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NASA'S CFD VALIDATION PROGRAM

by

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With computational fluid dynamics (CFD) becoming a productive research and design tool, the requirement to validate CFD codes has grown significantly. NASA has emphasized CFD validation activities since 1986 when a separate work element was formed to fund experimental activities related to validation. NASA's CFD and CFD validation programs are closely coordinated to ensure that experimental data bases are available as soon as possible for validating codes. In response to industry and academic requirements, four levels of experimental research have been defined as part of CFD validation with NASA's Aeronautics Advisory Committee (AAC) support although only the fourth level actually has the detailed information necessary for validating codes.

Critical flow physics especially turbulence modeling are key to improved CFD codes. NASA has focused additional resources on transition and turbulence physics to meet these requirements. With improved turbulence models, CFD codes will be more accurate, robust, and efficient. However, with the level of detailed information available from CFD codes, highly accurate and detailed experiments are required to capture the critical information for validating codes. Advanced instrumentation especially non-intrusive instrumentation is required to acquire this information in validation experiments. The CFD validation program is being coordinated and managed to address these critical activities. A list of experiments which are currently being supported at least partially has been included with this presentation.

CFD CODE VALIDATION DEFINITION

OAST

- DETAILED SURFACE-AND-FLOW-FIELD COMPARISIONS WITH EXPERIMENTAL DATA TO VERIFY THE CODE'S ABILITY TO ACCURATELY MODEL THE CRITICAL PHYSICS OF THE FLOW. VALIDATION CAN OCCUR ONLY WHEN THE ACCURACY AND LIMITATIONS OF THE EXPERIMENTAL DATA ARE KNOWN AND THROUGHLY UNDERSTOOD AND WHEN THE ACCURACY AND LIMITATIONS OF THE CODE'S NUMERICAL ALGORITHMS, GRID-DENSITY EFFECTS, AND PHYSICAL BASIS ARE EQUALLY KNOWN AND UNDERSTOOD OVER A RANGE OF SPECIFIED PARAMETERS.

CFD VALIDATION CATEGORIES

OAST

CATEGORIES OF CFD-RELATED EXPERIMENTATION

A. EXPERIMENTS DESIGNED TO UNDERSTAND FLOW PHYSICS

B. EXPERIMENTS DESIGNED TO DEVELOP PHYSICAL MODELS FOR CFD CODES

C. EXPERIMENTS DESIGNED TO CALIBRATE CFD CODES

D. EXPERIMENTS DESIGNED TO VALIDATE CFD CODES

ALL FOUR CATEGORIES ARE IMPORTANT AND ARE NECESSARY TO BUILD A MATURE CFD CAPABILITY

IMPLEMENTATION PLAN

OAST

- ALL EXPERIMENTS HAVE BEEN CLASSIFIED AND DOCUMENTED
  - GOALS
  - LIMITATIONS
  - MODELING
  - PARTICIPATION
  - LEVEL OF EFFORT
- SEVERAL KEY EXPERIMENTS INVOLVE MULTIPLE RESEARCH CENTERS
- CFD VALIDATION WORKSHOP HELD TO IDENTIFY CRITICAL NEEDS
- COORDINATING BOARD FOR CFD VALIDATION DEVELOPING UPDATED DETAILED IMPLEMENTATION PLAN
- EFFORTS INITIATED TO INVOLVE THE AEROSPACE INDUSTRY AND UNIVERSITIES

CFD VALIDATION PROGRAM

OAST

EXPERIMENTS HAVE BEEN CLASSIFIED INTO MULTIPLE CATEGORIES

CATEGORY	AMES	LANGLEY	LEWIS	TOTAL
A. FLOW PHYSICS	16	35	29	80
B. FLOW MODELING	8	7	13	28
C. CODE CALIBRATION	6	19	12	37
D. CODE VALIDATION	7	24	16	47
TOTAL NUMBER OF EXPERIMENTS	27	45	29	101

CFD VALIDATION PROGRAM

OAST

- EXPERIMENTS COVER LARGE SPEED RANGE
  - SUBSONIC: 33 EXPERIMENTS
  - TRANSONIC: 27 EXPERIMENTS
  - SUPERSONIC: 23 EXPERIMENTS
  - HYPERSONIC: 18 EXPERIMENTS
- EXPERIMENTS FALL INTO SEVERAL VEHICLE CLASSES
  - GENERIC
  - FIGHTER/ATTACK
  - SUBSONIC TRANSPORT
  - ROTORCRAFT
  - ASTOVL
  - PROPULSION SYSTEMS

CFD VALIDATION EVENTS

OAST

• NEW RTOP ELEMENT, FLOW MODELING AND VERIFICATION, CREATED	FY 1986
• NRC ASEB REVIEW OF CFD ACTIVITIES	FY 1986
• NASA REVIEW AND DEVELOPMENT OF IMPLEMENTATION PLAN FOR CFD VALIDATION	FEB., 1986
• AAC AD HOC SUBCOMMITTEE REVIEW OF CFD VALIDATION	FY 1987
• NASA COORDINATING BOARD FOR CFD VALIDATION FORMED	JUNE, 1987
• FIRST NASA CFD VALIDATION WORKSHOP AT AMES	JULY, 1987
• IMPLEMENTATION PLAN REVISED BY COORDINATING BOARD	AUG., 1987
• AGARD CFD VALIDATION CONFERENCE IN LISBON	MAY, 1988
• CFD VALIDATION ACTIVITIES AND IMPLEMENTATION PLAN REVIEW	NOV., 1988
• NASA CFD CONFERENCE AT AMES	MAR., 1989
• SECOND NASA CFD VALIDATION WORKSHOP	JULY, 1990

NASA CFD VALIDATION WORKSHOP

OAST

- 103 PERSONS ATTENDED FROM NASA, DOD, INDUSTRY, AND UNIVERSITIES
- 31 PRESENTATIONS WERE GIVEN ON CFD VALIDATION STATUS
- 6 WORKING GROUP SESSIONS FOCUSED ON NEAR AND FAR TERM NEEDS
- NUMEROUS RECOMMENDATIONS
  - STANDARDIZED TEST CASES FOR CALIBRATION
  - CLOSE COOPERATION BETWEEN CFD DEVELOPERS AND EXPERIMENTALISTS
  - INCREASE FLIGHT-BASED ACTIVITIES
  - DETAILED MEASUREMENTS OF FLOW FIELD AND BOUNDARY CONDITIONS
  - IMPROVED OR NEW NON-INTRUSIVE MEASUREMENT CAPABILITIES
  - REDUNDANCY IN BOTH MEASUREMENTS AND EXPERIMENTS

SUMMARY

OAST

- AAC AD HOC TASK TEAM RECOMMENDATIONS IMPLEMENTED
- NASA PROGRAM EXPANDING TO COVER ADDITIONAL AREAS
- INSTRUMENTATION HAS BEEN ADDED TO SEVERAL FACILITIES BY VALIDATION PROGRAM
- INCREASED EMPHASIS ON COOPERATIVE PROGRAMS WITH UNIVERSITIES AND INDUSTRY

AMES CFD VALIDATION PROGRAM FOR FY 1989

LEX/DELTA VORTICAL FLOW
TRANSONIC LOW ASPECT RATIO WING-BODY
REARWARD FACING STEP
SSME TURNAROUND DUCT
SUPERSONIC SHOCK BOUNDARY LAYER INTERACTION
COMPRESSIBLE PRESSURE-DRIVEN 3-D INTERACTIONS
2-D TRANSONIC CIRCULATION CONTROL
3-D SPIN FLOWS
3-D LOW SPEED WEDGE FLOW WITH SEPARATION
TRANSONIC SUPERCRITICAL AIRFOIL
LOW SPEED HIGH ALPHA INVESTIGATION
CFD VALIDATION FOR WING AERODYNAMICS
3-D HIGH ASPECT RATIO SEPARATED FLOW
STOVL AERO/PROPULSION INTERACTION
THERMO-CHEMICAL NONEQUILIBRIUM FLOWS
PHOTODIAGNOSTIC INSTRUMENTATION
UNSTEADY VISCOUS FLOW
HYPERSONIC SHOCK BOUNDARY INTERACTION
TURBULENT SHEAR LAYERS
TURBULENT BOUNDARY LAYERS
ALL-BODY HYPERSONIC TEST
HIGH SPEED ROTOR FLOWS
HYPERSONIC REAL GAS
SHOCK TUNNEL NOZZLE TESTS
3.5' HWT NOZZLE TESTS
COMBUSTION/DETONATION
FLIGHT/CFD CORRELATION OF F-18 WING PRESSURES AT HIGH ALPHA
SUPERSONIC VORTEX-SHOCK WAVE INTERACTION

LANGLEY CFD VALIDATION PROGRAM FOR FY 1989

TRANSONIC HIGH ASPECT-RATIO WING
TRANSONIC LOW ASPECT RATIO WING
REARWARD FACING STEP IN WATER TUNNEL
REARWARD FACING STEP IN BART
DELTA WING VORTEX FLOWS
SUPERSONIC COAXIAL JET
TURBULENT MODELING IN SEPARATED FLOWS
45-DEG SWEEP AIRFOIL
BARF LDV TEST
SUPERSONIC BOUNDARY LAYER TRANSITION
NTF FLAT PLATE TEST
VORTEX BURST EXPERIMENTS
HYPERSONIC FLIGHT INSTRUMENTATION
HYPERSONIC INLET TESTS IN HELIUM
HYPERSONIC SHOCK-ON-LIP
HALIS ORBITER EXPERIMENT
BLUNT BODIES (AOTV/AFE) EXPERIMENT
HYPERSONIC WINGED SLENDER BODY
OSCILLATING CANARD/WING UNSTEADY PRESSURES
VALIDATION OF JET PLUME MODULES
SUPERSONIC JET PLUME DYNAMICS
SUPERSONIC HIGH-ALPHA FLOWFIELD
OFF-AXIS WING-BODY STUDY
STORE/CAVITY SEPARATION EXPERIMENTS
WAVERIDER DESIGN PROCEDURE
5 DEG CONE EXPERIMENT
75/76-DEG DELTA WINGS
NTF FOREBODY/MISSLE MODEL
LEADING EDGE VORTEX FLAP
X-29 EXPERIMENT IN NTF
3-D TRANSONIC CAVITY FLOW
LOW REYNOLDS NUMBER AIRFOIL EXPERIMENTS
CONFLUENT BOUNDARY LAYER
GORTLER INSTABILITY ON AIRFOILS
EXPERIMENTAL INVESTIGATION OF TURBULENCE
RANGE AND ACCURACY OF THIN FILM ARRAYS
JUNCTURE FLOW EXPERIMENT
SWEPT SUPERCRITICAL HLFC AIRFOIL EXPERIMENTS
TWIN ENGINE AFTERBODY EXPERIMENT

LEWIS CFD VALIDATION PROGRAM FOR FY 1989

3-D SHOCK WAVE/TURBULENT BOUNDARY LAYER INTERACTIONS
3-D FLOWS IN HIGH SPEED TURBOMACHINERY
BLADE SURFACE BOUNDARY LAYER
FUNDAMENTAL SEPARATION BUBBLE RESEARCH
AIRFOIL (BLADING) FLOW CONTROL
LEADING EDGE STAGNATION REGION
BOUNDARY LAYERS IN TRANSITION
UNSTEADY HEAT TRANSFER IN ROTOR WAKES
TRANSITION DUCT - AERO & HEAT TRANSFER
VORTEX GENERATORS
SHEAR LAYER EXCITATION - JET MIXING
SHEAR LAYER EXCITATION - SLOT RESONATOR
MULTI-PHASE FLOWS
MULTI-PHASE FLOW AND FLUID SPRAY STUDY
LOW TEMPERATURE HEAT TRANSFER
FUEL SWIRLER CHARACTERIZATION
COMBUSTION CHARACTERISTICS OF HYDROCARBON FLAMES
KINETIC STUDY OF H2/O2 SYSTEM
FLOW INTERACTION EXPERIMENT
HOT GAS INGESTION
COHERENT STRUCTURES IN SUPERSONIC SHEAR LAYER
AERO CHARACTERISTICS OF AIRFOIL WITH ICE ACCRETION
TURBOMACHINERY BLADE ROW INTERACTIONS
SUPERSONIC THROUGH-FLOW CASCADE RESEARCH
CENTRIFUGAL COMPRESSOR FLOW RESEARCH
SUPERSONIC THROUGH-FLOW FAN RESEARCH
HIGH REYNOLDS NUMBER (HEAT TRANSFER)
DETAILED AERO OF ADVANCED TURBOPROPS
FUEL RICH CATALYTIC COMBUSTION

SESSION III

TRANSITION AND TURBULENCE

Chairman:
Thomas A. Pulliam
Chief, Computational Physics Section
Fluid Dynamics Division
NASA Ames Research Center