SENSITIVITY OF INLET PERFORMANCE PREDICTIONS TO CFD NUMERICAL AND PHYSICAL MODELING

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PRESENTATION AT
JANNAF CFD CODE VALIDATION/CALIBRATION
WORKSHOP SERIES WORKSHOP NO. 1 –
HIGH-SPEED INLET FOREBODY INTERACTIONS

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OUTLINE

- CNS/UPS CODE OVERVIEWS
- CODE VALIDATION EFFORTS
- INLET ANALYSIS REQUIREMENTS
- CFD MODELING UNCERTAINTIES
- SUMMARY

HYPERSONIC FOREBODY/INLET ANALYSIS CODES

- CNS - COMPRESSIBLE NAVIER-STOKES
- UPS - UPWIND PNS SOLVER
- NASP TIP-TO-TAIL SOLUTION CAPABILITY
- EXTENSIVELY VALIDATED FOR HYPERSONIC FOREBODY FLOW FIELDS

COMPRESSIBLE NAVIER-STOKES CODE CHARACTERISTICS

- THIN-LAYER NAVIER-STOKES EQUATIONS
- DIAGONALIZED BEAM-WARMING SCHEME OR FLUX-SPLIT STEGER-WARMING SCHEME
- GENERAL ZONAL GRID CAPABILITY
- PERFECT GAS, EQUILIBRIUM AND NONEQUILIBRIUM AIR CHEMISTRY MODELS
- LAMINAR OR TURBULENT (BALDWIN-LOMAX MODEL)
- EXTERNAL AND/OR INTERNAL ANALYSIS

UPS CODE CHARACTERISTICS

- PARABOLIZED NAVIER-STOKES EQUATIONS
- ROE SCHEME FOR CROSSFLOW TERMS
- ALGEBRAIC OR HYPERBOLIC GRID GENERATORS WITH SOLUTION-ADAPTIVE GRID OPTION
- PERFECT GAS, EQUILIBRIUM AND NONEQUILIBRIUM AIR CHEMISTRY
- LAMINAR, TRANSITIONAL, AND TURBULENT FLOW
- INLET PERFORMANCE POST-PROCESSOR

CODE VALIDATION SUMMARY

- OVER 40 EXPERIMENTAL DATASETS
  - MACH 2 TO 20 (MOSTLY PERFECT GAS)
  - LAMINAR, TRANSITIONAL, AND TURBULENT
  - FLAT PLATES, BLUNT BODIES, CONES, COMPLETE GEOMETRIES
  - EXTERNAL AND INTERNAL FLOW FIELDS
  - FORCES, SURFACE PRESSURE AND HEAT TRANSFER, PITOT PROFILES, SCHLIERENS
- CODE-TO-CODE VALIDATION FOR NONEQUILIBRIUM FLOWS
- GRID REFINEMENT, MASS CONSERVATION, AND CONVERGENCE STUDIES

INLET PERFORMANCE PARAMETERS

- BOW SHOCK LOCATION (0.05%)
- INLET AREA
- MASS CAPTURE (0.5%)
- STREAM THRUST (NORMAL AND TANGENTIAL)
- KINETIC ENERGY EFFICIENCY (0.1%)
- AREA RATIO
- BOUNDARY LAYER THICKNESS
- GAS COMPOSITION
- HEAT TRANSFER ON FOREBODY AND COWL

SOURCES OF UNCERTAINTY

- FREESTREAM CONDITIONS
- CHEMISTRY EFFECTS
- GEOMETRY AND GRID RESOLUTION
- BOUNDARY LAYER STATE
- POST-PROCESSING METHODS*

AIR CHEMISTRY SENSITIVITY STUDY

C-3

- OBJECTIVE: INVESTIGATE EFFECT OF GAS MODELS ON PREDICTION OF INLET PERFORMANCE PARAMETERS

- APPROACH: COMPUTE FLOW OVER GENERIC OPTION AT NASP-LIKE TRAJECTORY POINTS USING CNS/UPS CODES WITH PERFECT GAS, EQUILIBIRUM AIR AND FINITE-RATE AIR GAS MODELS

NOSE BLUNTNESS STUDY

- GENERIC OPTION BODY
- SHARP NOSE – CONICAL STEP-BACK
- BLUNT NOSE – CNS STARTING SOLUTION
- FIRST-ORDER EFFECTS ON:
  - SHOCK LOCATION
  - BOUNDARY LAYER THICKNESS
  - BOUNDARY LAYER STABILITY
  - GAS COMPOSITION

NASP CONTRACTOR FOREBODY CONTOUR TRADE STUDY

- PARTICIPANTS: GD, RI, MCD, LARC, ARC
  - NS BLUNT BODY + PNS FOREBODY
  - UPWIND SCHEMES
- FAMILY OF NASP FOREBODY SHAPES
  - NOSE BLUNTNESS
  - FINENESS RATIO
  - TRAJECTORY POINTS
- BENCHMARK CASE
  - LAMINAR AND TRANSITIONAL
  - EQUILIBRIUM AIR
  - COWL LOCATED RELATIVE TO BOW SHOCK

UNREFINED RESULTS

PREDICTED MASS CAPTURE AND KINETIC ENERGY EFFICIENCY FOR LAMINAR BENCHMARK CASE

METHOD	MASS CAP - AVG	KE EFF - AVG
1	-3%	+.0002
2	+2%	+.0019
3	+.6%	-.0020
4	-.7%	+.0030
5	+1%	-.0007
6	-.2%	-.0019

- SAME GEOMETRY
- SAME GRID DIMENSIONS
- SAME FLOW MODELING
- DIFFERENT ALGORITHMS
- DIFFERENT PRE- AND POST-PROCESSING

INDEPENDENT ANALYSES PRODUCED UNACCEPTABLE SCATTER

NUMERICAL MODELING SENSITIVITIES

UPS CODE COMPUTATIONS

SOLUTION PARAMETERS	MASS CAP - AVG	KE EFF - AVG
UNADAPTED GRID	-3%	+.0010
ADAPTED GRID *	+.4%	+.0021
(*) + 1-DIRN. THIN-LAYER	+.5%	+.0022
(*) + LOWER ENTROPY FIX	+.5%	+.0023

GRID RESOLUTION IS LARGEST SOURCE OF ERROR

SHOCK LOCATION SENSITIVITY

UPS MASS CAPTURE COMPUTED FROM REPORTED SHOCK LOCATIONS

METHOD	MASS CAP - AVG	UPS MASS CAP - AVG
2	+.04%	-.8%
3	+.3%	+1%
4	-.3%	+.4%
5	0.0%	-.09%

FIXING COWL LOCATION REDUCES UNCERTAINTY 5X

SUMMARY

- PRIOR VALIDATION IS NECESSARY BUT NOT SUFFICIENT
- UNCERTAINTY CAN BE ESTIMATED WITH SENSITIVITY STUDIES
- POST-PROCESSING CAN INTRODUCE LARGEST ERRORS OF ALL

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DISCUSSION OF PAPERS PRESENTED BY WEI CHYU AND BY TOM EDWARDS

John Porter: Prior validation of codes in some parameters does not appear since certain parameters did not agree while other parameters did agree. What are you calling prior validation?

Tom Edwards: I'm saying that CNS and PNS have been validated extensively with experimental data. We've looked at inlet forebody flowfields and heat transfer. Different geometries have different modeling requirements. Just because you have Mach 16 does not mean you have equilibrium air.

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