Overview of MSFC's Applied Fluid Dynamics Analysis Group Activities

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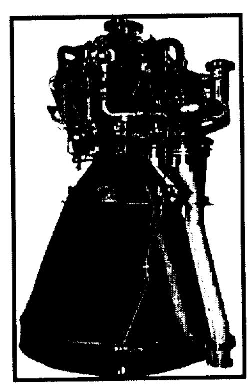
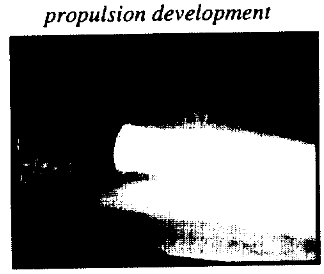
Presented at:
Marshall Space Flight Center's Fluids Workshop
MSFC, AL
April 4-5, 2001

Overview

- **TD64 group information**
  - Roles and responsibility
  - Analysis and design tool focus
- **Fluid dynamic technologies under development**
  - Turbomachinery
  - Combustion devices
  - Vehicle-propulsion integration
  - CFD process improvements (tool-to-tool)
  - Multidisciplinary analysis
- **Concluding remarks**



Focus CFD on liquid propulsion development



Fluid Dynamics at MSFC

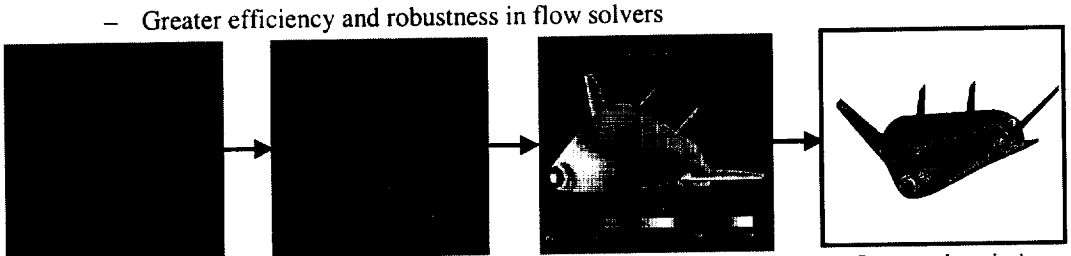
- **High-fidelity fluids design & analysis expertise at MSFC focused in the space transportation directorate**
  - Science and flight projects directorates not big customers
  - CFD (TD64), induced environments (TD63), cold flow testing (TD62, TD63, TD74)
- **Focused on improving the safety, reliability, and cost of space transportation systems**
  - We define geometry, quantify environments, and predict performance
  - Develop advanced hardware concepts and designs (analysis and test)
  - Environments and performance definition (analysis and test)
  - Incident investigation support (analysis and test)
- **Fluid dynamics expertise a core competency**
  - A means to an end
- **Support focused in two broad areas**
  - Space launch initiative (2nd generation RLV)
  - Spaceliner 100 (3rd generation RLV)

TD64 Group Objectives

- **Support space transportation directorate strategic plan**
  - "In partnership with other NASA centers, other government agencies, and industry, we will establish and maintain the U.S. As the preeminent leader in space"
- **Support the programs in meeting their goals**
  - Assist the programs in being "smart buyers"
  - Provide innovative technical solutions
- **Identify and work with external partners who possess key capabilities**
  - Other NASA centers, other government agencies, industry, academia
- **Provide personnel with the tools to succeed**
  - Maintain and enhance civil service personnel capabilities
  - Provide challenging work, hands-on experience, training
  - Continuously improve analysis techniques, computing resources, and test facilities

TD64 Design and Analysis Tools Objectives

- **Recent focus of design and analysis process in two areas**
- **Acquire/develop capability to perform broad, CFD-based parametric design studies**
  - Spend more time engineering, less time "CFDing"
  - More efficient use of available computing resources
  - Requires automation in all phases: grid generation, flow solver, post-processing
- **Expand range of CFD applicability**
  - Combustion processes, transient processes, relative motion, multi-component
  - Improved physical models
  - Greater efficiency and robustness in flow solvers



Geometry engine → *CFD grid* → *CFD solution* → *Structural analysis*

TD64 Constraints

- **Must have continuous access to capability, personnel, and codes**
  - Expertise cannot be confined to contractor (prime, support, software vendor)
- **Cannot afford numerous specialized codes**
  - Driven by maintenance (upgrades), training, quality-control considerations
  - Codes must be as general as possible to address broad range of problems
  - Specialized codes in certain high-volume areas or to fill gap temporarily
- **Funding is not consistently available**
  - License overhead competes with funding for technology development
- **Push-button CFD is not the goal for our organization**
  - Promotes lack of creativity, creates distance from our underpinning technology
  - As this becomes reality in specific areas, tools moved to non-cfd-specialist
- **In general cannot rely on industry wide trends to meet our need**
  - We have unique applications, represent a small market
  - Commercial products typically do not offer cost advantages for our needs
  - Computing environment and cost structure of software often incompatible
  - Pre- and post-processing software an exception (so far)

TD64 Design and Analysis Tools Development Areas

Needs	Rational	Activity
Automated viscous grid generation (hybrid grid)	Reduce labor, primary initial focus to support vehicle and thrust chamber, < 1 hr. labor per configuration	Initiating activity w/ MSU, participating in LaRC activity, Gridgen
Automated Chimera grid generation	Reduce labor, vehicle stage separation, quick delta to configurations, rotor-stator analyses; ability to deflect control surfaces	None, plan to participate in the CTK development
Quick turnaround vehicle analysis	Expand into preliminary design phase; less than 15 minutes per case, , capability to spawn parametric analyses; inlet, plume, drag, and aeroheating models, control surfaces	CART3D – Aftosmis, enhancement w/LaRC proposed
Fully coupled pump rotor-stator capability	Expand range of applications, most TP design shortcomings associated with rotating assembly dynamics, initial capability < 1 week per case	INS3D Development–Kiris; HAH3D demonstration; TASCflow; Corsair
Two-phase (cavitation) analysis capability	Expand range of applications, support pump design, all rocked pumps cavitate all the time, major impact on loads; cavitation inherently unsteady process	SBIR for developing empirical design tool, pre-evaluation of CFD codes
Automated, uni-element pump CFD analysis capability	Reduce labor, expand number of parametric cases analyzed, <15 minutes per case	In-house code 85% done, requires further work; TASCflow; Corsair
Improve turbulence closure	Expand range of applications, turbulence major driver in pump diffusers, RBCC ejectors, injector analysis, vehicle aerodynamics	Joe Oefelein LES model dev elopment

TD64 Design and Analysis Tools Development Areas

Needs	Rational	Activity
Expand turbine rotor-stator code to include secondary flows	Expand range of applications, coupling between primary and secondary flow path affects performance, cooling, loads; requires two-phase capability	CORSAIR being enhanced
Generalized grid flow solver w/ combustion, time accuracy, auto-grid refinement	Reduce labor and overall analysis time/cost, improve numerical accuracy (completely conservative), refinement based on flow features or model needs (i.e., y-plus); needed for multi-component analysis or viscous vehicle analysis w/ plume	Initial release being applied; combustion and auto grid refinement being implemented (SBIR)
Increased model fidelity & increase code speed for super-critical combustion	Apply CFD directly in the design process iterations, allow one finite-rate calculation with multiple injector elements per day	Activity being funded by ASTP program
Sub-critical combustion kinetics, especially for hydrocarbons	Expand range of applications, need for 2-phase, atomization, vaporization, combustion; necessary for injector & combustion chamber design	None active
Automated visualization & engineering data extraction	Reduce labor, large multi-species problems, hundreds of parametric cases, transient, multiple components, capability for automatic animation	In-house activity
Optimization technique	Expand range of applications, improve productivity, objective trade evaluation, make maximum use of available data, reduce # of cases that need to be run w/ trained neural network	Developing w/ U.F. and LaRC; TPO activity; 2nd Gen Injector task

TD64 Design and Analysis Tools Development Areas

Needs	Rational	Activity
Plasma flow physics	Expand range of applications, support evaluation of advanced propulsion & vehicle concepts (laser light craft, nuclear propulsion, etc.)	Developing capability into UNIC under program funding
Multi-disciplinary integrated analysis capability	Expand range of applications, reduce time and cost; seamless analysis capability from geometry generation to design drawing output	ISE/AEI funded activity w/LaRC, U.F., Rkdn. ★

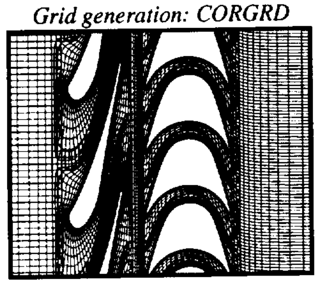
- **Activities in support of these needs generally tied to a hardware program**
  - SBIR, CDDF not tied, but require hardware need justification
  - Helps keep activities focused
  - Capabilities generally developed incrementally
- **Schedules determined by hardware needs**
- **End-user in charge**

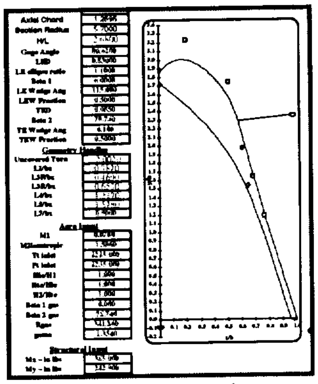
Turbine Dynamic Environments and Performance

- **Technology Need**
  - High power density of rocket engine turbines requires high-fidelity definition of the turbine environments
  - Large leverage on performance, development cost, and operational life
  - Supported in TD64 w/ CORSAIR and w/ test definition & support
- **Recent Activities**
  - Fastrac: parallelization, non-airfoil flow paths, supersonic turbine rotor-stator CFD
  - SSME on-rotor data tests: benchmark data for rotor-stator interaction
- **Present Activities**
  - RLV optimized turbine: automated design code, geometry generator, and solver, optimization applications for time-accurate analyses, 2D & 3D CFD design parametrics
  - Simplex turbine: partial admission turbine , additional boundary conditions and domain decomposition options
- **Future Activities**
  - Turbopump throttling tech.: 2-phase flow, automated visualization, radial turbines
  - Second Generation RLV Turbine dynamic environments (analysis and test)

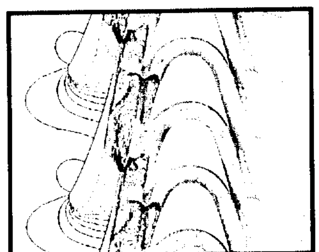
Turbine Dynamic Environments & Performance
Turbine Optimization Design and Analysis Procedure

Grid generation: CORGRD

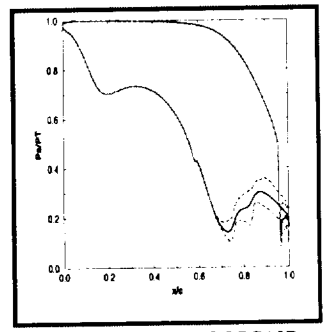




Geometry generation
Riverbend Design
(Frank Huber)



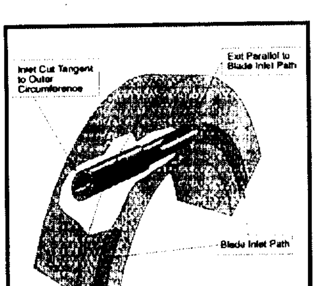
CFD analysis: WILDCAT/CORSAIR



Post processing: CORSAIR

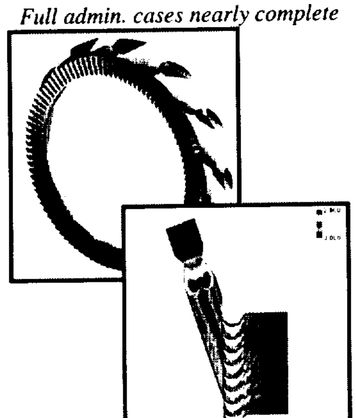
Expanding Corsair Capability Via Simplex Turbine

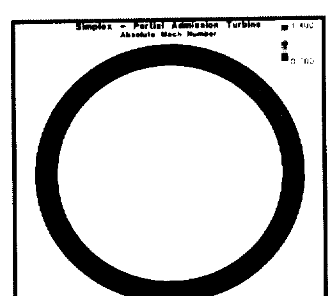
- **Generating loads for assessment of non-metallic blisk tested at MSFC on simplex turbopump**
- **Full admission and partial admission cases**
- **Expansion of corsair's domain decomposition utilities and b.C. Generalization**
  - Preparing for full annulus turbine analyses in support of second generation RLV



Simplex turbine nozzle configuration (TD61, TD62)

Full admin. cases nearly complete



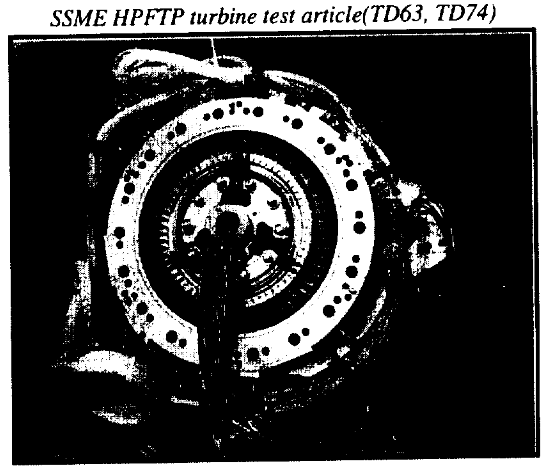


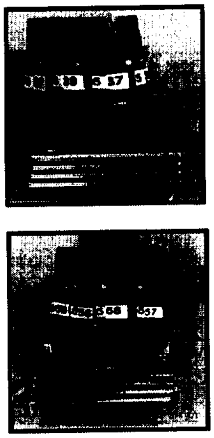
Partial admission case underway

On-blade High Frequency Pressure Measurements

- **SSME HPFTP turbine test article instrumented with on-blade Kulite pressure transducers**
- **Turbopump optimization task turbine (supersonic)**
- **Second generation RLV turbines**

SSME HPFTP turbine test article(TD63, TD74)



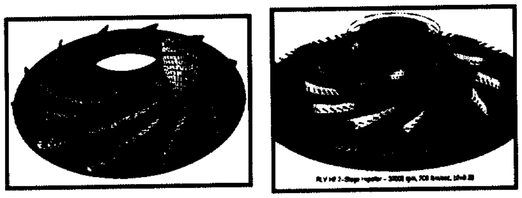


SSME HPFTP turbine test article - instrumented 1st blades

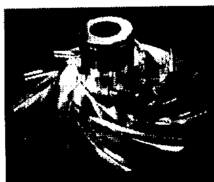
Pump Environments and Performance

- **Technology need**
  - High power density (high q) of rocket engine pumps requires high-fidelity definition of the pump environments
  - Large leverage on perf., Dev. Cost, operational life, & operational flexibility
  - Cavitating and non-cavitating dynamic environments
- **Recent activities**
  - Fastrac LOX pump baseline design inlet treatment tests and pump redesign
  - Adv. High-head unshrouded impeller design, baseline unshrouded impeller tests
- **Present activities**
  - Adv. High-head unshrouded impeller testing, TASCflow initial assessment
  - Inducer design code development and integration into pump design process
- **Future activities**
  - Introduction of pump rotor-stator CFD analysis into design process
  - Deep throttle TP technology CFD analysis and testing
  - Axial inlet inducer test rig tests (rotor loads, blade loads)
  - Second generation pump and inducer analysis and tests

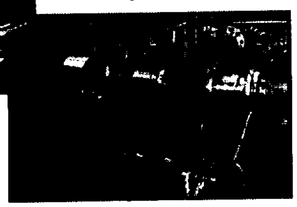
Pump Environments and Performance
RLV Focused Unshrouded Impeller Technology

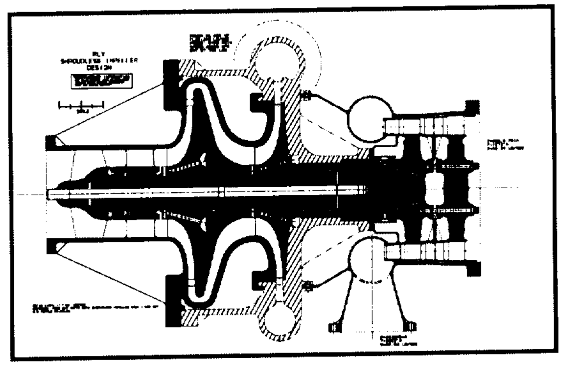


Automated geometry and grid generation template
Boeing-Rocketdyne



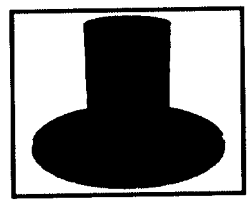
Unshrouded impeller water rig (TD63, TD74)





RLV turbopump concept, ~700 lb weight savings over baseline

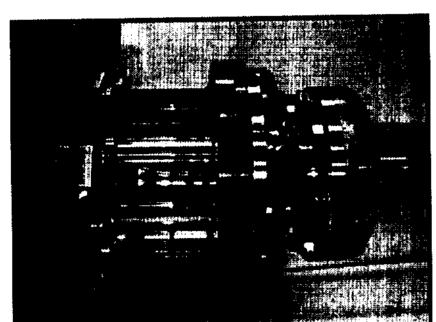
★ *Reference geometry for pump rotor-stator CFD capability development: Ames, GRC, AEA, TD64*



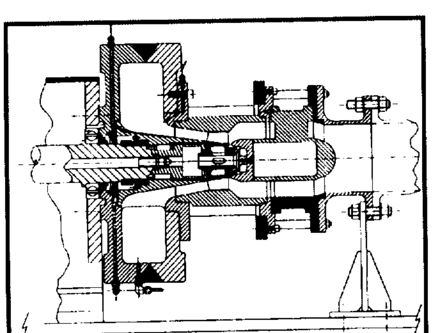
Pump Environments and Performance
Cavitation Testing

All cavitation work is experimental, leading to empirical models (TD62, TD63, TD74)

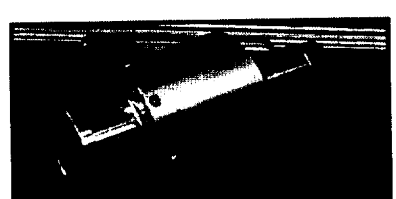
Inducer test loop Fastrac configuration



Axial inlet inducer test rig with Simplex inducer



Axial inlet inducer test rig cross-section



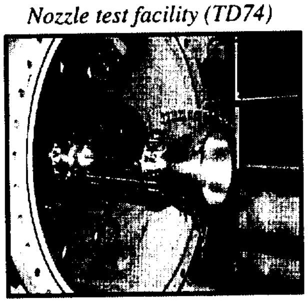
Rotating balance assembly

Altitude Compensating Nozzle (ACN) Technology

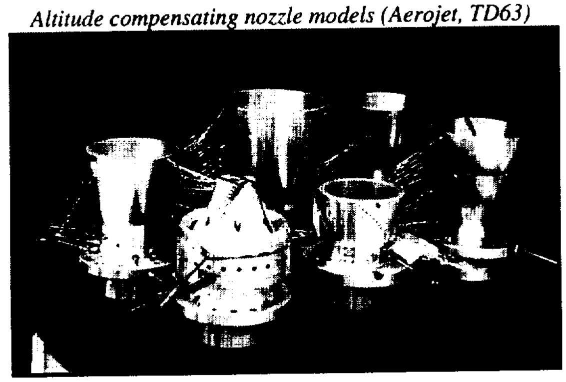
- **Technology need**
  - Altitude compensating nozzles (ACN) have promise of increased performance, packaging, and robustness over SOA nozzles
  - ACN design technology relatively immature
- **Recent activities**
  - RLV phase 1 ACN task with Aerojet, cold flow models
  - Development of automated grind generation module
  - RLV advanced ACN concept CFD analysis
- **Present activities**
  - RLV advanced ACN test rig design, manufacture, and test
  - CDDF for ACNs: design tools, test database, TVC technology
- **Future activities**
  - Perform ACN optimization for baseline vehicle
  - Cold flow and hot-fire testing of ACN concepts

Altitude Compensating Nozzle (ACN) Technology

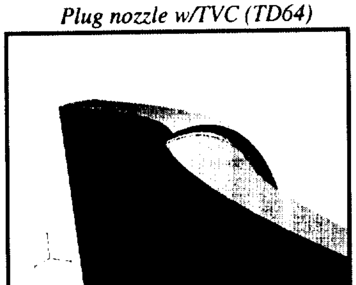
Nozzle test facility (TD74)



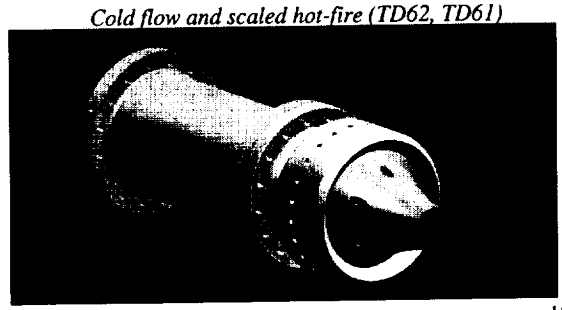
Altitude compensating nozzle models (Aerojet, TD63)



Plug nozzle w/TVC (TD64)



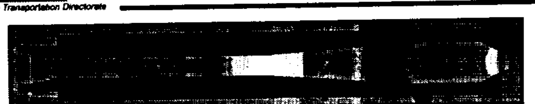
Cold flow and scaled hot-fire (TD62, TD61)



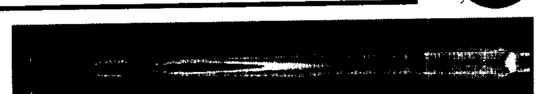
RBCC Propulsion Flow Path Design

- **Technology need**
  - Rocket based combined cycle (RBCC) engines offer potential large performance improvement over all-rocket concepts, potential for airline-like operations
  - Severe operational environments and performance sensitivities require high fidelity analysis penetration early in the design process
- **Recent activities**
  - DRACO RBCC concept assessment with FDNS
  - GTX initial nozzle concept analyses with FDNS
- **Present activities**
  - Benchmarks of FDNS with PSU data (single rocket in duct, O2-H2)
  - Beginning VULCAN from LaRC assessment
- **Future activities**
  - Expand benchmarks with PSU data (two rockets in a duct, hydrocarbon fuel)
  - Introduce generalized grid CFD solver (UNIC) into analysis of RBCC flow paths
  - Support consortium RBCC engine development

RBCC Propulsion Flow Path Design

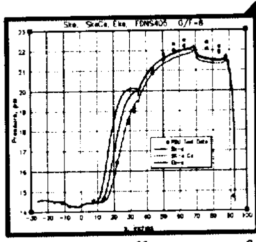


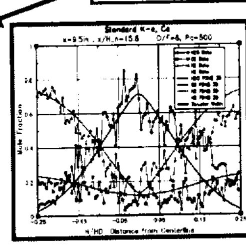
Pressure contours



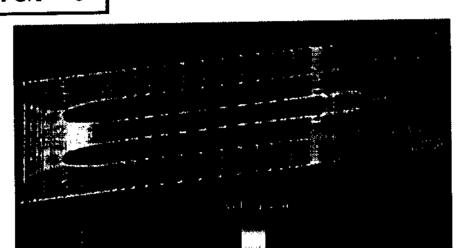
Mach # contours

Flow Solution for PSU rig at O/F = 8

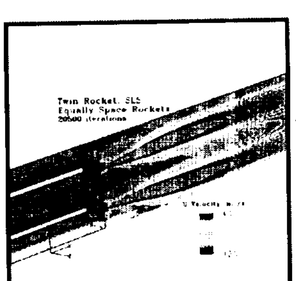




Top wall pressure & specie concentrations

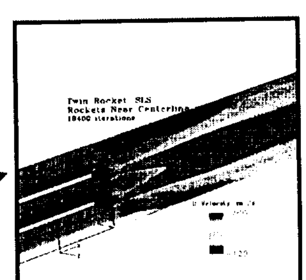


Dual rocket testing: close spacing



Separations in duct with rockets equally spaced

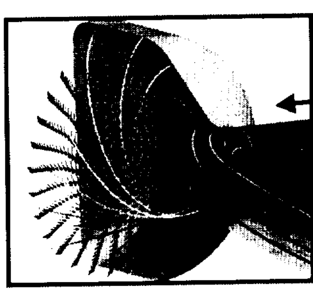
Separations in duct with rockets close together



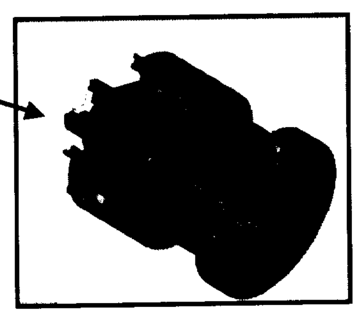
Long-life Combustion Devices Technology

- **Technology need**
  - Contemporary rocket engine combustion devices similar to 1960s-1970s designs
  - Longer life (robust), higher T/W designs required
  - Improved analytical models required to impact development & operational costs
- **Recent activities**
  - Gas-gas injector technology: concepts, testing, benchmarks
  - Led to CDDF on optimization techniques
  - Improved RP-1 kinetics model developed to support Fastrac engine analysis
- **Present activities**
  - Vortex chamber concept development
  - "Real-fluids" model, improved parallelization efficiency for FDNS (SECA & ESI)
  - Highly throttleable injector concept development (PSU)
- **Future activities**
  - Develop cfd-based injector optimization capability
  - Second generation RLV injector optimization, combustion devices testbed

Long-life Combustion Devices Technology

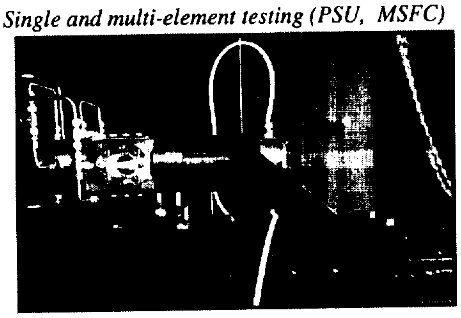


Vortex chamber impinging injector concept, initial test configuration TD61, TD62, TD64

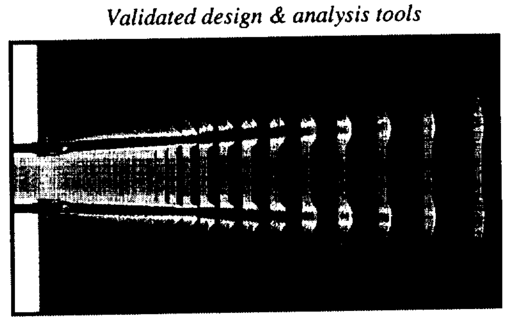


NASA-led second generation injector design and concepts technology

Single and multi-element testing (PSU, MSFC)



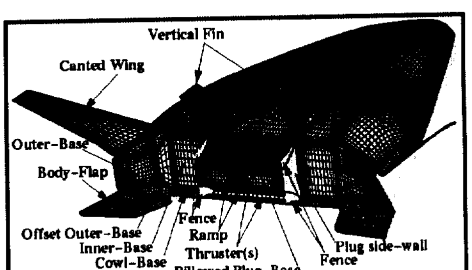
Validated design & analysis tools

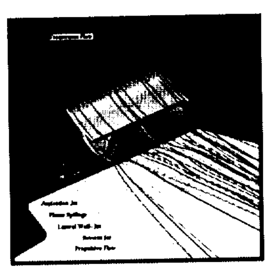


Propulsion-vehicle Integration

- **Technology need**
  - SOA vehicle concepts require a high level of propulsion-to-airframe integration
  - Air-breathers (RBCC or TBCC), parallel-burn multi-stages
  - Installed performance, induced environments, control, safety (abort, separation)
- **Recent activities**
  - X-33 base heating environments: development of radiation code, addition of embedded grip capability into FDNS
  - Assessment of CART3D: Euler, Cartesian code from ARC
- **Present activities**
  - Laser lightcraft concept development: real gas effects (high temperature)
  - SBIR base heating (UNIC): generalized grid solver, automated grid refinement, automated domain decomposition, coupled radiation heating calculations
- **Future activities**
  - Enhance CART3D with propulsion, heating, and drag models
  - Apply UNIC to X-43B and 2nd gen reference configuration
  - Develop automated grid generation templates

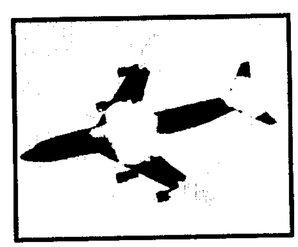
Propulsion-vehicle Integration



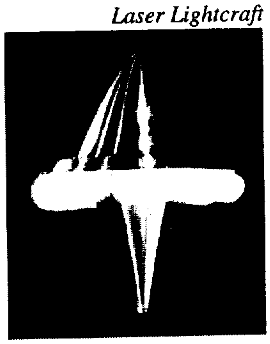


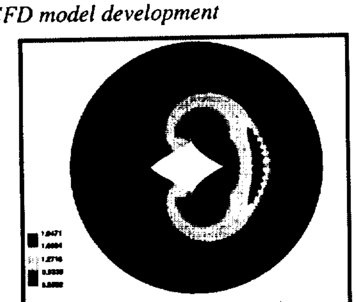
Complex geometry+ complex physics = labor intensive structured grids

Generalized grid CFD solver development: automated domain decomposition

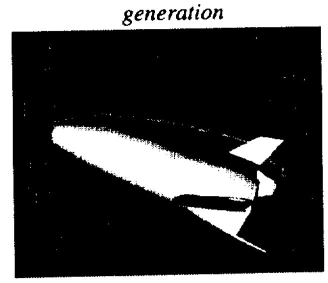


Laser Lightcraft CFD model development



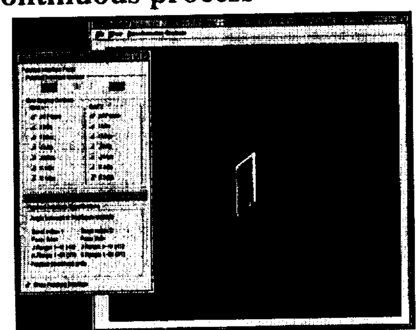


Potential for automated grid generation

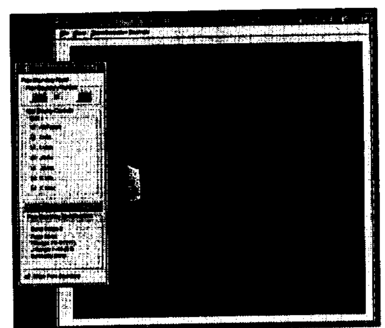


CFD Process Improvements (Tool-to-tool)

- **Tendency towards greater CFD based design parametrics**
  - Enabled by inexpensive "super-computers"
- **Reducing labor requirements is key increased efficiency**
- **Dedicated personnel for internal process improvement**
  - Provide customized utilities for group members (process)
  - Create or improve labor reducing GUIs for CFD process
  - Integrate hardware specific templates (turbine codes, injector codes, nozzle etc.)
  - Develop visualization technology for pre- and post-processing (Previewer)
- **Continuous process**



Patched Interface Panel



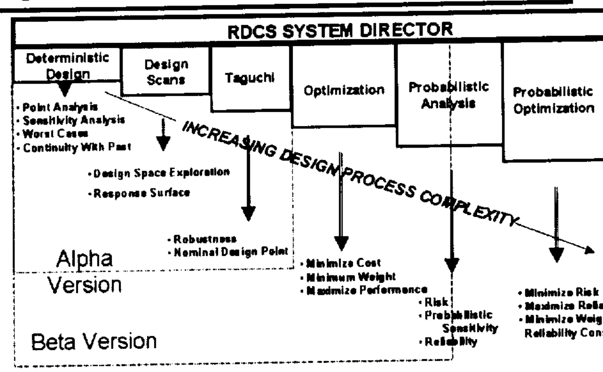
Flow Boundary Panel

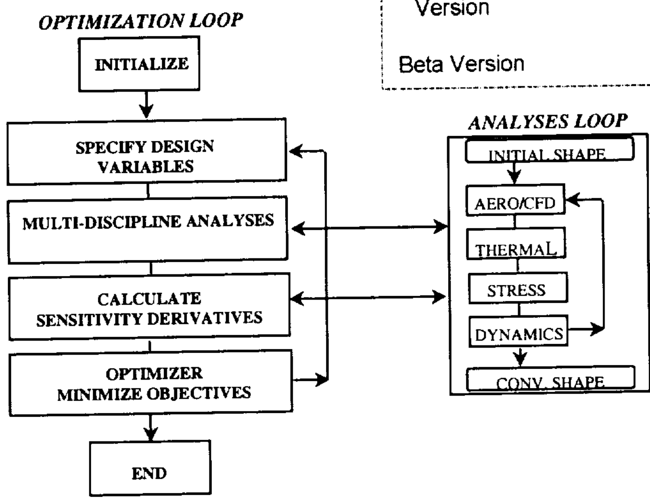
MDA/MDO Development

- **Technology need**
  - Engineering and re-engineering major portion of development cost
  - Transfer of data among disciplines becoming clog in the design process
  - Significant portion of failures are multi-disciplinary in nature
  - Subsystem and system optimization requires a multi-disciplinary approach
- **Recent activities**
  - Fastrac design experience: reinforced shortcoming of traditional design process
  - RRTT and NRA 8-15 turbopump and combustion devices: Rocketdyne demonstrated advantage of 1-way coupling of design & analysis tools
- **Present activities**
  - Activity with Rocketdyne for MDO & IDA technology
  - Initial focus on RBCC flow path, assessment of RDCS
- **Future activities**
  - Develop loci for MDA & for CFD methodology development framework (SSC, MSU)
  - Assess RDCS as framework for high fidelity MDA (pumps and turbines)

MDA/MDO Development
Boeing RDCS With an IDA

- *Large investment by Boeing*
- *60-70% of TD64 effort is direct partnership(critical path) w/ industry*

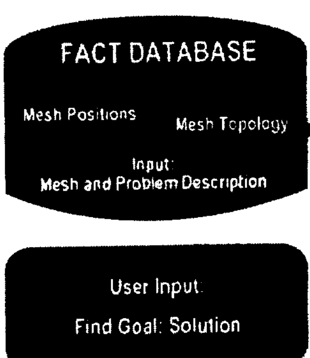


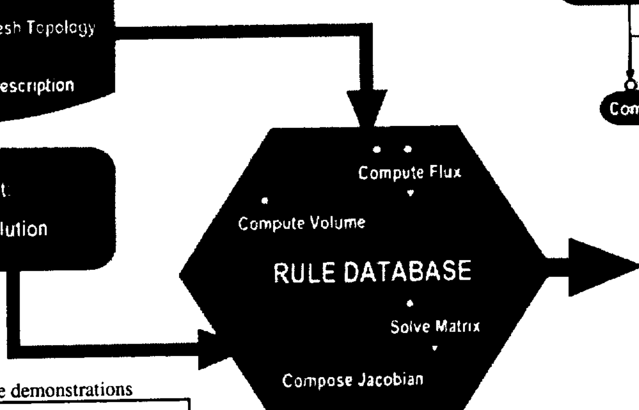


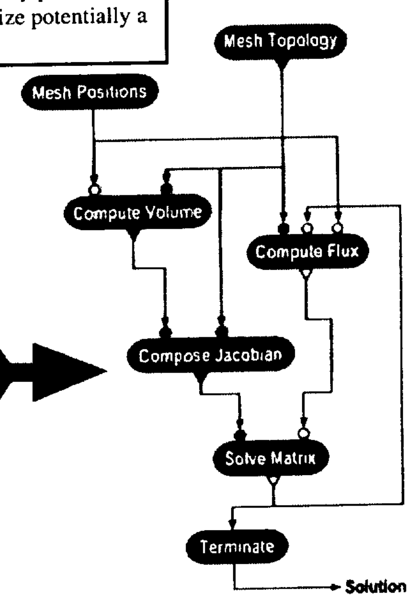
- *This module largely exists*
- *Expected to be primary near term benefit*
- *Maintenance largest concern*

MDA/MDO Development
LOCI, Ed Luke, MSU

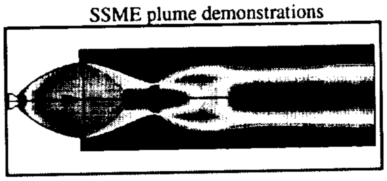
- Conceptually very sound
- Initial single discipline demonstrations very positive
- May require large investment to synthesize potentially a large population of algorithms







SSME plume demonstrations



Conclusion

- **TD64 focused on supporting the space transportation programs**
  - Strategically located in the organization
  - Access to computing and testing facilities
  - Tool developments driven by hardware design needs
- **Design and analysis tools under development in the major applications area**
  - Turbines, pumps, propulsion-to-airframe integration, combustion devices
- **Increasing the design process efficiency**
- **Expanding the range of applicability of the high fidelity tools**
- **Initial focus of MDA activities to establish connectivity across disciplines**
  - Fluids a support element in the system model
- **Prepared to support next generation of launch vehicle developments**