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COMPUTATIONAL FLUID DYNAMICS PROGRAM AT NASA AMES RESEARCH CENTER

Terry L. Holst

Chief, Applied Computational Fluids Branch
NASA Ames Research Center, Moffett Field, California

ABSTRACT

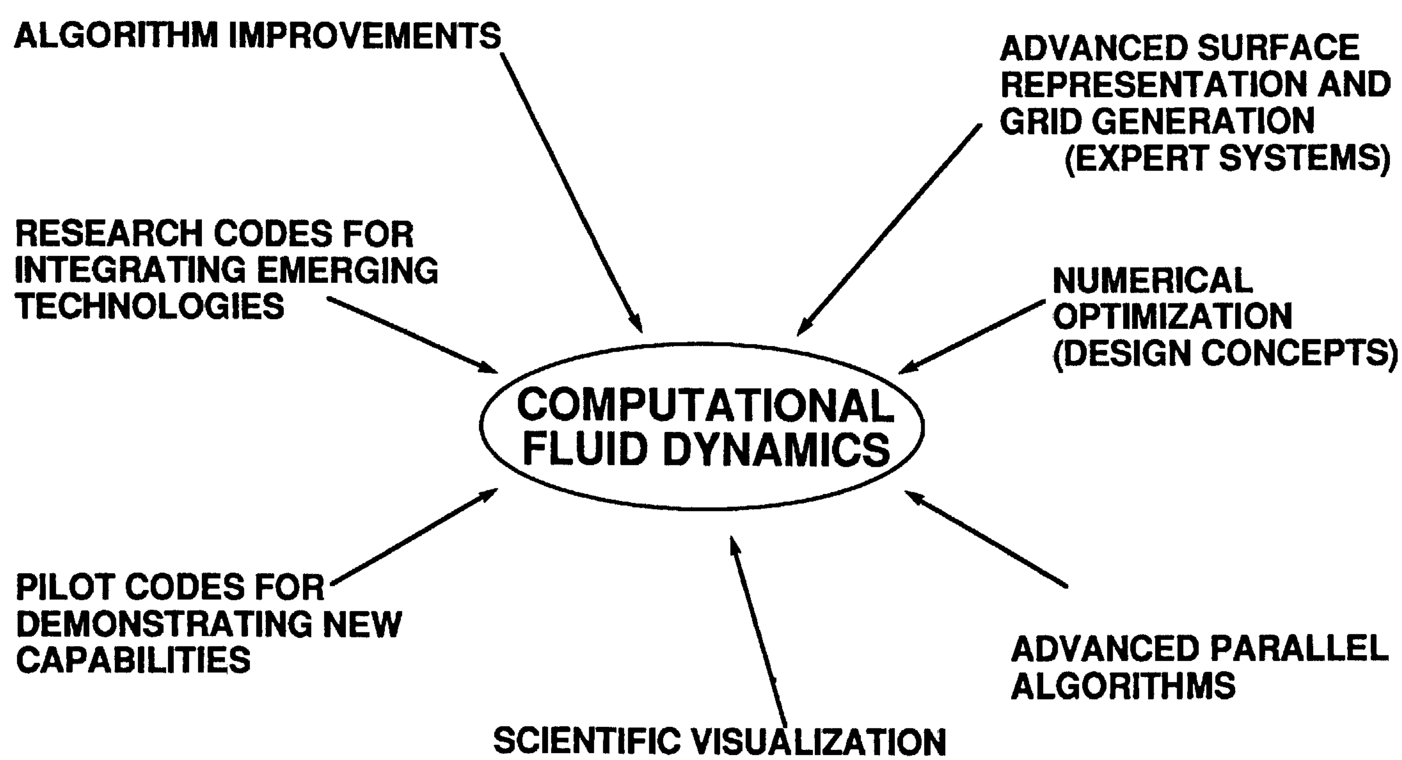
The Computational Fluid Dynamics (CFD) Program at NASA Ames Research Center is reviewed and discussed. The presentation is broken into several sections as follows: First, the technical emements of the CFD Program are generally listed and briefly discussed. These elements include algorithm research, research and pilot code development, scientific visualization, advanced surface representation, volume grid generation, and numerical optimization. Next, the discipline of CFD is briefly discussed and related to other areas of research at NASA Ames including Experimental Fluid Dynamics, Computer Science Research, Computational Chemistry, and Numerical Aerodynamic Simulation. These areas combine with CFD to form a larger area of research, which might collectively be called computational technology. The ultimate goal of computational technology research at NASA Ames is to increase the physical understanding of the world in which we live, solve problems of national importance, and increase the technical capabilities of the aerospace community.

Next, the major programs at NASA Ames that either use CFD technology or perform research in CFD are listed and discussed. Briefly, this list includes turbulent/transition physics and modeling, high-speed real gas flows, interdisciplinary research, turbomachinery demonstration computations, complete aircraft aerodynamics, rotorcraft applications, powered lift flows, high alpha flows, multiple body aerodynamics, and incompressible flow applications. Some of the individual problems actively being worked in each of these areas is listed to help define the breadth or extent of CFD involvment in each of these major programs.

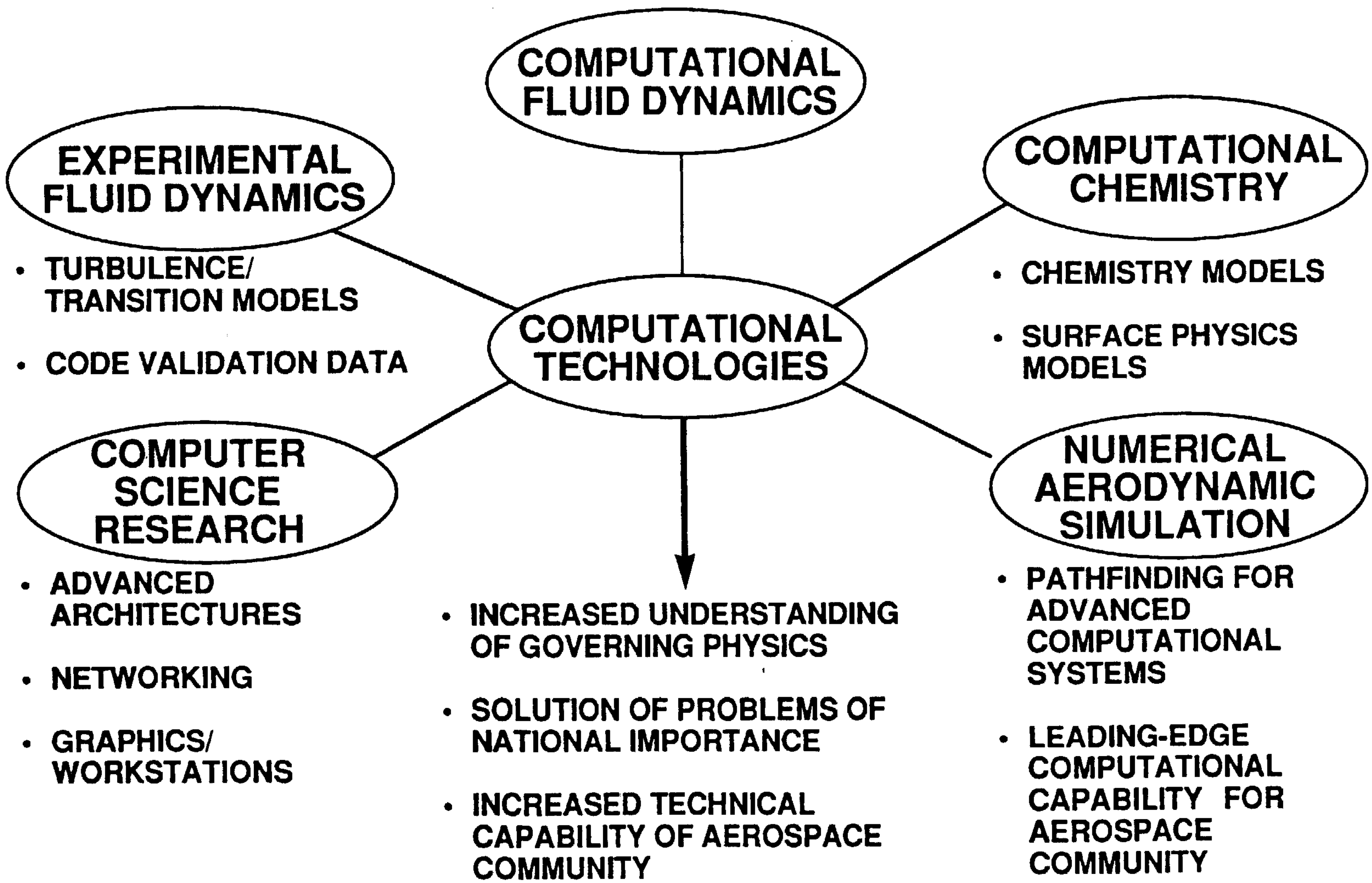
State-of-the-art examples of various CFD applications are presented to highlight most of these areas. The main emphasis of this portion of the presentation is on examples which will not otherwise be treated at this conference by the individual presentations. Thus, a good survey of CFD applications research at NASA Ames can be obtained by looking at this presentation in conjunction with the individual NASA Ames presentations made at this conference.

Finally, this overview is concluded with a list of principal current limitations and expected future directions. Some of the future directions include algorithm research, turbulence/transition research, multidisciplinary research, graphics and workstation research and applications which will address more realistic simulations in the engineering world.

COMPUTATIONAL FLUID DYNAMICS
TECHNICAL ELEMENTS



COMPUTATIONAL TECHNOLOGIES
THRUSTS



MAJOR PROGRAMS USING CFD
NASA Ames Research Center

TURBULENT/TRANSITION PHYSICS AND PHYSICAL MODELING

HIGH-SPEED REAL GAS FLOWS
- THERMO- AND CHEMICAL-NONEQUILIBRIUM
- RADIATION
- COMBUSTION
- RAREFIED FLOW EFFECTS

INTERDISCIPLINARY RESEARCH
- CFD + COMPUTATIONAL ELECTROMAGNETICS
- CFD + COMPUTATIONAL STRUCTURAL MECHANICS
- CFD + ACTIVE CONTROLS
- CFD + HEAT CONDUCTION

TURBOMACHINERY DEMONSTRATION COMPUTATIONS
- 3D TURBINE ROTOR-STATOR
- MULTI-STAGE COMPRESSOR ROTOR-STATOR

COMPLETE AIRCRAFT AERODYNAMICS
- NASP
- F-16 (TNS, TRANAIR)

MAJOR PROGRAMS USING CFD (CONTINUED)

NASA Ames Research Center

ROTORCRAFT APPLICATIONS

- AEROACOUSTICS
- ROTOR/FUSELAGE INTERACTION
- HELICOPTER/TILTROTOR PERFORMANCE PREDICTIONS
- DYNAMIC STALL COMPUTATIONS

POWERED LIFT

- STOVL AIRCRAFT (HARRIER, E-7)
- UPPER SURFACE BLOWING APPLICATIONS
- JET FREESTREAM MIXING
- THRUST AUGMENTOR EJECTORS
- STOVL DELTA WING IN GROUND EFFECT

HIGH ALPHA

- HARV APPLICATIONS (F-18)
- OGIVE CYLINDER COMPUTATIONS
- UNSTEADY FLOWS

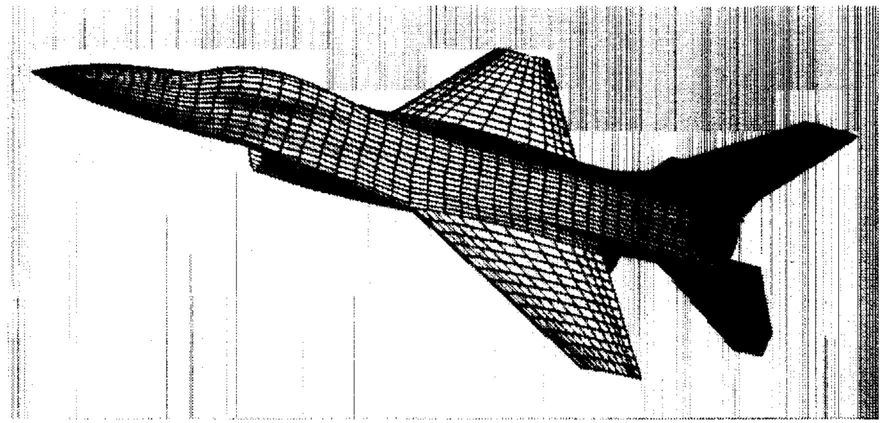
MAJOR PROGRAMS USING CFD (CONCLUDED)
NASA Ames Research Center

MULTIPLE BODY AERODYNAMICS
- SPACE SHUTTLE (LAUNCH CONFIGURATION)
- SRB/ET-ORBITER SEPARATION
- AIRCRAFT STORE SEPARATION
- SPACE SHUTTLE C/ SPACE SHUTTLE II

INCOMPRESSIBLE NAVIER-STOKES
- SSME APPLICATIONS
- HYDRODYNAMICS
- HIGH LIFT CONFIGURATIONS
- ARTIFICIAL HEART BLOOD FLOW SIMULATION

ADVANCED SIMULATION AND ANALYSIS PROJECT (ASAP)

VAN DALSEM, VOGEL, LUH, SORENSON, ATWOOD



OBJECTIVE

- REDUCE THE "CLOCK TIME" REQUIRED TO OBTAIN THE SURFACE DEFINITION AND GRID ABOUT A COMPLEX CONFIGURATION BY AT LEAST AN ORDER OF MAGNITUDE

APPROACH

- DEVELOP AN INTEGRATED, INTERACTIVE SURFACE DEFINITION AND GRID GENERATION CAPABILITY TAILORED TO THE CFD ENVIRONMENT

FUTURE DIRECTIONS

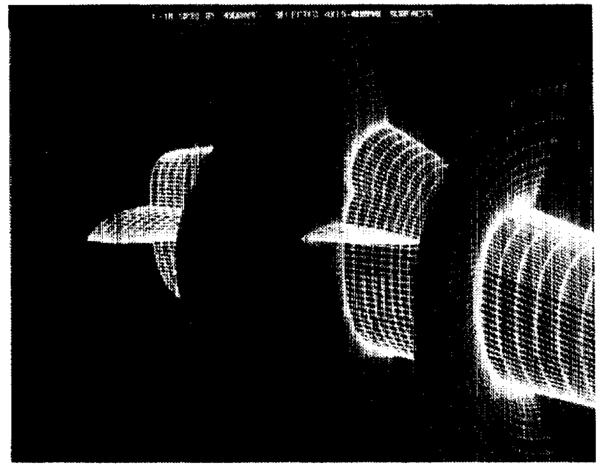
- EXPLORE APPLICATION OF AI TO ENHANCE NONEXPERT USER PERFORMANCE
- INVESTIGATE:
  - GRID QUALITY MEASURES
  - SOLUTION-ADAPTIVE TECHNIQUES
  - NEW GRID GENERATION APPROACHES (STRUCTURED AND UNSTRUCTURED)

PAYOFF

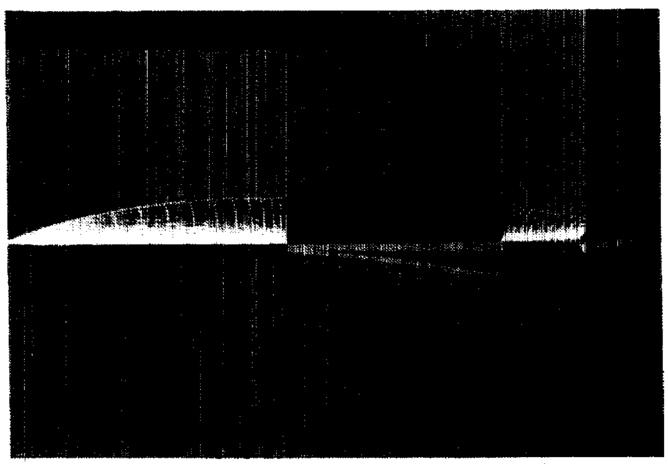
- A POWERFUL, EASY-TO-USE TOOL THAT SIGNIFICANTLY REDUCES THE TURNAROUND TIME FOR CURRENT AND FUTURE CFD ANALYSES

ADVANCED SIMULATION AND ANALYSIS PROJECT (ASAP)

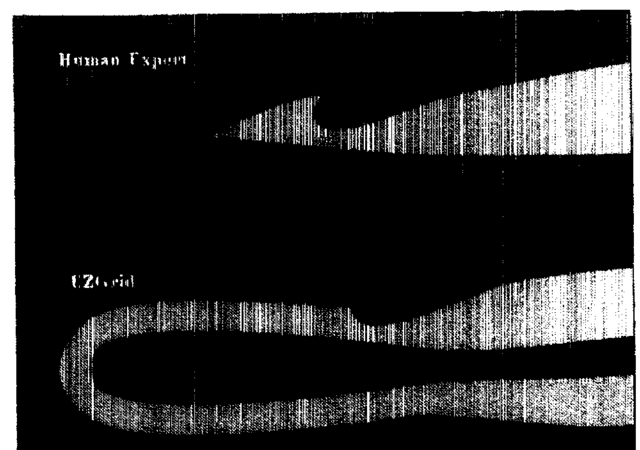
VOGEL, LUH, SORENSON, ATWOOD



F-18 FOREBODY GRID BY 3DGRAPE: SELECTED AXIS-NORMAL SURFACES



SURFACE GRID FOR GENERIC HYPERSONIC AIRPLANE



2D ZONING COMPARISON: HUMAN EXPERT vs EXPERT SYSTEM (EZGRID)

PANEL METHOD APPLICATIONS

ASHBY, IGUCHI, BROWN

OBJECTIVES

- DEVELOP CAPABILITY TO ANALYZE COMPLEX GEOMETRIES VERY QUICKLY
  - —INCLUDES LEADING-EDGE SEPARATION, JET PLUMES, AND UNSTEADY EFFECTS (TIME STEPPING)

APPROACH

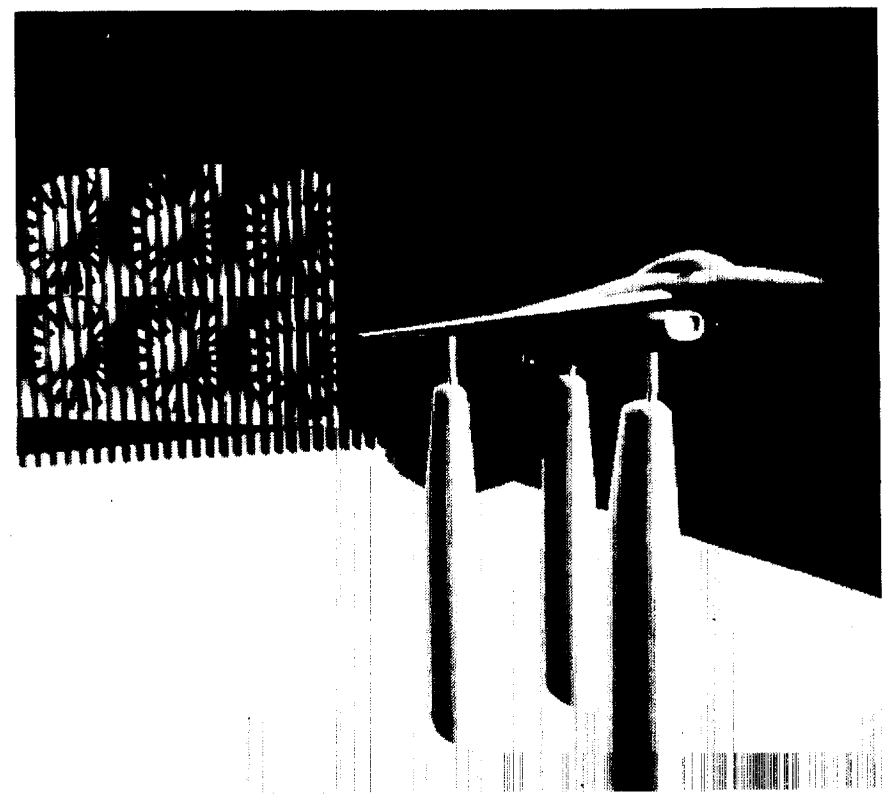
- LOW-ORDER PANEL METHOD WITH TIME-STEPPED WAKES

FUTURE DIRECTIONS

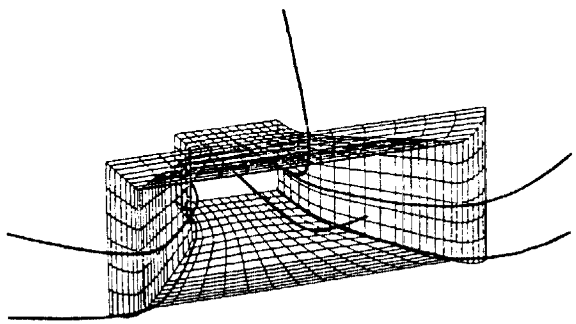
- COUPLE WITH BOUNDARY LAYER CODE TO INCLUDE VISCOUS EFFECTS
- USE FOR DESIGN AND ANALYSIS OF WIND TUNNEL MODELS AND TO DETERMINE WIND TUNNEL WALL INTERFERENCE

PAYOFF

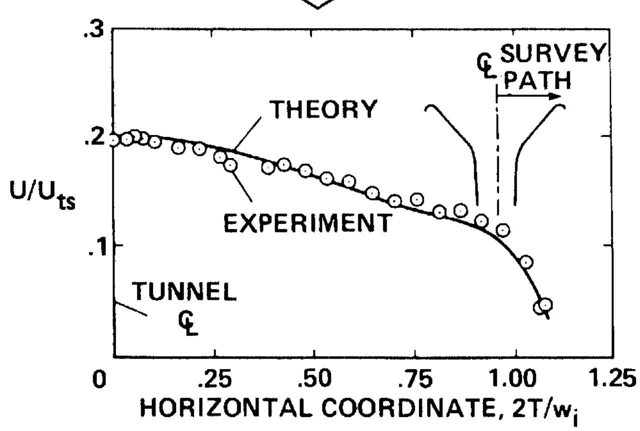
- EFFICIENT, RELIABLE TOOL FOR USE IN LOW SPEED APPLICATIONS



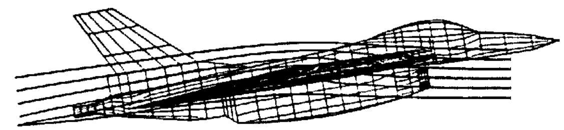
PANEL METHOD APPLICATIONS
ASHBY, IGUCHI, BROWN



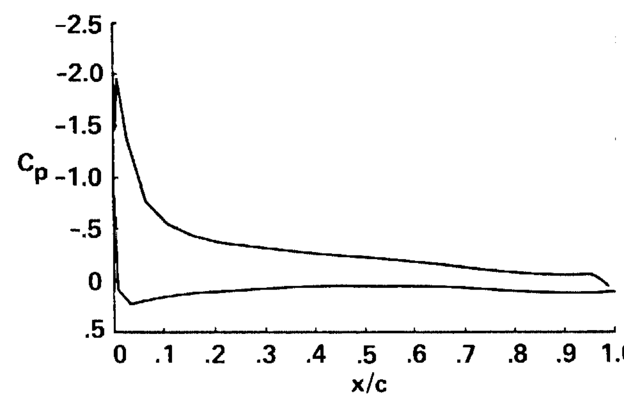
80- BY 120-FOOT WIND TUNNEL INLET



VELOCITY VARIATION ACROSS INLET



E-7 STOVL MODEL



CHORDWISE PRESSURE DISTRIBUTION ON E-7 WING PMARC COMPUTATION; $2y/b = 0.6$, $\alpha = 8°$

TWO-DIMENSIONAL COMPUTATIONS OF MULTI-STAGE COMPRESSOR FLOWS

GUNDY-BURLET, RAI

OBJECTIVE

- DEVELOP CAPABILITY TO CALCULATE UNSTEADY VISCOUS FLOWS WITHIN MULTI-STAGE TURBOMACHINES

CURRENT APPROACH

- SOLVE THE TWO-DIMENSIONAL NAVIER-STOKES EQUATIONS USING A ZONAL METHOD TO SIMULATE ROTOR-STATOR INTERACTION

FUTURE DIRECTIONS

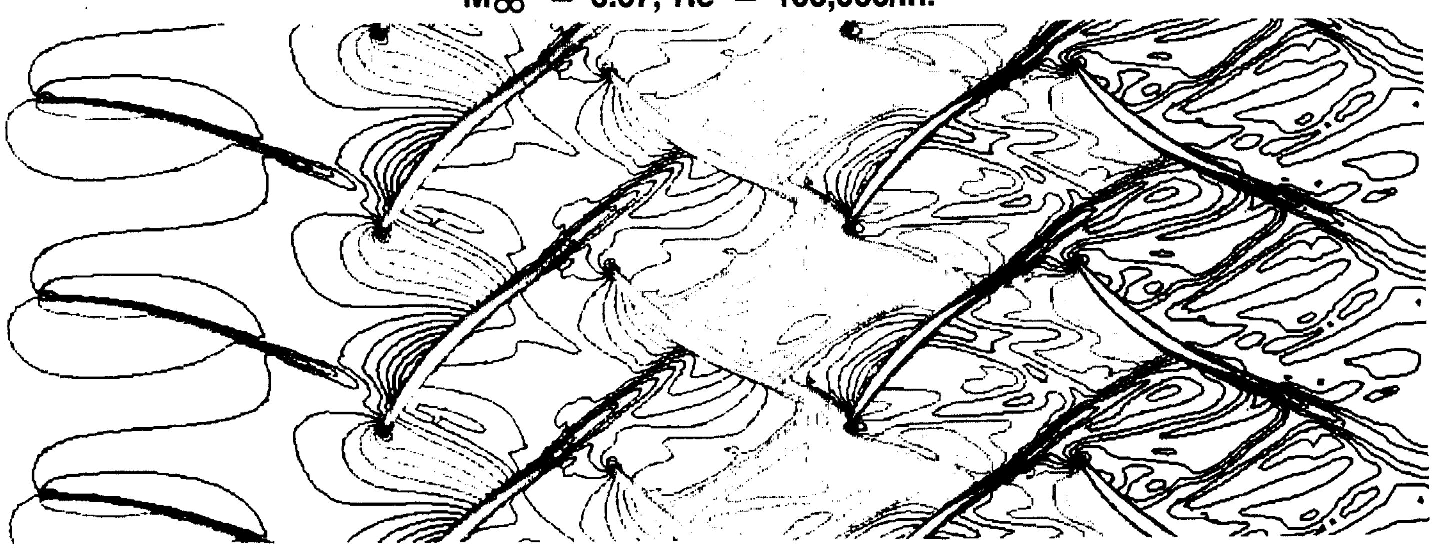
- EXTEND TO THREE-DIMENSIONS

PAYOFF

- BETTER UNDERSTANDING OF UNSTEADY FLUID DYNAMICS IN TURBOMACHINES
- INCREASED RELIABILITY AND EFFICIENCY OF TURBOMACHINES

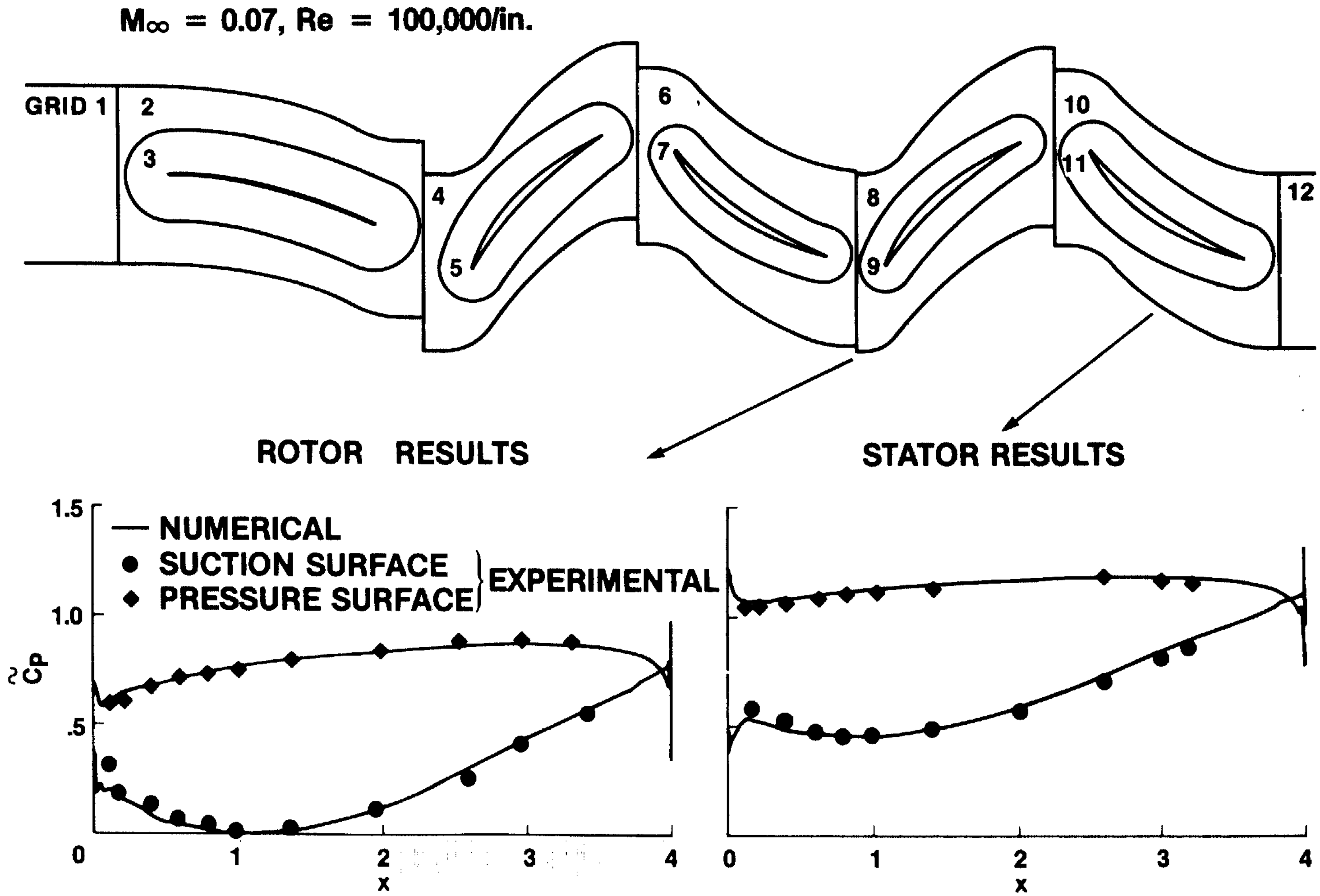
INSTANTANEOUS TEMPERATURE CONTOURS

$M_\infty = 0.07$, Re = 100,000/in.



TIME-AVERAGED PRESSURES IN THE SECOND STAGE OF A 2.5 STAGE COMPRESSOR

GUNDY-BURLET, RAI



EFFECT OF TANGENTIAL LEADING EDGE BLOWING ON VORTICAL FLOW

YEH, TAVELLA, ROBERTS

OBJECTIVE

- TO INVESTIGATE THE ABILITY OF TANGENTIAL LEADING EDGE BLOWING TO CONTROL VORTICAL FLOW AT HIGH ALPHA

APPROACH

- UTILIZE DELTA WING GEOMETRY
- SOLVE THIN-LAYER NAVIER-STOKES EQUATIONS USING MULTIPLE-ZONE GRID APPROACH TO ACCOMODATE JET-SLOT GEOMETRY
- UTILIZE ALGEBRAIC TURBULENCE MODEL FOR SURFACE BL AND WALL JET

FUTURE DIRECTIONS

- EXTEND TO FULL AIRCRAFT CONFIGURATIONS
- INVESTIGATE BLOWING CONTROL CONCEPTS

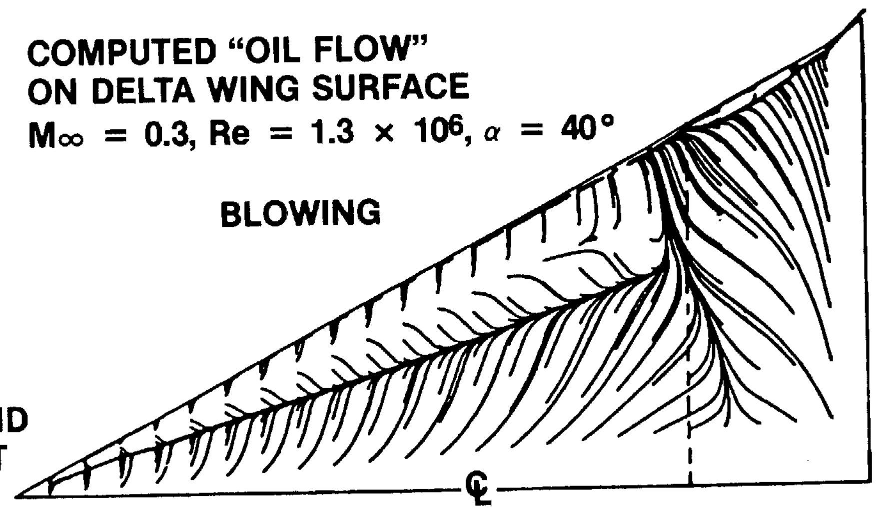
PAYOFF

- INCREASED UNDERSTANDING OF VORTICAL FLOW PHYSICS
- NEW TOOL FOR STUDYING BLOWING CONTROL CONCEPTS

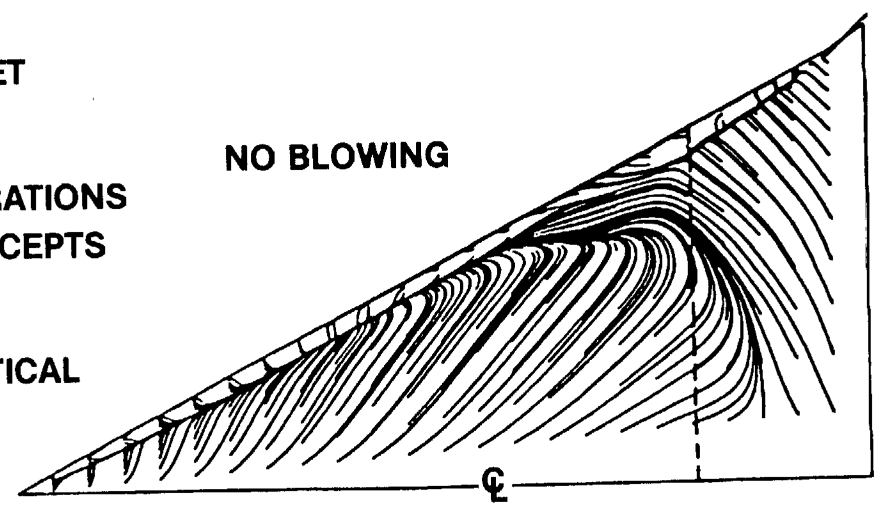
COMPUTED "OIL FLOW" ON DELTA WING SURFACE

$M_\infty = 0.3$, $Re = 1.3 \times 10^6$, $\alpha = 40°$

BLOWING



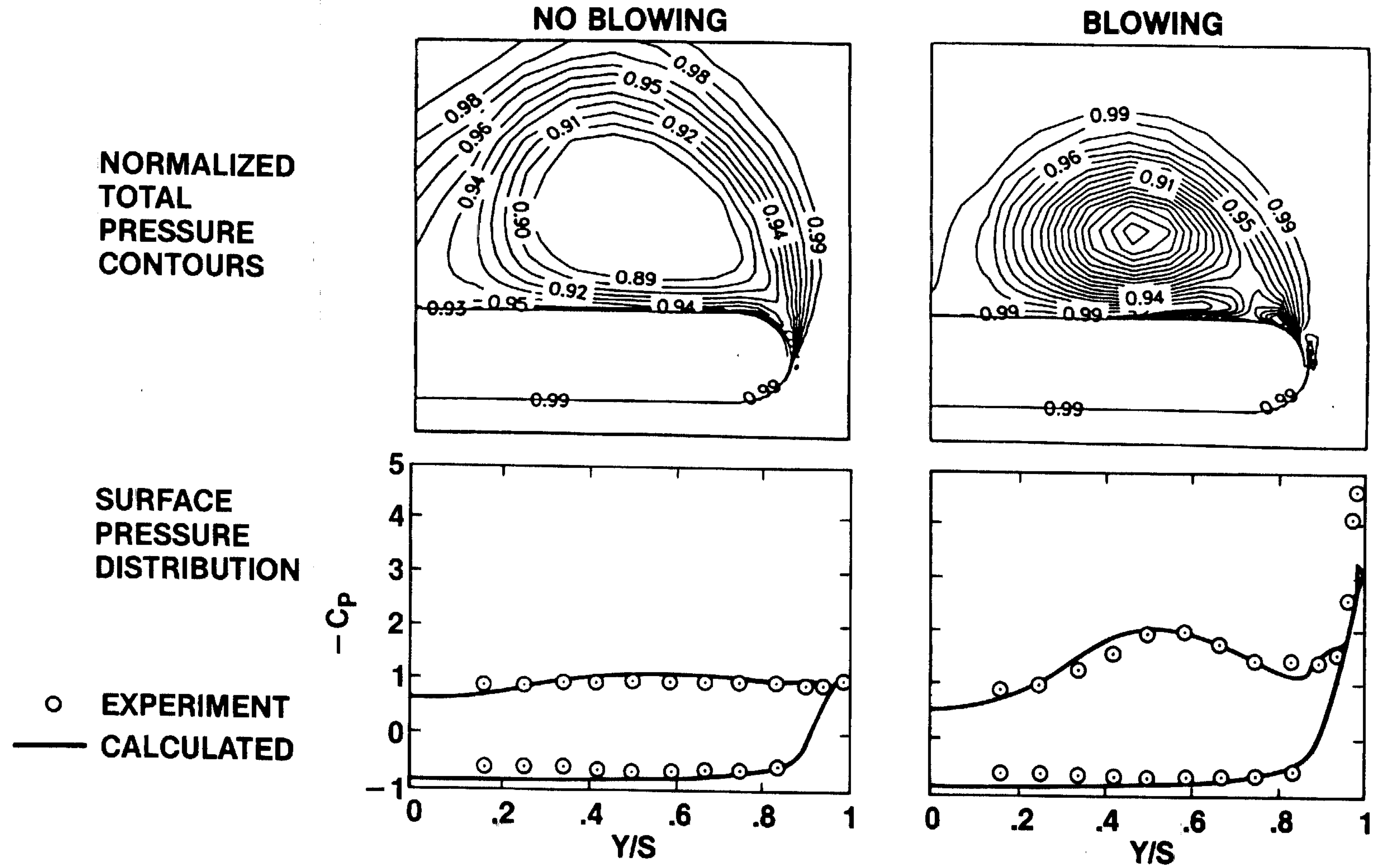
NO BLOWING



EFFECT OF TANGENTIAL LEADING EDGE BLOWING ON VORTICAL FLOW

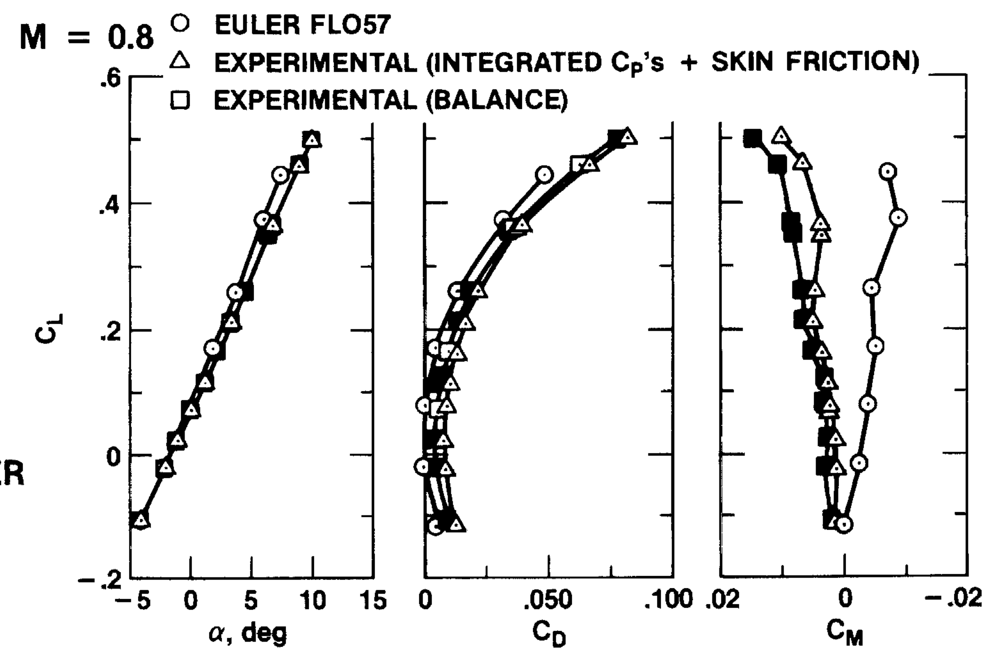
YEH, TAVELLA, ROBERTS

(M_∞ = 0.3, α = 40°, Re = 1.3 × 10^6, X/C = 0.36)



EULER VALIDATION/PRESSURE INTEGRATION

MELTON, ROBERTSON, MOYER



OBJECTIVES

- CFD VALIDATION FOR FLO57 EULER CODE
- ENHANCE WIND TUNNEL PRESSURE INTEGRATION FOR PREDICTING FORCES AND MOMENTS

APPROACH

- FLO57 FINITE VOLUME 3D EULER CODE
- COMPUTE DISCRETIZATION ERROR BY COMPARING CFD FORCE AND MOMENT INTEGRATION WITH CFD PRESSURES INTERPOLATED AND INTEGRATED AT MODEL TAP LOCATIONS

FUTURE DIRECTIONS

- INVESTIGATE NEW METHODS FOR INTEGRATING CFD AND EXPERIMENTAL RESULTS

PAYOFF

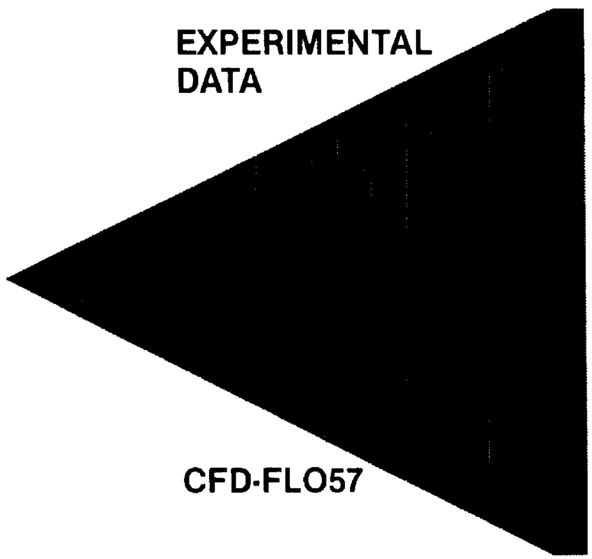
- VALIDATION OF FLO 57 FOR DELTA CONFIGURATIONS
- REDUCE INSTRUMENTATION CONSTRAINTS ON COMPLEX WIND TUNNEL MODELS
- INCREASE ACCURACY OF FORCE AND MOMENT PREDICTIONS FROM WIND TUNNEL PRESSURE INTEGRATIONS

EULER VALIDATION/PRESSURE INTEGRATION

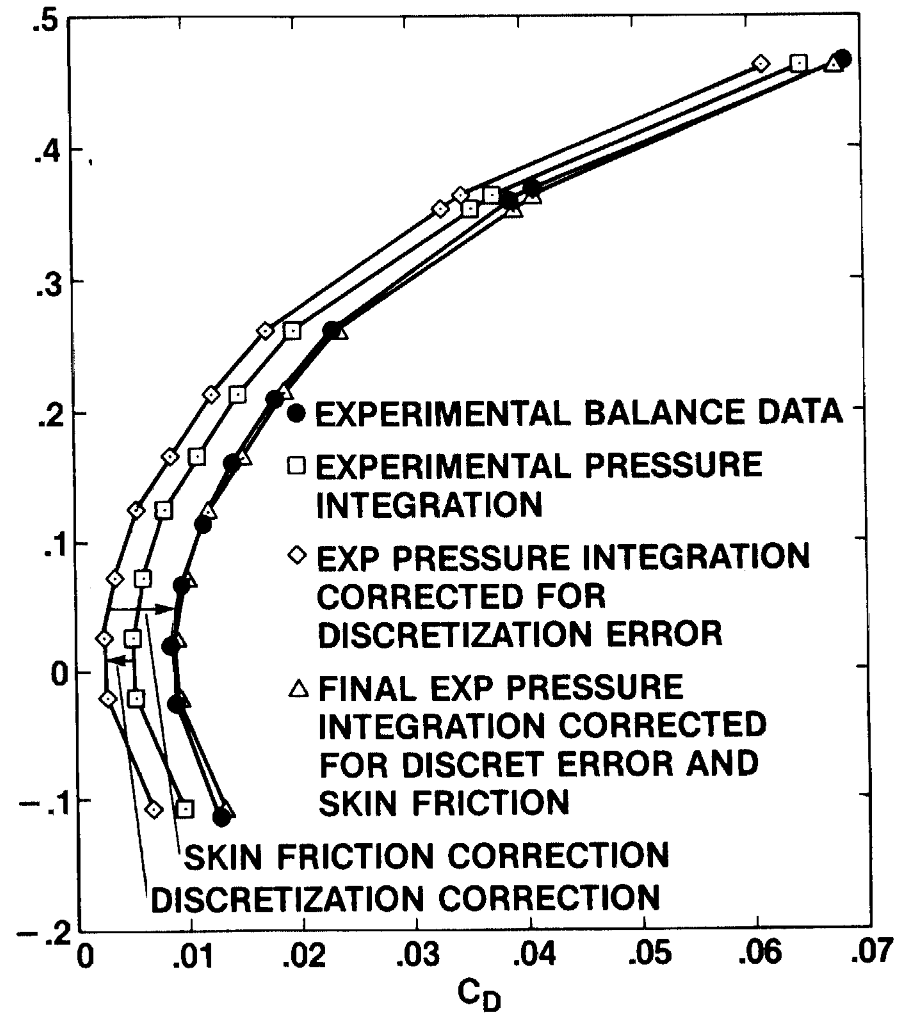
MELTON, ROBERTSON, MOYER

UPPER SURFACE Cp's

$M = 0.8 \quad \alpha = 9.0° \quad C_L = 0.45$

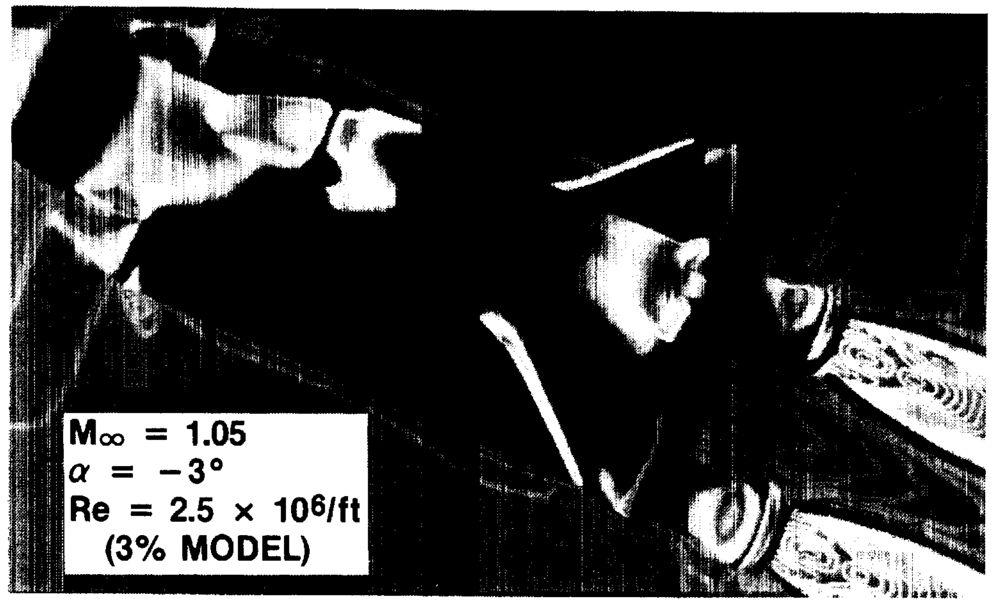


M = 0.8 DRAG POLAR



SPACE SHUTTLE LAUNCH CONFIGURATION

STEGER, RIZK, OBAYASHI, MARTIN, CHIU, BUNING



OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE FLOW OVER INTEGRATED SPACE SHUTTLE IN ASCENT

APPROACH

- SOLVE 3D REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS
- USE CHIMERA GRID APPROACH

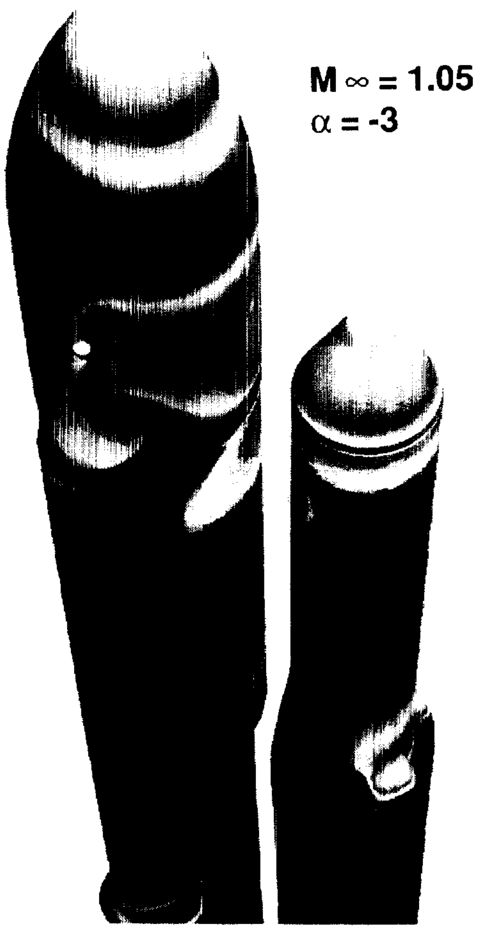
FUTURE DIRECTIONS

- IMPROVE PLUME SIMULATION CAPABILITY AND CODE EFFICIENCY
- VALIDATE UNSTEADY MODE AND STUDY FAST SEPARATION SIMULATIONS

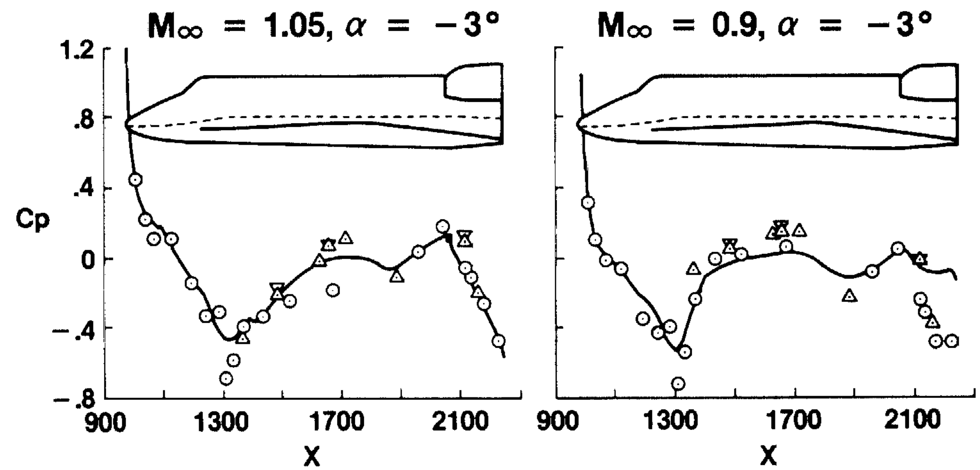
PAYOFF

- PREDICTIVE TOOL FOR UNDERSTANDING AND REFINING AERODYNAMIC PERFORMANCE OF MULTIPLE BODY VEHICLES

SPACE SHUTTLE ASCENT-MODE RESULTS

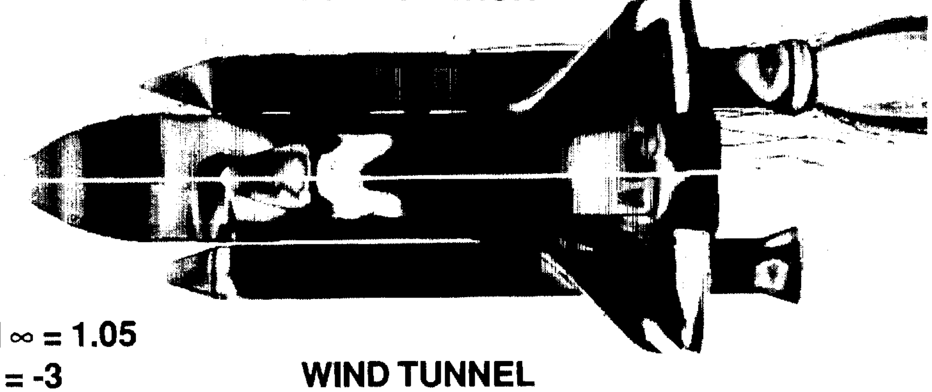


SURFACE PRESSURES
ON SHUTTLE C



Cp COMPARISONS ALONG
ORBITER FUSELAGE DURING ASCENT

COMPUTATION



WIND TUNNEL

COMPARISON OF SURFACE PRESSURES

UNSTEADY MULTIPLE BODY AERODYNAMICS

OBJECTIVE

- TO DEVELOP A GENERAL CAPABILITY FOR TIME-ACCURATE SIMULATION OF 3-D MULTIPLE BODY VISCOUS FLOWS GIVEN ARBITRARY GRID COMBINATIONS, BODY SHAPES, AND RELATIVE MOTION BETWEEN GRID SYSTEMS

CURRENT APPROACH

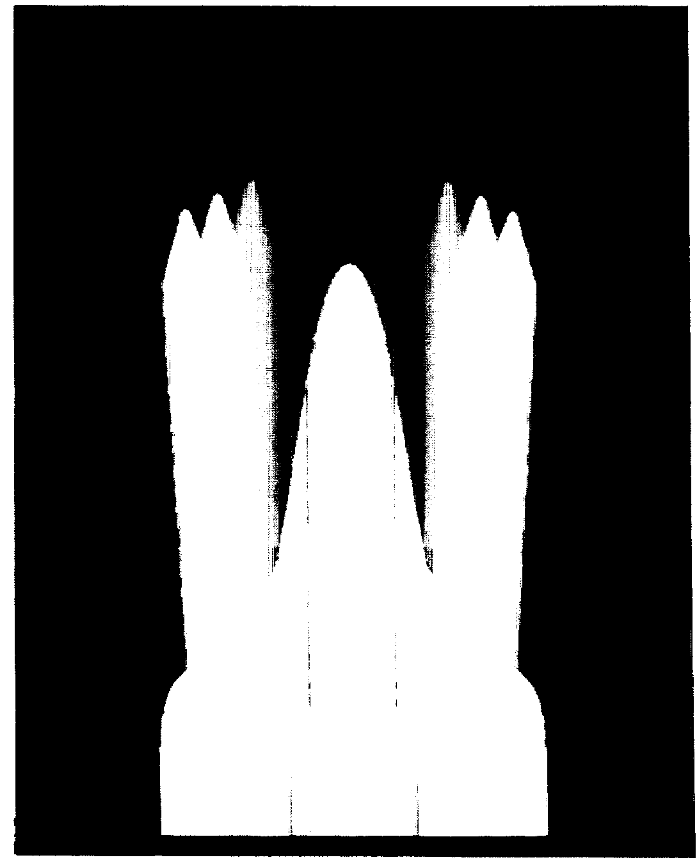
- UNSTEADY CHIMERA COMPOSITE GRID TECHNIQUES
- IMPLICIT TIME-ACCURATE SOLVER FOR THE THIN-LAYER NAVIER-STOKES EQUATIONS

FUTURE DIRECTIONS

- DEVELOP TRAJECTORY PREDICTION ROUTINES
- IMPROVE EFFICIENCY AND ACCURACY OF BASIC ALGORITHMS
- CODE VALIDATION STUDIES

PAYOFF

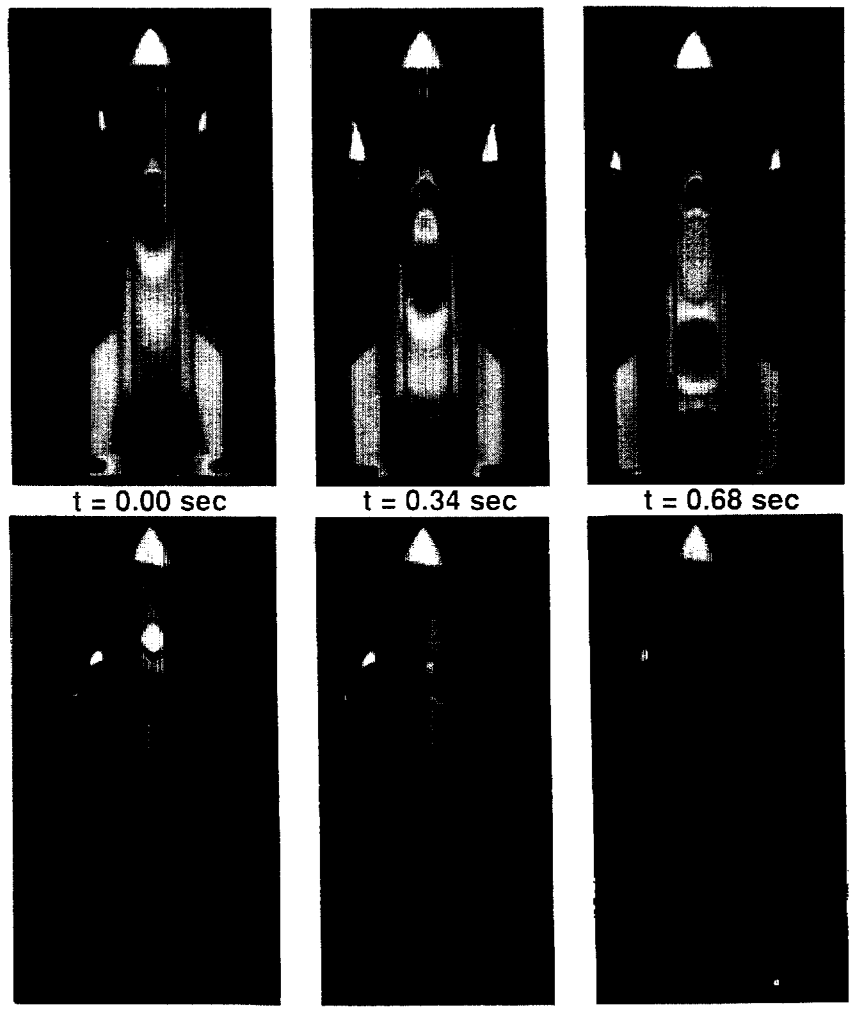
- A VALIDATED COMPUTATIONAL TOOL FOR ANALYZING COMPLEX AERODYNAMIC PROBLEMS INVOLVING MULTIPLE BODIES IN RELATIVE MOTION



TIME-ACCURATE SIMULATION OF THE SPACE SHUTTLE SRB SEPARATION SEQUENCE

PRESSURE CONTOURS

$M_{\infty} = 4.5$
$\alpha = +2^{\circ}$
$R_e = 6.95 \times 10^6$



DISCRETIZATION

GRIDS:

ET	73X39X45
SRB	53X37X21
ORB	74X77X33

TIME-STEP = 1.36×10^{-3} sec

500 STEPS THROUGH BSM BURN

BOOSTER SEPARATION MOTOR (BSM)

BURN-TIME = 0.68 sec

ASSUMPTIONS:
- SIMPLIFIED GEOMETRY
- NO PLUMES
- PRESCRIBED SRB TRAJECTORY

(MEAKIN, SUHS)

AIRCRAFT STORE SEPARATION

MEAKIN, SUHS

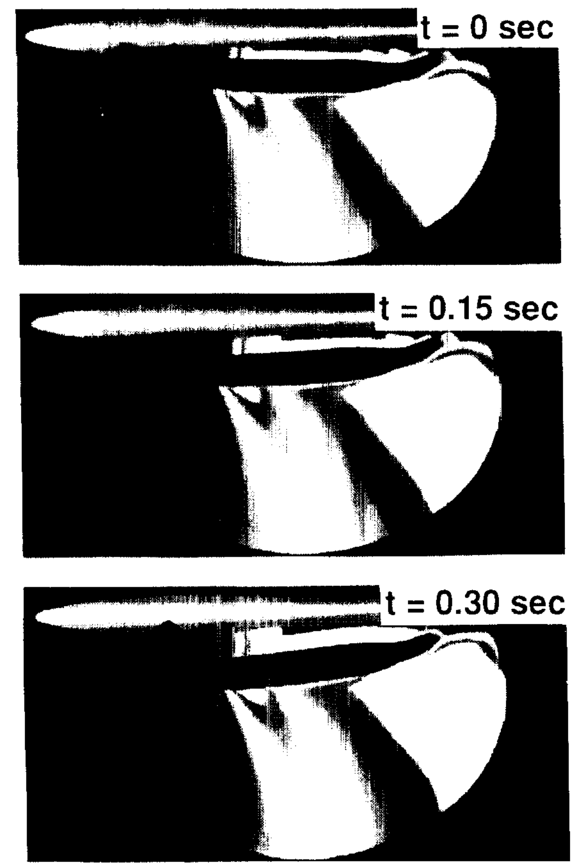
FREESTREAM CONDITIONS: $M_\infty = 1.05$, $\alpha = +2°$, $Re = 2.4 \times 10^6$

WING LOWER SURFACE C_p DISTRIBUTION

STEADY-STATE

MACH CONTOURS ABOUT STORE

TIME-ACCURATE STORE-SEPARATION SIMULATION



TURBULENCE MODELING FOR HYPERSONIC FLOWS

COAKLEY, HORSTMAN, KUSSOY, MARVIN

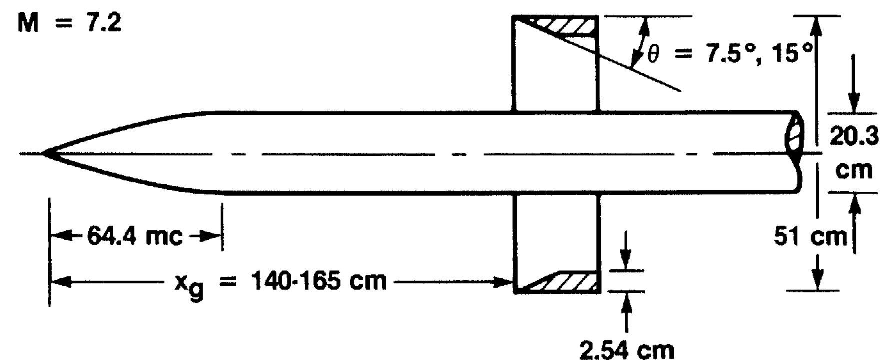
OBJECTIVE

- IMPROVE AND DEVELOP MODELS FOR HYPERSONIC FLOWS

CURRENT APPROACH

- PERFORM COMBINED COMPUTATIONAL AND EXPERIMENTAL STUDIES

TEST MODEL GEOMETRIES USED FOR COMPARISONS OF COMPUTATION AND EXPERIMENT



FUTURE DIRECTIONS

- IMPROVE COMPUTATIONAL EFFICIENCY
- DEVELOP SECOND ORDER CLOSURE MODELS
- PERFORM EXPERIMENTS USING NEWLY DEVELOPED NON INTRUSIVE INSTRUMENTATION

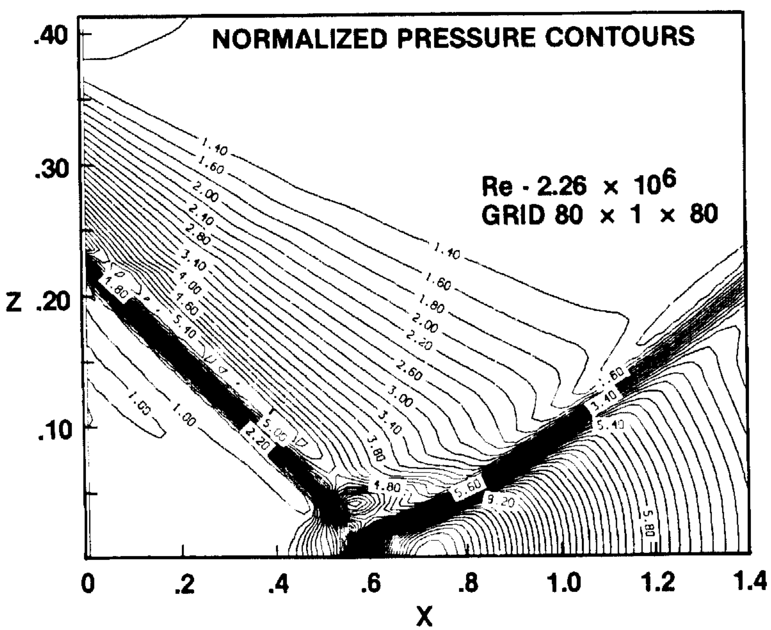
PAYOFF

- ACCURATE COMPUTATIONS OF HEAT TRANSFER, SKIN FRICTION, AND COMPLEX FLOW STRUCTURES

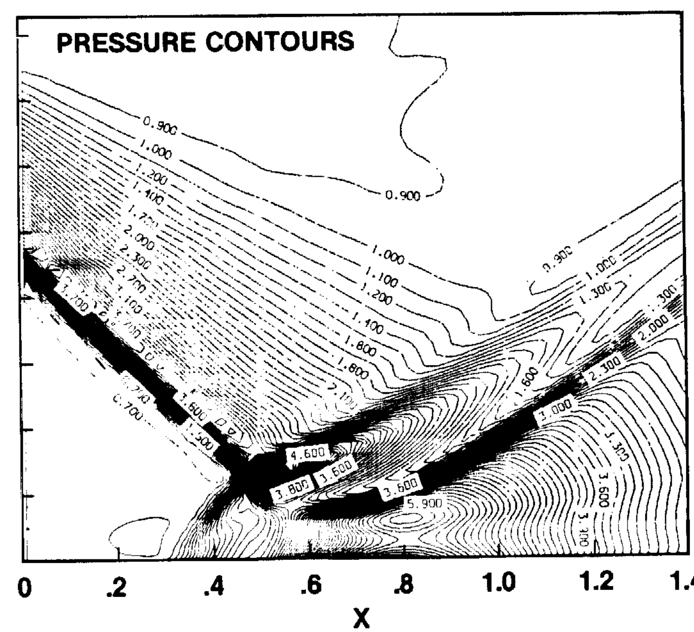
PRESSURE CONTOURS FOR AN IMPINGING SHOCK WAVE FLOW

$M_\infty = 7.2 \qquad \theta = 15°$

BALDWIN-LOMAX MODEL

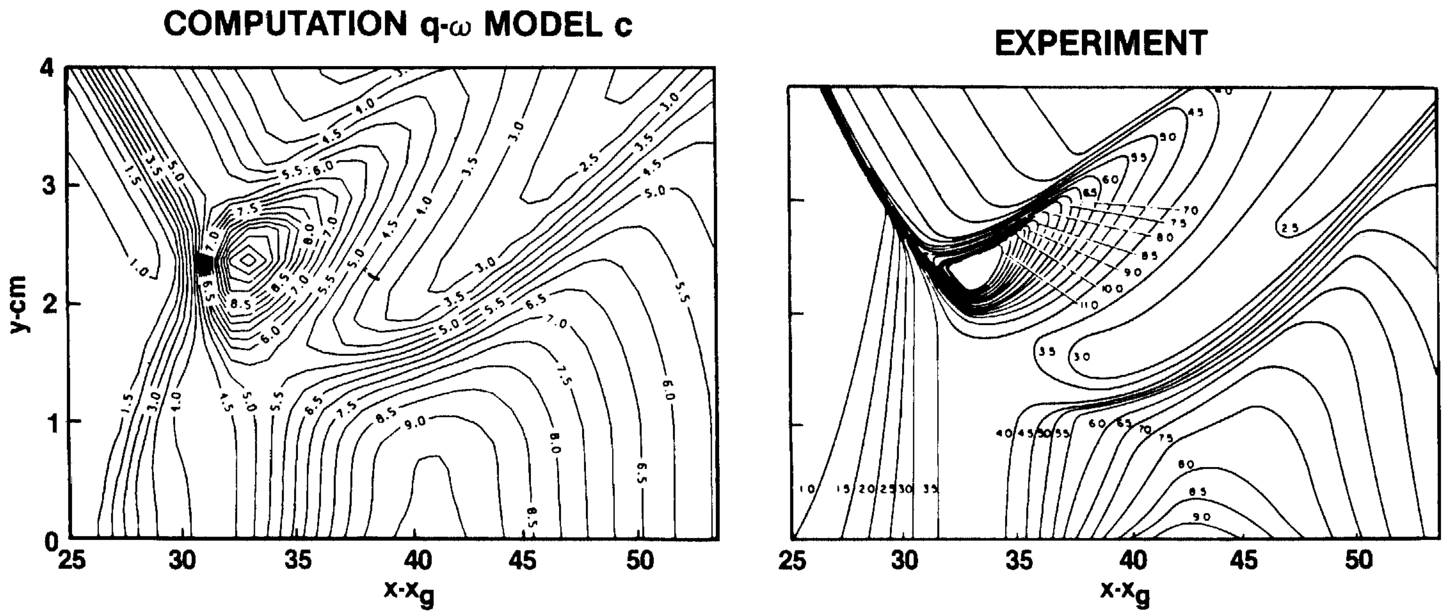


q-ω MODEL c



PRESSURE CONTOURS FOR AN IMPINGING SHOCK WAVE FLOW

$M_\infty = 7.2$ $\theta = 15°$



HYPERSONIC APPLICATIONS

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE REAL-GAS AEROTHERMODYNAMIC CHARACTERISTICS OF HYPERSONIC VEHICLES
- USE CAPABILITY TO GUIDE VEHICLE DESIGNS

APPROACH

- SOLVE 3D REYNOLDS-AVERAGED NAVIER-STOKES AND PARABOLIZED NAVIER-STOKES EQUATIONS USING VARIOUS TRANSITION/TURBULENCE MODELS WITH PERFECT GAS, EQUILIBRIUM REAL GAS AND NONEQUILIBRIUM REAL GAS MODELS

FUTURE DIRECTIONS

- IMPROVE TRANSITION/TURBULENCE MODELS, REAL GAS MODELS, AND COMPUTATIONAL EFFICIENCY
- EXTEND APPLICATIONS TO MORE COMPLEX GEOMETRIES

PAYOFF

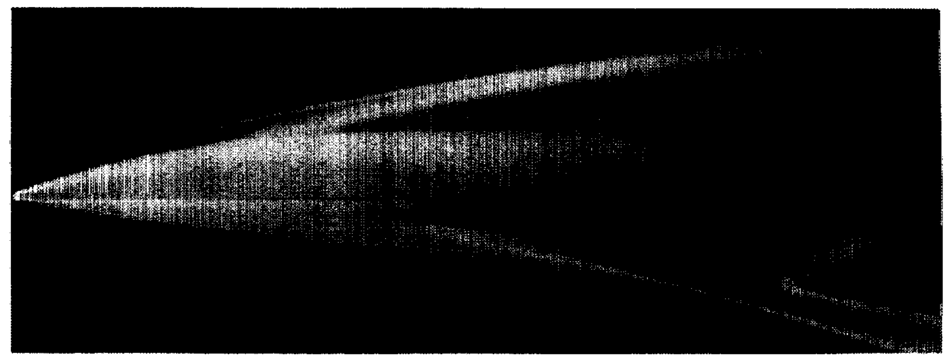
- PROVIDE DESIGN INFORMATION NOT POSSIBLE TO MEASURE IN GROUND-BASED TEST FACILITIES
- ENABLE DEVELOPMENT OF AEROASSISTED VEHICLES AND AIRBREATHING HYPERSONIC AIRCRAFT

GENERIC HYPERSONIC AEROTHERMODYNAMIC RESULTS

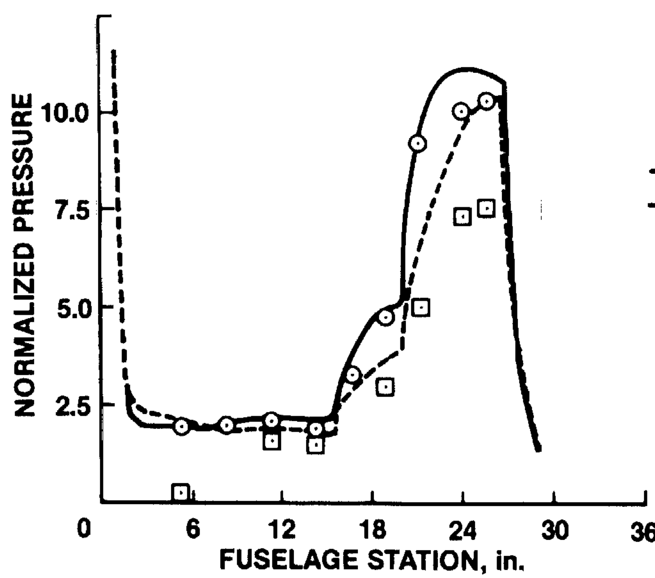
LAWRENCE

$M_\infty = 11.4, \alpha = 0°, Re_L = 29 \times 10^6$

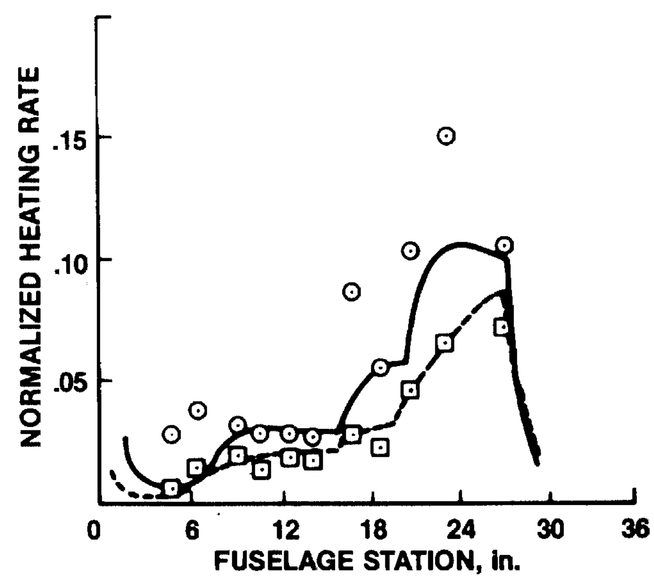
SYMMETRY PLANE
PRESSURE CONTOURS



WINDWARD SYMMETRY PLANE PRESSURES



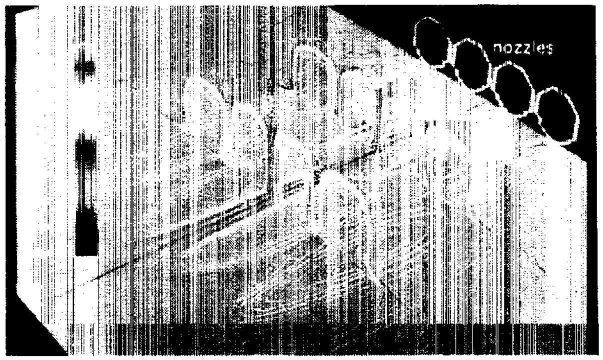
WINDWARD SYMMETRY PLANE HEAT TRANSFER



HYPERSONIC EXHAUST PLUME/AFTERBODY INTERACTION

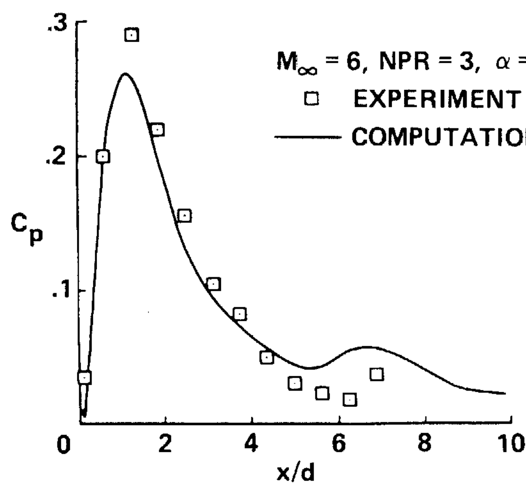
EDWARDS

NOZZLE/AFTERBODY MODEL



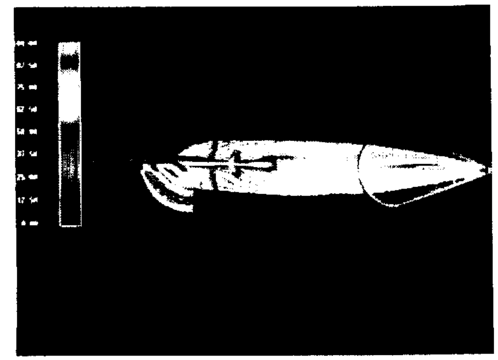
EXHAUST GAS CONCENTRATION CONTOURS

$M_\infty = 6$, NPR = 4, $\alpha = 0°$



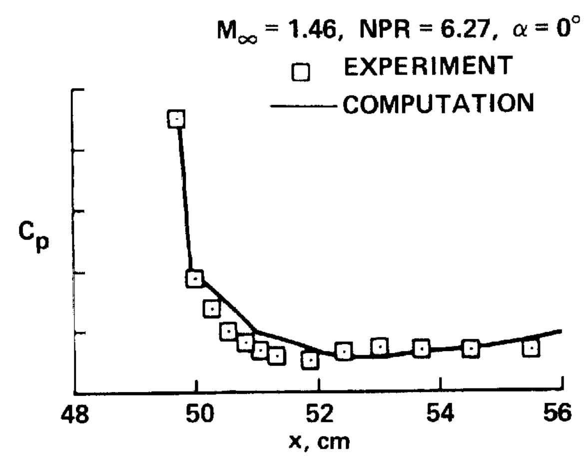
AFTERBODY PRESSURE COMPARISON BETWEEN 2ND AND 3RD NOZZLES

GENERIC HYPERSONIC VEHICLE



PRESSURE CONTOURS

$M_\infty = 6$, NPR = 100, $\alpha = 0°$



PRESSURE COMPARISON WINDWARD PLANE OF SYMMETRY DOWNSTREAM OF NOZZLE

BLUNT 5° CONE WITH SHOCK GENERATORS

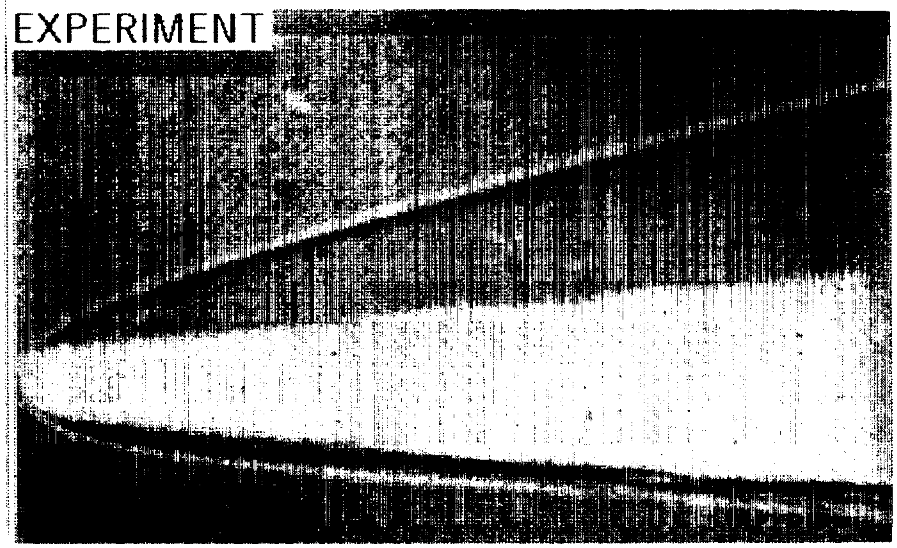
Molvik, Strawa

Conditions: $M_\infty = 14.4$
$Re_L = 10^6$
$P_\infty = 0.0932$atm
$T_\infty = 298^o$K
$\alpha = 6.35^o$

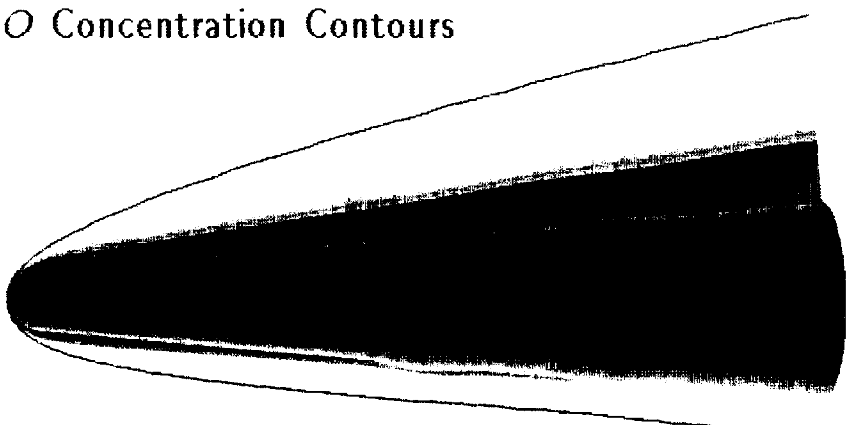
Experimental Facility: Ames Ballistic Range

Flow Solvers: Three-Dimensional Navier-Stokes with Finite Rate Chemistry (TUFF and STUFF)

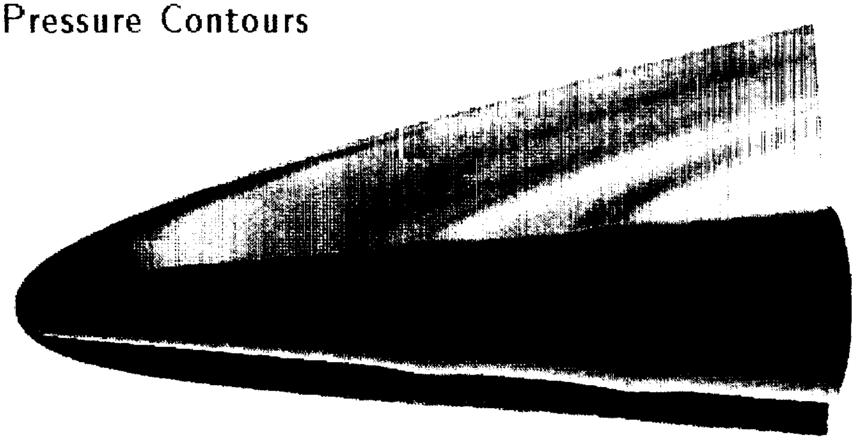
EXPERIMENT



REAL GAS COMPUTATION
O Concentration Contours



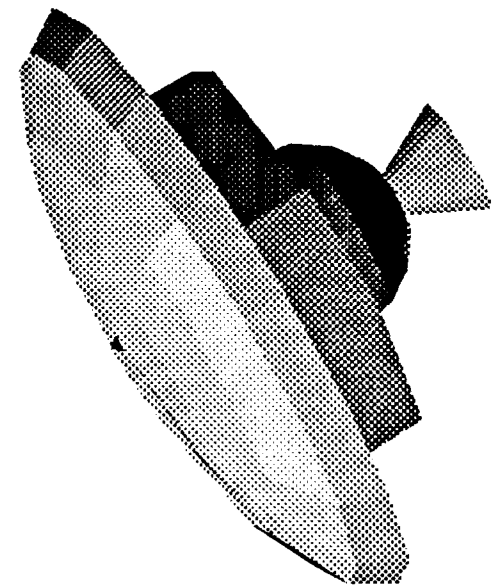
REAL GAS COMPUTATION
Pressure Contours



DIRECT PARTICLE SIMULATION OF HYPERSONIC FLOWS

OBJECTIVE:

- DEVELOP THE CAPABILITIES OF A NEW DISCRETE PARTICLE SIMULATION METHOD FOR RAREFIED HYPERSONIC FLOWS IN 3D WITH NON-EQUILIBRIUM CHEMISTRY.



APPROACH:

- FLUID IS MODELED AS A LARGE COLLECTION OF DISCRETE PARTICLES THAT INTERACT WITH EACH OTHER THROUGH COLLISIONS.
- SIMPLIFIED PHYSICAL MODELS ARE USED ALLOWING ORDERS OF MAGNITUDE INCREASE IN COMPUTATIONAL EFFICIENCY WHILE ENHANCING STATISTICAL ACCURACY.

FUTURE DIRECTIONS:

- REALISTIC 3D GEOMETRIES WITH MORE GENERAL BOUNDARY CONDITIONS.
- EXTENDED MOLECULAR MODELS TO ACCOUNT FOR ADDITIONAL INTERNAL DEGREES OF FREEDOM, CHEMISTRY AND WALL-PARTICLE INTERACTIONS.

PAYOFF:

- DIRECT PARTICLE SIMULATION IS APPLICABLE AT LOW DENSITIES AND HIGH MACH NUMBERS BEYOND THE REACH OF CONTINUUM METHODS.
- ENABLES PARTICLE SIMULATIONS ON A MUCH LARGER SCALE THAN PREVIOUSLY POSSIBLE.
- PROVIDES NEEDED INSIGHT IN THE DESIGN OF PROPOSED HYPERSONIC VEHICLES.

PRINCIPAL CURRENT LIMITATIONS

PHYSICAL MODELS/ALGORITHMS

- BOUNDARY LAYER TRANSITION MODELS
- TURBULENCE MODELS FOR SEPARATING AND REATTACHING FLOWS
- TRANSITION/TURBULENCE MODELS FOR REAL GAS FLOWS AND FLOWS WITH COMBUSTION
- REAL GAS FLOW VALIDATION DATA
- FAST, USER FRIENDLY GEOMETRY DEFINITION/GRID GENERATION SOFTWARE
- FAST, ACCURATE ALGORITHMS FOR COMPLETE SIMULATIONS
- SCIENTIFIC VISUALIZATION SOFTWARE

COMPUTER SYSTEMS

- COMPUTATIONAL SPEED
- NETWORK BANDWIDTHS
- HIGH-SPEED LARGE-VOLUME MASS STORAGE
- TOOLS FOR ANALYZING MASSIVE RESULT FILES

FUTURE DIRECTIONS

ALGORITHM RESEARCH

- IMPROVED ALGORITHMS FOR COMPUTING REAL-GAS TURBULENT FLOWS
- NEW ALGORITHMS TO EXPLOIT ADVANCED MULTIPLE PROCESSOR COMPUTER ARCHITECTURES
- NEW GRID-GENERATION CONCEPTS FOR COMPLEX CONFIGURATIONS, MULTIPLE MOVING BODIES AND UNSTEADY FLOWS

TURBULENCE RESEARCH

- IMPROVED TURBULENCE MODELS FOR PERFECT-GAS SEPARATING AND REATTACHING FLOWS
- NEW TURBULENCE MODELS FOR REAL-GAS FLOWS
- METHODS FOR MANAGING TURBULENCE TO REDUCE DRAG, IMPROVE COMPONENT PERFORMANCE, MINIMIZE HEAT TRANSFER, AND CONTROL COMBUSTION PROCESSES

MULTIDISCIPLINARY RESEARCH

- NUMERICAL METHODS FOR SOLVING FULLY COUPLED COMBINATIONS OF EQUATIONS FOR AERODYNAMICS, GAS CHEMISTRY, STRUCTURES, CONTROLS, PROPULSION AND ELECTROMAGNETICS

FUTURE DIRECTIONS
(CONCLUDED)

GRAPHICS AND WORKSTATION RESEARCH

- IMPROVED USER EFFICIENCY THROUGH ADVANCES IN GRAPHICS AND WORKSTATION TECHNOLOGY

APPLICATIONS CODES

- AIRCRAFT MANEUVERING NEAR PERFORMANCE BOUNDARIES
- POWERED LIFT AIRCRAFT OPERATING IN AND OUT OF GROUND EFFECT
- HYPERSONIC VEHICLES INCLUDING INLET, ENGINE AND EXHAUST FLOWS
- ROTORCRAFT IN HOVER, TRANSITION AND FORWARD FLIGHT
- TURBOMACHINERY INCLUDING PUMPS, COMPRESSORS AND TURBINES
- METHODS FOR NUMERICALLY OPTIMIZING DESIGNS
- DESIGNER-FRIENDLY CODES WITH 'EXPERT SYSTEMS' ELEMENTS