N91-10843

Marshall Space Flight Center CFD Overview

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Computational Fluid Dynamics (CFD) activities at Marshall Space Flight Center (MSFC) have been focused on hardware specific and research applications with strong emphasis upon benchmark validation. The purpose of this overview is to provide insight into the MSFC CFD related goals, objectives, current hardware related CFD activities, propulsion CFD research efforts and validation program, future near-term CFD hardware related programs, and CFD expectations. The current hardware programs where CFD has been successfully applied are the Space Shuttle Main Engines (SSME), Alternate Turbopump Development (ATD), and Aeroassist Flight Experiment (AFE). For the future near-term CFD hardware related activities, plans are being developed that address the implementation of CFD into the early design stages of the Space Transportation Main Engine (STME), Space Transportation Booster Engine (STBE), and the Environmental Control And Life Support System (ECLSS) for the Space Station. Finally, CFD expectations in the design environment will be delineated.

MARSHALL SPACE FLIGHT CENTER CFD
OVERVIEW

- COMPUTATIONAL FLUID DYNAMICS BRANCH ACTIVITIES
  - OBJECTIVES
  - INTERACTION
  - APPROACH TOWARD SOLUTIONS OF COMPLEX FLOWS
- MSFC HARDWARE RELATED ACTIVITIES
  - INHOUSE
  - ROCKETDYNE - SSME
  - PRATT AND WHITNEY - ATD
- NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM
  - PROGRAM DEFINITION
  - WORK ELEMENT SUMMARY; CFD EMPHASIS
  - EXPERIMENTAL APPARATUS
  - CONSORTIUM
- NEW NEAR TERM CFD ACTIVITIES
  - ADVANCED LAUNCH SYSTEM, ALS
  - ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM, ECLSS
- CFD EXPECTATIONS

5-1536-9-105

COMPUTATIONAL FLUID DYNAMICS BRANCH ACTIVITIES

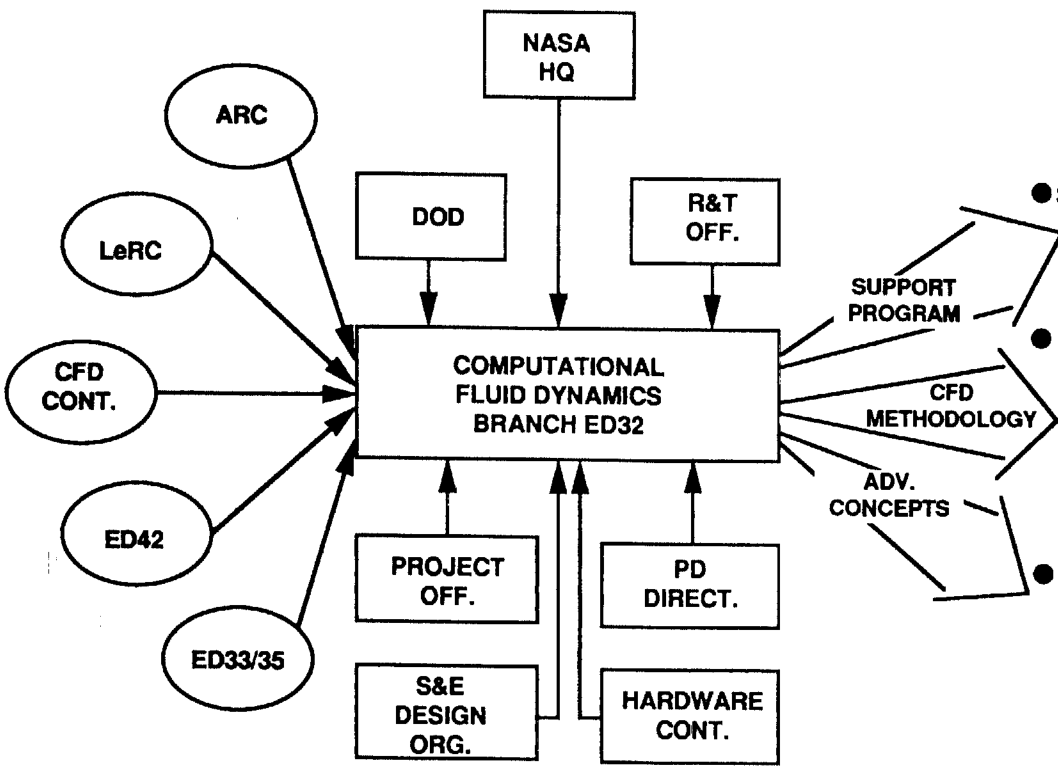
OBJECTIVES

- SUPPORT PROGRAM OFFICES
  - "QUICK TURNAROUND" APPLICATIONS
  - INTERACT WITH HARDWARE CONTRACTORS IN DEVELOPMENT OF DESIGN ENVIRONMENTS
  - PROVIDE "SMART BUYER" CAPABILITY FOR LONG-TERM APPLICATIONS
  - DEVELOP SUBSYSTEMS CFD MODELS
  - FOCUS MSFC CFD ACTIVITIES/PROVIDE CENTERWIDE CFD SUPPORT
- FOCUS DEVELOPMENT OF CFD METHODOLOGY
  - INTERACT WITH ARC, LeRC, LaRC, AND OTHER RESEARCH ORGANIZATIONS TO FOCUS TECHNOLOGY DEVELOPMENT TOWARDS MSFC HARDWARE RELATED PROBLEMS
  - DEVELOP REQUIREMENTS FOR CFD CODE VERIFICATION
  - VERIFY CODES THROUGH BENCHMARK COMPARISONS
  - ADVANCE CFD TECHNOLOGY FOR APPLICATIONS
- DEVELOP ADVANCED HARDWARE TECHNOLOGY CONCEPTS
  - TURBINE STAGE
  - IMPELLER STAGE
  - NOZZLES, PREBURNERS, ETC.

5-1009-8-16

COMPUTATIONAL FLUID DYNAMICS BRANCH ACTIVITIES

ORGANIZATIONAL INTERACTIONS AND UNIQUE CFD RESOURCES CAPABILITY



- SUBSYSTEMS MODELS FOR APPLICATIONS
  - "QUICK TURNAROUND" APPLICATIONS
  - "SMART BUYER" CAPABILITY
  - INTERACT WITH HARDWARE CONTRACTORS
- BENCHMARKED CODES AND SUPPORT
  - FOCUS NATIONAL CFD ACTIVITIES
  - FOCUS MSFC CFD ACTIVITIES
  - REQUIREMENTS FOR CODE VERIFICATION
  - BENCHMARK COMPARISONS
  - TECHNOLOGY TRANSFER IN MSFC
  - ADVANCED CFD TECHNOLOGY
- ADVANCED DESIGN TOOLS
  - AFE
  - TURBINE/IMPELLER STAGES
  - BORE/JOINT FLOW MODELS

5-3344-8-26

COMPUTATIONAL FLUID DYNAMICS BRANCH ACTIVITIES

CFD CROSS FERTILIZATION

BASIC RESEARCH	APPLIED CFD	ENGINEERING ANALYSIS
— ALGORITHM DEVELOPMENT	— LIBRARY OF CODES	— PARAMETRIC STUDIES
— NUMERICAL METHODS	— BENCHMARK VALIDATION	— HARDWARE OPTIMIZATION
— GRID GENERATION	— DESIGN CODES FROM VARIOUS SOURCES	— PERFORMANCE OPTIMIZATION
— ADAPTIVE GRIDS	— DEVELOP DESIGN CODES	— ANOMALY INVESTIGATION
— CODE DEVELOPMENT	— DEVELOP CRITERIA TO ASSESS CODES	— SYSTEM DESIGN
— FLOW PROCESS MODELING	— EVALUATE ADVANCED HARDWARE TECHNOLOGY CONCEPTS	— DESIGN ASSESSMENT
— ADVANCED COMPUTER SYSTEMS		
ARC, LeRC, LaRC ↔	MSFC ↔	MSFC

5-1010-8-16

COMPUTATIONAL FLUID DYNAMICS BRANCH ACTIVITIES

APPROACH TOWARD SOLUTIONS OF COMPLEX FLOWS

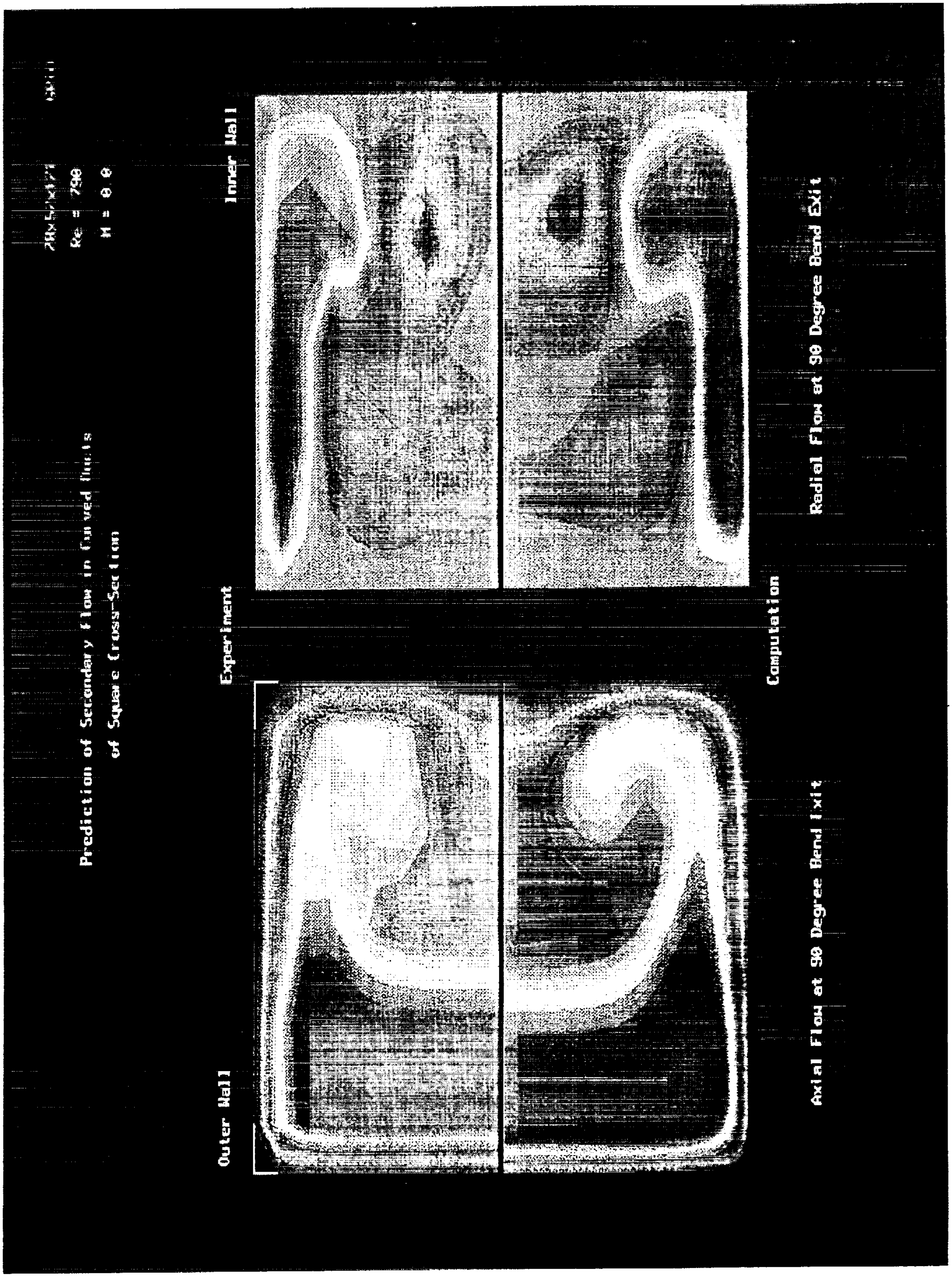
- DEVELOP DATA BASE
  - LITERATURE SEARCH
  - COLLATE RELEVANT EXPERIMENTAL RESULTS
  - IDENTIFY SIGNIFICANT PARAMETERS, SCALING LAWS
  - DEFINE REQUIREMENTS FOR BENCHMARK EXPERIMENTS
- PERFORM FUNDAMENTAL ENGINEERING ANALYSIS
  - SIMPLIFIED 1-D OR 2-D ANALYSES
  - ELEMENTARY SENSITIVITY ANALYSIS
- PERFORM CFD CALCULATIONS
  - EXERCISE BENCHMARKED STATE-OF-THE-ART CODES
  - IMPLEMENT STATE-OF-THE-ART FLOW PROCESS MODELS

5-1014-8-16

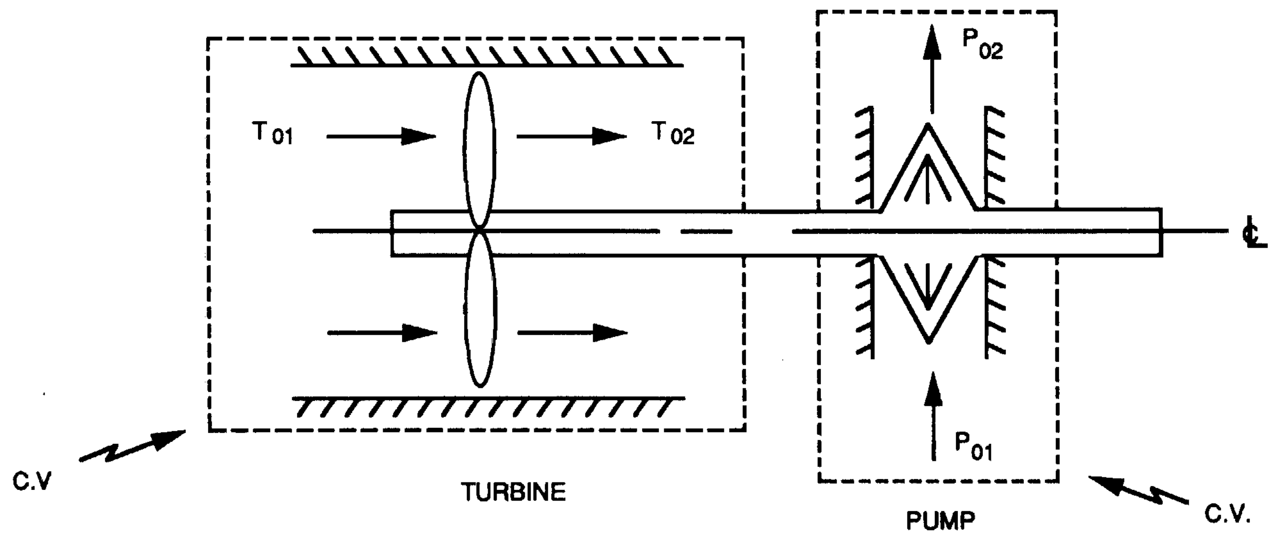
PREDICTION OF SECONDARY FLOW IN CURVED DUCTS OF SQUARE CROSS-SECTION

OBJECTIVE:	TO VERIFY NAVIER-STOKES CODES FOR THE ACCURATE PREDICTION OF SECONDARY FLOW IN CURVED DUCTS
APPROACH:	APPLICATIONS OF A 3-D INCOMPRESSIBLE NAVIER-STOKES CODE (INS3D) TO FLOW IN A 90° AND 180° BEND AND A 22.5° S-DUCT OF SQUARE CROSS-SECTION (25000, 50000, 100000, AND 175000 GRID POINTS); COMPARE PREDICTIONS TO LDV MEASUREMENTS
COMPUTER RESOURCES REQUIRED:	2 TO 6 MW STORAGE ON A CRAY X-MP; 3/4 HOUR RUN TIME ON CRAY X-MP FOR THE 10^5 GRID POINT CASES
IMPACT:	VERIFICATION OF INCOMPRESSIBLE NAVIER-STOKES CODE FOR THE PREDICTION OF SECONDARY FLOWS IN COMPLEX INTERNAL FLOW FIELDS

5-1287-9-88


Prediction of Secondary Flow in Curved Ducts
of Square Cross-Section
Re = 790
Outer Wall
Inner Wall
Experiment
Computation
Axial Flow at 90 Degree Bend Exit
Radial Flow at 90 Degree Bend Exit

TURBOPUMP DESIGN EQUATIONS



$$P_{02} - P_{01} = \eta_t \eta_p \frac{\dot{m}_t}{\dot{m}_p} \rho_p \left(T_{01} - T_{02}\right) C_P$$

5-714-8-20

MSFC HARDWARE RELATED ACTIVITIES

INHOUSE PROGRAM SUPPORTING ACTIVITIES

		INHOUSE	CONT.
SSME	→ ● HPFTP TURBINE BLADES	X	
	● SINGLE CRYSTAL HOLLOW CORE TURBINE BLADES		X
	● TURBINE DISK CAVITIES	X	
	→ ● LOX PUMP BEARING INLET CAVITY	X	
	● LOX PUMP BEARINGS		X
	● FUEL PREBURNER	X	
	● LOX PREBURNER	X	
	● LOX MANIFOLD TEE (4000 Hz)	X	X
	● HOT GAS MANIFOLD/MANIFOLD STRUTS	X	X
	● PUMP COOLANT FLOW PATHS	X	
	● NOZZLE/MCC MISMATCH	X	X
	→ ● HPOTP NOZZLE PLUG TRAJECTORIES	X	X
	● TRANSIENT BEHAVIOR OF FUEL PREBURNER MANIFOLD		X
	● UTRC HPFTP COOLANT FLOW EXPERIMENT		X
	● BEARING DEFLECTOMETER (TTBE)	X	
ATD	● TURBINE INLET TEMP. REDISTRIBUTION		X
	● TURBINE TEMP. PROFILE REDISTRIBUTION		X
	● ROTOR-STATOR INTERACTION		X
	● TURNAROUND DUCT AND HOT GAS MANIFOLD	X	X
	● BEARING ANALYSIS		X
	● LOX PUMP INLET SCROLL		X
	● FUEL PUMP INTERSTAGE CROSSOVER DUCTS		X
	● FUEL PUMP INLET SCROLL		X
	● LOX PUMP DISCHARGE VOLUTE		X
	● SEALS		X
SRB	● BORE FLOW		
	—CANTED NOZZLE	X	X
	—BROKEN INHIBITOR		X
	→ ● FIELD JOINT		
	—FLOW AND THERMAL TRANSIENT	X	X
	—PRESSURIZATION TRANSIENT	X	X
	→ ● NOZZLE-TO-CASE JOINT		
	—FLOW AND THERMAL TRANSIENT	X	X
	—PRESSURIZATION TRANSIENT	X	X

5-1995-8-43

MSFC HARDWARE RELATED ACTIVITIES

INHOUSE PROGRAM SUPPORTING ACTIVITIES (CONTINUED)

		INHOUSE	CONT.
AFE	● AEROTHERMAL ENVIRONMENTS		
	→ — DSMC	X	
	— NS	X	X
SPACE STATION	● CONTAMINATION	X	
	● ECLSS	X	X
ADVANCED PROGRAM DEVELOPMENT	● EXTERNAL TANK GAMMA RAY IMAGING TELESCOPE	X	

5-2599-8-41

MSFC HARDWARE RELATED ACTIVITIES
ROCKETDYNE APPLICATION OF CFD TO SSME

TURBOMACHINERY	CODE
HPFTP IMPELLER CAVITY	STEP
HPOTP P/B BEARING DISCH CAVITY	STEP
HPOTP TURBINE END BRG DISCH CAVITY	STEP
HPOTP 2ND STG TURBINE NOZZLE	REACT 2D
HPFTP 1ST STG TURBINE DISK CAVITY	STEP
HPOTP TURBINE END BRG FLOOD COOL	STEP
HPOTP R/S INTERACTION	ROTOR
HPFTP TURBINE DISK CAVITIES	REACT 2D
HPFTP 2ND STG TURBINE DISK CAVITY/DIVERTER	STEP
SC/HC 2ND STG TURBINE DISK CAVITY DIVERTER	STEP
ROUGH SURFACE SEAL FLOW	REACT 2D
SC/HC 1ST STG TURBINE	REACT 2D
HPFTP 1ST STG TURBINE	REACT 2D
SC/HC 1ST STG TURBINE	REACT 3D
HPFTP 1ST STG TURBINE	REACT 3D
SC/HC 1ST STG TURBINE R/S	ROTOR
HPFTP 1ST STG TURBINE R/S	ROTOR
HPOTP 1ST STG TURBINE R/S	ROTOR
LPOTP 4TH STG TURBINE R/S	ROTOR
HPOTP IMPELLER-DIFFUSER UNSTEADY	ROTOR
HPOTP BRG FLOWFIELD	REACT 3D
HPFTP 1ST STG TURBINE W/STRUTS	REACT 3D
HPOTP IMPELLER	REACT 3D
HPOTP 1ST STAGE TURBINE W/STRUTS	REACT 3D
HPOTP P/B DIFFUSER	REACT 2D/3D
T/P HARDWARE DEVIATION SENSITIVITIES TO REDUCE MR'S	REACT 2D/3D

NONTURBOMACHINERY	CODE
HOT GAS MANIFOLD	INS3D
FUEL-SIDE	
2-DUCT TURBULENT	
3-DUCT TURBULENT	
OXIDIZER-SIDE	
AXISYMMETRIC	
3D	
COMBINED HGM	INS3D
MAIN INJECTOR	REACT3D
FLUCTUATING PRESSURE & DYNAMIC LOADING	
NOZZLE	
MCC/NOZZLE MISMATCH	USA
NOZZLE TRANSIENT AND OPERATION	USA
4KHZ RESONANCE	USA
TEST BED LOX FLOWMETER	STEP

5-1539-9-105

MSFC HARDWARE RELATED ACTIVITIES
PRATT AND WHITNEY APPLICATION OF CFD TO ATD

- MOTIVATION
  - DESIGN VERIFICATION
    - CFD ANALYSIS OF CRITICAL FLOWPATHS IN SSME TURBOPUMPS
    - IDENTIFY POTENTIAL FLOWFIELD NONUNIFORMITIES, REGIONS OF SEPARATED FLOWS
    - PROVIDE DETAILED FLOW DATA TO MECHANICAL DESIGN GROUPS FOR ADDITIONAL STRUCTURAL, THERMAL ANALYSES
  - ANALYTICAL SUPPORT
    - WHERE NECESSARY, PERFORM FUNDAMENTAL CFD RESEARCH TO SUPPORT THE DESIGN VERIFICATION PROCESS
    - INCORPORATE THESE IMPROVEMENTS INTO THE DESIGN DECKS

5-1537-9-105

MSFC HARDWARE RELATED ACTIVITIES
PRATT AND WHITNEY APPLICATION OF CFD TO ATD

- ACCOMPLISHMENTS
  - ANALYZED COMPLETE HOT GAS FLOW PATH
  - PROVIDED TURBINE INLET CONDITIONS
  - PROVIDED STRUT PRESSURE LOADS FOR MECH DESIGN
  - TAD CALCULATIONS RESULTED IN SUBSTANTIAL REDUCTION IN INSTRUMENTATION
  - CFD MODELS OF TAD-HGM, LOX PUMP INLET, PREBURNER AND FUEL PUMP CROSSOVER DUCTS READY FOR HOT TEST SUPPORT
  - TURBULENCE MODEL SELECTED FOR COMPLEX DUCT FLOWS
  - ARICC SUBSTANTIALLY UPGRADED
  - CAD TO CFD CAPABILITY IMPLEMENTED
  - 2 D INVISCID ROTOR-STATOR INTERACTION CAPABILITY DEVELOPED AND DEMONSTRATED

5-1538-9-105

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

PROGRAM DEFINITION

- TECHNOLOGY ACQUISITION PHASE
  - SEEKS IMPROVED UNDERSTANDING OF THE BASIC CHEMICAL AND PHYSICAL PROCESSES OF PROPULSION
  - DEVELOPS ANALYSIS METHODS, DESIGN MODELS, AND CODES USING ANALYTICAL TECHNIQUES SUPPORTED BY EMPIRICAL LABORATORY DATA AS REQUIRED
  - RESULTS ARE OBTAINED THROUGH TEN DISCIPLINE WORKING GROUPS

- BEARINGS
- STRUCTURAL DYNAMICS
- TURBOMACHINERY √
- FATIGUE/FRACTURE/LIFE
- IGNITION/COMBUSTION √
- FLUID & GAS DYNAMICS √
- INSTRUMENTATION
- CONTROLS
- MANUFACTURING/PRODUCIBILITY/INSPECTION
- MATERIALS

5-1543-9-105

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM
PROGRAM DEFINITION

- LARGE SCALE SUBSYSTEM TECHNOLOGY VALIDATION
  - VALIDATES TECHNOLOGY EMANATING FROM THE ACQUISITION PHASE AT THE LARGE SCALE COMPONENT OR SUBSYSTEM LEVEL
  - THREE CATEGORIES OF EFFORT
    - LARGE SCALE COMBUSTORS √
    - LARGE SCALE TURBOMACHINERY √
    - CONTROLS AND HEALTH MONITORING
- TECHNOLOGY TEST BED VALIDATION
  - VALIDATES TECHNOLOGY EMANATING FROM THE ACQUISITION PHASE AT THE ENGINE SYSTEM LEVEL
  - THREE CATEGORIES OF EFFORT
    - COMBUSTORS √
    - TURBOMACHINERY √
    - CONTROLS AND HEALTH MONITORING

5-1540-9-105

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM
WORK ELEMENT SUMMARY

- TECHNOLOGY ACQUISITION

G2	TURBINE DRIVE COMBUSTOR DESIGN
G29	TTB COMBUSTION MODELS
G31	COMBUSTION CODE ENHANCEMENTS
G32	COMBUSTION STABILITY CODE
G33	TURBULENCE MODELS FOR COMB. ANALYSIS
G39	ERE PREDICTION METHODS
H6	FLUID STRUCTURE INTERACTION
H16	VERIFICATION OF INTERNAL FLOW ANALYSIS IN 3D GEOMETRIES
H19	EVALUATION CRITERIA FOR INTERNAL FLOW CFD NUMERICAL MODELING
H22	ADAPTIVE COMPUTATIONAL METHOD FOR HIGH REYNOLDS NUMBER INTERNAL FLOWS IN ADVANCED PROPULSION SYSTEMS
H23	DEVELOPMENT OF CONVERGENCE ACCELERATION TECHNIQUES FOR ALGORITHMS APPLIED TO COMPLEX 3D INTERNAL FLOWS
H35	ADVANCED INS3D CFD CODE
H36	CFD CONSORTIUM

- LARGE SCALE SUBSYSTEM TECHNOLOGY VALIDATION

LSVT1	EXP. VER. OF CFD TURB. STAGE DESIGN
LSVT4	HI PRESS TURBOMACHINERY SYS. VALIDATION
LSVT5	3D TURBOPUMP FLOWFIELD
LSVT6	EXP. VER. OF IMPELLER STAGE DESIGN
LSVT10	MEASUREMENTS IN MULTI ELEMENT INJECTOR
LSVT12	CFD TURNAROUND DUCT DESIGN VALIDATION

5-1542-9-105

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

WORK ELEMENT SUMMARY (CONTINUED)

- TECHNOLOGY TEST BED VALIDATION

-TBVC4	INJECTOR DIAGNOSTICS
-TBVC1	IMPROVED HPOTP PREBURNER PUMP
-TBVT2	ENHANCED ROTOR CODES
-TBVT3	IMPROVED BEARING COOLANT PATH
-TBVT5	WATER FLOW MODELS
-TBVT8	HGM FUEL SIDE ANALYSIS
-TBVT9	CFD DATA REDUCTION HARDWARE
-TBVT10	HPOTP JET COOLANT RING
-TBVT13	PREBURNER DOME FILLING FLOW ANALYSIS
-TBVT24	TURBINE STAGE CFD ANALYSIS AND DATA BASE FOR UNSTEADY AERO/HEAT TRANSFER
-TBVT25	DEV. OF UNSTEADY AERO HEAT/TRANSFER EXPERIMENTS DATA BASE FOR AXIAL TURBINE STAGES
-TBVT26	ADVANCED AXIAL TURBINE STAGE DESIGN METHODS
-TBVT27	ADVANCED IMPELLER DESIGN METHODS
-TBVT28	CFD ANALYSIS OF BSMT
-TBVT29	UTRC ROTOR/STATOR HEAT/TRANSFER

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NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

CONSORTIUM OBJECTIVES

- FOCUS CFD APPLICATIONS IN PROPULSION
  - TECHNOLOGY ACQUISITION PHASE
    - DIRECT BASELINE PROGRAM TOWARDS IMPROVED ACCURACY, STABILITY, AND EFFICIENCY
  - LARGE SCALE SUBSYSTEM TECHNOLOGY VALIDATION
    - STIMULATE CFD VALIDATION TOWARDS PROPULSION FLOWS
    - DIRECT APPLICATIONS CODES TOWARD DESIGN TOOLS AND ADVANCED HARDWARE TECHNOLOGY CONCEPTS
- IDENTIFY NATIONAL CFD PROPULSION REQUIREMENTS
- STIMULATE A FORUM FOR GOVERNMENT, INDUSTRY, AND UNIVERSITY INTERACTIONS
- ENCOURAGE INDUSTRY TO PARTICIPATE IN CFD DEVELOPMENT WITH IRAD FUNDS
- PROVIDE SYNERGISM IN THE CFD COMMUNITY
- PROVIDE PEER REVIEW OF CFD PROGRAMS

5-794-8-24

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

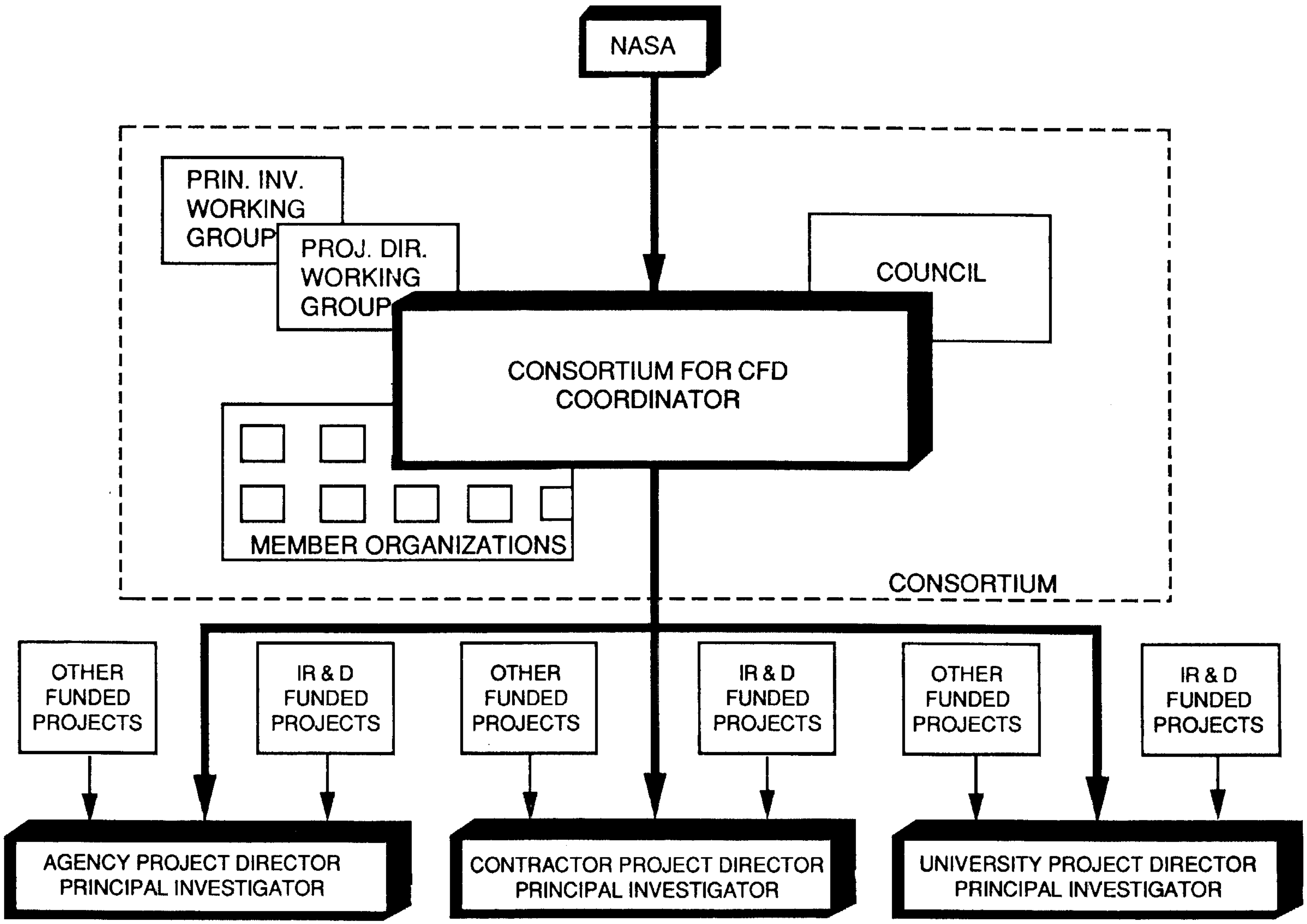
CONSORTIUM TASKS

- DEVELOP A PLAN TO APPLY CFD TO CURRENT AND FUTURE PROPULSION SYSTEMS
  - IDENTIFY AND RANK CRITICAL FLOW PROBLEMS RELATED TO PROPULSION SYSTEMS
  - IDENTIFY NATIONAL CFD RELATED RESOURCES
  - DEFINE HIGH PERFORMANCE COMPUTING REQUIREMENTS TO ACCOMPLISH CFD FOR PROPULSION APPLICATIONS
- DIRECT CFD TECHNOLOGY DEVELOPMENT TO PROPULSION APPLICATIONS
- ASSESS AND VALIDATE CFD APPLICATIONS IN PROPULSION SYSTEMS
  - DEVELOP EVALUATION CRITERIA
  - DEFINE AND IMPLEMENT BENCHMARK VALIDATION
  - DEFINE AND IMPLEMENT VALIDATION TESTS
- DIRECT THE APPLICATION OF CFD DESIGN TOOLS TOWARDS ADVANCED HARDWARE TECHNOLOGY CONCEPTS
- ACCELERATE THE TRANSFER OF CFD TECHNOLOGY FROM UNIVERSITIES AND RESEARCH CENTERS TO INDUSTRY AND HARDWARE DEVELOPMENT CENTERS

5-795-8-24

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

CONSORTIUM ORGANIZATIONAL STRUCTURE

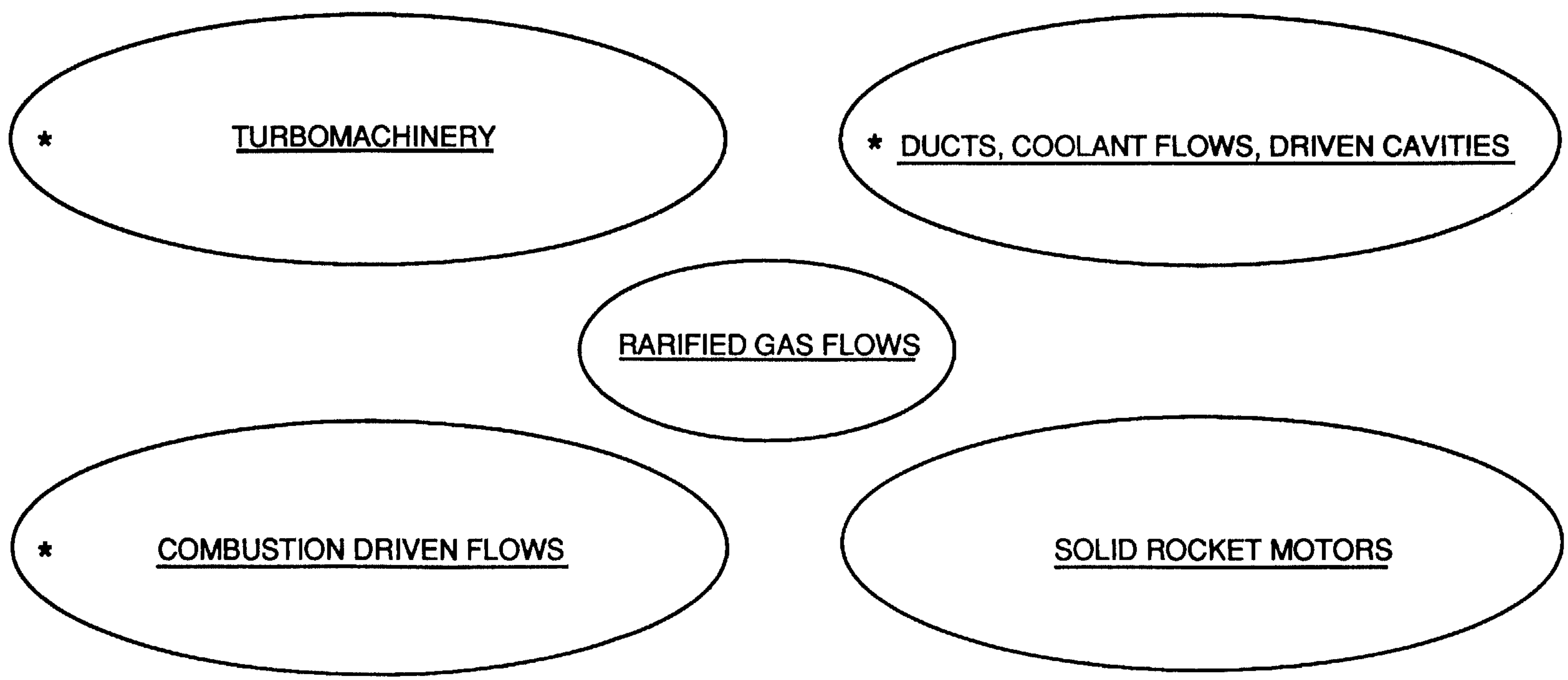


5-799-8-24

NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAM

CONSORTIUM TEAMING

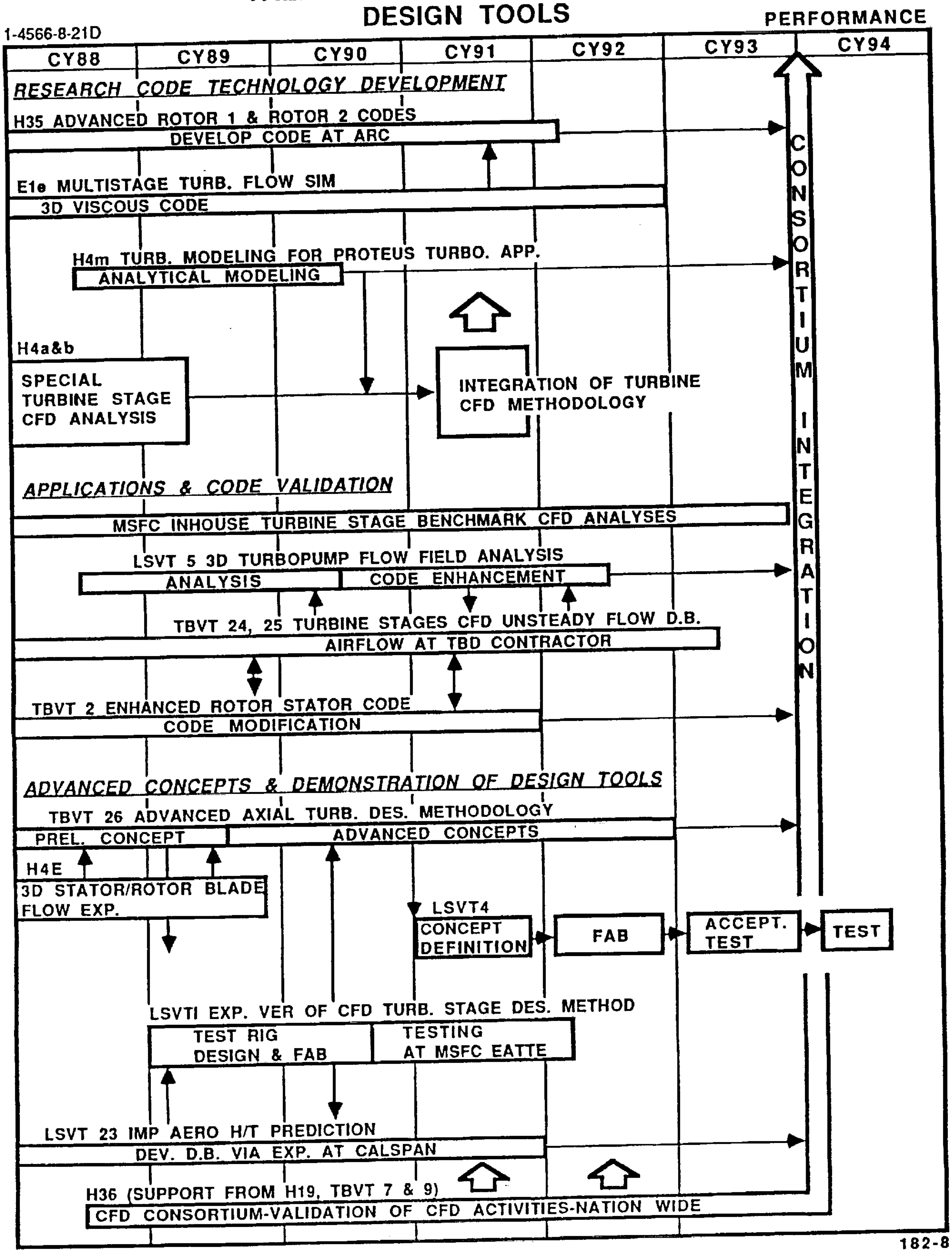
FOCUS DEVELOPMENT OF CFD METHODOLOGY
AND
DEVELOP ADVANCED HARDWARE TECHNOLOGY CONCEPTS



* ACTIVITIES SUPPORTED BY ETO RESOURCES

5-1013-8-16

VALIDATION OF TURBINE STAGE DESIGN TOOLS



NASA EARTH-TO-ORBIT PROPULSION R&T PROGRAMS
DELIVERABLE PRODUCTS/MILESTONES
TURBINE STAGES

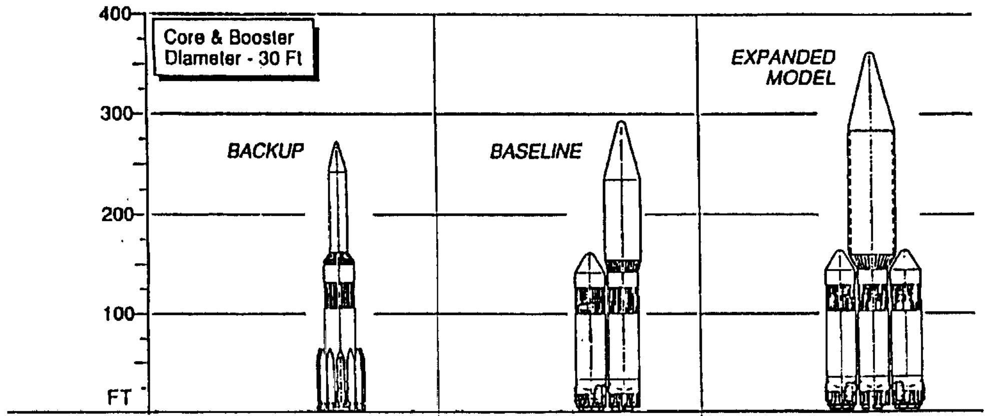
- THREE-DIMENSIONAL MULTISTAGE CFD CODES
  - RESEARCH CODE
    - 3-D MULTISTAGE CFD CODE TO PREDICT STEADY AND UNSTEADY FLOW FIELD CHARACTERISTICS, PERFORMANCE, LOADS AND HEAT TRANSFER — 1/90
  - PRODUCTION CODE
    - MODIFICATION TO RESEARCH CODE TO ENHANCE ENGINEERING APPLICATION — 8/89
      - IMPROVED EFFICIENCIES — 8/89
      - STREAMLINE PRE/POST PROCESSING ETC.
- UNSTEADY THREE-DIMENSIONAL DATA BASE FOR MULTISTAGE TURBINE
  - INITIAL UNSTEADY AERO DATA BASE — 6/89
  - ENHANCED UNSTEADY AERO DATA BASE — 6/90
  - HEAT TRANSFER DATA BASE — 1/90
- IMPROVED FLOW PROCESS MODELING
  - TURBULENCE MODEL FOR PROTEUS — 6/90
  - TURBULENCE MODEL FOR AXIAL TURBOMACHINERY — 6/89
- ADVANCED CONCEPTS AND DEMONSTRATION OF DESIGN TOOLS
  - PRELIMINARY CONCEPT DEFINITION — 9/89
  - TESTS — 1/89, 6/89, 10/89
  - ADVANCED CONCEPT DEFINITION — 1/91
  - FINAL RIG TEST VERIFICATION — 1/92
  - HOT FIRE TEST (TTVF) — 4/94

5-4588-8-53

NEW NEAR TERM CFD ACTIVITIES

STBE/STME DESIGN APPROACH FOR LOW COST

THE ALS FAMILY



	ALS-S	ALS-L	ALS-L2
PAYLOAD (w/o MARGIN)	106 (116)KLB	150 (160)KLB	226 (236)KLB
BOOSTER PROPELLANT	SOLID (12)	O_2/H_2	O_2/H_2
THRUST vac			
- CORE	4 x 612 KLB	3 x 612 KLB	3 x 612 KLB
- BOOSTER	12 x 718 KLB	7 x 612 KLB	12 x 612 KLB

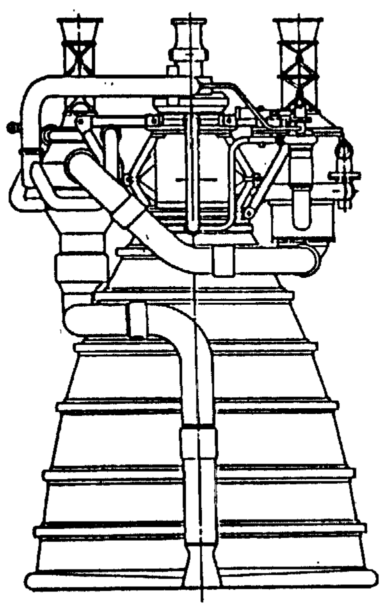
- DESIGN PRIORITIES
  - RELIABILITY
  - COST
  - PERFORMANCE/WEIGHT
  - COMMONALITY

- DESIGN BENEFITS
  - REDUCED INTERNAL ENVIRONMENTS
  - ROBUSTNESS
  - REDUCED DEVELOPMENT TIME
  - REDUCED INVENTORIES/INTERCHANGEABILITY

5-1607-9-99

NEW NEAR TERM CFD ACTIVITIES

STME BASELINE DESIGN REQUIREMENTS



- GAS GENERATOR CYCLE, SERIES TURBINE DRIVE,
- LOX/LH2 PROPELLANTS
  CHAMBER PRESSURE = 2250 psi
- FIXED THRUST OF 580K (VAC)
- DUAL THRUST: 580K AND 435K (VAC)
- RELIABILITY = .99, 90% CONFIDENCE LEVEL (DEMONSTRATED)
- EXPENDABLE OR REUSABLE (15 CYCLES)
- GIMBAL CAPABILITY FOR TVC, +/-6 DEGREES
- FIXED NOZZLE, AR = 62:1
- USABLE IN SINGLE OR MULTI-ENGINE ARRANGEMENT
- HIGH RELIABILITY, LOW COST

5-1606-9-99

NEW NEAR TERM CFD ACITVITIES

CFD ACTIVITIES TO SUPPORT STBE/STME DESIGN

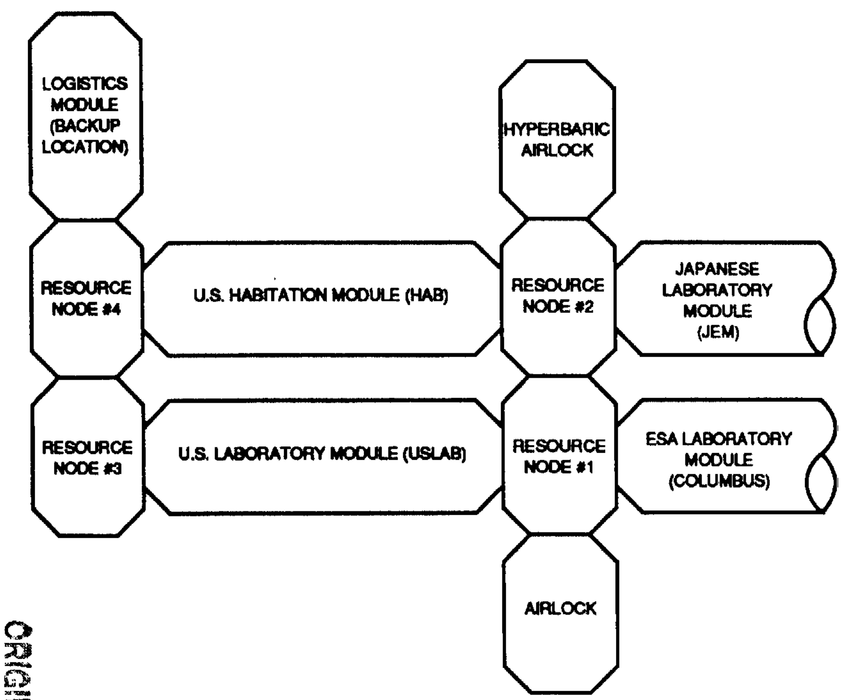
- THRUST CHAMBER
  - INJECTOR
  - MAIN COMBUSTION CHAMBER
  - NOZZLE
  - COOLING CHANNELS
- GAS GENERATOR
  - INJECTOR
  - COMBUSTION CHAMBER
- PUMPS
  - INLET FLANGE
  - VOLUTE/INDUCER/IMPELLER
  - DIFFUSER/CROSSOVER DUCTS
  - DISCHARGE COLLETOR/DUCTS
  - BEARINGS
  - SEALS
- TURBINE
  - INLET FLANGE
  - INLET MANIFOLD
  - ROTOR-STATOR INTERACTION
  - MULTISTAGE ANALYSIS
  - AIRFAILS/GUIDE VANES
  - TURBINE EXHAUST — TURN AROUND DUCT
- SYSTEM ANALYSIS
  - DUCTS
  - MANIFOLDS
  - VALVES
  - CAVITIES
- ENGINE AIRFRAME INTERACTION
  - PLUME
  - AEROHEATING/LOADS

5-1601-9-99

NEW NEAR TERM CFD ACTIVITIES

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)

SPACE STATION CONFIGURATION



RESPIRABLE ATMOSPHERE AND WATER REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	DEGRADED	EMERGENCY
CO_2 PARTIAL PRESSURE	N/m² (mmHg)	400 MAX (3.0 MAX)	1013 MAX (7.6 MAX)	1600 MAX (12 MAX)
O_2 PARTIAL PRESSURE	N/m² x 10³ (psia)	19.5 – 23.1 (2.83 – 3.35)	16.5 – 23.7 (2.4 – 3.45)	15.8 – 23.7 (2.3 – 3.45)
TOTAL PRESSURE	N/m² x 10³ (psia)	99.9 – 102.7 (14.5 – 14.9)	99.9 – 102.7 (14.5 – 14.9)	99.9 – 102.7 (14.5 – 14.9)
TEMPERATURE	°K (°F)	291.5 – 299.8 (65 – 80)	291.5 – 299.8 (65 – 80)	288.8 – 302.6 (60 – 85)
DEWPOINT	°K (°F)	277.6 – 288.8 (40 – 60)	273.9 – 294.3 (35 – 70)	273.9 – 294.3 (35 – 70)
VENTILATION	m/sec (ft/min)	.076 – .203 (15 – 40)	.051 – .508 (10 – 100)	.051 – 1.016 (10 – 200)
TRACE CONTAMINANTS	mg/m³	TBD	TBD	TBD
PARTICULATES	PARTICLES/ m³	3,530,000 0.5 MICRO-METERS TBD > 150 MICROMETERS	—	—
MICRO-ORGANSISMS	CFU/m³	1000	1000	1000

5-1604-9-99

NEW NEAR TERM CFD ACITVITIES

CFD ACTIVITIES TO SUPPORT ECLSS

- GENERIC BASELINE CFD MODELS
  - PLANAR, ONE MODULE (NS)
  - 3D, ONE MODULE (NS)
  - 3D, INNER LOCK DUCTS (NS)
  - PLANAR INTERMODULE (NS)
  - 3D, INTERMODULE (NS)

- FLOW CONTROL DESIGN PARAMETRIC OPTIMIZATION
  - INTERNAL CONFIGURATION VARIATIONS
  - VENTILATION CONTROL
  - INTRAMODULE VENTILATION (FANS)
  - CONTAMINATION TRANSPORT
  - CO_2 /FLOW MANAGEMENT
  - BODY FORCE EFFECTS

- BENCHMARK COMPARISONS
  - PARAMETRIC DESIGN OF EXPERIMENTS
  - CODE VALIDATION

5-1602-9-99

CFD EXPECTATIONS

- DIRECT HARDWARE DESIGN UTILIZING CFD
  - — PROVIDE INITIAL IMPACT IN DESIGN
  - — PERFORM DESIGN OPTIMIZATION STUDIES
  - — DEVELOP ADVANCED HARDWARE TECHNOLOGY CONCEPTS
- ESTABLISH EVALUATION CRITERIA FOR CODES AND CLASSES OF PROBLEMS
- BENCHMARKED/VALIDATED CODES
  - — LAMINAR FLOWS
  - — TURBULENT FLOWS $\overline{u}_i, \overline{p}$
  - — ACOUSTIC PROBLEMS
  - — CERTAIN CLASS OF UNSTEADY PROBLEMS
- USER FRIENDLY CODES
  - — B.S. LEVEL ENGINEER 2-3 YRS EXPERIENCE
  - — GUIDELINES FOR CLASSES OF PROBLEMS
  - — CAD/CAM/CAE; GEOMETRY GRID GENERATION
  - — GENERALIZED BOUNDARY CONDITIONS
  - — ALGORITHM/GRID OPTIMIZATION FOR SOLUTION EFFICIENCY
  - — ARTIFICIAL INTELLIGENCE/EXPERT SYSTEMS
  - — MODULAR CODES
- FLOW ADAPTIVE GRIDS FOR CURRENT CLASS OF PROBLEMS
- MULTIPLE SCALE AND/OR ZONAL TURBULENCE MODELS, MULTIPHASE, MULTISPECIES, COMBUSTION FLOW PROCESS ENGINEERING MODELS EVOLVED FROM EXPERIMENTS AND CFD ANALYSIS

5-2005-8-43