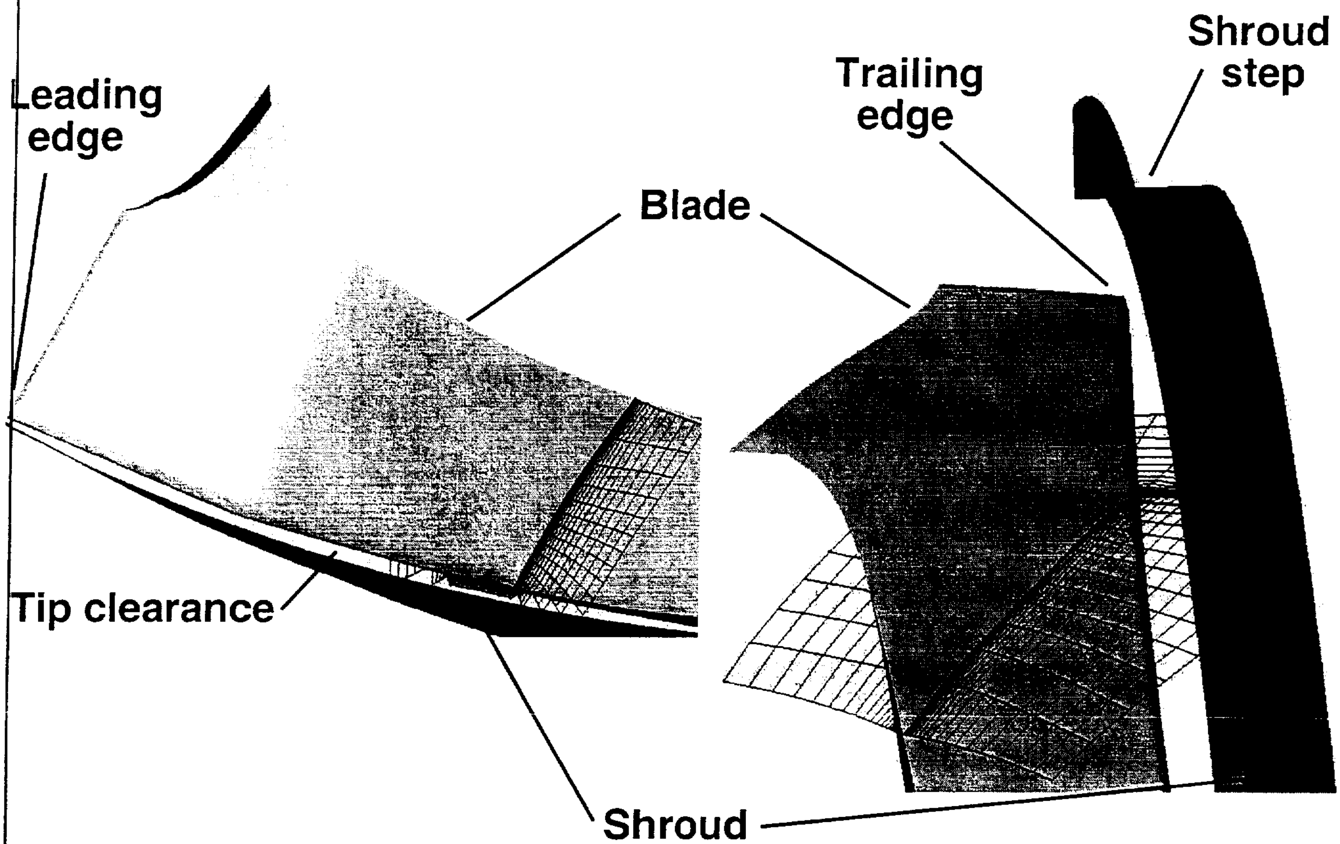
- no tip clearance / tip clearance no step / tip clearance with step




- 1 or 2 control points at blade leading/trailing edges



# IMPELLER BLADE TIP CLEARANCE AND SHROUD STEP




## INPUT AND OUTPUT

Input

- profile curves for hub and shroud in PLOT3D format (rotated by script to form surface of revolution)

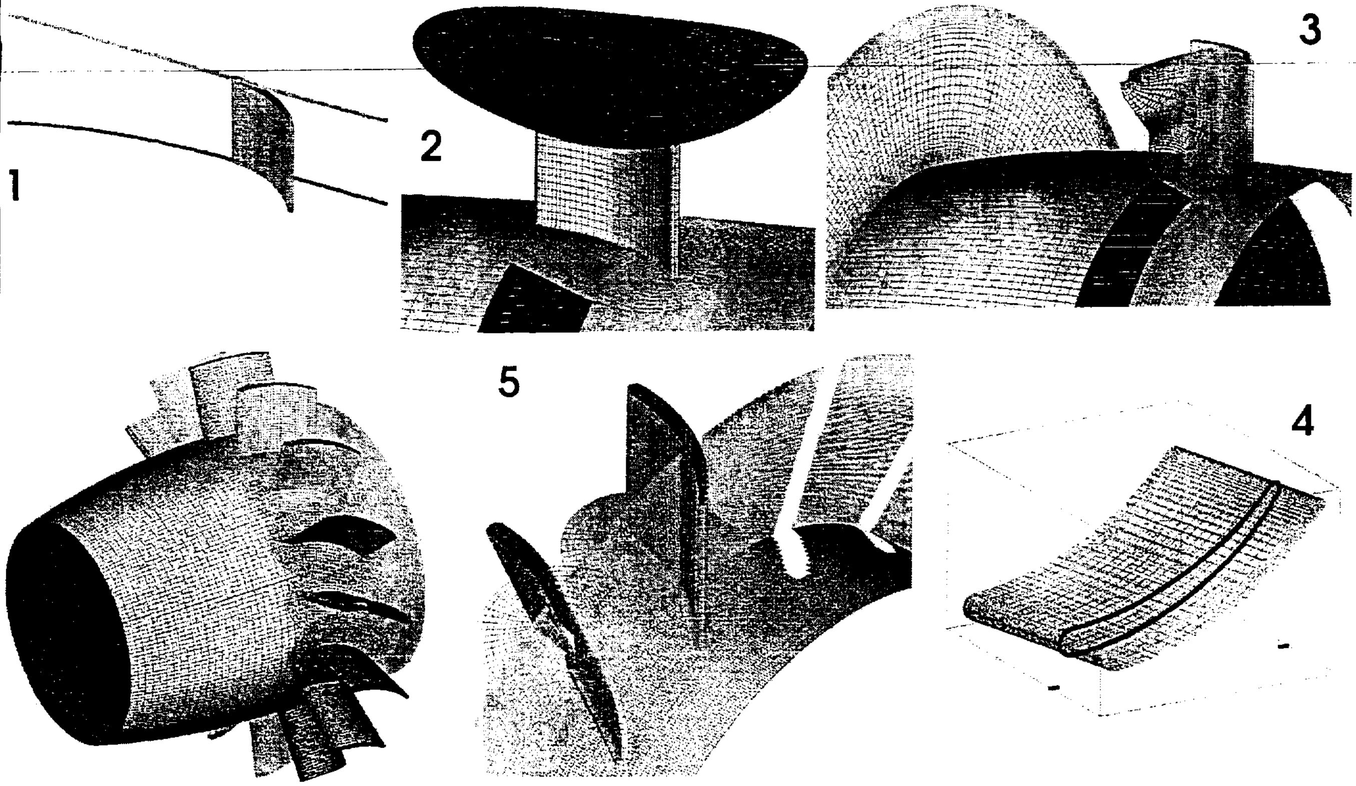
- blade (and tip) surfaces in PLOT3D format

- Parameters that can be changed
  - number of blades and sections
  - global surface grid spacing $\Delta s_g$ (on smooth regions)
  - local surface grid spacing, some independent (e.g., leading/ trailing edge spacing) and some expressed as multiples of $\Delta s_g$ (e.g., blade span spacing)
  - viscous wall normal grid spacing
  - marching distances
  - grid stretching ratio

Output

- overset surface and volume grids for hub, shroud, blades
- object X–rays for hole cutters using DCF
- domain connectivity namelist input for OVERFLOW–D

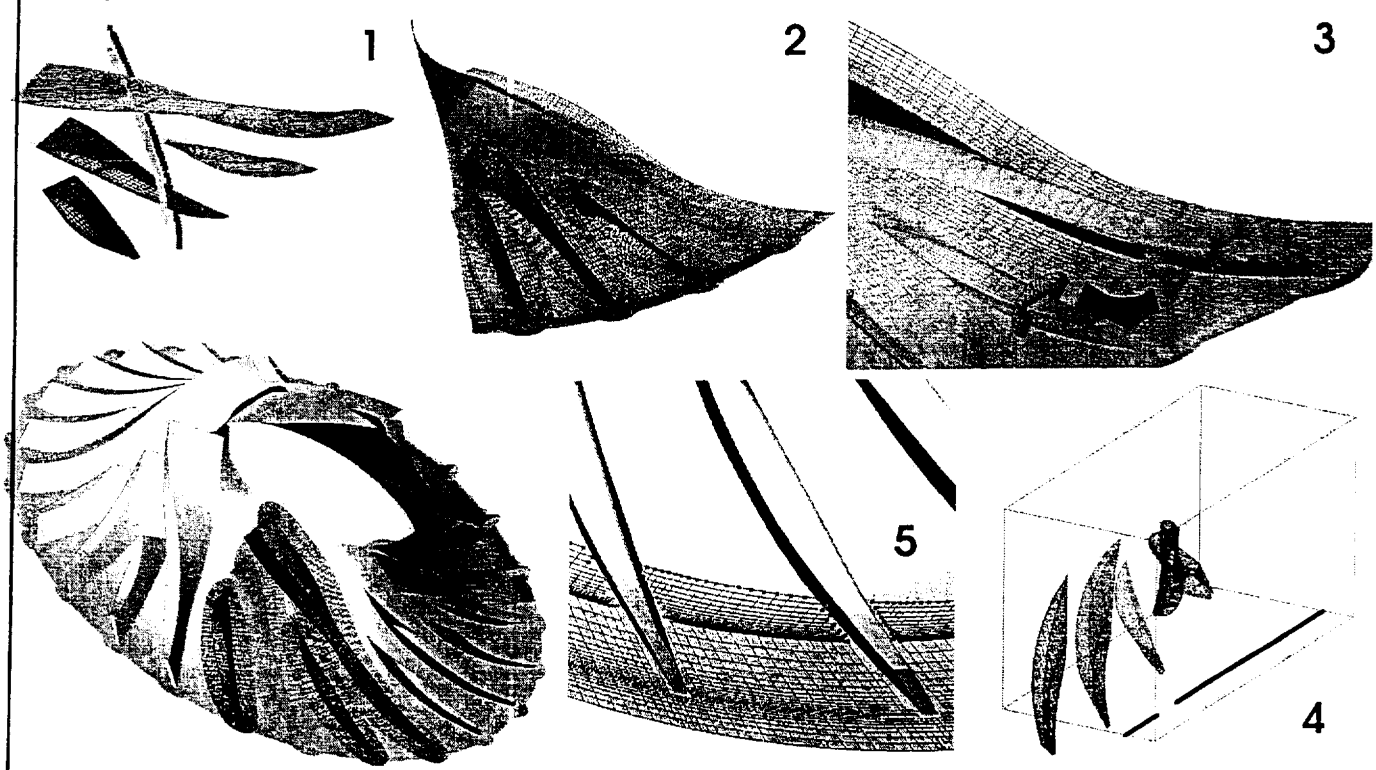
## INLET GUIDE VANES (N repeated blades, no tip clearance)




| | Manual | Script (fine) | Script (coarse) |
|---|---|---|---|
| No. of pts (million) | 7.1 | 5.8 | 1.1 |
| User time * | 1 day | 43 sec. | 20 sec. |

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

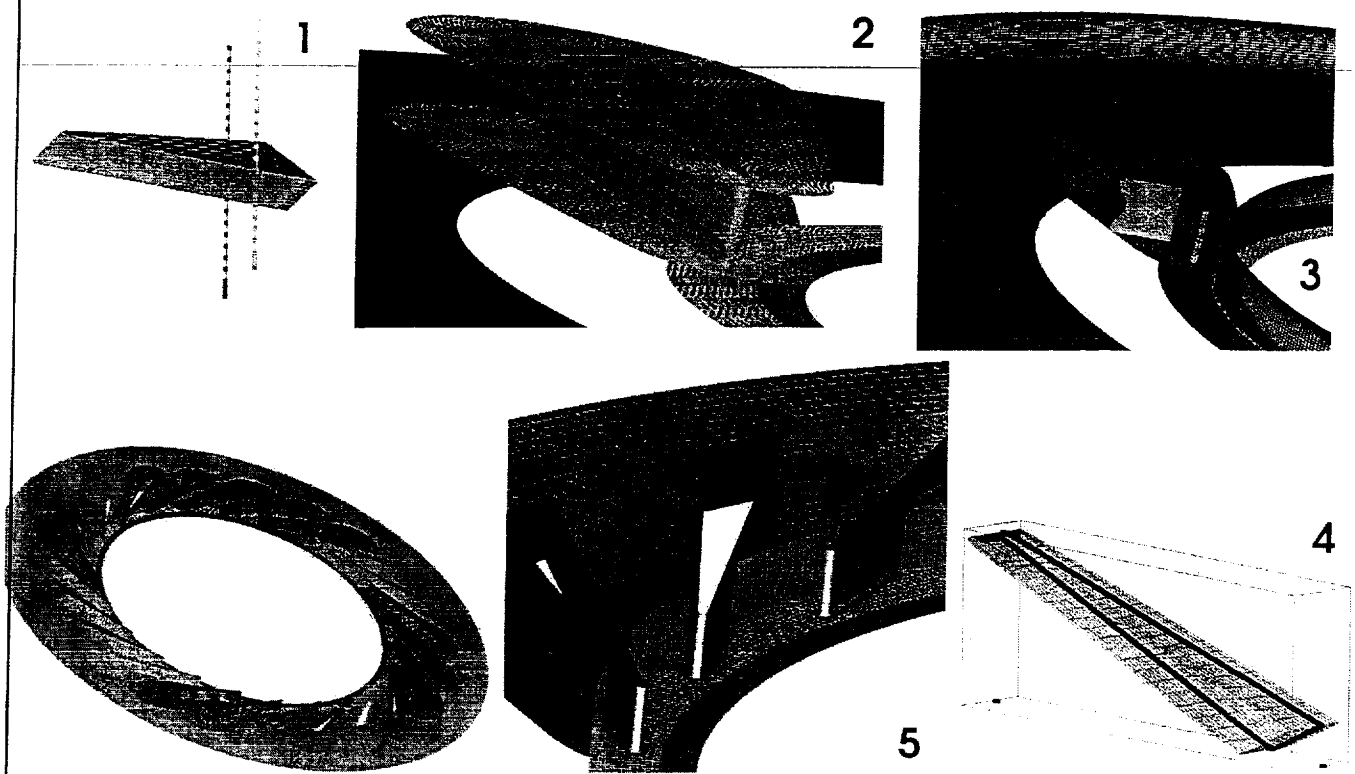
## IMPELLER
## (M sections, N different blades in each section, tip clearance)




| | Manual | Script (fine) | Script (coarse) |
|---|---|---|---|
| No. of pts (million) | 19.2 | 15.2 | 8.8 |
| User time * | ~ 2 weeks | 319 sec. | 234 sec. |

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

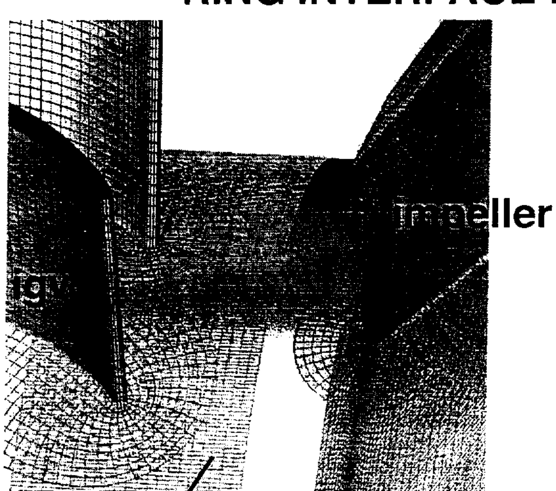
## DIFFUSER (N repeated blades, no tip clearance)

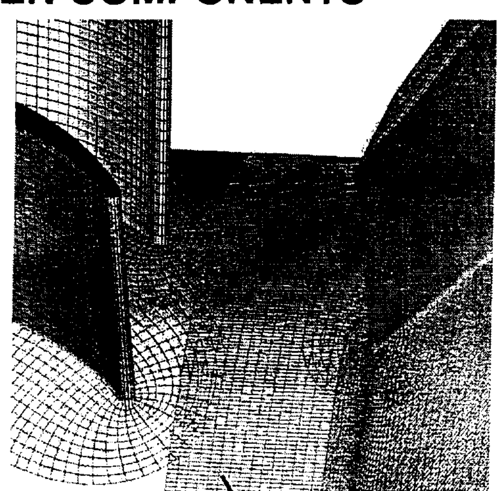



| | Manual | Script (fine) | Script (coarse) |
|---|---|---|---|
| No. of pts (million) | 8.0 | 6.4 | 1.6 |
| User time * | 1 day | 37 sec. | 22 sec. |

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

## RING INTERFACE BETWEEN COMPONENTS

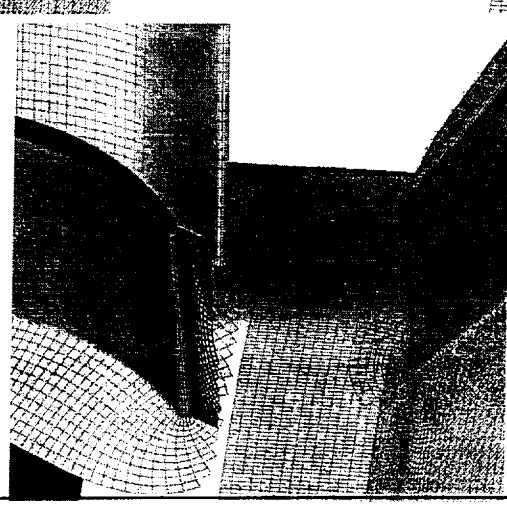


igv outflow ring

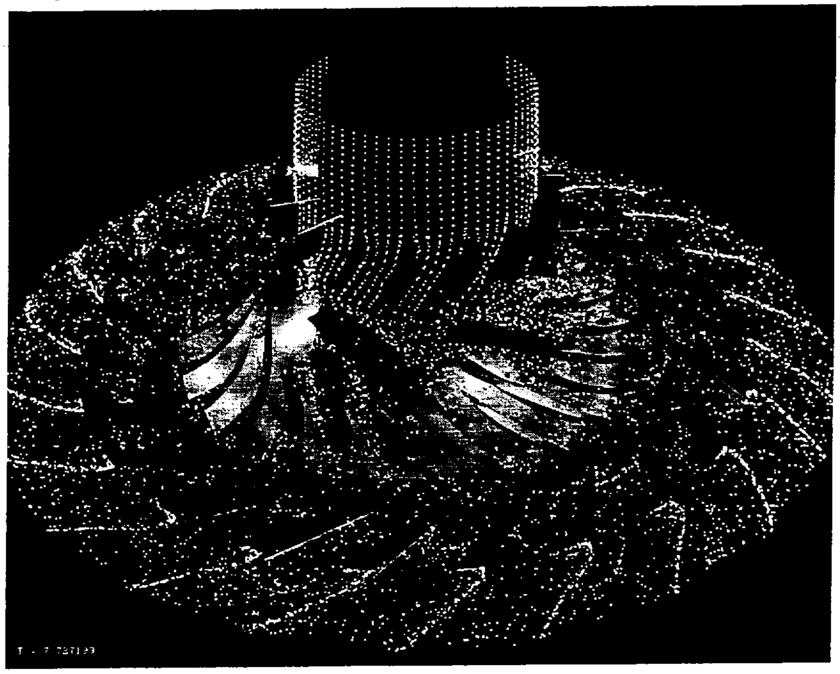
impeller inflow ring

- 9–point overlap between rings
- no impeller points beyond last plane of igv ring
- no igv points beyond first plane of impeller ring



## UNSTEADY COMPUTATIONAL RESULTS

Snapshot of particle traces and pressure surfaces near end of third rotation



Grid system – 34 million points
Wall clock time – 3.5 days/rotation on 128 dedicated Origin processors using INS3D–MLP

Kiris, C., Chan, W., and Kwak, D., A Three–Dimensional Parallel Time–Accurate Turbopump Simulation Procedure Using Overset Grid Systems, *Proceedings of the 2nd International Conference on Computational Fluid Dynamics*, Sydney, Australia, July 15–19, 2002.

## FUTURE PLANS FOR TURBOPUMP SCRIPTING

- Flow solver input creation in scripts
- More input error checks
- Automatic selection of more parameters
- Further robustness improvements
- Perform more tests on different geometry and parameters
- Documentation
- Graphical interface front end

## CRITICAL FUTURE WORK

In order for overset technology to gain wider utilization, improvements to the process should be made with the following attributes in mind

| | Important | Critical | |
|---|---|---|---|
| Automation | yes | no | |
| Speed | yes | no | |
| Robustness | yes | yes | |
| Low user's effort | yes | yes | e.g., less than about 1 hour's effort on complex geometry |

- Low effort and robust surface grid generation
  - surface feature extraction
  - surface domain decomposition
  - auto-surface coverage (grid resolution matching, overlap optimization)
- Low effort and robust domain connectivity
  - hybrid methods
  - fast enough for moving-body problems