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106P.

NASA's
COMPUTATIONAL FLUID DYNAMICS PROGRAM

DOD, NASA AND DARPA
TOPICAL REVIEW ON COMPUTATIONAL FLUID DYNAMICS
January 27 - 28, 1988

Presented by
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Director of Aerophysics

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NASA Ames Research Center

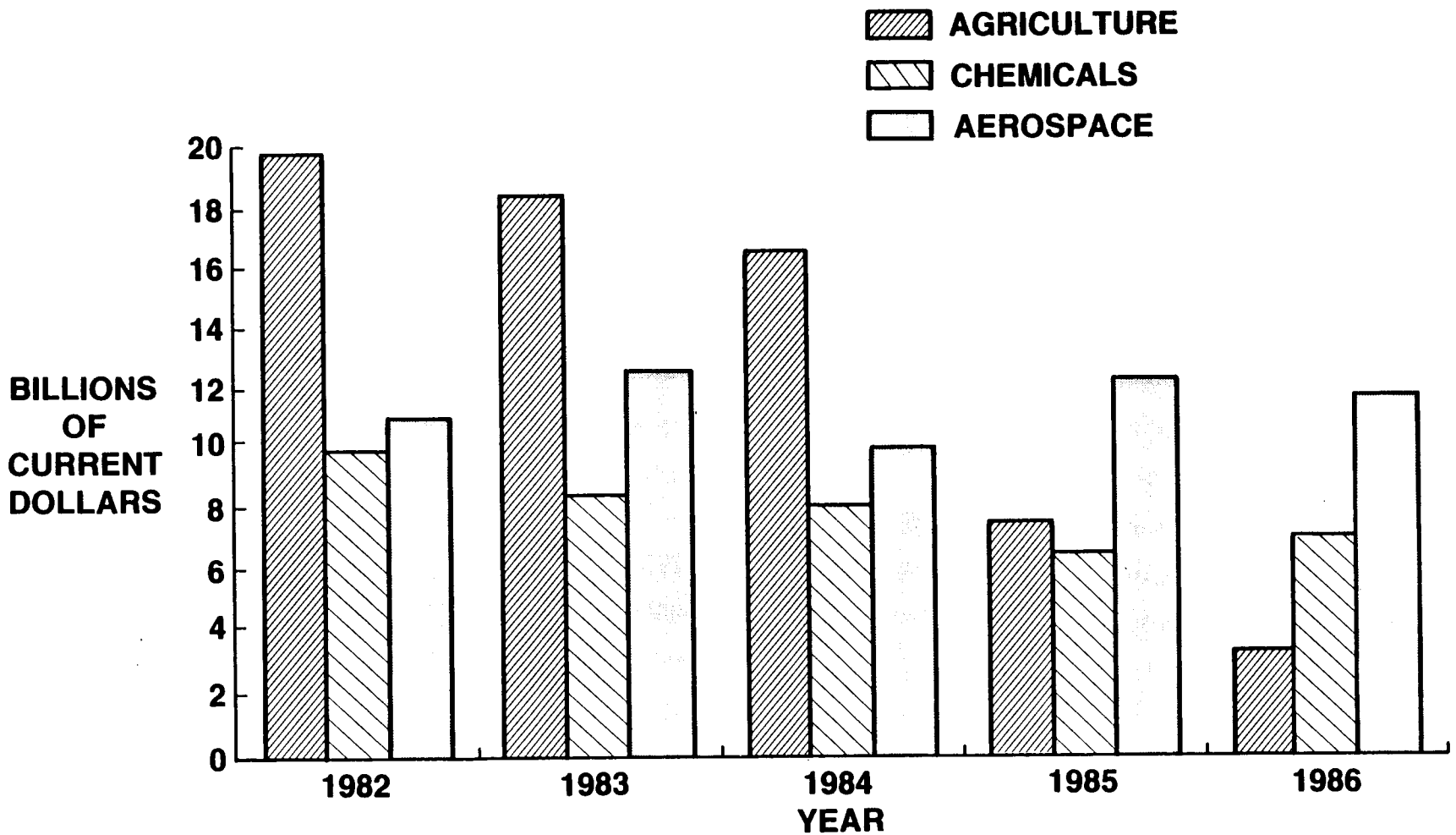
OUTLINE OF PRESENTATION

- IMPORTANCE OF AEROSPACE PROGRAMS TO NATION
- NASA'S ROLE AND APPROACH TO AEROSPACE RESEARCH
- IMPORTANCE OF COMPUTATIONAL FLUID DYNAMICS
- ELEMENTS OF COMPUTATIONAL FLUID DYNAMICS PROGRAM
- STATE-OF-THE-ART EXAMPLES OF COMPUTATIONAL FLUID DYNAMICS
- COMPUTER PERFORMANCE RELATED TO PROBLEM SOLVING
- NAS, OTHER MAJOR COMPUTER FACILITIES AND SUPPORTING INSTITUTIONS
- PRINCIPAL CURRENT LIMITATIONS AND FUTURE DIRECTIONS
- RESOURCES
- SUMMARY AND SPECIAL ISSUES

IMPORTANCE OF AEROSPACE PROGRAMS TO THE NATION

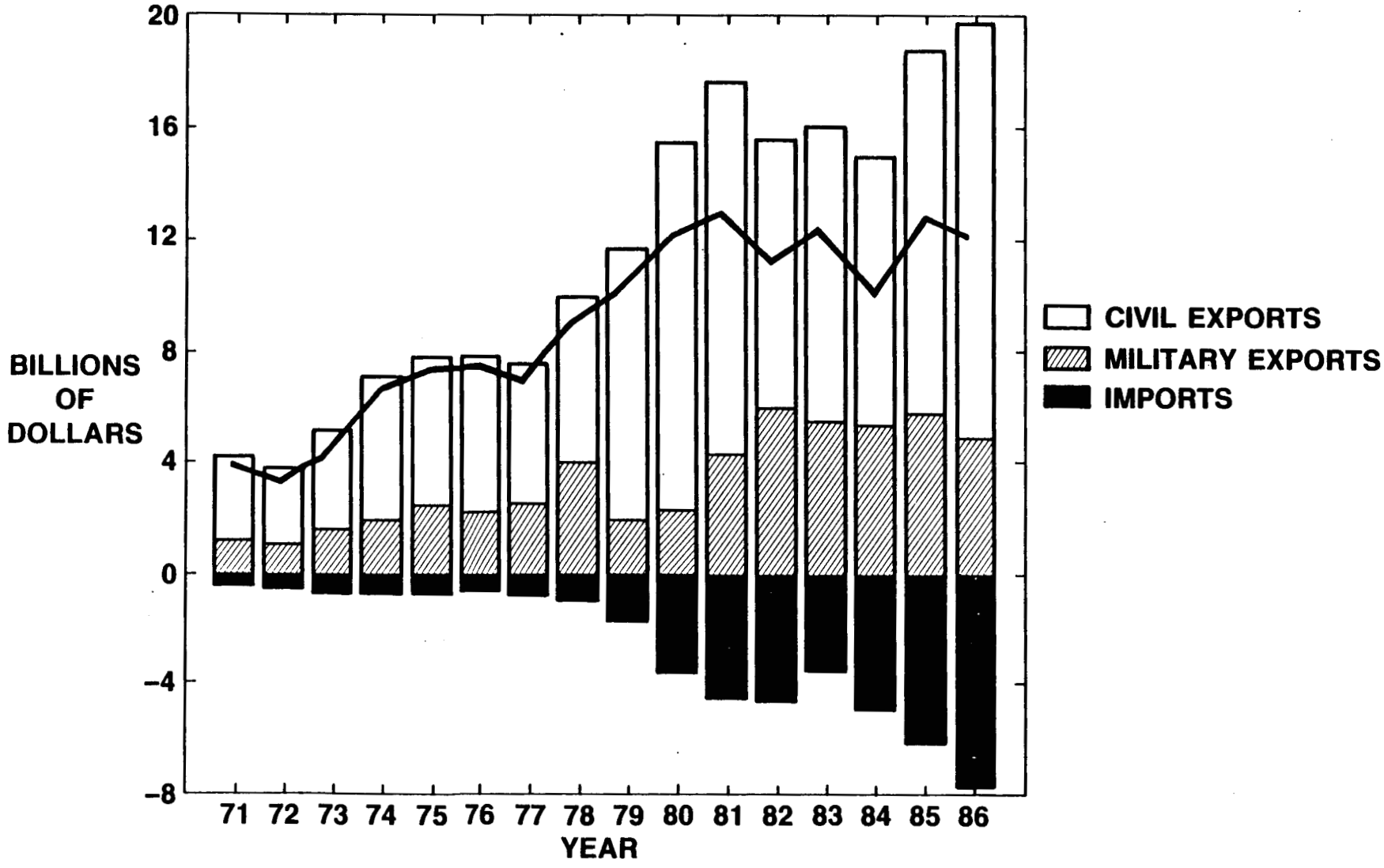
TOP U.S. TRADE PERFORMERS

TRADE SURPLUS



SOURCE: COMPILED FROM OFFICIAL STATISTICS OF THE U.S. DEPARTMENT OF COMMERCE

AEROSPACE TRADE BALANCE



NASA'S ROLE AND APPROACH TO AEROSPACE RESEARCH

NATIONAL AERONAUTICS AND SPACE ACT OF 1958

"THE CONGRESS DECLARES THAT THE GENERAL WELFARE AND SECURITY OF THE UNITED STATES REQUIRE THAT ADEQUATE PROVISION BE MADE FOR AERONAUTICAL AND SPACE ACTIVITIES . . ."

"THE AERONAUTICAL AND SPACE ACTIVITIES OF THE UNITED STATES SHALL BE CONDUCTED SO AS TO CONTRIBUTE MATERIALLY TO ONE OR MORE OF THE FOLLOWING OBJECTIVES:

(2) THE IMPROVEMENT OF THE USEFULNESS, PERFORMANCE, SPEED, SAFETY, AND EFFICIENCY OF AERONAUTICAL AND SPACE VEHICLES; . . .

(5) THE PRESERVATION OF THE ROLE OF THE UNITED STATES AS A LEADER IN AERONAUTICAL AND SPACE SCIENCE AND TECHNOLOGY; . . .

(6) THE MAKING AVAILABLE TO AGENCIES DIRECTLY CONCERNED WITH NATIONAL DEFENSE OF DISCOVERIES THAT HAVE MILITARY VALUE OR SIGNIFICANCE, AND THE FURNISHING BY SUCH AGENCIES, TO THE CIVILIAN AGENCY ESTABLISHED TO DIRECT AND CONTROL NON-MILITARY AERONAUTICAL AND SPACE ACTIVITIES, OF INFORMATION AS TO DISCOVERIES WHICH HAVE VALUE OR SIGNIFICANCE TO THAT AGENCY; . . .

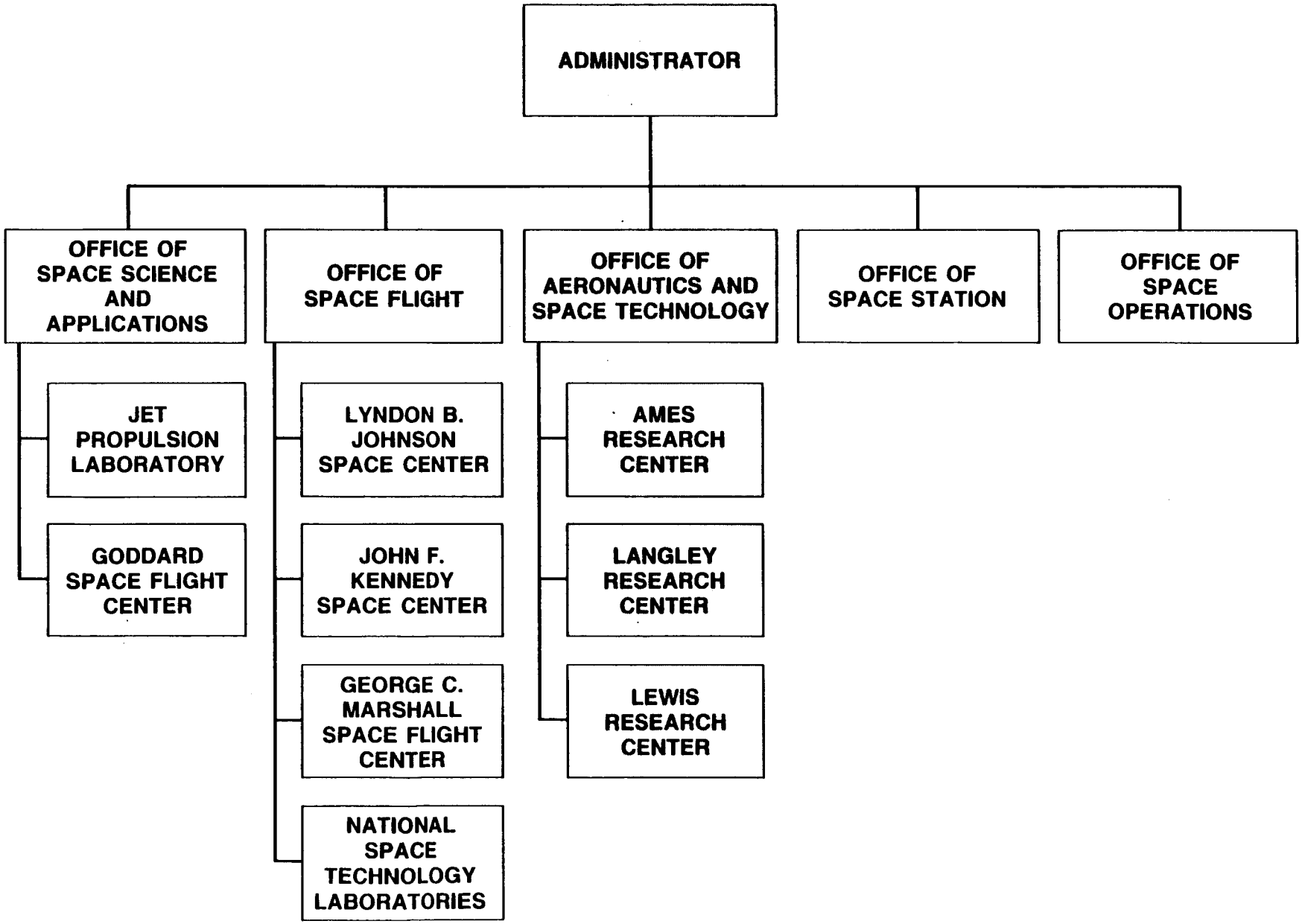
(8) THE MOST EFFECTIVE UTILIZATION OF THE SCIENTIFIC AND ENGINEERING RESOURCES OF THE UNITED STATES, WITH CLOSE COOPERATION AMONG ALL INTERESTED AGENCIES OF THE UNITED STATES IN ORDER TO AVOID UNNECESSARY DUPLICATION OF EFFORT, FACILITIES, AND EQUIPMENT."

NASA'S ROLE IN AEROSPACE

- TO MAINTAIN NASA RESEARCH CENTERS IN POSITIONS OF EXCELLENCE IN FACILITIES, COMPUTATIONAL CAPABILITY, AND TECHNICAL STAFF
- TO MAINTAIN AN AGGRESSIVE AERONAUTICAL R&T PROGRAM COMPRISING A BALANCE OF LEADING-EDGE DISCIPLINARY RESEARCH, SYSTEMS RESEARCH, AND SELECTED PROOF-OF-CONCEPT ACTIVITIES APPLICABLE TO BOTH CIVIL AND MILITARY AVIATION
- TO STRENGTHEN THE NASA PROGRAM BY INCREASED PARTICIPATION OF U.S. INDUSTRY AND UNIVERSITIES
- TO PROVIDE AERONAUTICAL DEVELOPMENT SUPPORT TO OTHER GOVERNMENT AGENCIES AND TO U.S. INDUSTRY

SOURCE: NASA REPORT TO OSTP AERONAUTICAL POLICY REVIEW COMMITTEE, JULY 6, 1984

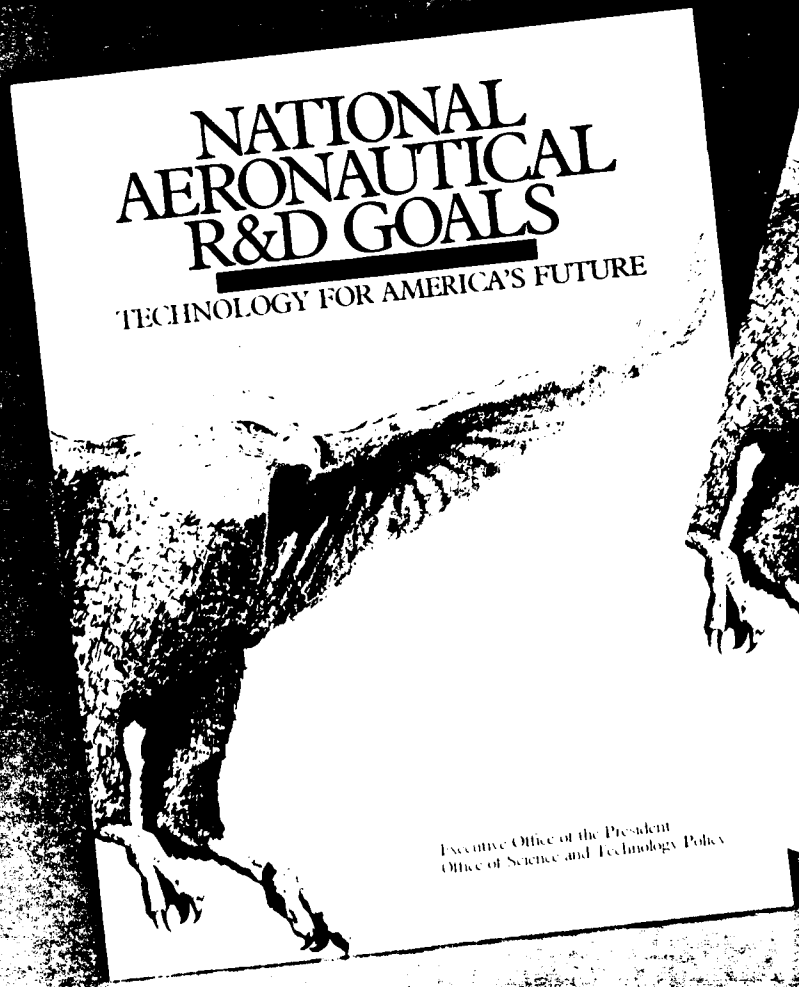
ELEMENTS OF NASA RESPONSIBLE FOR AEROSPACE RESEARCH

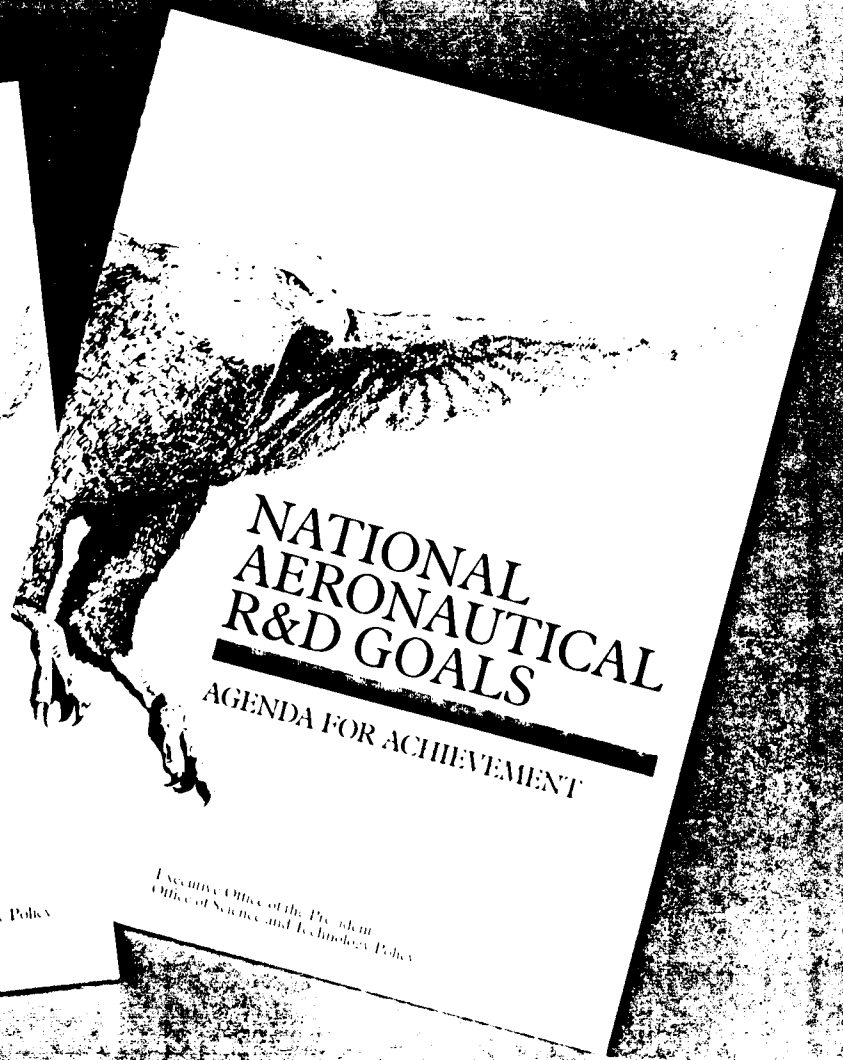


NASA APPROACH TO AEROSPACE RESEARCH AND TECHNOLOGY DEVELOPMENT

- NASA INDEPENDENT RESEARCH
  - FRONTIER PROBLEMS IN AERODYNAMICS, PROPULSION, STRUCTURES, AND FLIGHT SYSTEMS
  - FUNDAMENTAL IN NATURE
  - PHYSICAL UNDERSTANDING, DESIGN DATA, AND NEW CONCEPTS
  - VALIDATED DESIGN AND ANALYSIS PROCEDURES
- COOPERATIVE/JOINT EFFORTS
  - MORE APPLIED IN NATURE
  - QUID PRO QUO RELATIONSHIPS WITH DOD, INDUSTRY, AND UNIVERSITIES
  - AUGMENTS NASA CAPABILITIES AND PROGRAM
  - ACCELERATES TECHNOLOGY TRANSFER
- SPECIFIC REQUESTS
  - INVOLVES CONSULTATION, STUDIES, AND TESTS
  - DEVELOPS AWARENESS OF PRACTICAL PROBLEMS
  - IDENTIFIES PROBLEMS NEEDING RESEARCH
  - AUGMENTS DOD CAPABILITIES IN CONTRACTOR SELECTION

AMERICA'S PLAN FOR AERONAUTICS





EXCERPT FROM NATIONAL AERONAUTICAL R&D GOALS: AGENDA FOR ACHIEVEMENT

"THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) IS THIS COUNTRY'S FOCAL POINT FOR AERONAUTICAL RESEARCH AND TECHNOLOGY AND NATIONAL AERONAUTICAL FACILITIES. NASA MUST STRENGTHEN ITS CAPABILITIES AND TAKE A MORE ASSERTIVE LEADERSHIP ROLE IN COORDINATING AND FACILITATING LONG-TERM U.S. RESEARCH EFFORTS FOR MAXIMUM EFFECTIVENESS."

SOURCE: EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
FEBRUARY, 1987

IMPORTANCE OF COMPUTATIONAL FLUID DYNAMICS

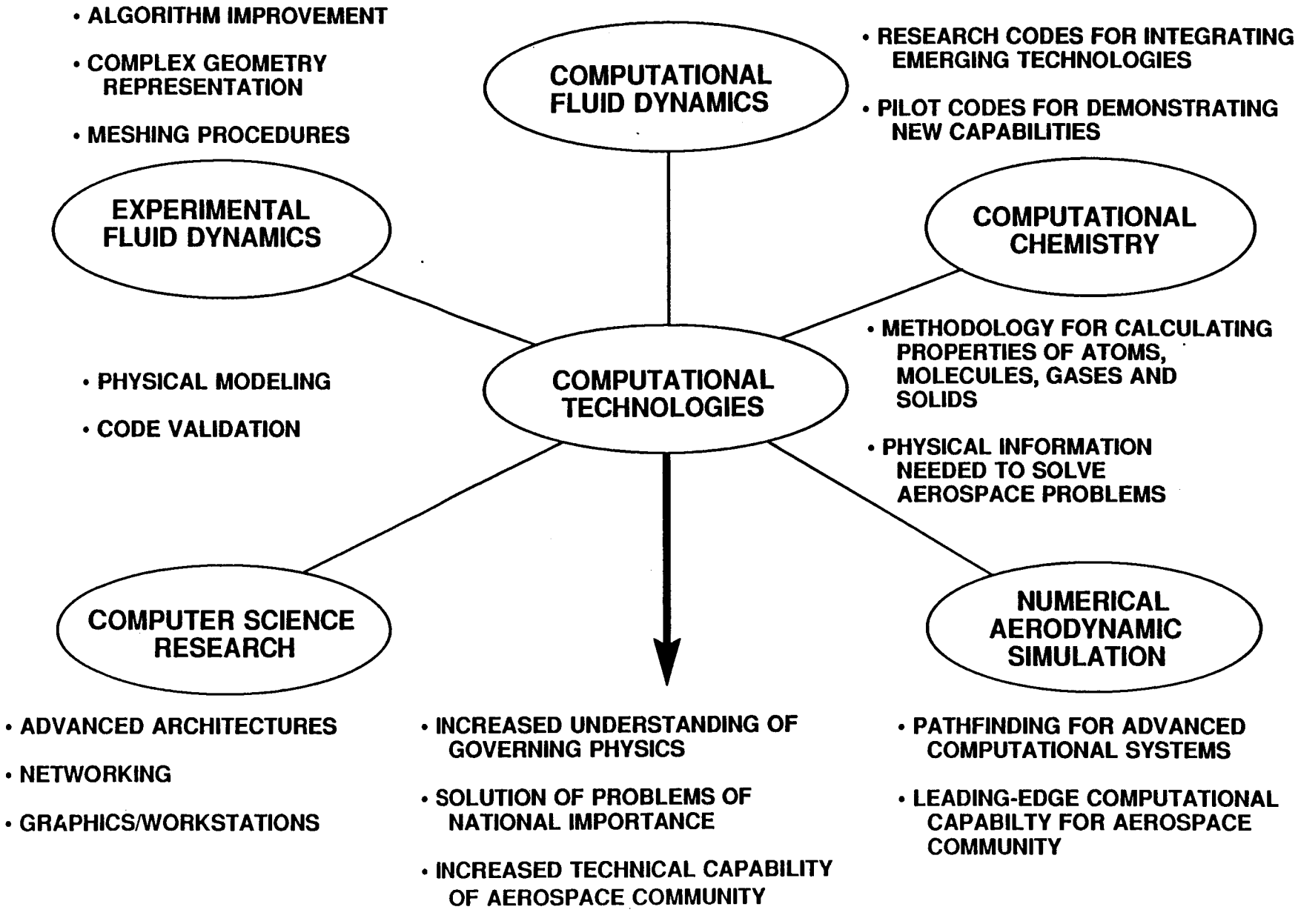
IMPORTANT USES OF COMPUTATIONAL FLUID DYNAMICS IN AEROSPACE RESEARCH AND DEVELOPMENT

- COMPLEMENT EXPERIMENTS
  - CORRECT MEASUREMENTS FOR LABORATORY-INDUCED EFFECTS
  - EXTEND RESULTS BEYOND THE RANGE OF EXPERIMENT
  - INTERPRET MEASUREMENTS
- PROVIDE NEEDED INFORMATION NOT OTHERWISE ACCESSIBLE
  - SIMULATE PHENOMENA NOT REPRODUCIBLE IN LABORATORY
  - OBTAIN RELATIONSHIPS BETWEEN VARIABLES NOT POSSIBLE TO MEASURE
  - SOLVE GOVERNING EQUATIONS TOO COMPLEX TO TREAT ANALYTICALLY
- INCREASE PRODUCTIVITY OF SCIENTISTS AND ENGINEERS
  - PROVIDE INFORMATION IN LESS TIME AND FOR LESS COST
  - PERMIT INVESTIGATORS TO USE TIME MORE EFFECTIVELY
  - ENABLE EFFICIENT MULTIVARIABLE OPTIMIZATION
- PROVIDE COMPETITIVE ADVANTAGE
  - ENHANCE CAPABILITY OF INVESTIGATOR, LABORATORY, INDUSTRIAL CORPORATION AND COUNTRY
  - ENABLE RAPID DEVELOPMENTS NOT OTHERWISE POSSIBLE

DEVELOP HIGHER PERFORMANCE VEHICLES WITH REDUCED DESIGN TIME, COST AND RISK

ELEMENTS OF COMPUTATIONAL FLUID DYNAMICS PROGRAM

COMPUTATIONAL TECHNOLOGIES
THRUSTS



PHASES OF CFD DEVELOPMENT RELATED TO PRACTICAL PAYOFF

NASA EMPHASIS		INDUSTRY EMPHASIS	
ENABLING TECHNOLOGIES	**RESEARCH CODES**	**PILOT CODES**	**PRODUCTION CODES**
• GOVERNING EQUATIONS • PHYSICAL MODELS • ALGORITHMS • GRIDS	• INTEGRATION OF TECHNOLOGIES • LIMITED PIONEERING APPLICATIONS	• CALIBRATION AND VALIDATION FOR WIDE RANGE OF APPLICATIONS	• USED IN DESIGN ENVIRONMENT • COST EFFECTIVE

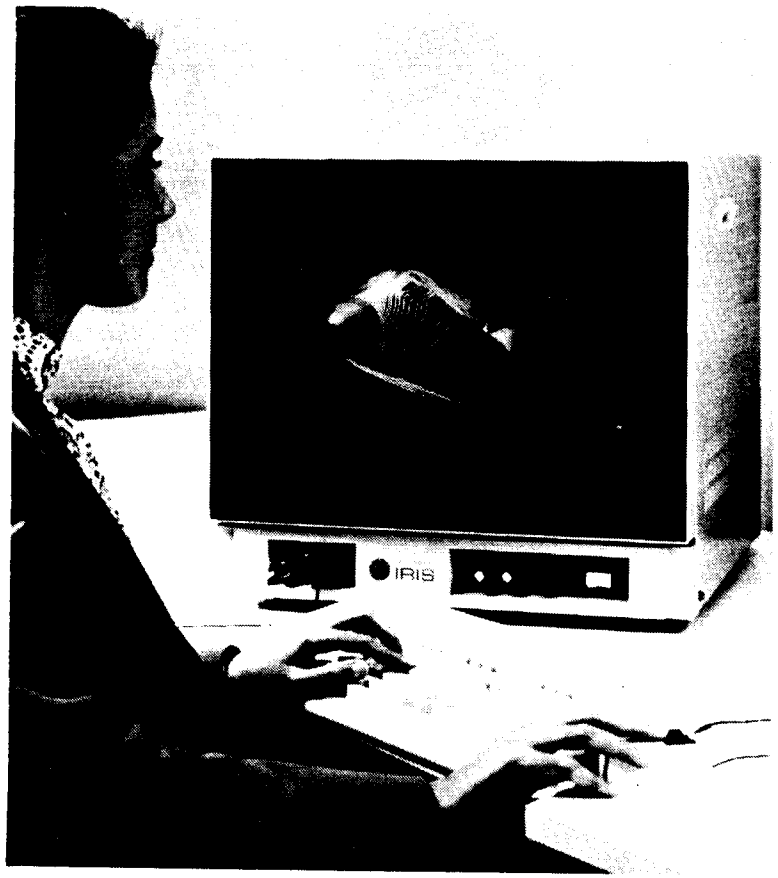
LEVEL OF PRACTICAL PAYOFF

STATE-OF-THE-ART EXAMPLES OF COMPUTATIONAL FLUID DYNAMICS

WORKSTATION TECHNOLOGY

OBJECTIVE

- DEVELOP ADVANCED METHODS FOR INTERACTIVELY COUPLING THE SCIENTIST AND THE COMPUTER
- IMPROVE THE UNDERSTANDING OF BOTH COMPUTED AND MEASURED RESULTS THROUGH ENHANCED VISUALIZATION AND ANALYSIS TOOLS



CURRENT APPROACH

- COMBINE ADVANCED COMPUTER GRAPHIC DISPLAY TECHNOLOGY WITH CONCEPTS FROM HUMAN VISION RESEARCH TO CREATE DISPLAYS THAT BETTER CONVEY THE PHYSICS OF KEY RESULTS
- PROVIDE DIRECT COUPLING OF SUPER-COMPUTER AND EXPERIMENTAL DATA BASES TO WORKSTATIONS IN SCIENTIST'S OFFICES

FUTURE DIRECTIONS

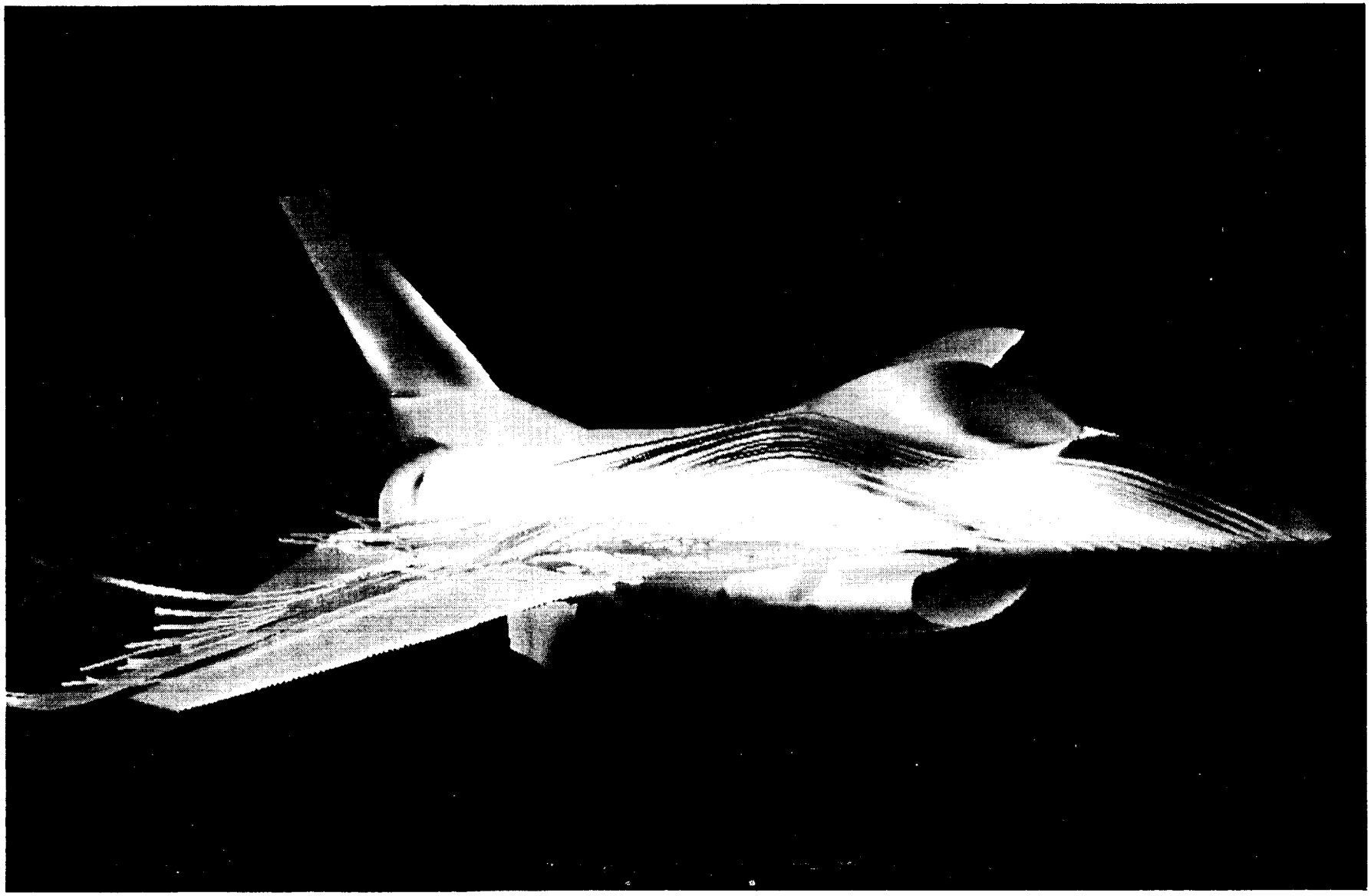
- CONTINUE TO ADVANCE HARDWARE AND SOFTWARE TECHNOLOGY
- DEVELOP EXPERT SYSTEMS BASED ON TOPOLOGICAL RULES TO EXTRACT AND DISPLAY KEY FLOWFIELD FEATURES

PAYOFF

- FASTER AND MORE COMPLETE UNDERSTANDING OF RESULTS
- IMPROVED CAPABILITY FOR TECHNOLOGY TRANSFER

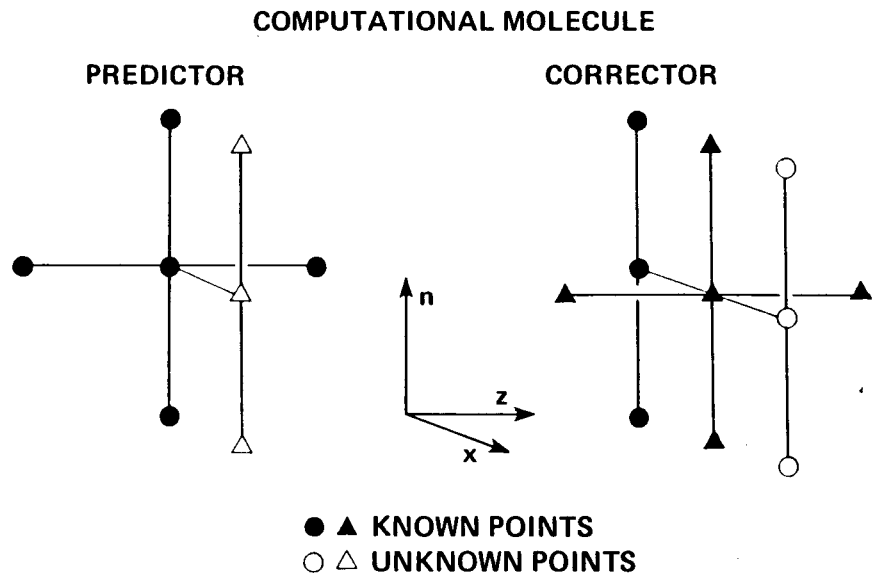
WORKSTATION TECHNOLOGY

EXAMPLE DISPLAY OF COMPUTED RESULTS



NUMERICAL METHODS

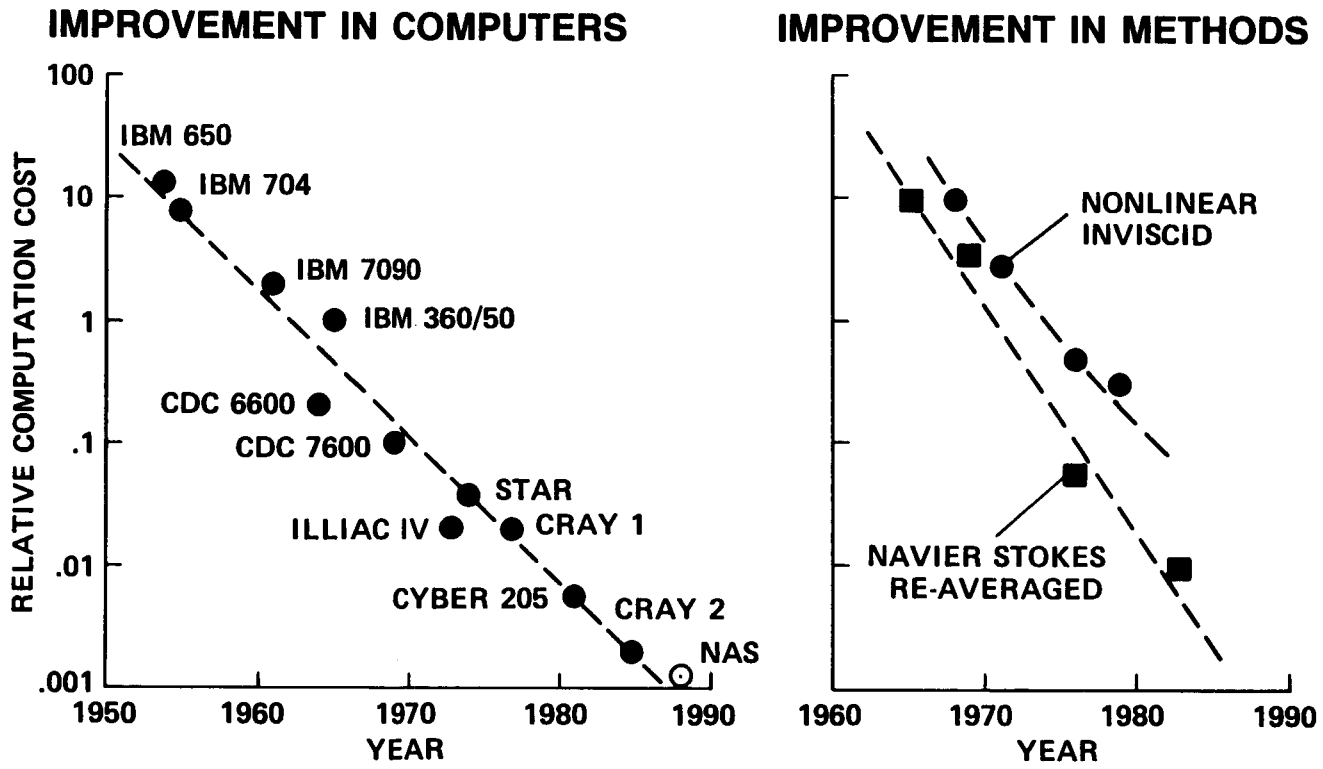
- **OBJECTIVE**
  - DECREASE COMPUTER TIME REQUIRED TO SOLVE SYSTEMS OF FLUID-FLOW EQUATIONS BY IMPROVING EFFICIENCY OF NUMERICAL ALGORITHMS



- **CURRENT APPROACH**
  - CONTINUE SEARCH FOR IMPROVEMENTS BY MEANS OF NUMERICAL ANALYSIS AND EXPERIMENT
- **FUTURE DIRECTIONS**
  - INCREASE EMPHASIS ON METHODS FOR SOLVING REAL-GAS EQUATIONS
- **PAYOFF**
  - REDUCE COST OF COMPUTATION (100-FOLD REDUCTION REALIZED IN 15-YEAR PERIOD)
  - ENABLE INCREASINGLY COMPLEX PHYSICAL MODELS TO BE USED IN THE DESIGN ENVIRONMENT

NUMERICAL METHODS

COMPARISON OF METHOD—AND COMPUTER—IMPROVEMENTS

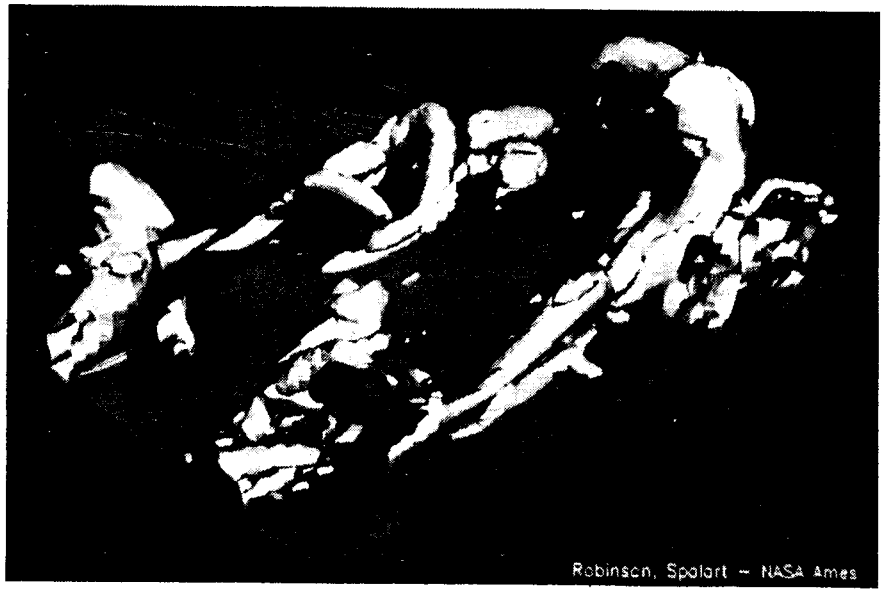


IMPROVEMENTS COMPOUND TO RESULT IN 10^5 REDUCTION IN COST OF PERFORMING A COMPUTATION OVER A 15-YEAR PERIOD

PHYSICS OF TRANSITION AND TURBULENCE

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE THE PHYSICAL CHARACTERISTICS OF TRANSITION FROM LAMINAR TO TURBULENT FLOW AND OF FULLY-DEVELOPED TURBULENCE



CURRENT APPROACH

- SOLVE FULL NAVIER-STOKES EQUATIONS WITHOUT MODELING AND WITH SUBGRID-SCALE MODELS FOR SIMPLE FLOWS AT LOW REYNOLDS NUMBERS
- DEVELOP NEW TURBULENCE MODELS BASED ON NEW FINDINGS
- CONDUCT VALIDATING EXPERIMENTS

FUTURE DIRECTIONS

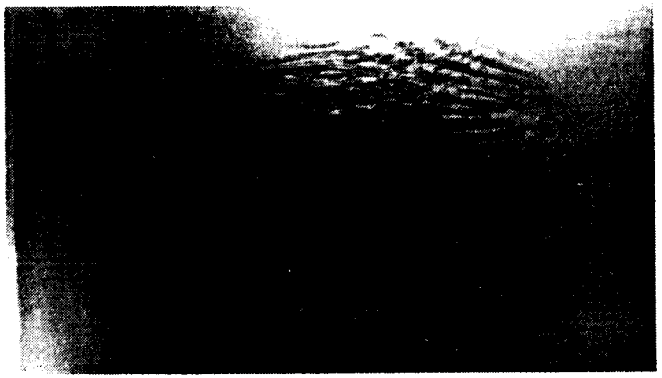
- EXPAND CAPABILITY TO INCLUDE MORE COMPLICATED GEOMETRIES, REALISTIC REYNOLDS NUMBERS AND ADDITIONAL PHENOMENA SUCH AS COMBUSTION

PAYOFF

- IMPROVED TURBULENCE MODELS FOR COMPLEX FLOWS
- METHODS FOR CONTROLLING TRANSITION AND TURBULENCE
- MORE ACCURATE PREDICTION OF VEHICLE PERFORMANCE

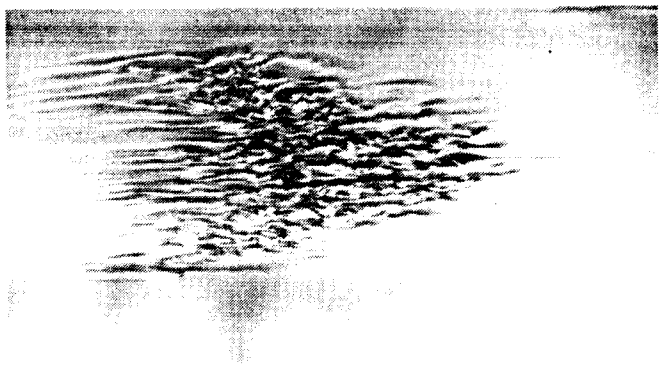
PHYSICS OF TRANSITION AND TURBULENCE
TURBULENT SPOT

PLANE POISEUILLE FLOW | **BOUNDARY LAYER**

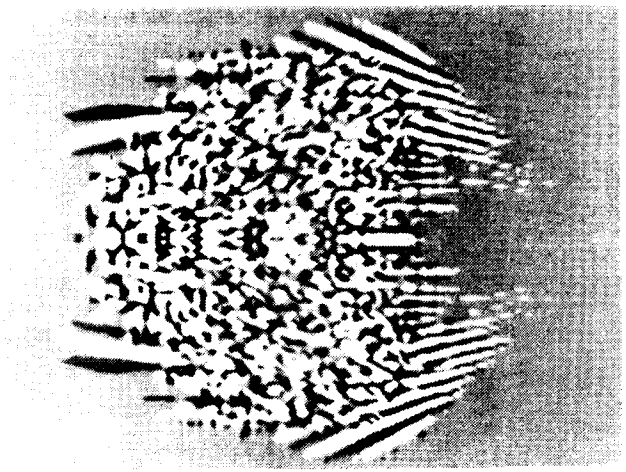


CARLSON, WIDNALL AND PEETERS (1982)

EXPERIMENT



CANTWELL, COLES AND DIMOTAKIS (1978)



HENNINGSON AND KIM (1987)

COMPUTATION

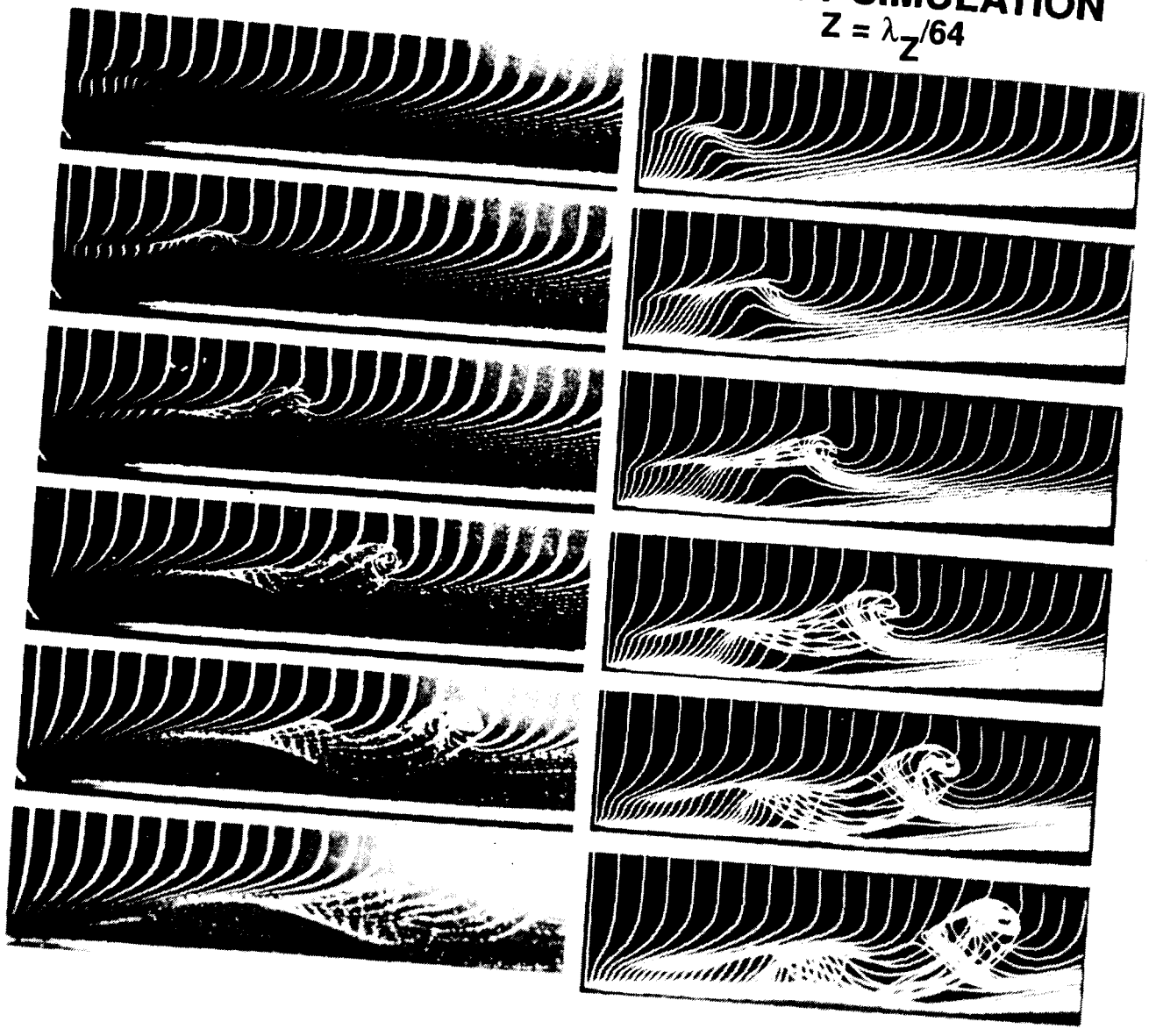
SPALART (1987)

PHYSICS OF TRANSITION AND TURBULENCE
BREAKDOWN OF LAMINAR FLOW

EXPERIMENT

DIRECT SIMULATION

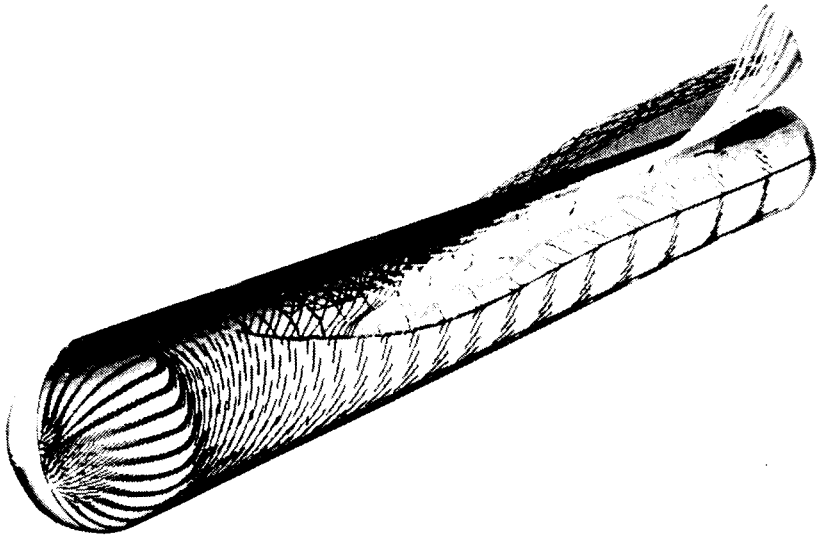
$Z = \lambda_Z/64$



BODIES AND WINGS AT HIGH ANGLES OF ATTACK

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE THREE-DIMENSIONAL SEPARATED AND VORTEX FLOWS ABOUT BODIES AND WINGS AT HIGH ANGLES OF ATTACK



CURRENT APPROACH

- SOLVE TIME-DEPENDENT REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS FOR BOTH LAMINAR AND TURBULENT FLOWS
- VALIDATE RESULTS WITH EXPERIMENTS

FUTURE DIRECTIONS

- INVESTIGATE ONSET OF FLOW ASYMMETRIES
- DETERMINE EFFECTS OF HIGH-RATE PITCH AND ROLL MOTIONS ON FLOWS
- APPLY METHODS TO IDENTIFY WAYS TO CONTROL VORTICAL FLOWS

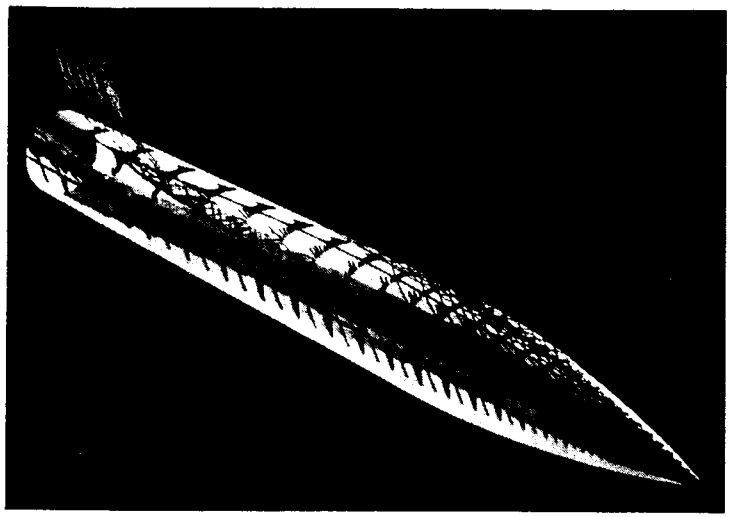
PAYOFF

- NEW TOOLS FOR EVALUATING AIRCRAFT PERFORMANCE IN EXTREME-ATTITUDE MANEUVERS
- SAFER AND MORE MANEUVERABLE AIRCRAFT

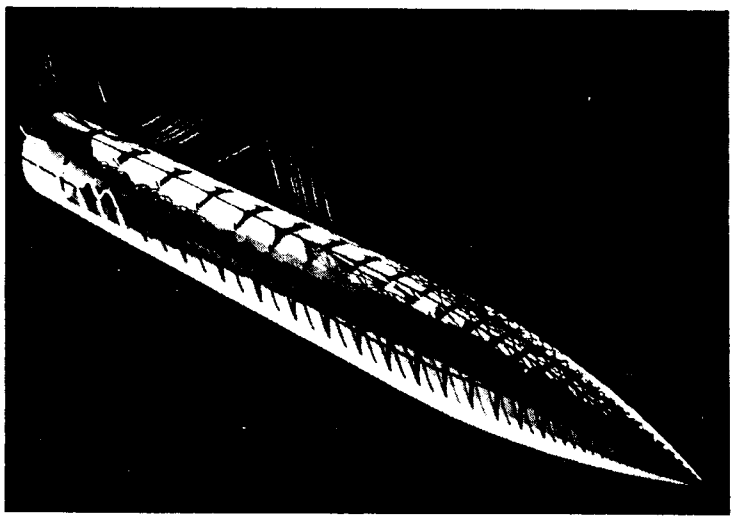
BODIES AND WINGS AT HIGH ANGLES OF ATTACK

COMPUTED VORTEX SHEDDING – OGIVE CYLINDER

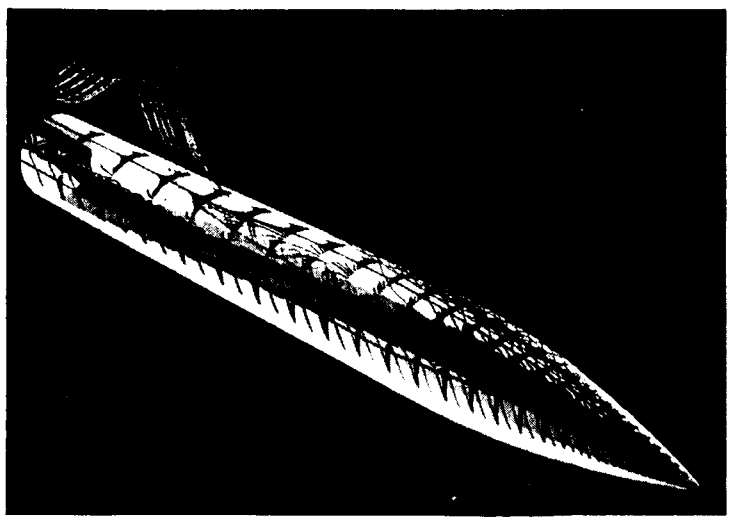
$M_\infty = 0.2$, $\alpha = 40°$, $Re_d = 200{,}000$ (LAMINAR)



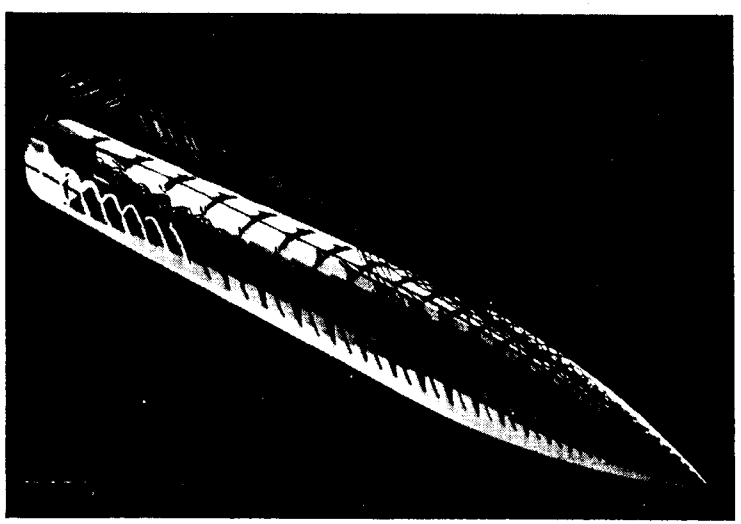
CYCLE TIME = 0



CYCLE TIME = 25%



CYCLE TIME = 50%



CYCLE TIME = 75%

BODIES AND WINGS AT HIGH ANGLE OF ATTACK
75° SWEPT DELTA WING

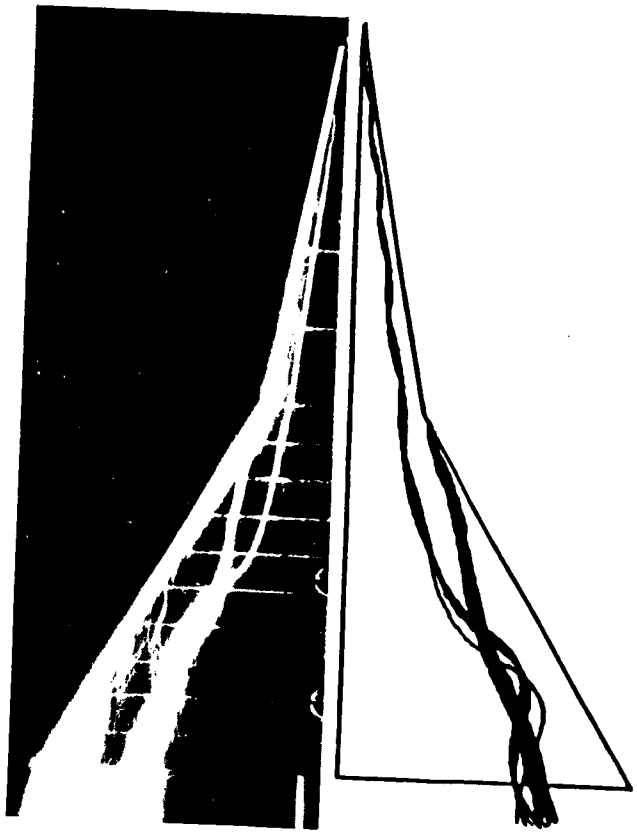
$M_\infty = 00.0$

BODIES AND WINGS AT HIGH ANGLE OF ATTACK

DELTA WING WITH STRAKE

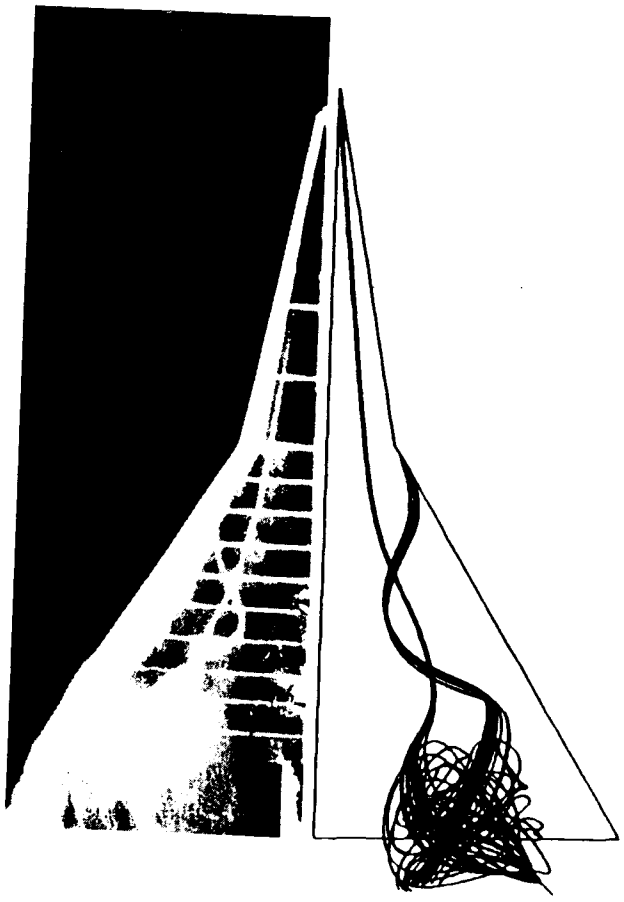
$M_\infty = 0.3$, REYNOLDS NUMBER = 1.3×10^6

$\alpha = 12°$



MEASURED COMPUTED

$\alpha = 30°$

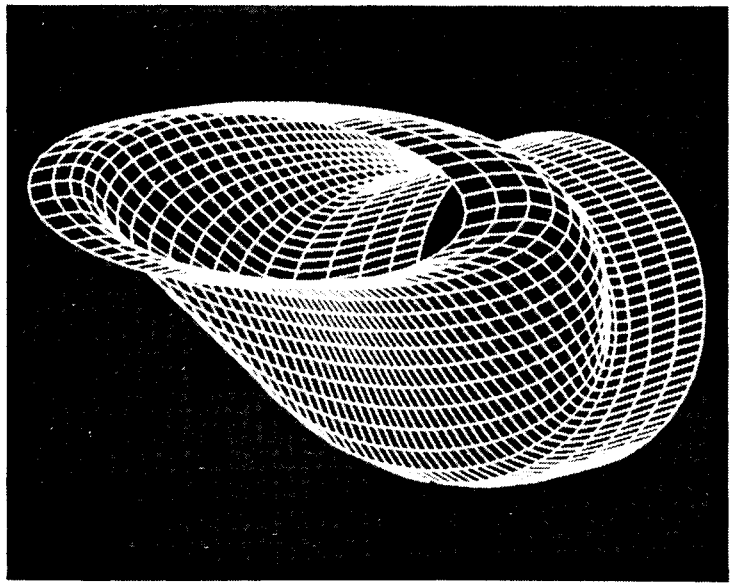


MEASURED COMPUTED

INLETS, DUCTS AND NOZZLES

OBJECTIVE

- DEVELOP VALIDATED CAPABILITY TO COMPUTE VISCOUS FLOWS ABOUT AND WITHIN INLETS, DUCTS AND NOZZLES FOR AIRCRAFT OPERATING AT EXTREME ATTITUDES



CURRENT APPROACH

- DEVELOP AND APPLY COMPUTATIONAL METHODS BASED ON VARIOUS FORMS OF THE NAVIER-STOKES EQUATIONS TO STUDY SHOCK-WAVE BOUNDRY-LAYER INTERACTIONS AND APPROACHES FOR CONTROLLING SHEAR LAYERS AND FLOWS THROUGH DUCTS
- CONDUCT APPROPRIATE VALIDATION EXPERIMENTS

FUTURE DIRECTIONS

- INCREASED EMPHASIS ON THREE-DIMENSIONAL FLOW PHYSICS AND IMPROVEMENT OF TURBULENCE MODELS

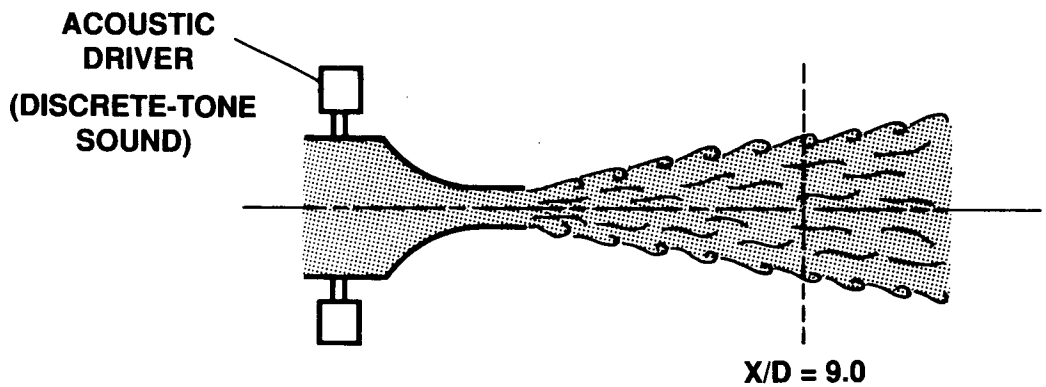
PAYOFF

- SHORTER, LIGHTER WEIGHT, QUIETER AND MORE EFFICIENT PROPULSION SYSTEMS FOR CRUISING AND MANEUVERING AIRCRAFT

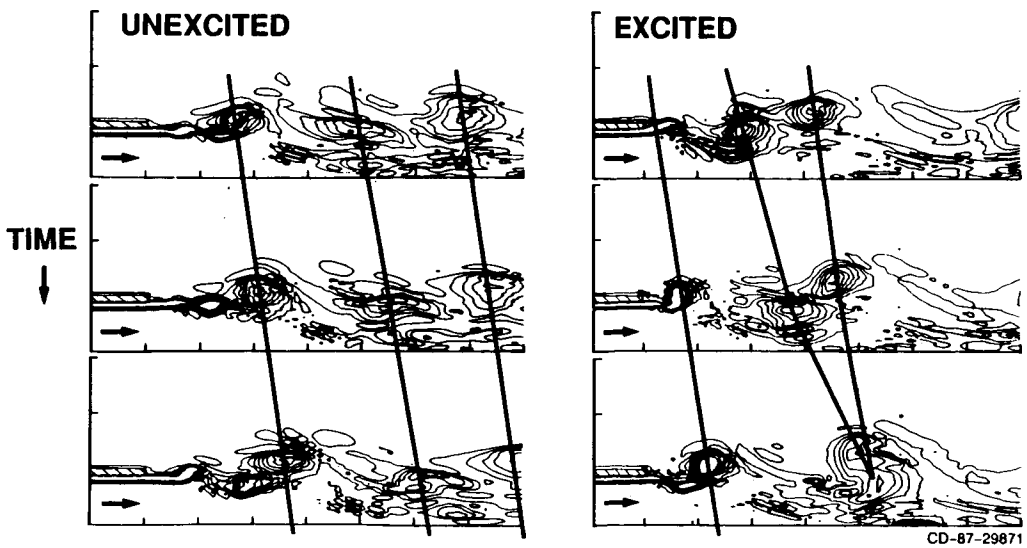
INLETS, DUCTS AND NOZZLES

ENHANCEMENT OF JET MIXING WITH ACOUSTIC EXCITATION

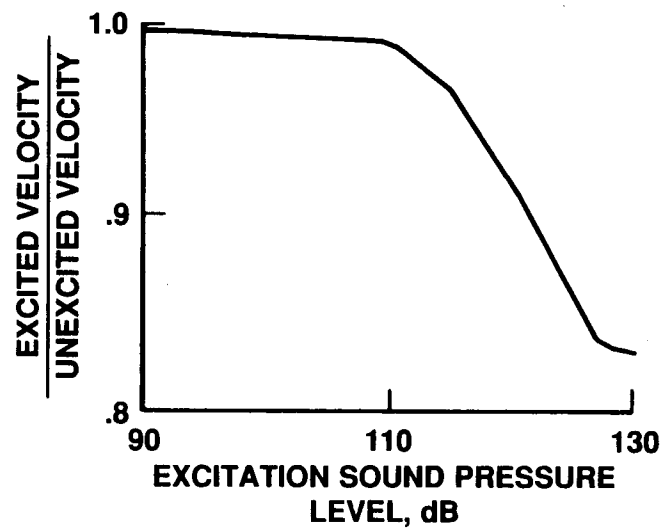
$M_{JET} = 0.3$



COMPUTED VORTICITY CONTOURS

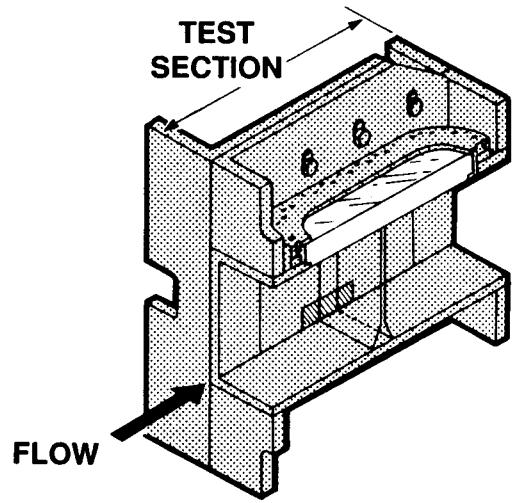


MEASURED



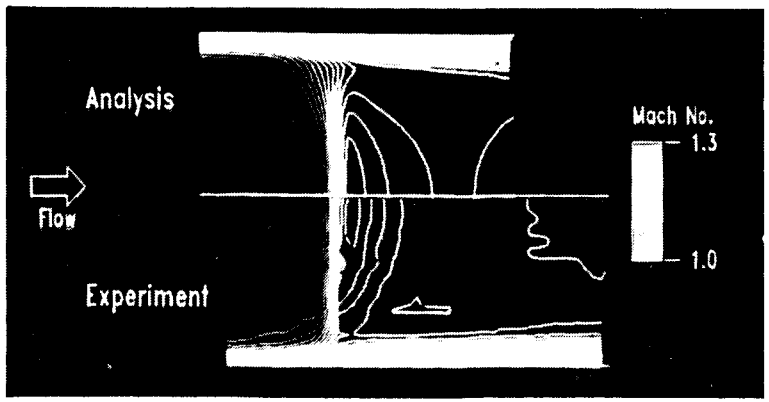
INLETS, DUCTS AND NOZZLES

NORMAL SHOCK-WAVE BOUNDARY-LAYER INTERACTION

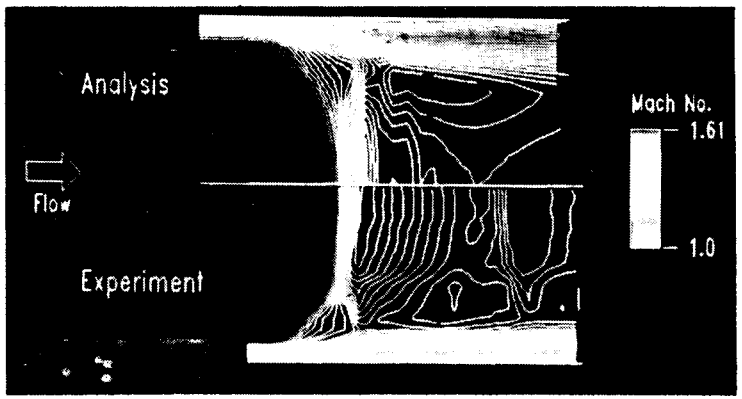


HALF SECTION OF 1- BY 1-FOOT SUPERSONIC WIND TUNNEL

M = 1.3



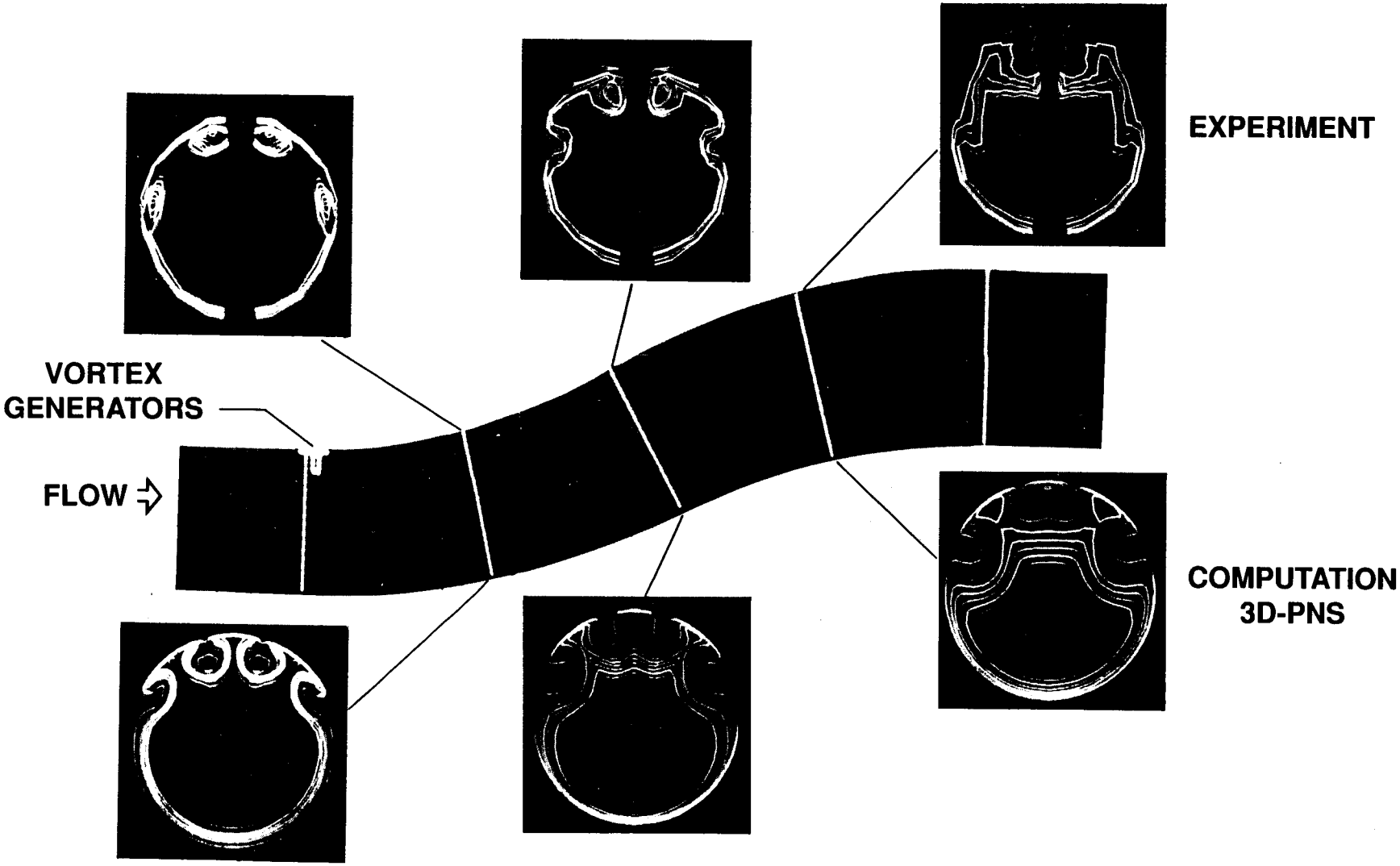
M = 1.6



INLETS, DUCTS AND NOZZLES

VORTEX GENERATORS IN DIFFUSING OFFSET DUCT

TOTAL PRESSURE CONTOURS; M = 0.6



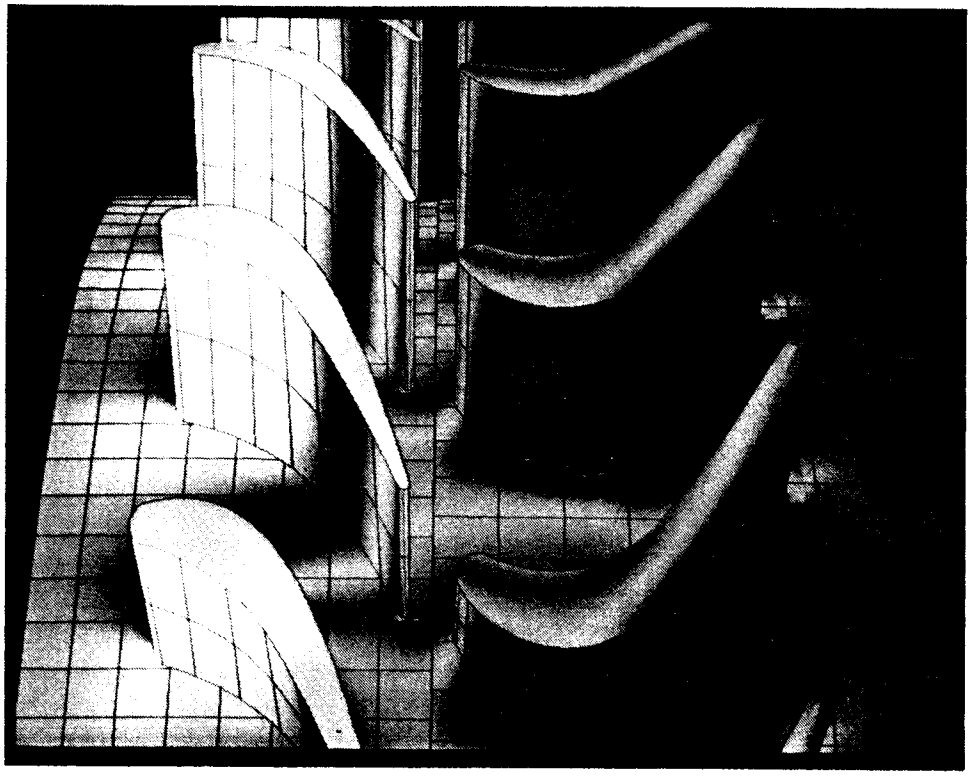
FLOWS THROUGH TURBINES AND COMPRESSORS

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE TIME-DEPENDENT VISCOUS FLOWS THROUGH TURBO MACHINERY

CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL TIME-DEPENDENT REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS USING ALGEBRAIC TURBULENCE MODEL



FUTURE DIRECTIONS

- INCORPORATE MORE GENERAL TURBULENCE MODELS AND FLOW TRANSITION METHODS
- EXTEND TECHNOLOGY TO HANDLE MULTIPLE STAGES
- MAKE MODIFICATIONS TO TREAT CENTRIFUGAL GEOMETRIES

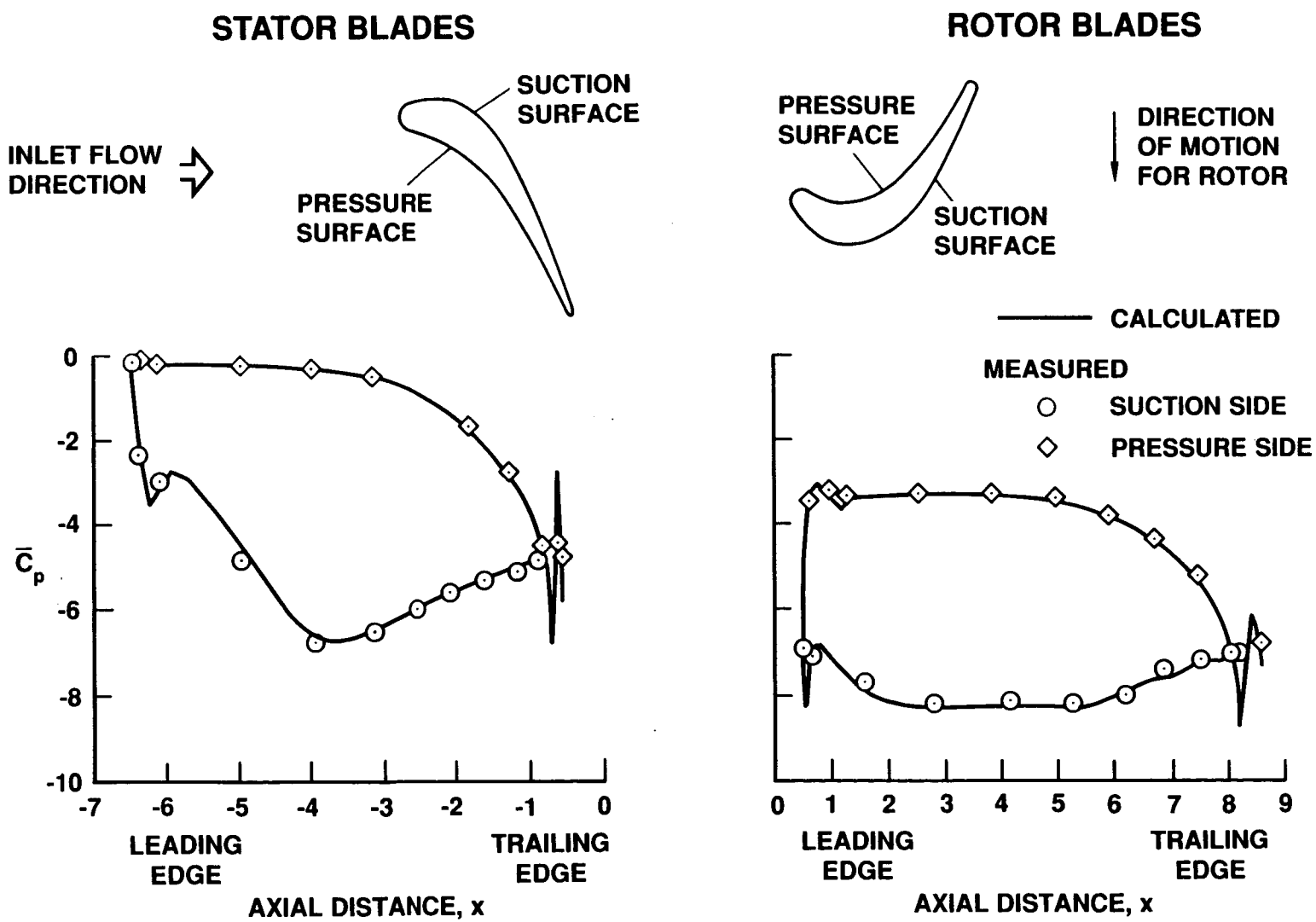
PAYOFF

- CODE TO PROVIDE DESIGN INFORMATION FOR:
  - INCREASING JET ENGINE EFFICIENCY (1% = $100M/yr)
  - UNDERSTANDING FATIGUE STRESSES AND HEAT TRANSFER
  - CONTROLLING NOISE GENERATION

FLOWS THROUGH TURBINES AND COMPRESSORS

MIDSPAN PRESSURE COEFFICIENTS TIME AVERAGED OVER ONE CYCLE

M = 0.1, REYNOLDS NUMBER = 1.2 x 10^6/ft

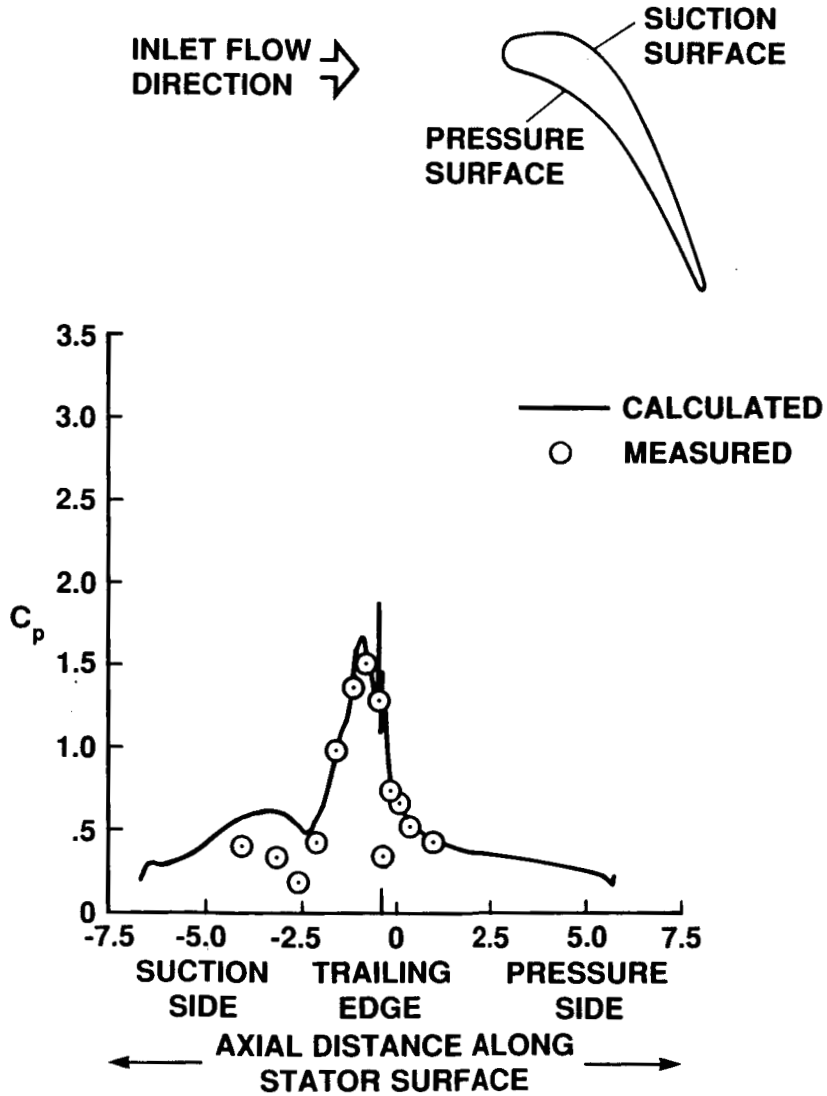


FLOWS THROUGH TURBINES AND COMPRESSORS

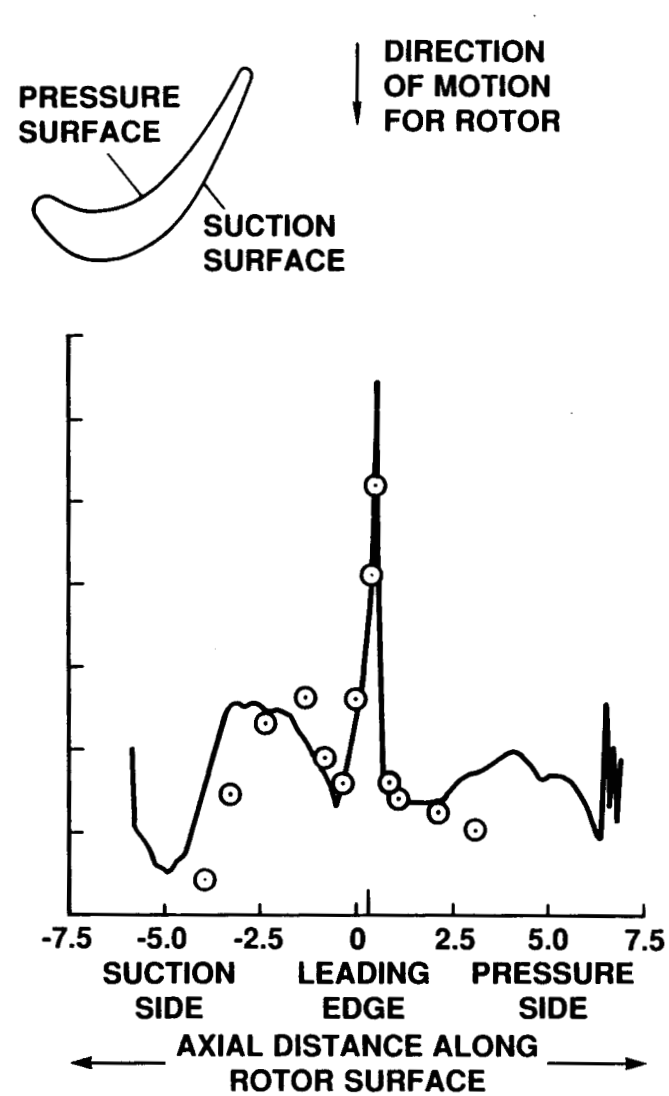
MAXIMUM MIDSPAN PRESSURE COEFFICIENTS

M = 0.1, REYNOLDS NUMBER = 1.2 x 10^6/ft

STATOR BLADES



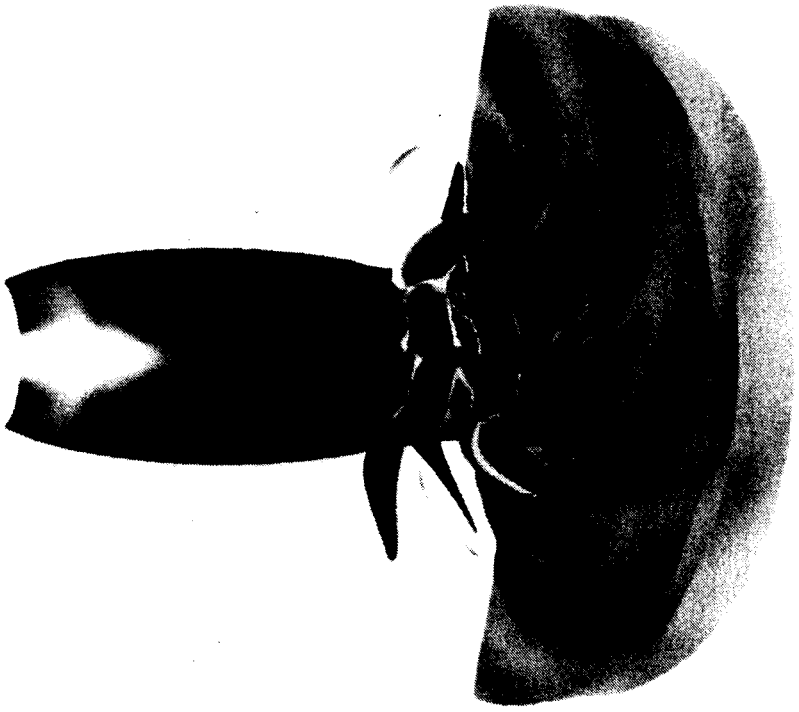
ROTOR BLADES



AERODYNAMICS AND AEROELASTICITY OF TURBOPROPS

OBJECTIVE

- DEVELOP AND VALIDATE CAPABILITY TO COMPUTE AERODYNAMIC AND AEROELASTIC BEHAVIOR OF SINGLE AND COUNTER-ROTATING TURBOPROPS



CURRENT APPROACH

- SOLVE UNSTEADY EULER EQUATIONS FOR AERODYNAMIC INFORMATION
- USE PANEL METHOD TOGETHER WITH BLADE NORMAL MODES FOR AEROELASTIC INFORMATION

FUTURE DIRECTIONS

- EXTEND AERODYNAMIC CODES TO INCLUDE VISCOUS EFFECTS, UNEQUAL BLADE COUNTS FOR COUNTER-ROTATING PROPELLERS AND DUCTED CONFIGURATIONS
- EXTEND AEROELASTIC ANALYSES TO HIGHER MACH NUMBERS BY SOLVING FULL POTENTIAL AND EULER EQUATIONS
- INCLUDE CAPABILITIES TO OPTIMIZE DESIGNS

PAYOFF

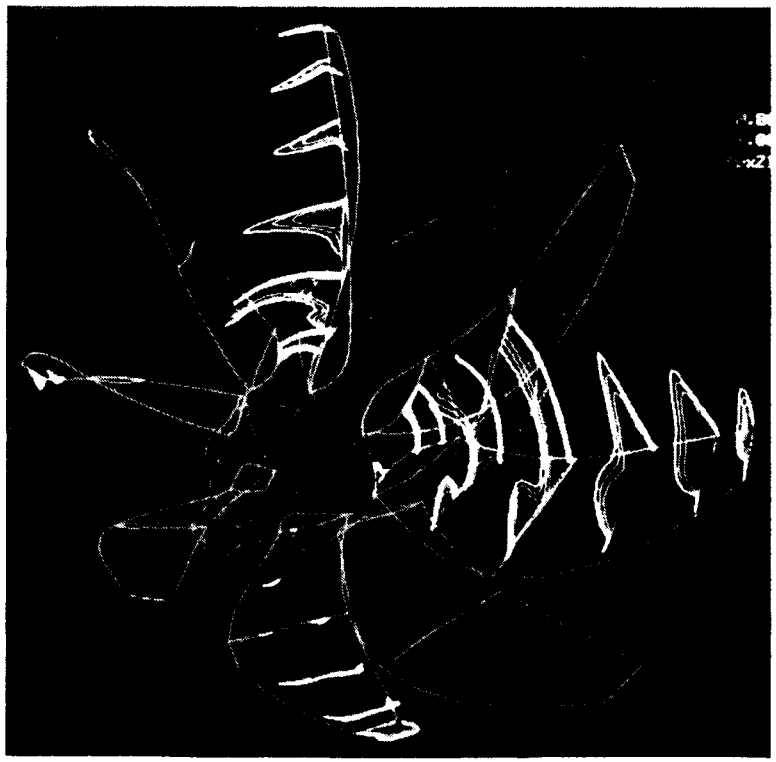
- TOOLS TO DESIGN MORE EFFICIENT PROPULSION SYSTEMS AND REDUCE DEVELOPMENT TIME AND COST

AERODYNAMICS AND ELASTICITY OF TURBOPROPS

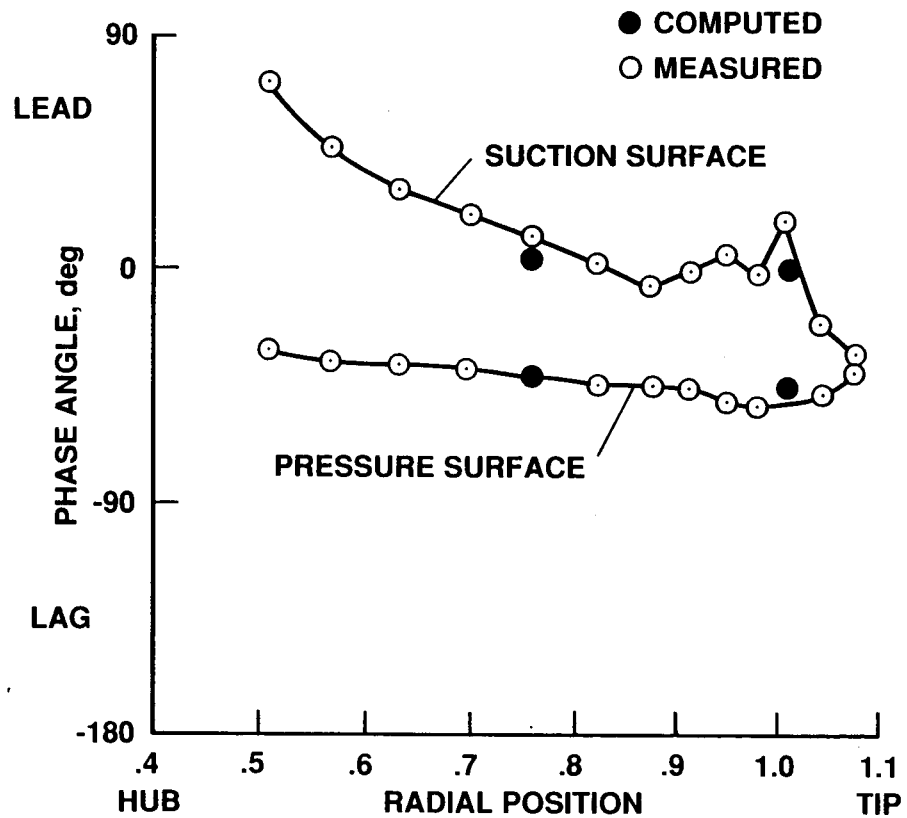
AERODYNAMIC RESULTS

$M_\infty = 0.8$, $\alpha = 4°$, $M_T = 1.15$

PRESSURE DISTRIBUTIONS (COMPUTED)



PHASE ANGLE OF PRESSURE RELATIVE TO FORCING FUNCTION

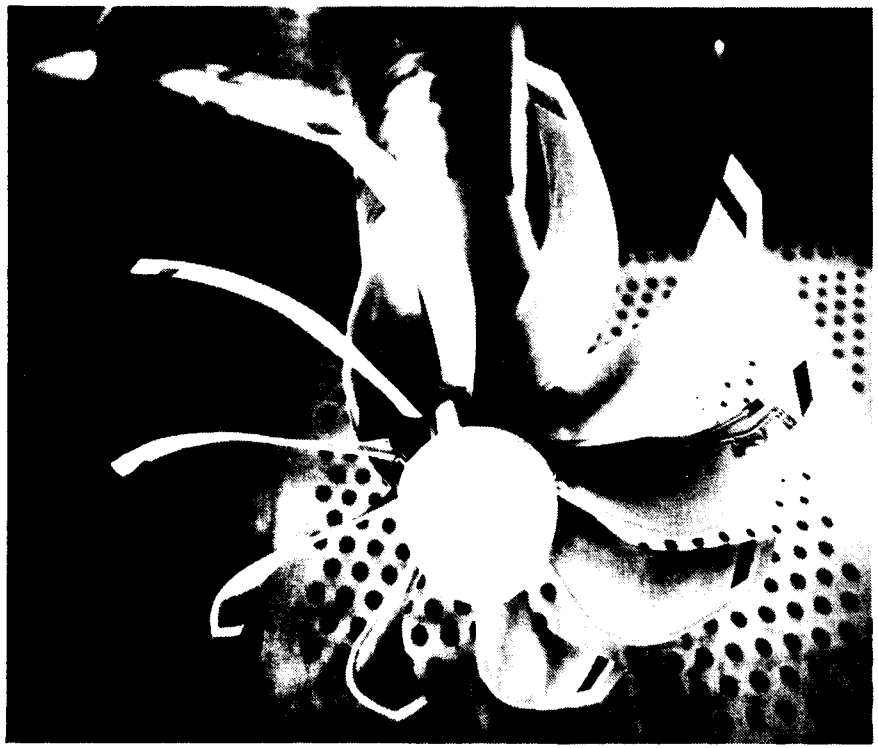


AERODYNAMICS AND AEROELASTICITY OF TURBOPROPS

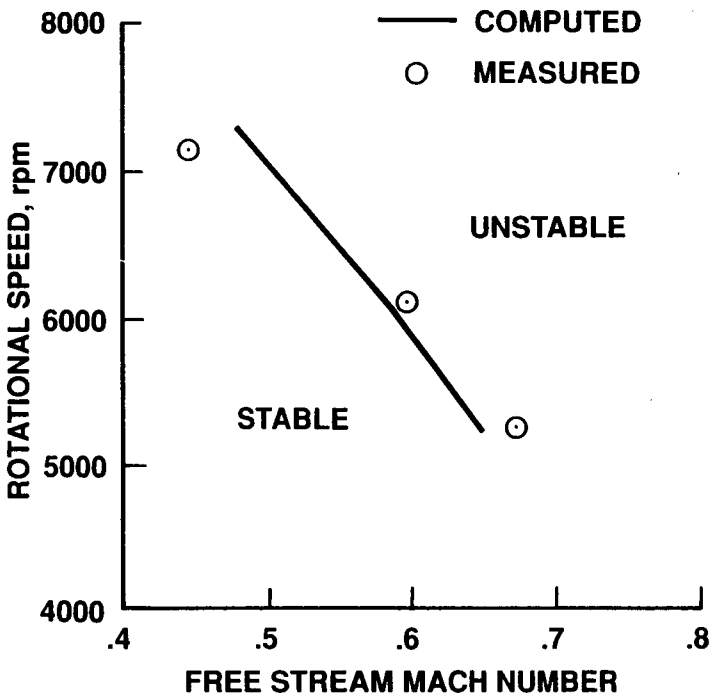
AEROELASTICITY RESULTS

$\alpha = 0°$

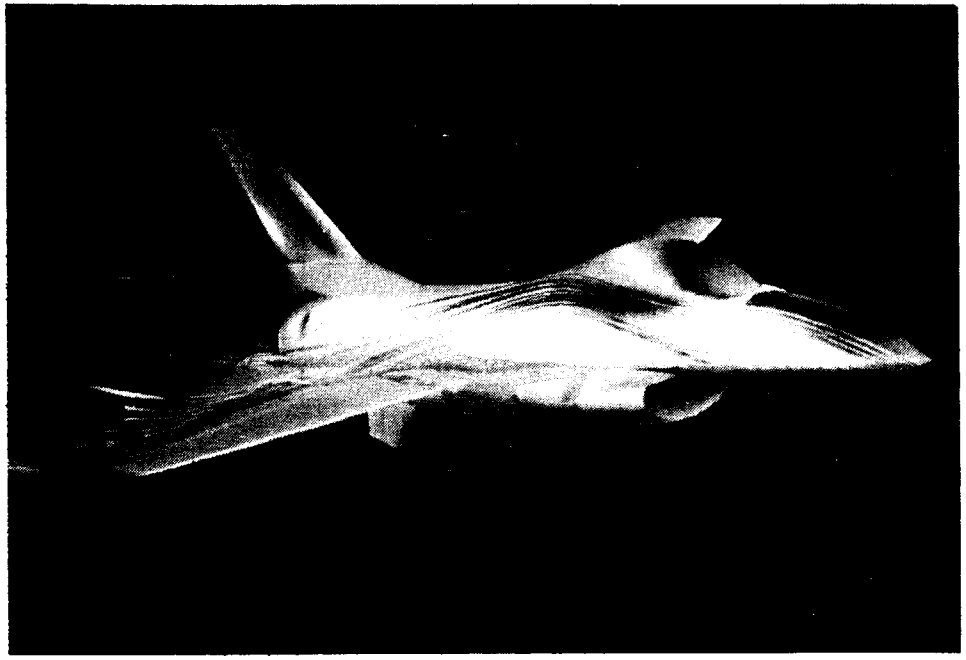
WIND TUNNEL MODEL



FLUTTER BOUNDARY



AERODYNAMICS OF COMPLETE FIXED-WING AIRCRAFT



OBJECTIVE

- DEVELOP CAPABILITY TO CALCULATE VISCOUS FLOWS ABOUT COMPLETE AIRCRAFT

CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS USING ALGEBRAIC TURBULENCE MODEL

FUTURE DIRECTIONS

- INCLUDE EXTERNAL STORES AND HOT-GAS EXHAUST PLUME
- APPLY CODE TO CALIBRATE MORE APPROXIMATE DESIGN METHODS
- DISSEMINATE TECHNOLOGY TO AEROSPACE INDUSTRY

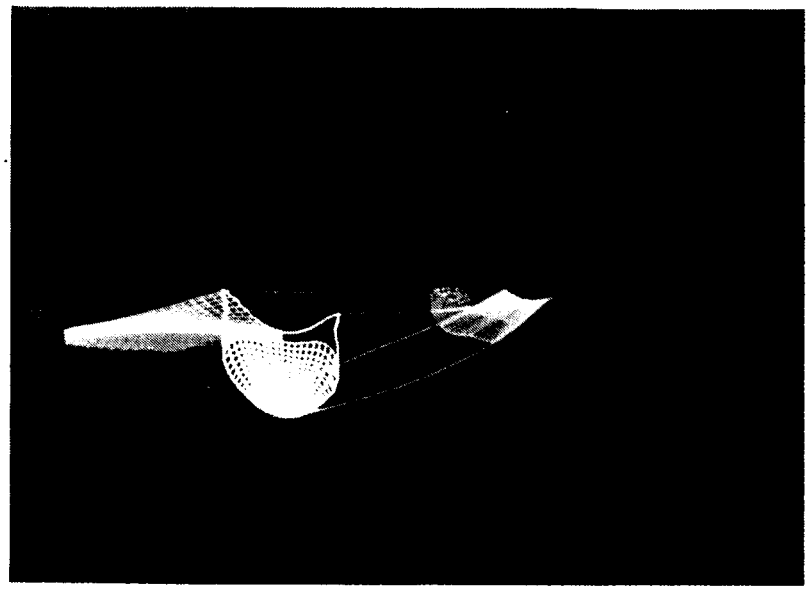
PAYOFF

- VALIDATED COMPUTATIONAL TOOL FOR DESIGNING FUTURE AIRCRAFT

AERODYNAMICS OF COMPLETE FIXED-WING AIRCRAFT

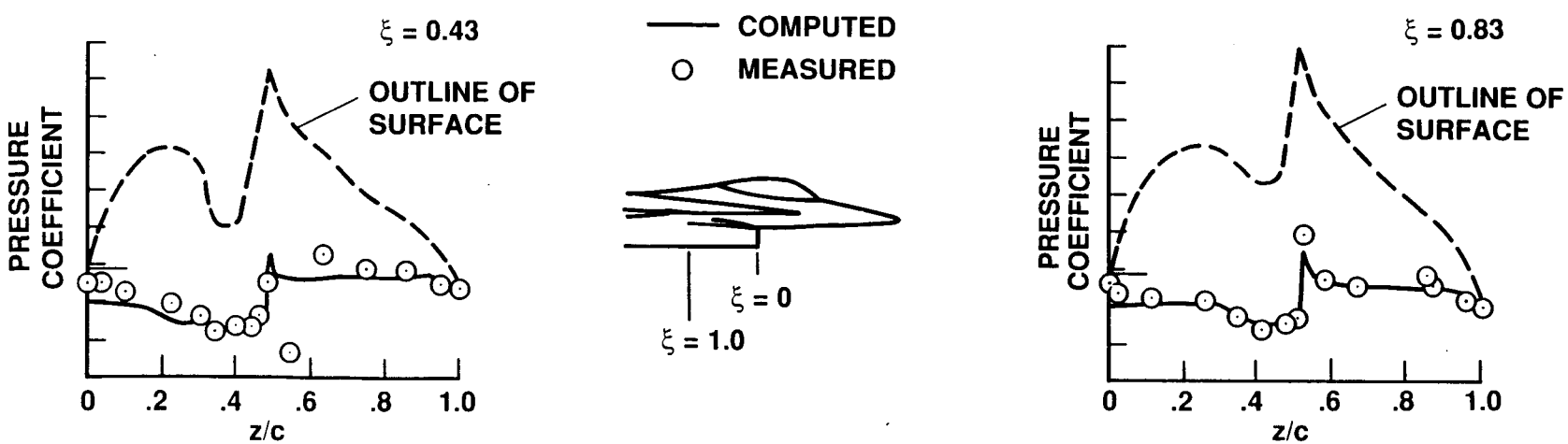
F-16A

M= 0.9, α = 4.12°, REYNOLDS NUMBER = 4.5 x 10^6



GEOMETRY AND GRID IN VICINITY OF INLET

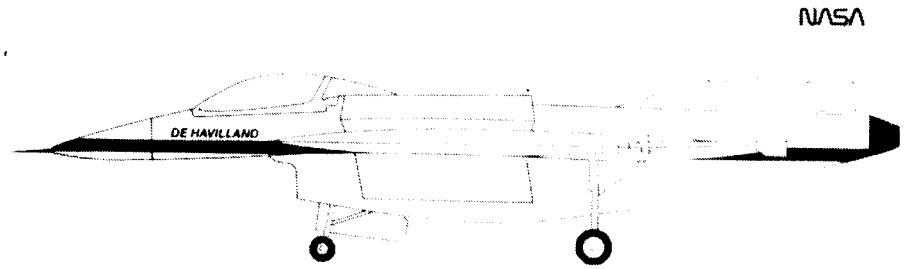
SIMULATED OIL FLOW IN VICINITY OF INLET



ASTOVL AIRFRAME-PROPULSION-GROUND INTERACTION

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE AERODYNAMICS OF POWERED-LIFT VEHICLES IN PRESENCE OF GROUND EFFECT



CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL TIME-DEPENDENT REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS USING VARIOUS TURBULENCE MODELS

FUTURE DIRECTIONS

- COORDINATED COMPUTATIONAL-EXPERIMENTAL-FLIGHT PROGRAM TO VALIDATE CODES UTILIZING:
  - AV8-B RESEARCH AIRCRAFT
  - FULL-SCALE E-7 AIRCRAFT IN 80- BY 120-FOOT WIND TUNNEL

PAYOFF

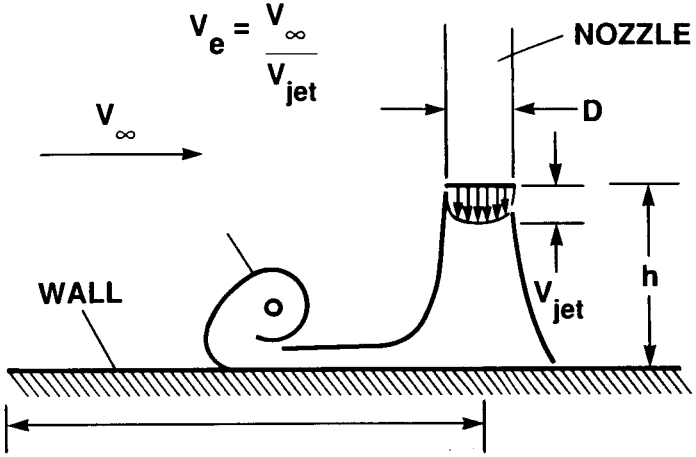
- COMPUTATIONAL TOOL TO COMPLEMENT WIND-TUNNEL TESTS REQUIRING COMPLEX AND EXPENSIVE POWERED MODELS
- MINIMIZATION OF EFFECTS OF AIRFRAME-PROPULSION-GROUND FLUID DYNAMIC INTERACTION ON TOTAL VEHICLE CAPABILITIES
- CONTRIBUTION TO UNDERSTANDING OF JET TURBULENCE AND NOISE

ASTOVL AIRFRAME-PROPULSION-GROUND INTERACTION

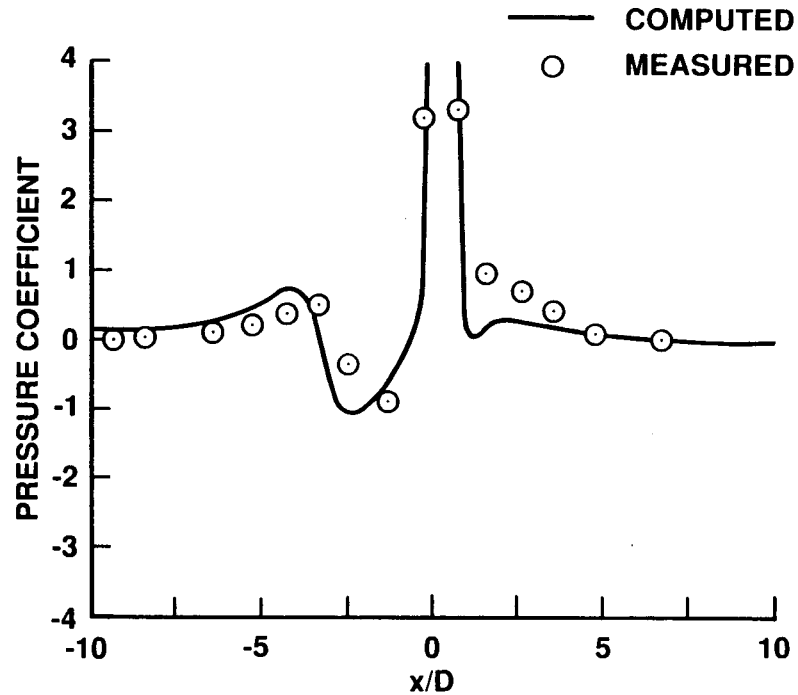
JET-GROUND-CROSSFLOW INTERACTION

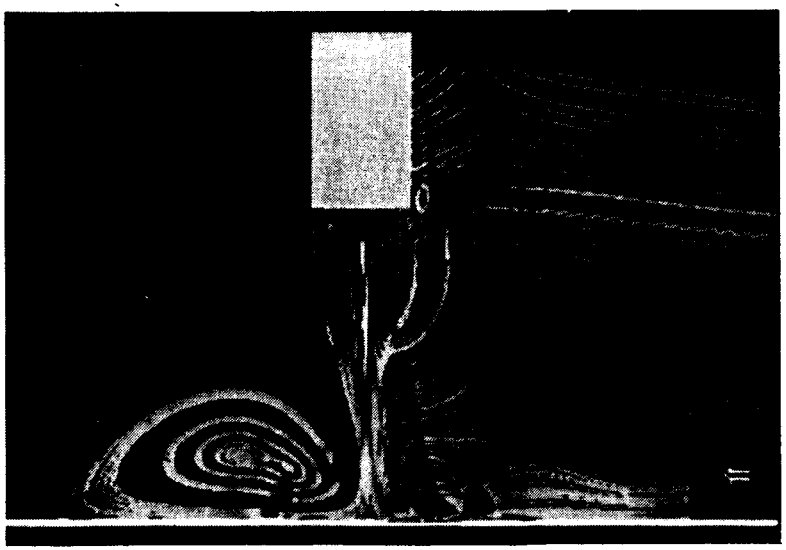
$V_e = 0.223$, $h/D = 3$

FLOW TOPOLOGY



PRESSURE COEFFICIENTS ALONG JET CENTERLINE



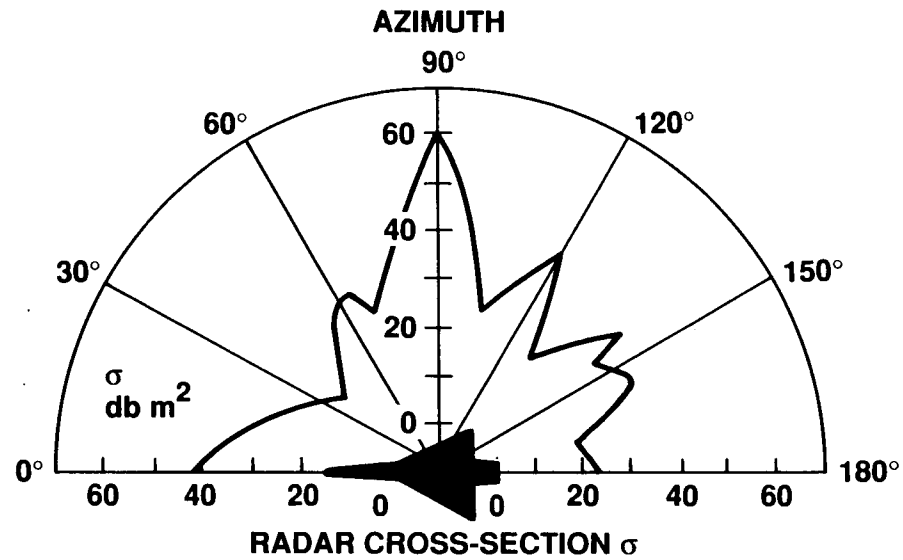


PARTICLE TRACES COLORED BY TIME DERIVATIVES OF VORTICITY

COMPUTATIONAL ELECTROMAGNETICS

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE ELECTROMAGNETIC CHARACTERISTICS OF AIRCRAFT



CURRENT APPROACH

- SOLVE MAXWELL'S EQUATIONS USING SPECTRAL METHODS

FUTURE DIRECTIONS

- DEVELOP MORE EFFICIENT ALGORITHMS FOR SOLVING MAXWELL'S EQUATIONS
- COUPLE ELECTROMAGNETIC AND FLUID DYNAMIC CODES TO OPTIMIZE AIRCRAFT SHAPES FOR EFFICIENT AERODYNAMIC PERFORMANCE AND ACCEPTABLE RADAR SIGNATURES

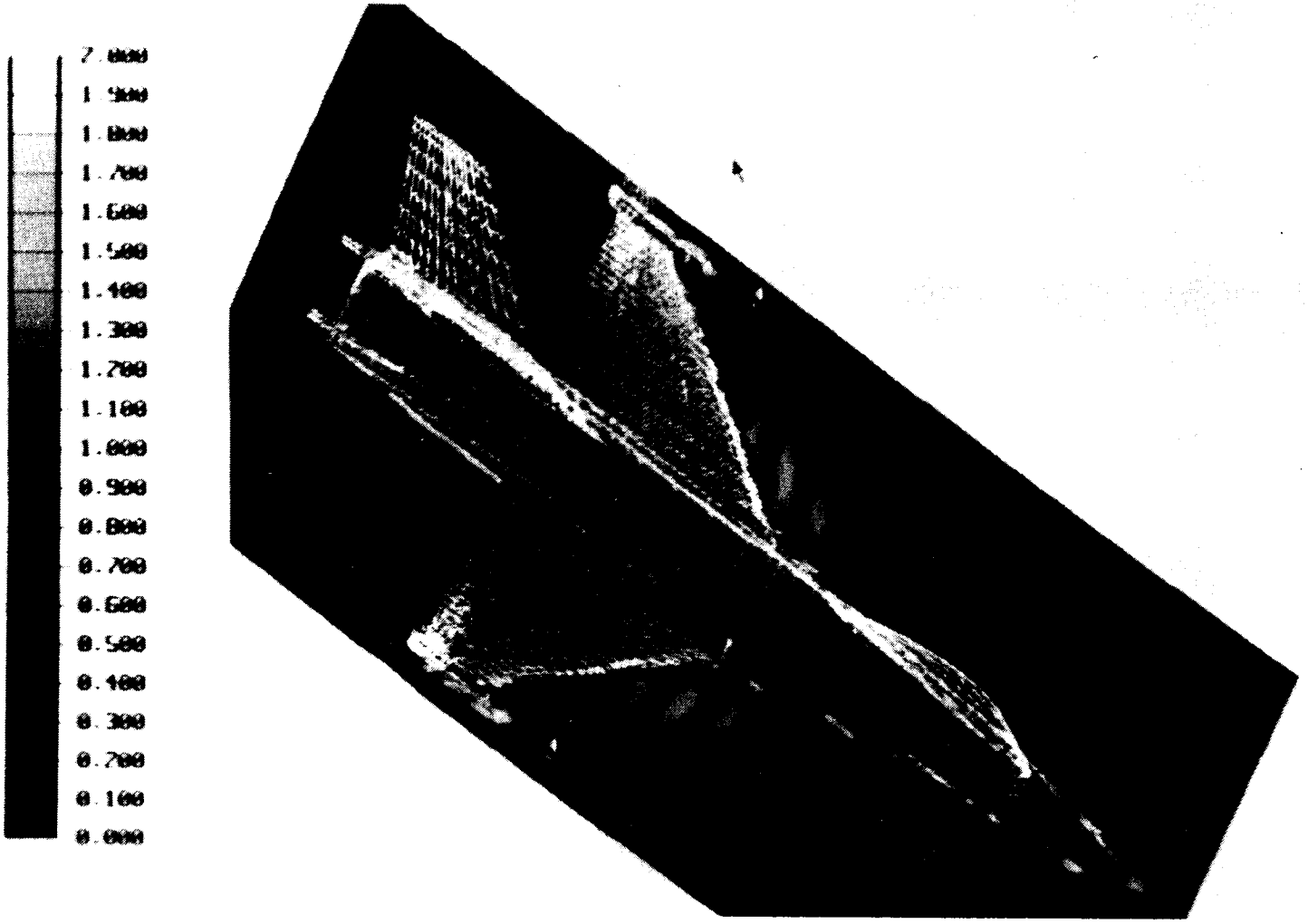
PAYOFF

- COMPUTATIONAL TOOL FOR DEVELOPING ADVANCED MILITARY AIRCRAFT

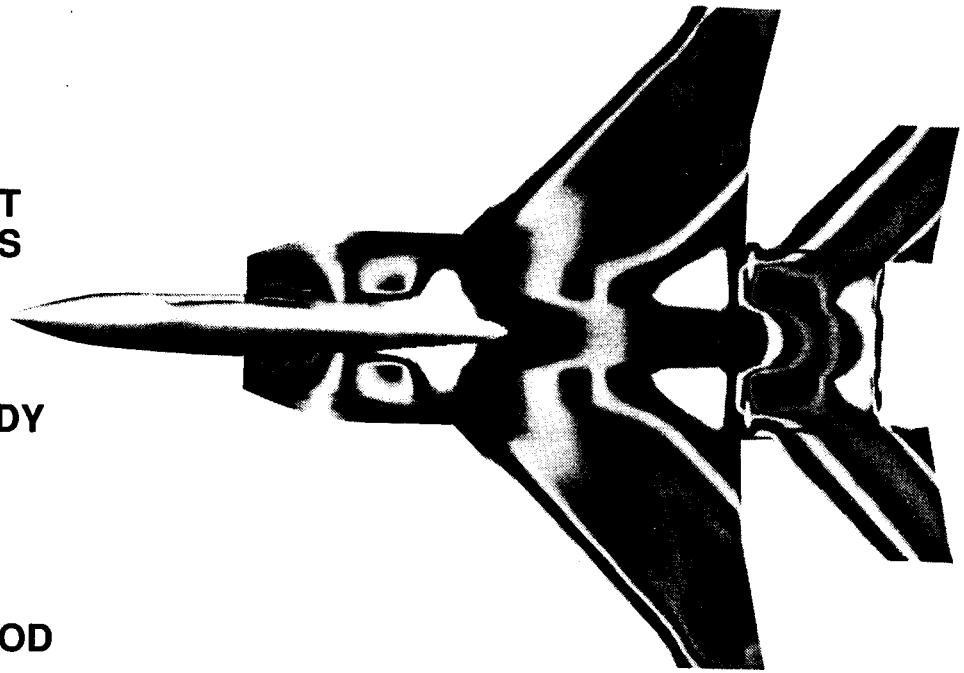
COMPUTATIONAL ELECTROMAGNETICS

NEAR-FIELD SCATTERING FROM AN F-16A

MAGNITUDE CONTOURS OF TOTAL ELECTRIC FIELD
NOSE-ON INCIDENT FIELD HAS HORIZONTAL POLARIZATION
AND A FREQUENCY OF 300 MHz



AIRCRAFT AEROELASTICITY



OBJECTIVE

- DEVELOP CAPABILITY TO CALCULATE AEROELASTIC BEHAVIOR OF AIRCRAFT WITH AND WITHOUT ACTIVE CONTROLS

CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL, UNSTEADY TRANSONIC SMALL-DISTURBANCE EQUATION COUPLED WITH MODAL STRUCTURAL EQUATIONS OF MOTION
- MODEL VISCOUS EFFECTS WITH INTERACTED BOUNDARY-LAYER METHOD

FUTURE DIRECTIONS

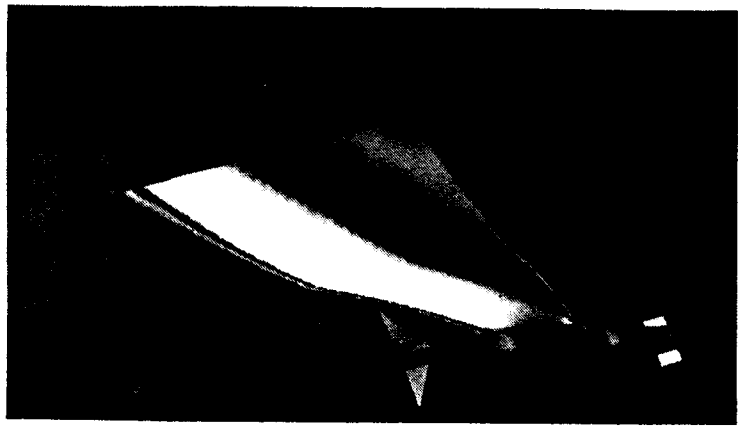
- MODEL AERODYNAMICS WITH UNSTEADY EULER AND REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS

PAYOFF

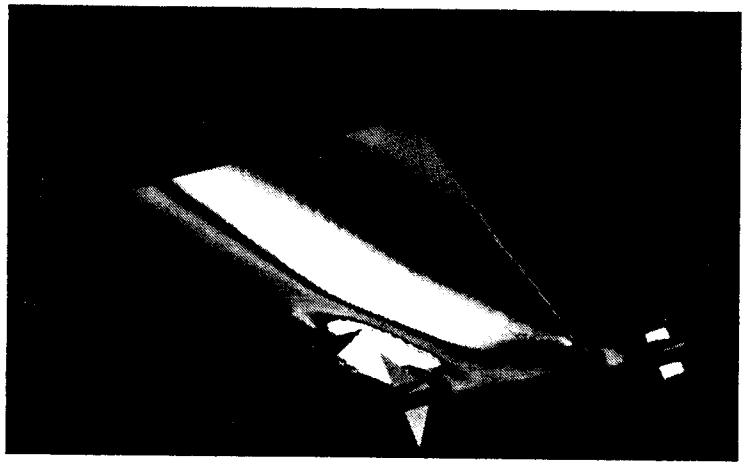
- TOOL FOR PREDICTING FLUTTER BOUNDARIES (TRANSONIC FLUTTER IS FREQUENTLY A CRITICAL DESIGN DRIVER)
- TOOL FOR DEVELOPING ACTIVE CONTROLS TO SUPPRESS FLUTTER

AIRCRAFT AEROELASTICITY
SUPPRESSION OF AEROELASTIC RESPONSE WITH ACTIVE CONTROL: FIGHTER WING

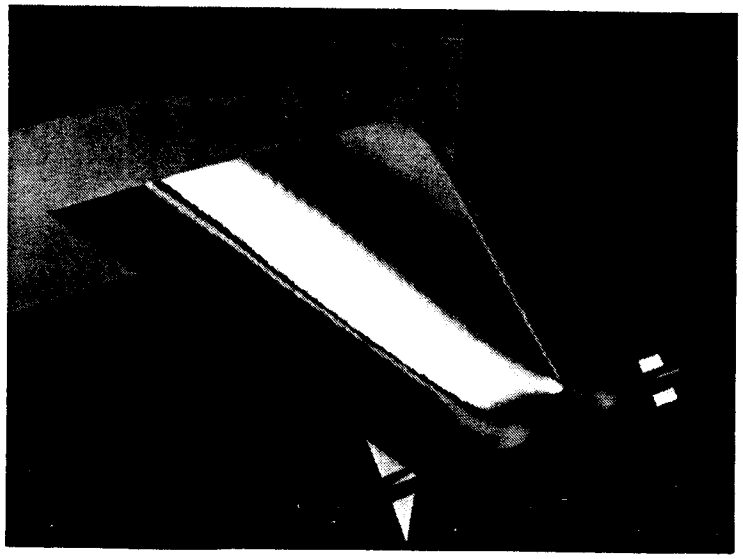
M_∞ = 0.9, ALTITUDE = 30,000 ft

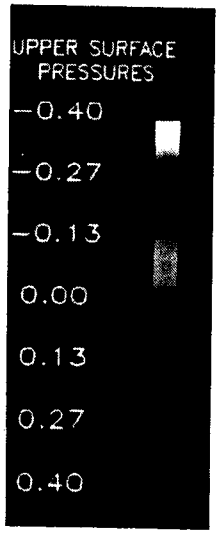


AEROELASTICALLY OSCILLATING WING



CONTROL SURFACE ACTIVATED





ACTIVE CONTROL SUPPRESSES OSCILLATION

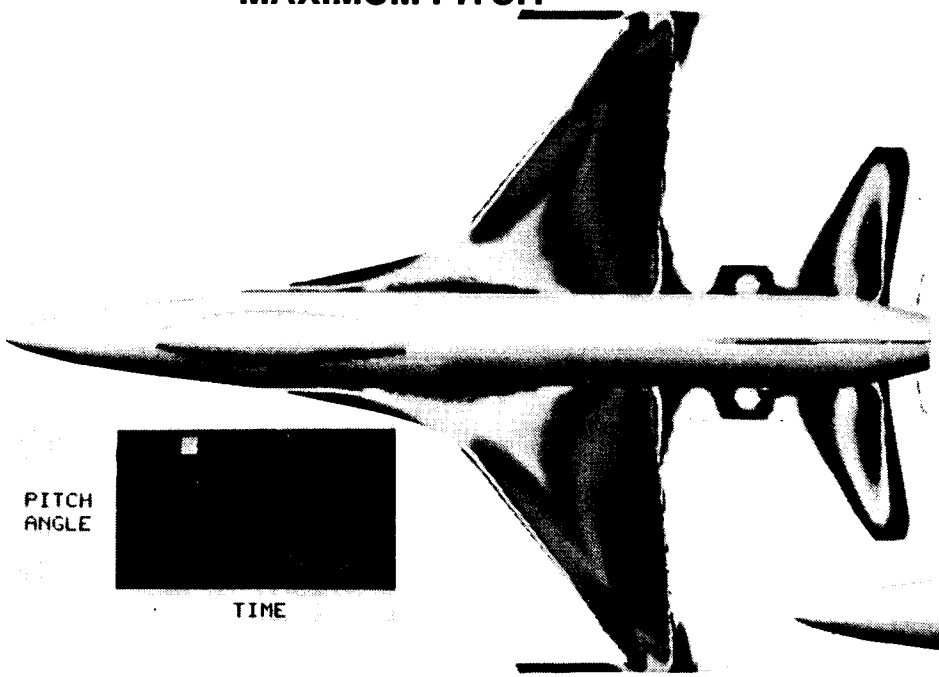
AIRCRAFT AEROELASTICITY

PITCHING F-16C MODEL

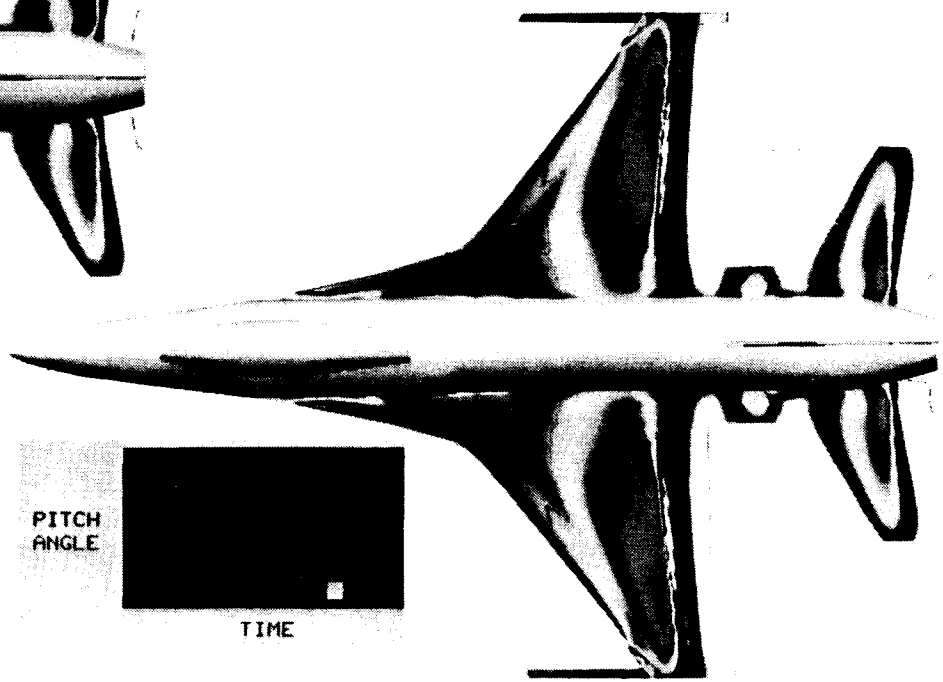
$M_\infty = 0.9, \alpha = 2.38 \pm 0.5°$

PRESSURE CONTOURS

MAXIMUM PITCH



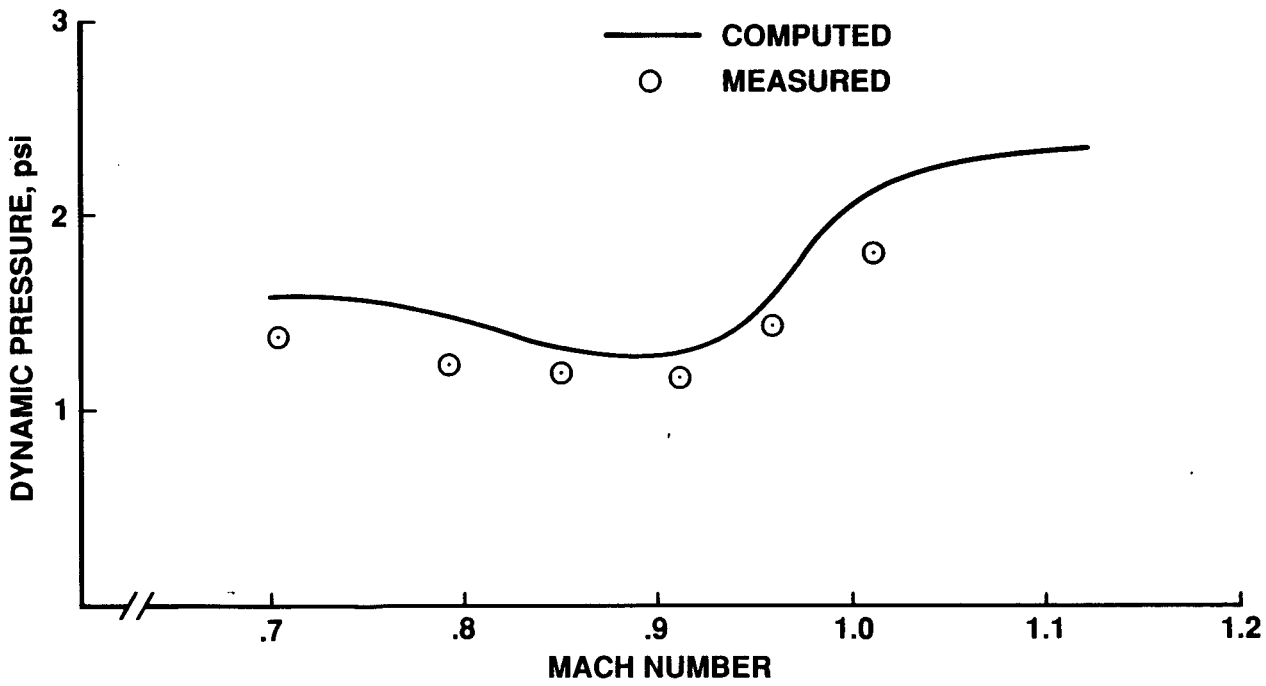
MINIMUM PITCH



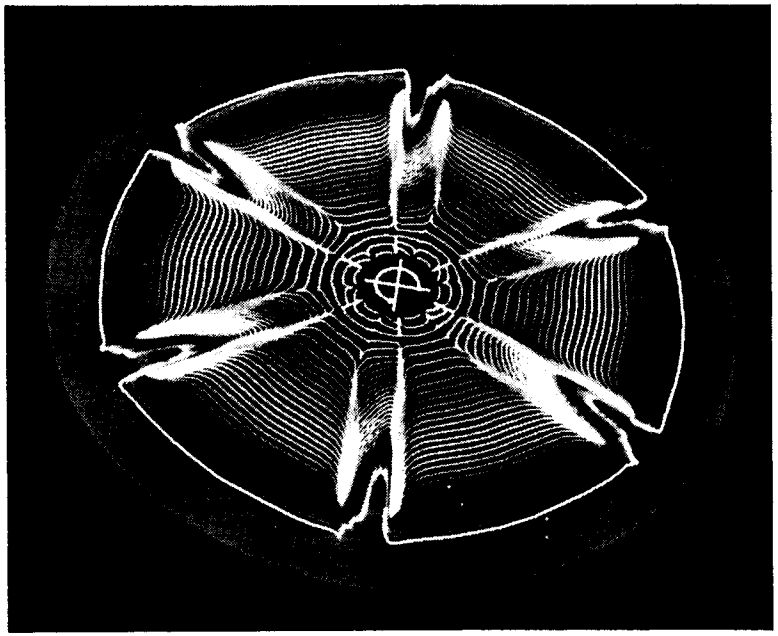
AIRCRAFT AEROELASTICITY

RECTANGULAR WING FLUTTER BOUNDARY

ASPECT RATIO = 5, 6-PERCENT THICK CIRCULAR ARC AIRFOIL



ROTORCRAFT AERODYNAMICS AND AEROACOUSTICS



OBJECTIVE

- DEVELOP AND VALIDATE CFD CODES FOR 3-D UNSTEADY FLOWS ABOUT ARBITRARY ROTORS

CURRENT APPROACH

- SOLVE FULL-POTENTIAL, EULER AND REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS COUPLED WITH INTEGRAL WAKE MODELS
- APPLY CODES TO DESIGN IMPROVED BLADE TIPS

FUTURE DIRECTIONS

- DEVELOP NEW CODES FOR ROTOR-BODY COMBINATIONS
- EXTEND AEROACOUSTIC CALCULATIONS TO THE FAR FIELD
- COMPUTE VORTICAL NEAR-WAKE STRUCTURE
- COUPLE FLOW-SOLVERS WITH STRUCTURAL DYNAMICS MODELS
- APPLY CODES TO
  - STUDY PHYSICS OF WAKE INTERACTIONS, NOISE GENERATION, BLADE STALL, AND VIBRATIONS
  - DESIGN AND PREDICT HIGH-PERFORMANCE ROTORS

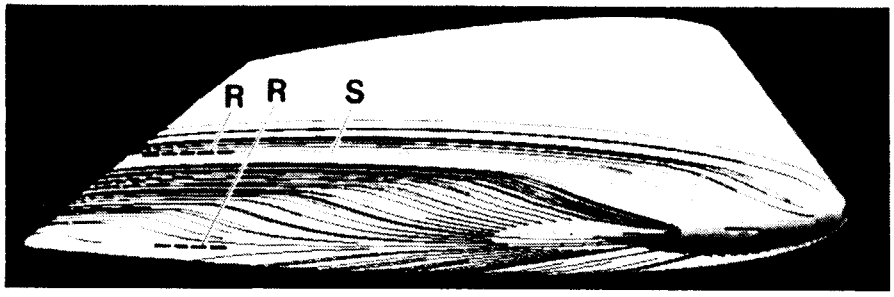
PAYOFF

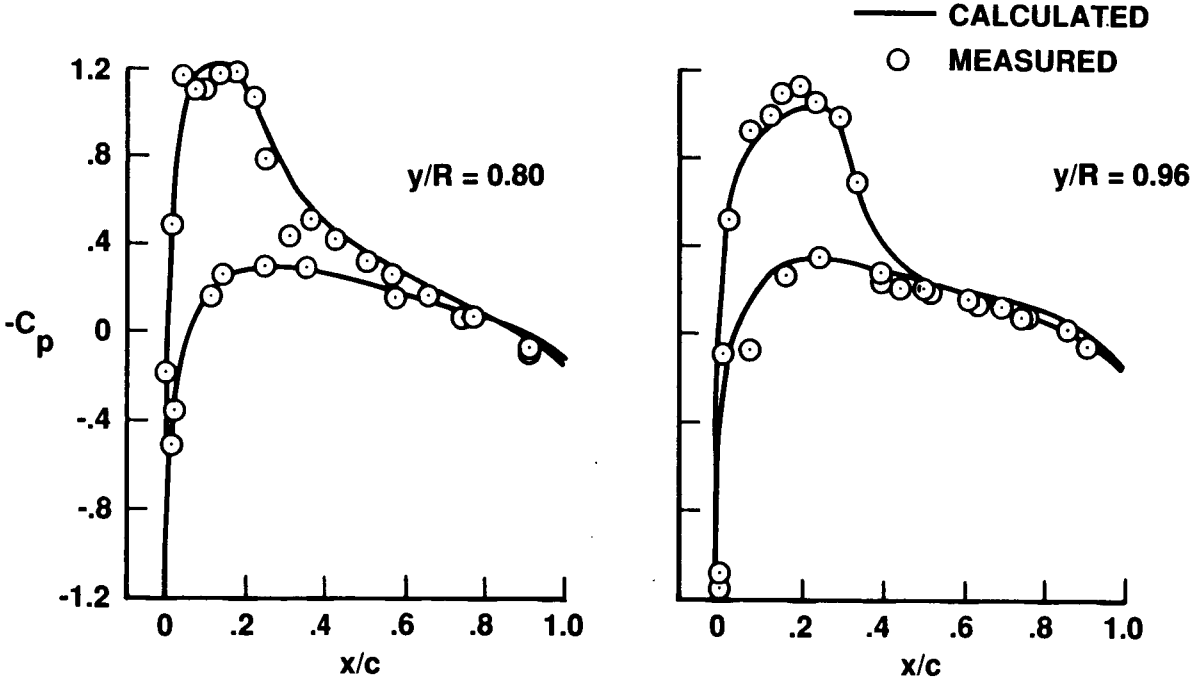
- REDUCED TECHNICAL RISKS FOR NEW CONFIGURATIONS
- MAJOR IMPROVEMENTS IN ROTORCRAFT DESIGN TOOLS
- INCREASED PERFORMANCE AND EFFICIENCY
- REDUCED VIBRATIONS AND NOISE

ROTORCRAFT AERODYNAMICS AND AEROACOUSTICS

AERODYNAMICS OF A HOVERING ROTOR

M_T = 0.877, REYNOLDS NUMBER = 4 x 10^6, θ_c = 8°

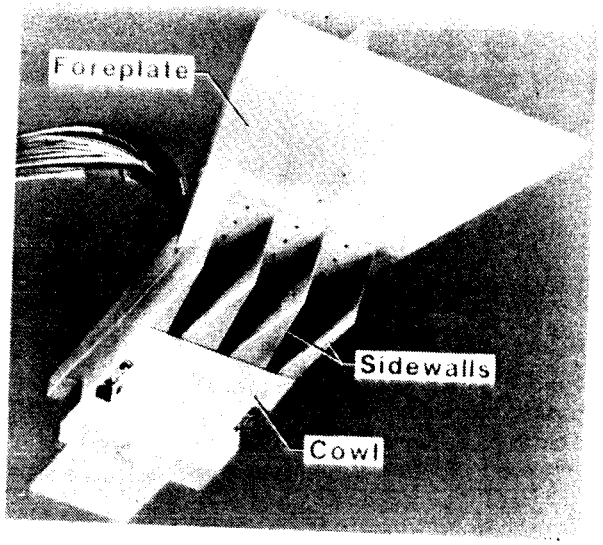




RAMJET/SCRAMJET FLOWFIELDS

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE FLOWS THROUGH RAMJET/SCRAMJET INLETS AND ENGINES INCLUDING COMBUSTION



CURRENT APPROACH

- SOLVE TWO- AND THREE-DIMENSIONAL REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS WITH ALGEBRAIC TURBULENCE MODEL. INCLUDE 8 SPECIES GAS MODEL WITH 14 REACTIONS FOR HYDROGEN-AIR COMBUSTION ANALYSES

FUTURE DIRECTIONS

- INCLUDE IMPROVED TURBULENCE MODELS
- APPLY CODES TO AEROSPACE PLANE DEVELOPMENT EFFORTS
- EXTEND COMBUSTION MODEL TO INCLUDE HYDROCARBON FUELS

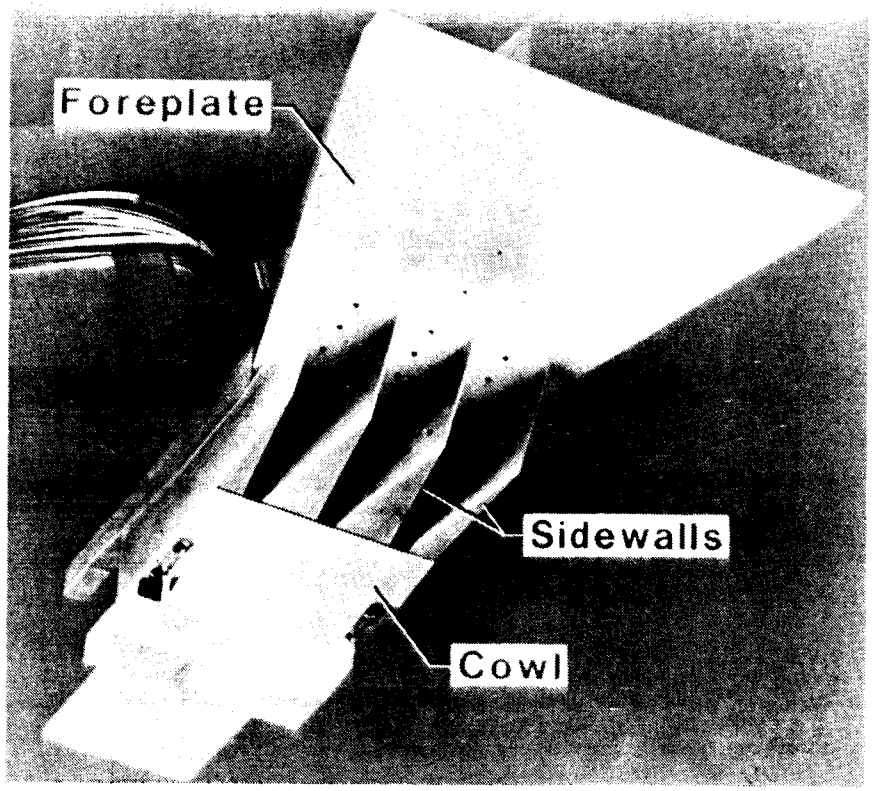
PAYOFF

- USE TOOLS TO DEVELOP EFFICIENT PROPULSION SYSTEMS FOR HIGH-SPEED VEHICLES

RAMJET/SCRAMJET FLOWFIELDS

FLOW THROUGH MULTIPLE MODULE SCRAMJET ENGINE INLET

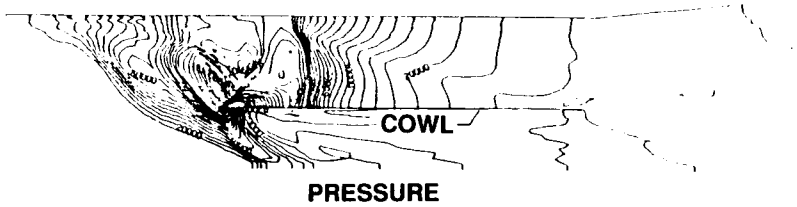
MULTIPLE INLET MODEL



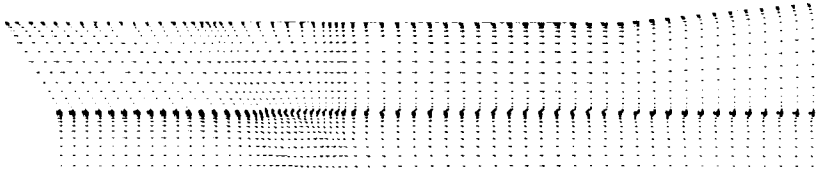
COMPUTED FLOW IN SYMMETRY PLANE OF SINGLE MODULE

$M_\infty = 4.03$, $\alpha = 0°$, CONTRACTION RATIO = 4.0

PRESSURE FIELD



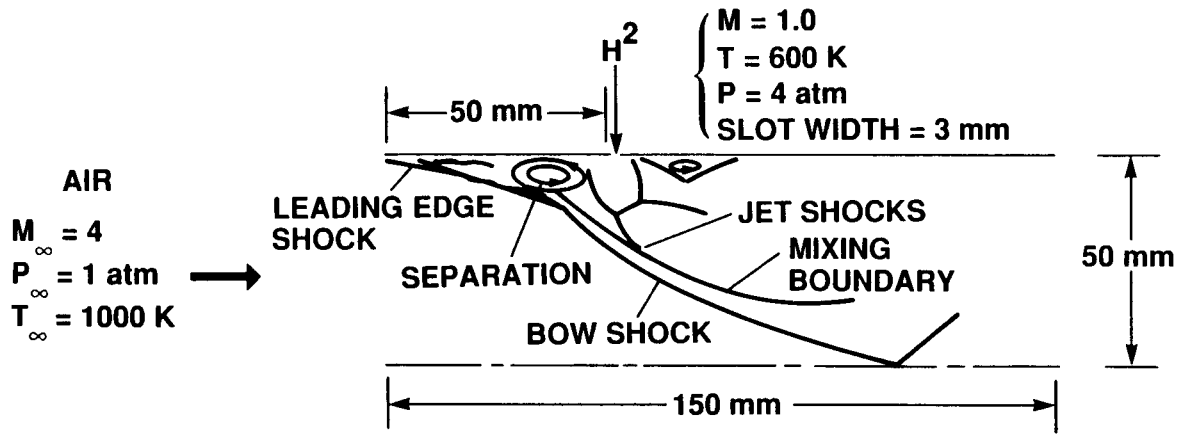
VELOCITY FIELD



RAMJET/SCRAMJET FLOWFIELDS

HYDROGEN INJECTION AND COMBUSTION IN 2-D DUCT

SKETCH OF EXPERIMENT SETUP



COMPUTED RESULTS

STATIC PRESSURE CONTOURS

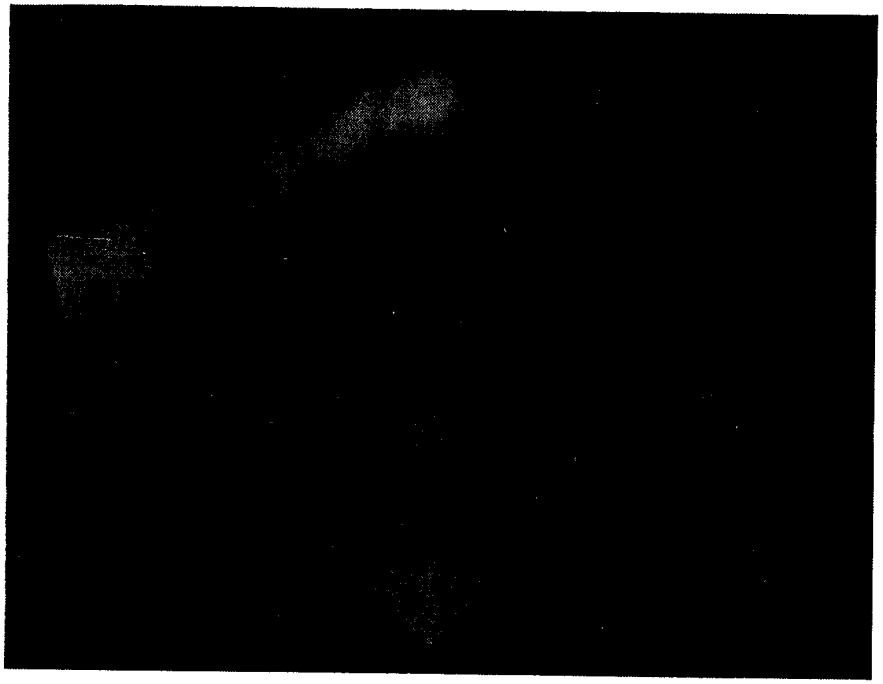
H_2O MASS FRACTION CONTOURS

COMPUTATIONAL CHEMISTRY

REACTION-RATE CONSTANTS

OBJECTIVE

- APPLY COMPUTATIONAL METHODS TO DETERMINE HIGH-TEMPERATURE REACTION RATES NEEDED FOR DESIGN OF HIGH-SPEED VEHICLES



CURRENT APPROACH

- SOLVE SCHRODINGER EQUATION FOR POTENTIAL ENERGY SURFACE
- PERFORM CLASSICAL TRAJECTORY CALCULATIONS USING POTENTIAL ENERGY SURFACE

FUTURE DIRECTIONS

- EXPAND CALCULATIONS TO 5 AND 6 ATOM COMPLEXES
- EXTEND METHODS TO INCLUDE TRANSITION METAL ATOMS FOR VITIATED FLOWS

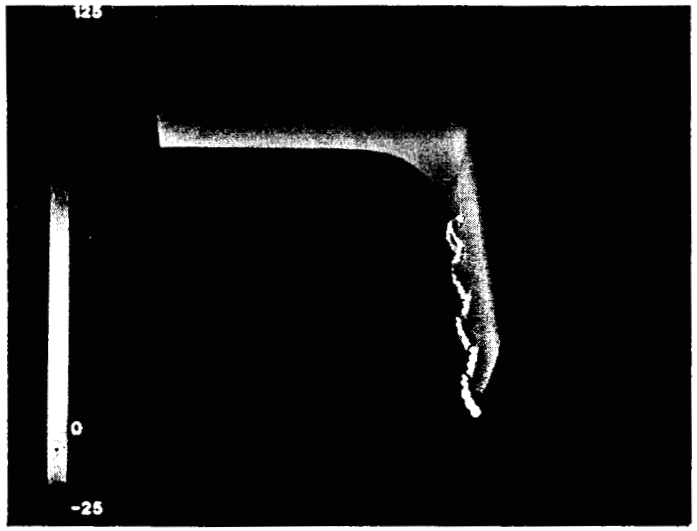
PAYOFF

- PROVIDES RATE CONSTANTS FOR CONDITIONS THAT ARE EITHER DIFFICULT OR IMPOSSIBLE TO OBTAIN EXPERIMENTALLY
- SIGNIFICANTLY REDUCED TIME AND COST FOR OBTAINING REACTION RATES

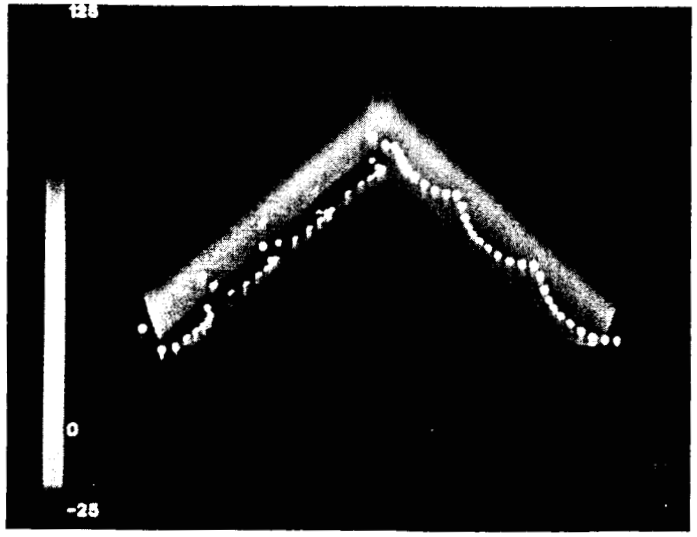
COMPUTATIONAL CHEMISTRY

$N + O_2 \rightarrow NO + O$ EXCHANGE REACTION

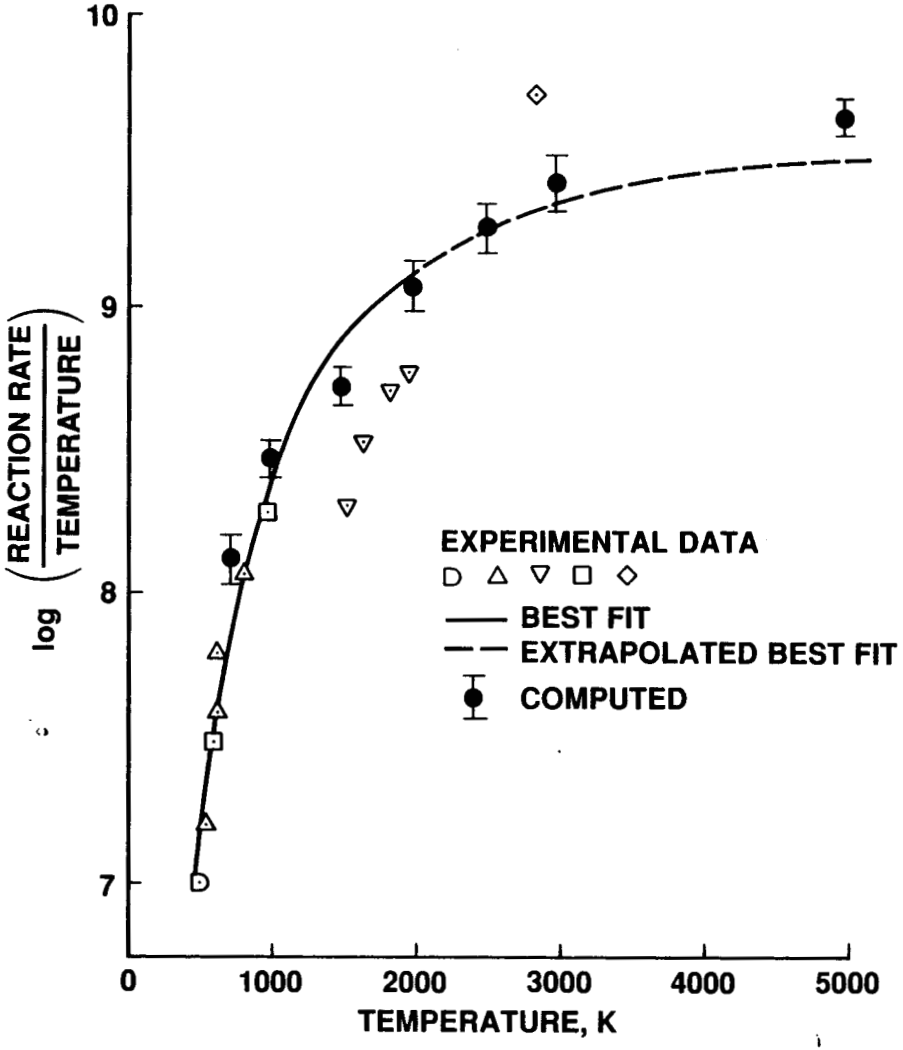
NON-REACTIVE TRAJECTORY



REACTIVE TRAJECTORY



REACTION RATES

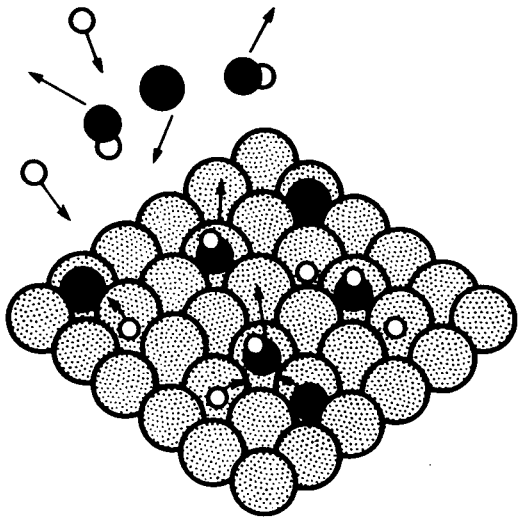


COMPUTATIONAL CHEMISTRY

GAS-MATERIAL INTERACTIONS

OBJECTIVE

- APPLY COMPUTATIONAL METHODS TO UNDERSTAND INTERACTIONS OF GASEOUS SPECIES (H, H_2, O, O_2, NO, CO) WITH METAL SURFACES (Ni, Pt, Al, Cu)



CURRENT APPROACH

- SOLVE SCHRODINGER EQUATION FOR INTERATOMIC FORCES
- MODEL METAL SURFACE
- IDENTIFY BONDING MECHANISMS

FUTURE DIRECTIONS

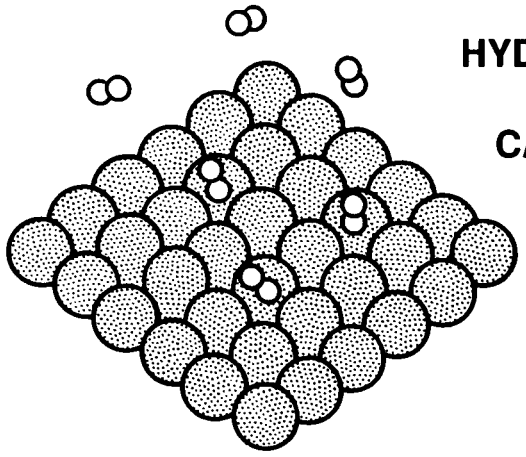
- INCREASE COMPLEXITY OF GAS AND MATERIAL SYSTEMS
- CONDUCT SYSTEMATIC STUDY OF TRANSITION METALS

PAYOFF

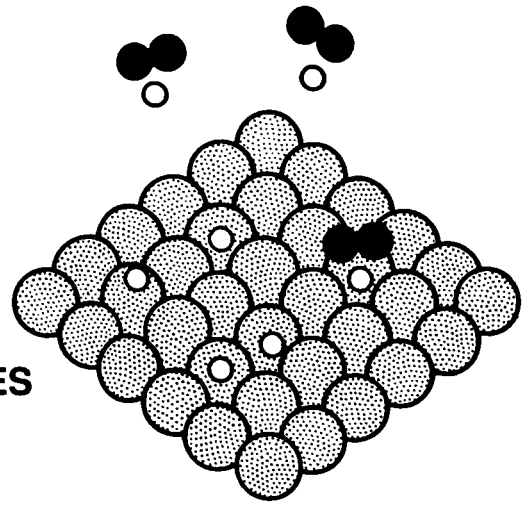
- INCREASED UNDERSTANDING OF CATALYSTS AND THIN FILMS
- IMPROVED ESTIMATES OF THERMAL PROTECTION SYSTEM AND COMBUSTOR PERFORMANCE

COMPUTATIONAL CHEMISTRY

ENHANCEMENT OF HYDROGEN-AIR IGNITION WITH PLATINUM CATALYST

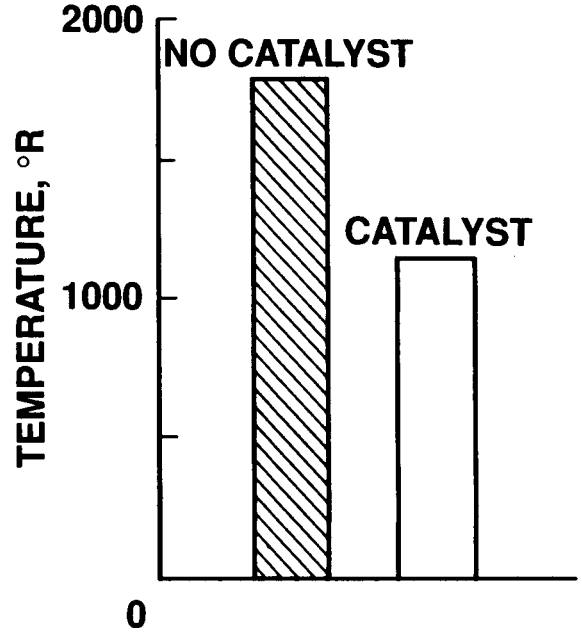


HYDROGEN MOLECULES INTERACT WITH A CATALYTIC SURFACE



HYDROGEN DISSOCIATES AND REACTS WITH OXYGEN MOLECULES

COMPUTED STATIC TEMPERATURE REQUIRED FOR SPONTANEOUS IGNITION OF AIR-HYDROGEN MIXTURE

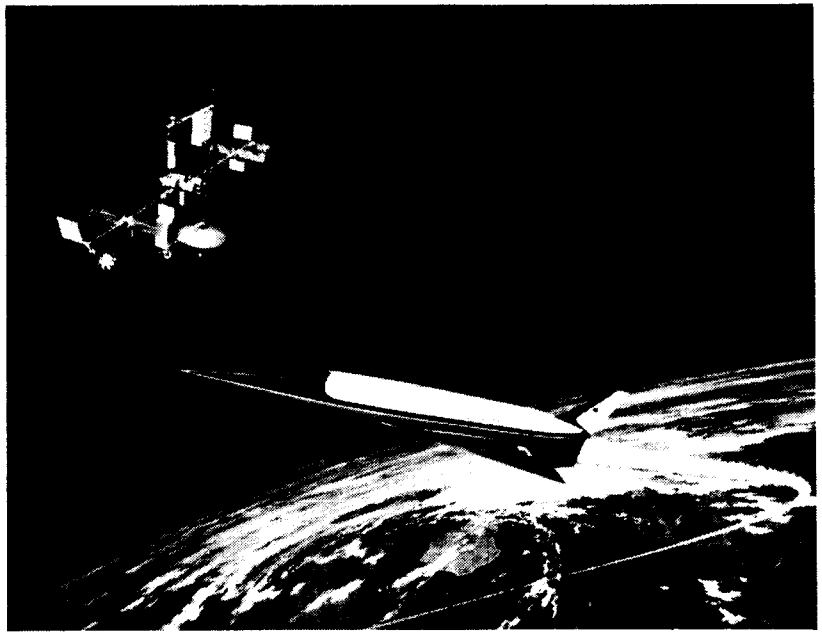


- PLATINUM CATALYST LOWERS SPONTANEOUS IGNITION TEMPERATURE FOR AIR-HYDROGEN MIXTURES
- USE OF CATALYST SIMPLIFIES COMBUSTOR DESIGNS

HYPERSONIC VEHICLES

OBJECTIVE

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



CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL REYNOLDS-AVERAGED NAVIER-STOKES AND PARA-BOLIZED NAVIER-STOKES EQUATIONS, USING ALGEBRAIC TURBULENCE MODELS, WITH PERFECT GAS AND VARIOUS REAL-GAS APPROXIMATIONS

FUTURE DIRECTIONS

- EXTEND APPLICATIONS TO MORE COMPLEX GEOMETRIES
- IMPROVE BOTH THE MODELING OF REAL-GAS PHYSICS AND THE COMPUTATIONAL EFFICIENCY

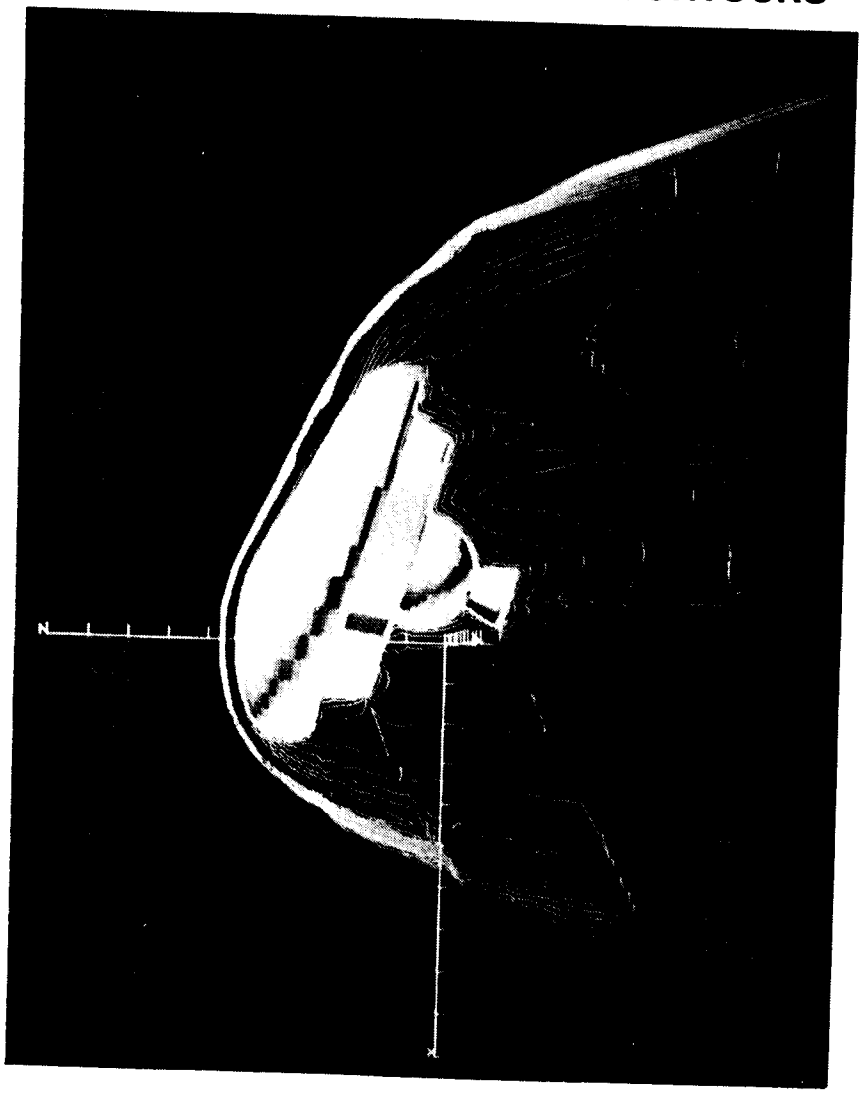
PAYOFF

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

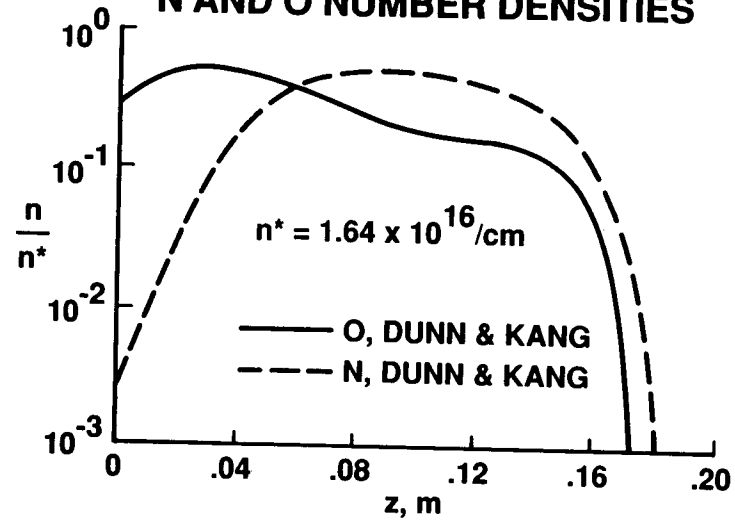
HYPERSONIC VEHICLES

AEROASSISTED ORBITAL TRANSFER VEHICLE

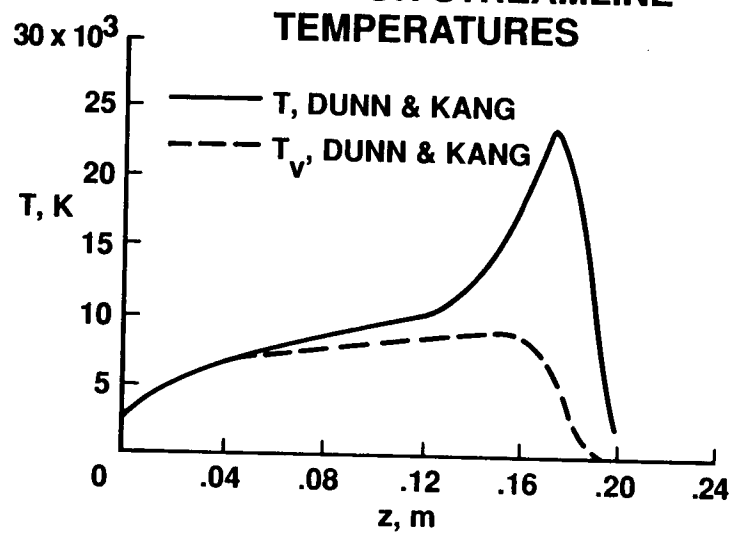
ELECTRON NUMBER DENSITY CONTOURS



N AND O NUMBER DENSITIES



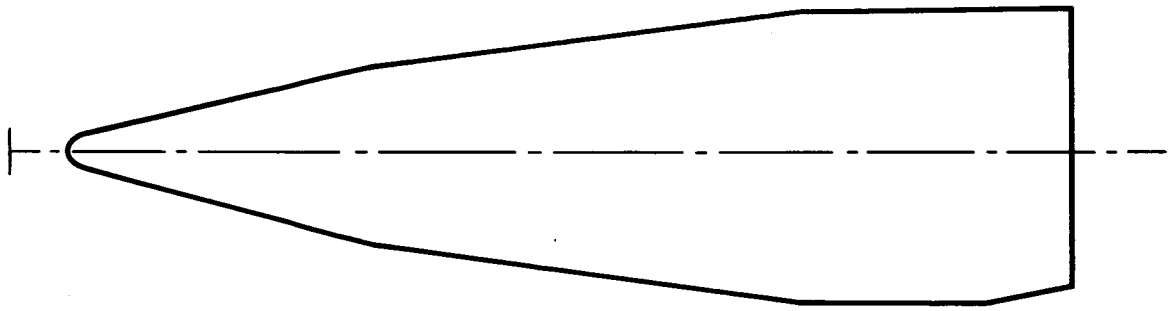
STAGNATION STREAMLINE TEMPERATURES

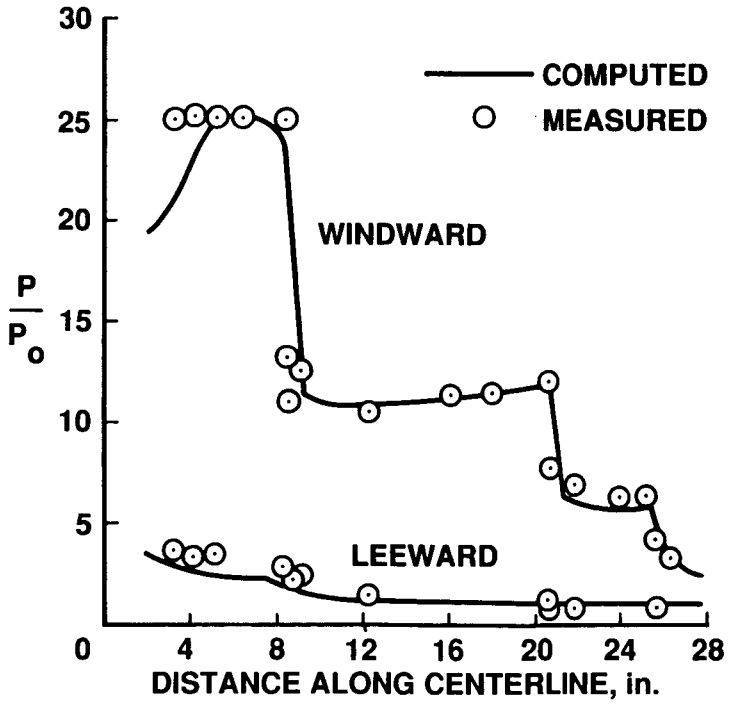


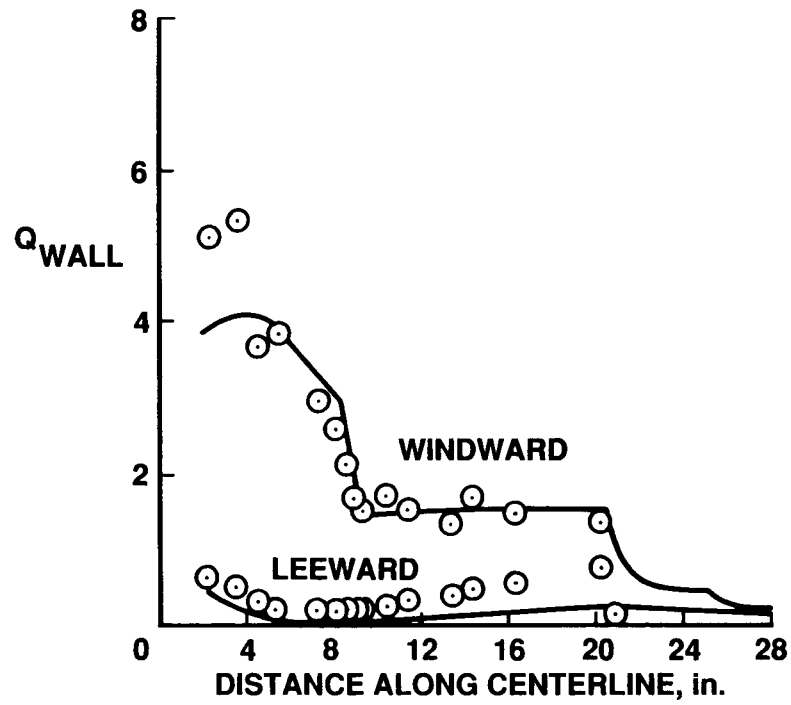
HYPERSONIC VEHICLES

BICONE WITH CUTS

$M_\infty = 10$, $\alpha = 10°$, REYNOLDS NUMBER = 1×10^6/ft





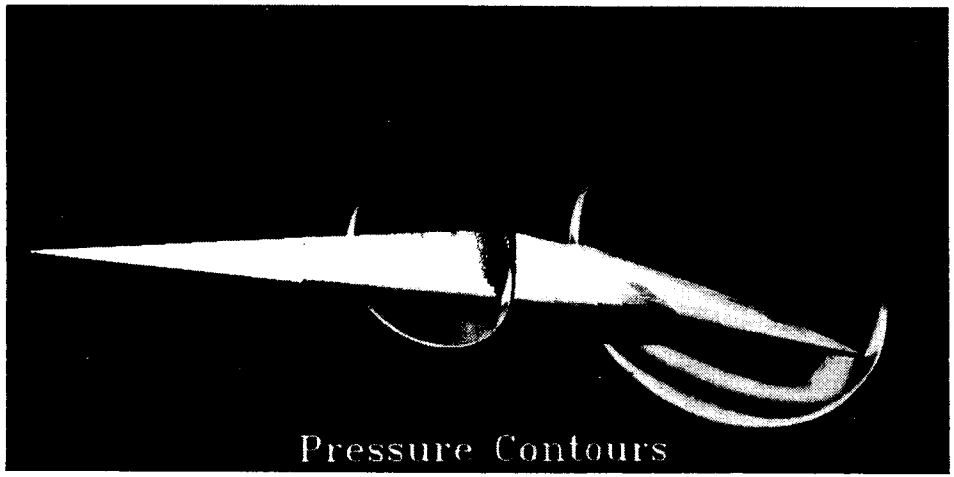


HYPERSONIC VEHICLES

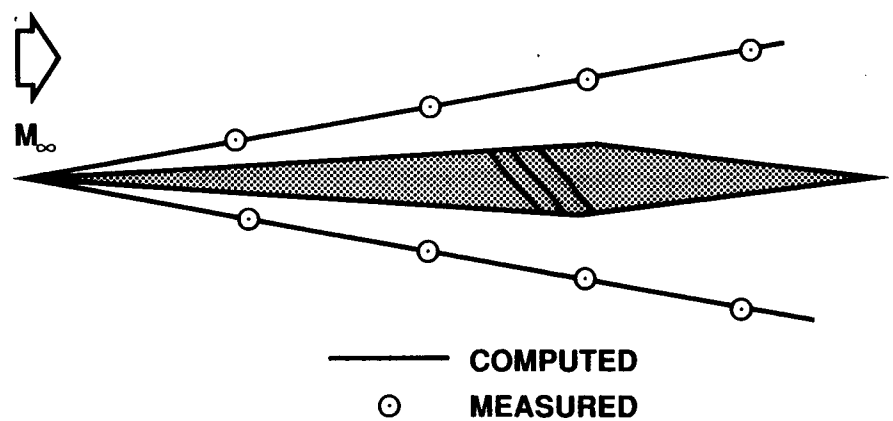
ALL-BODY AIRCRAFT

$M_\infty = 7.4$, $\alpha = 10°$, $(\text{REYNOLDS NUMBER})_L = 15 \times 10^6$

PRESSURE CONTOURS



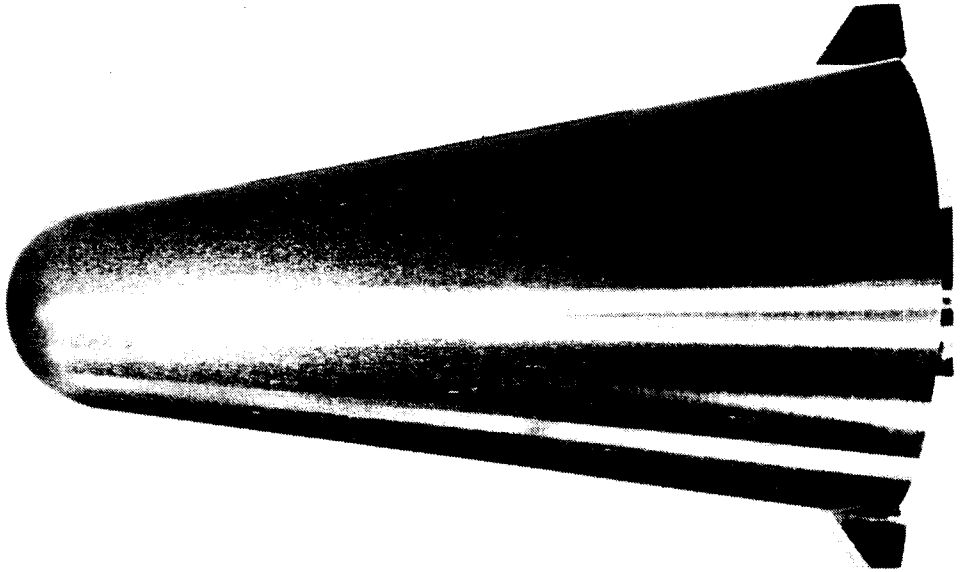
SHOCK SHAPES



COMMUNICATIONS BLACKOUT

OBJECTIVE

- DEVELOP CAPABILITY TO ACCURATELY COMPUTE ATTENUATION OF RADIO SIGNALS BY SHOCK LAYERS ABOUT ENTRY VEHICLES



CURRENT APPROACH

- SOLVE TWO-DIMENSIONAL REYNOLDS-AVERAGED NAVIER-STOKES EQUATIONS WITH EQUILIBRIUM AND MULTI-TEMPERATURE NONEQUILIBRIUM CHEMISTRY (7 SPECIES INCLUDING NO^+)
- VALIDATE APPROACH BY COMPARING CALCULATIONS WITH FLIGHT DATA

FUTURE DIRECTIONS

- EXTEND METHOD TO 3-DIMENSIONS AND IMPROVE KINETIC MODEL

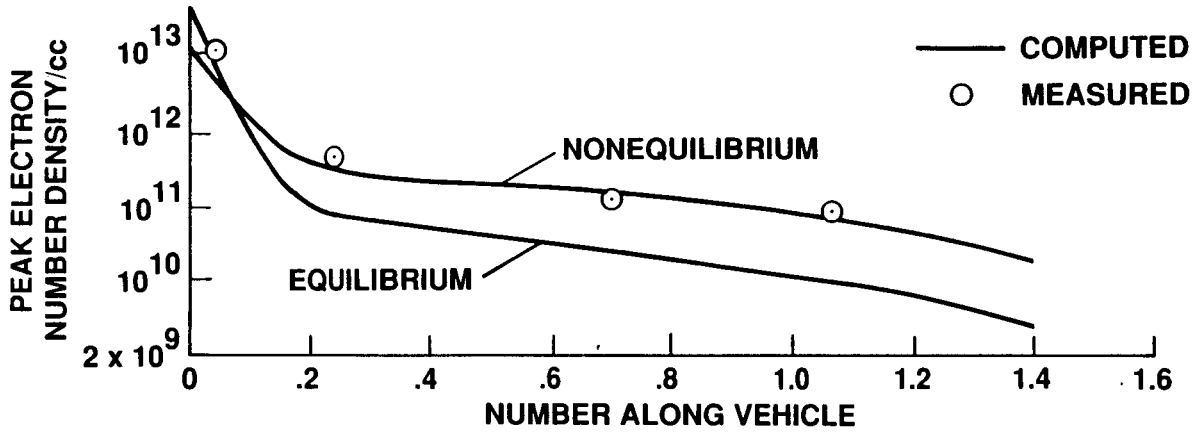
PAYOFF

- VALIDATED COMPUTATIONAL METHOD FOR PREDICTING EFFECTS OF ANTENNA LOCATION AND RADIATED POWER ON COMMUNICATIONS CAPABILITIES OF ENTRY VEHICLES

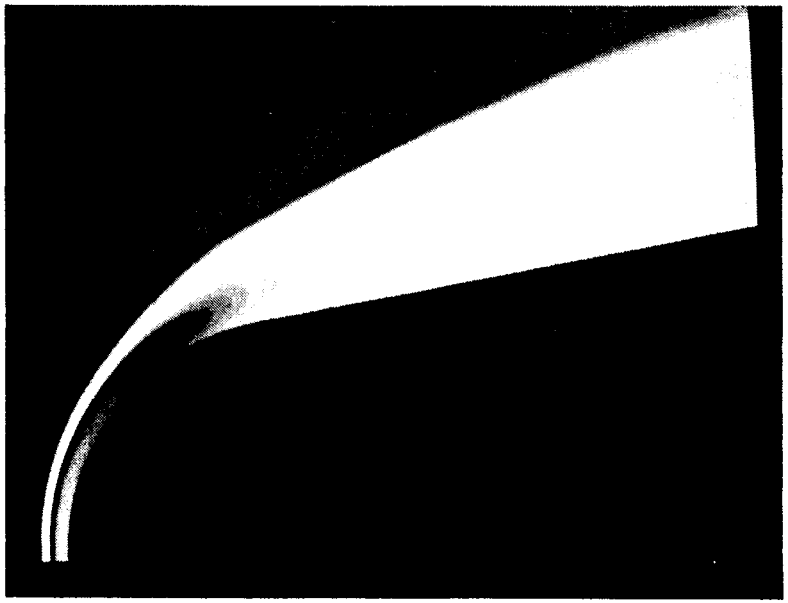
COMMUNICATIONS BLACKOUT

RAM-C II ENTRY VEHICLE

V = 25, 136 ft/s, ALT = 232,951 ft, REYNOLDS NUMBER = 6,280



CONTOURS OF
NO^+ CONCENTRATION

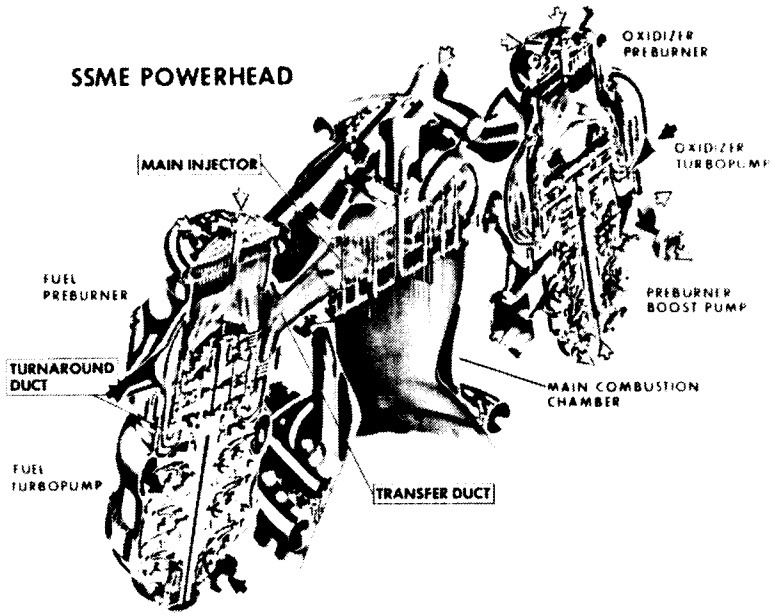


CONTOURS OF
ELECTRON NUMBER DENSITY

SPACE SHUTTLE MAIN ENGINE

OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE FLOWS OF FUEL AND OXIDIZER THROUGH SSME POWERHEAD
- USE CAPABILITY TO SUGGEST DESIGN IMPROVEMENTS



CURRENT APPROACH

- SOLVE REYNOLDS-AVERAGED, STEADY FLOW, INCOMPRESSIBLE NAVIER-STOKES EQUATIONS USING ONE- AND TWO-EQUATION TURBULENCE MODELS

FUTURE DIRECTIONS

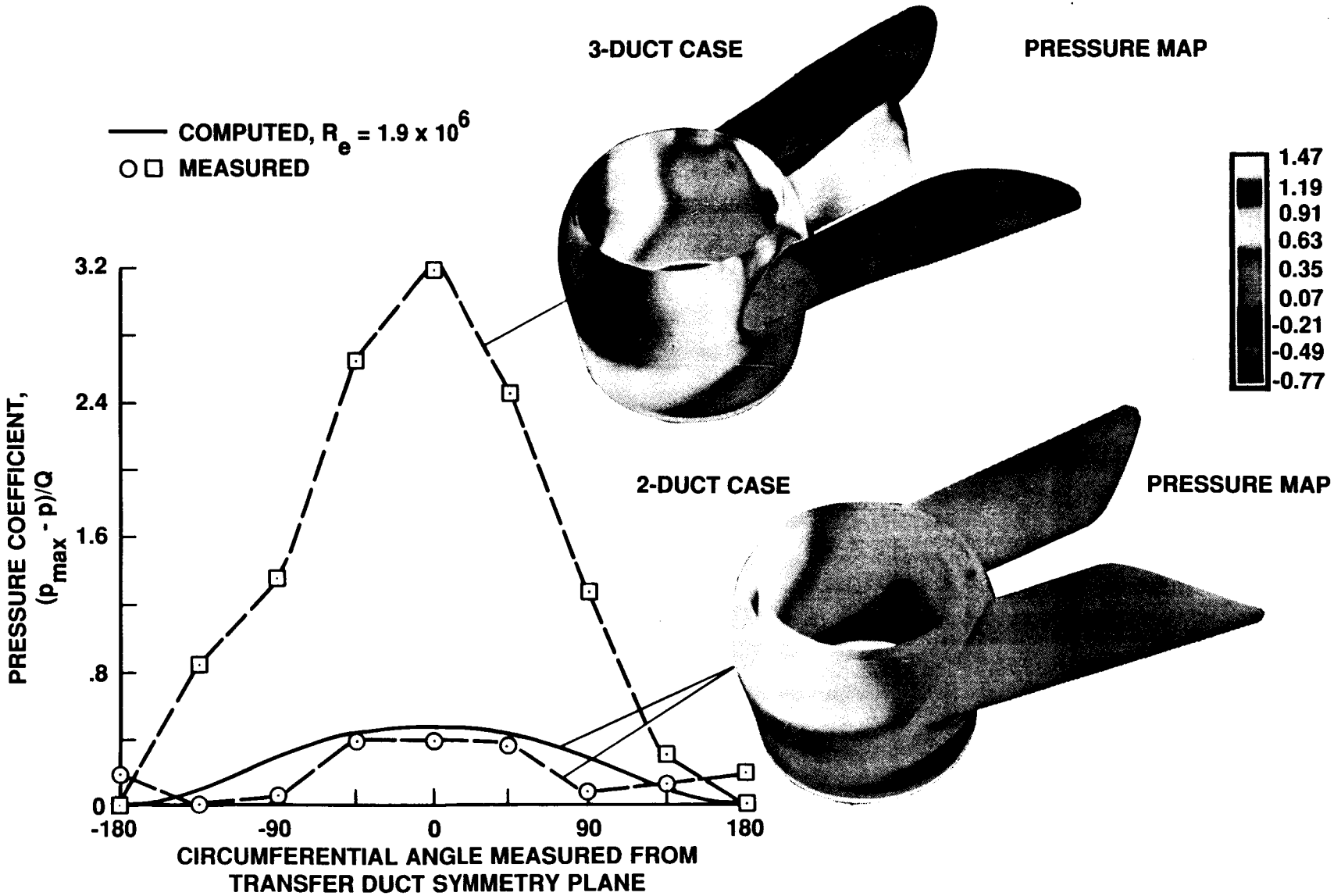
- EXTEND ANALYSES TO INCLUDE UNSTEADY FLOW AND HEAT TRANSFER

PAYOFF

- TOOL THAT CAN BE USED TO SUGGEST DESIGN CHANGES TO IMPROVE CURRENT ENGINE (HIGHER EFFICIENCY AND LONGER LIFETIME) AND FOR DESIGNING NEW ENGINES

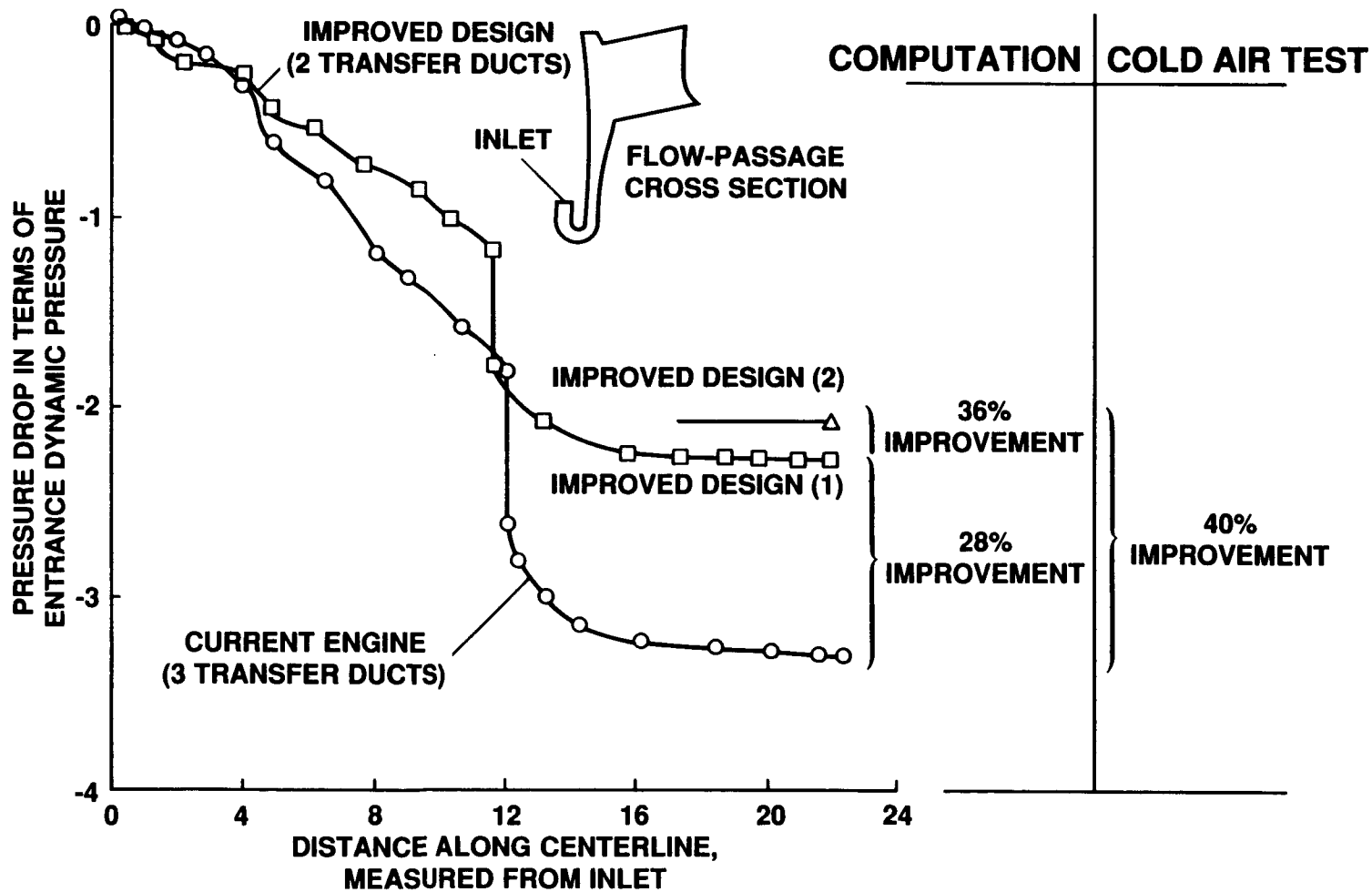
SPACE SHUTTLE MAIN ENGINE

PRESSURE COEFFICIENTS ON FUEL BOWL OUTER WALL IMMEDIATELY DOWNSTREAM OF 180° TURN

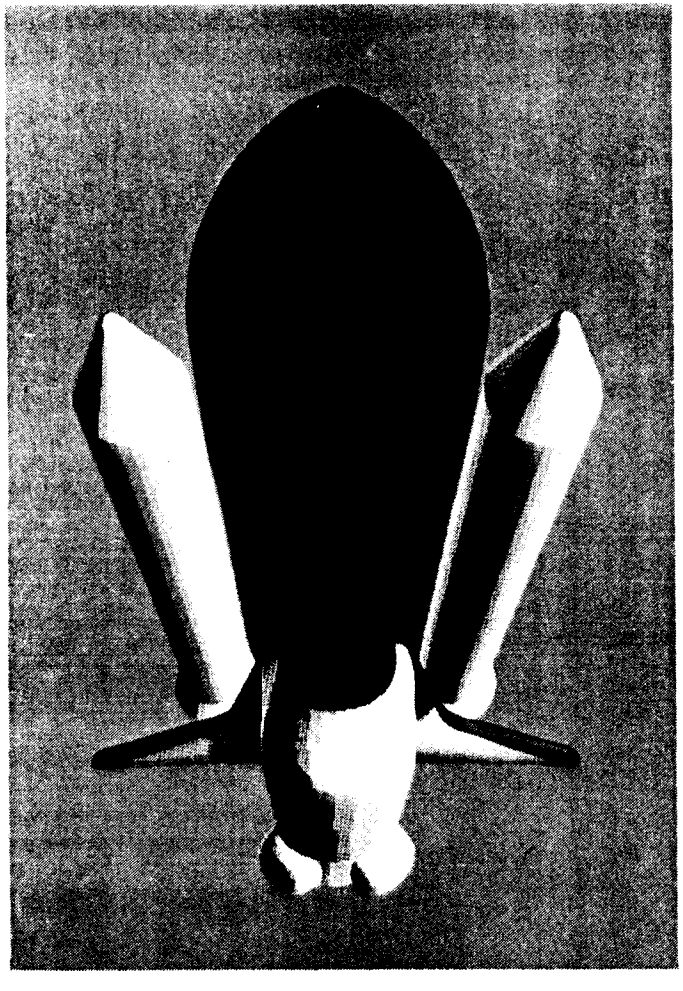


SPACE SHUTTLE MAIN ENGINE

MEASURED PRESSURE LOSSES IN ORIGINAL – AND COMPUTATIONALLY IMPROVED – HOT GAS MANIFOLD



SPACE SHUTTLE LAUNCH CONFIGURATION



OBJECTIVE

- DEVELOP CAPABILITY TO COMPUTE TIME-DEPENDENT FLOW OVER INTEGRATED SPACE SHUTTLE IN ASCENT AND STAGING MODES

CURRENT APPROACH

- SOLVE THREE-DIMENSIONAL REYNOLDS-AVERAGED UNSTEADY NAVIER-STOKES EQUATIONS USING CHIMERA COMPOSITE GRID (ALGEBRAIC TURBULENCE MODEL)

FUTURE DIRECTIONS

- VALIDATE CODE
- INCLUDE EXHAUST PLUMES AND BINDING LINKAGES
- APPLY CODE TO STUDY EMERGENCY CREW ESCAPE

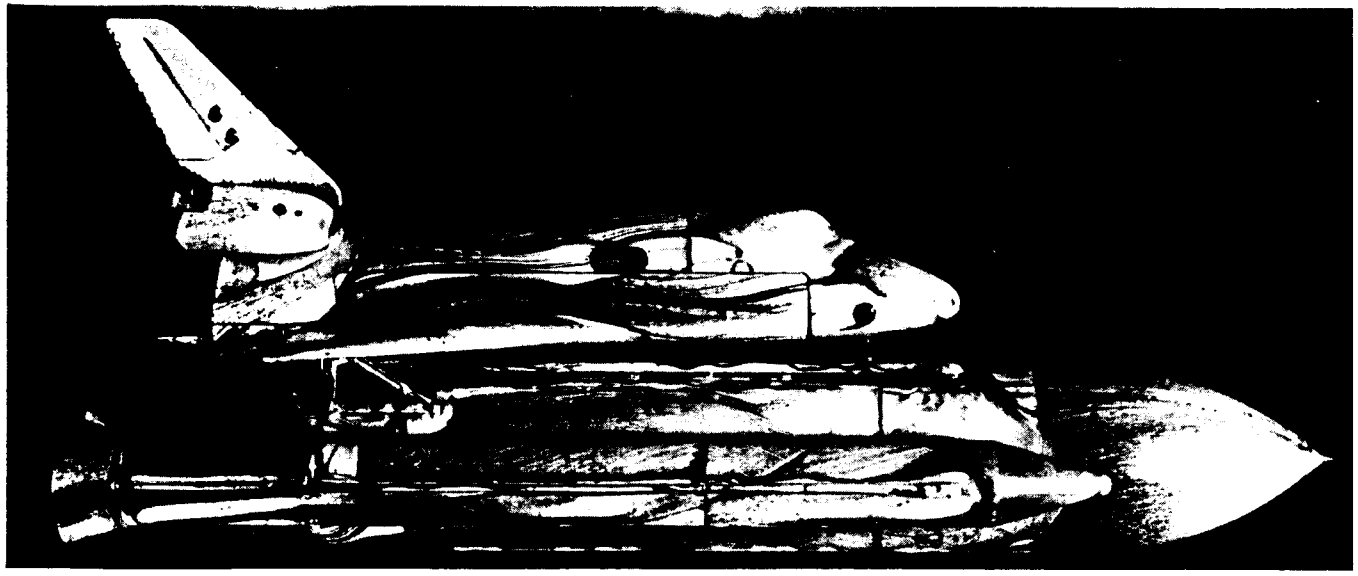
PAYOFF

- PREDECTIVE TOOL FOR REFINING UNDERSTANDING OF AERODYNAMIC PERFORMANCE EXTENDING FLIGHT ENVELOPE AND STUDYING CREW ESCAPE OPTIONS

SPACE SHUTTLE LAUNCH CONFIGURATION

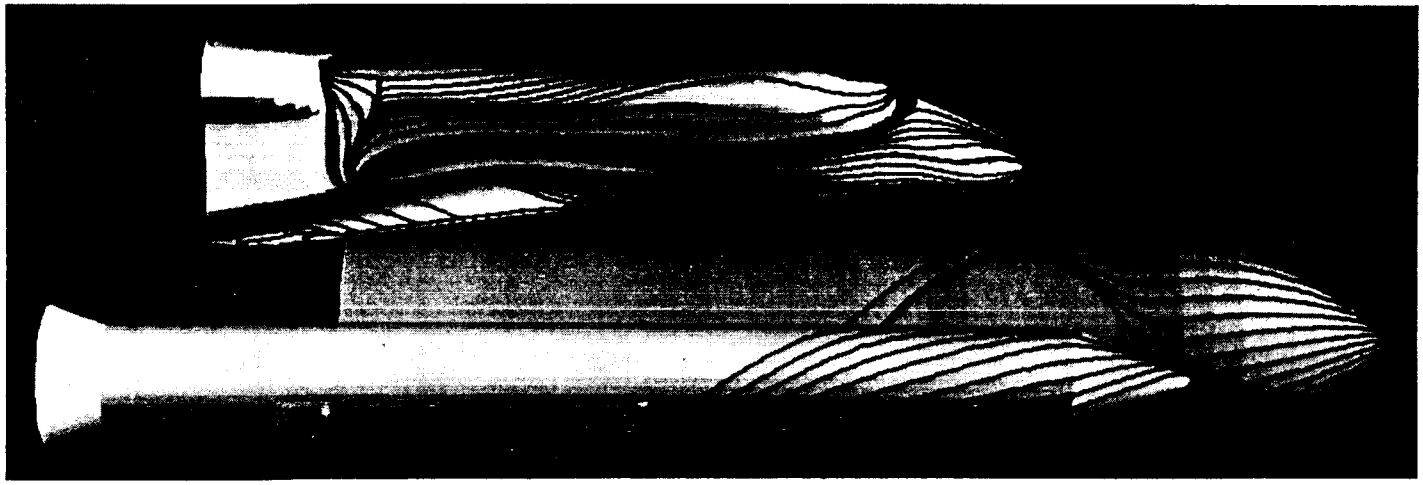
FLOW PATTERNS

M = 2.0, α = -4°, REYNOLDS NUMBER = 400,000

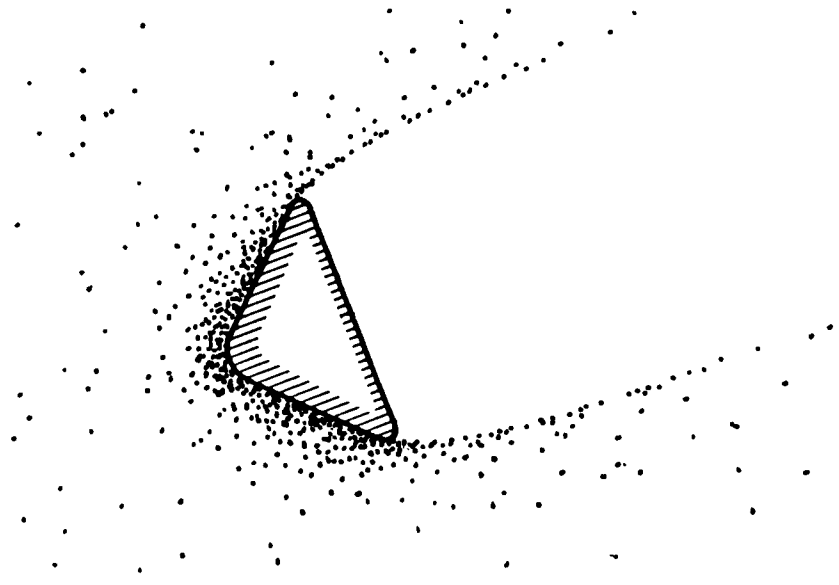


MEASURED OIL FLOW PATTERNS

COMPUTED PARTICLE TRACES (NEAR SURFACE)



RAREFIED HYPERSONIC FLOWS

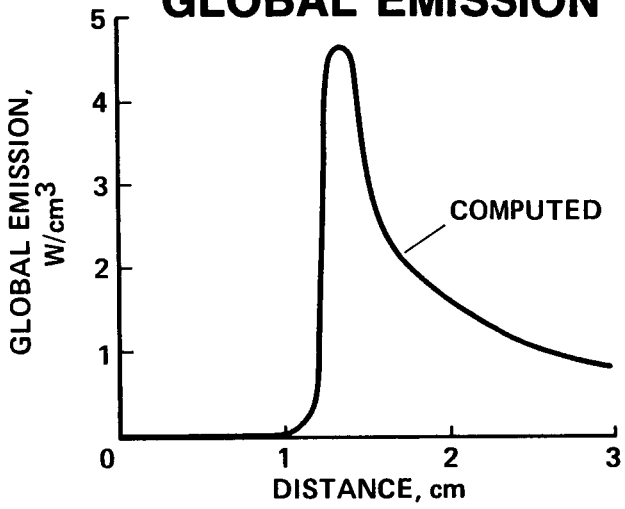


- OBJECTIVE
  - DEVELOP AND VALIDATE CAPABILITY TO COMPUTE HYPERSONIC RAREFIED FLOWS ABOUT ATMOSPHERE ENTRY VEHICLES
- CURRENT APPROACH
  - USE DIRECT SIMULATION MONTE CARLO METHOD
- FUTURE DIRECTIONS
  - IMPROVE PHYSICAL MODELING, PARTICULARLY RADIATION
  - APPLY CODE TO PROVIDE DESIGN INFORMATION FOR AEROASSIST FLIGHT EXPERIMENT, SHUTTLE REACTION CONTROL SYSTEM PLUME STUDIES AND LEADING EDGES FOR TRANS-ATMOSPHERIC VEHICLES
  - IDENTIFY IMPORTANT CHEMICAL AND RADIATION CHARACTERISTICS FOR NONEQUILIBRIUM FLOWS
- PAYOFF
  - TOOL FOR PROVIDING DESIGN INFORMATION IN SITUATIONS INVOLVING HIGHLY RAREFIED FLUID DYNAMIC FLOWS

RAREFIED HYPERSONIC FLOWS

STAGNATION STREAMLINE CALCULATIONS AND SHOCK TUBE EXPERIMENTS

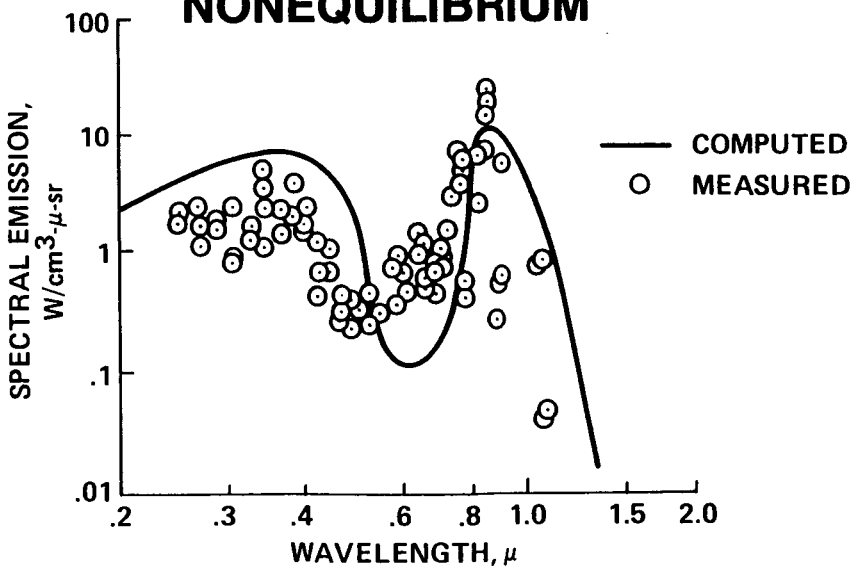
GLOBAL EMISSION



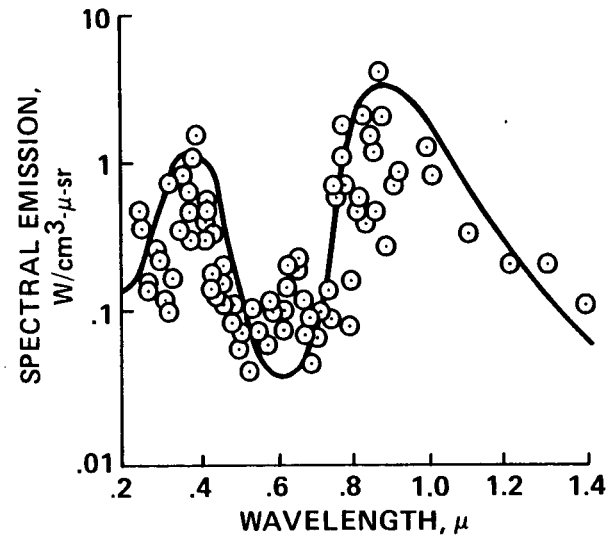
EXPERIMENT

AVCO SHOCK TUBE
10 km/sec SHOCK WAVE
AIR
MEASURED SPECTRUM: 0.2 TO 1.4 μ

NONEQUILIBRIUM

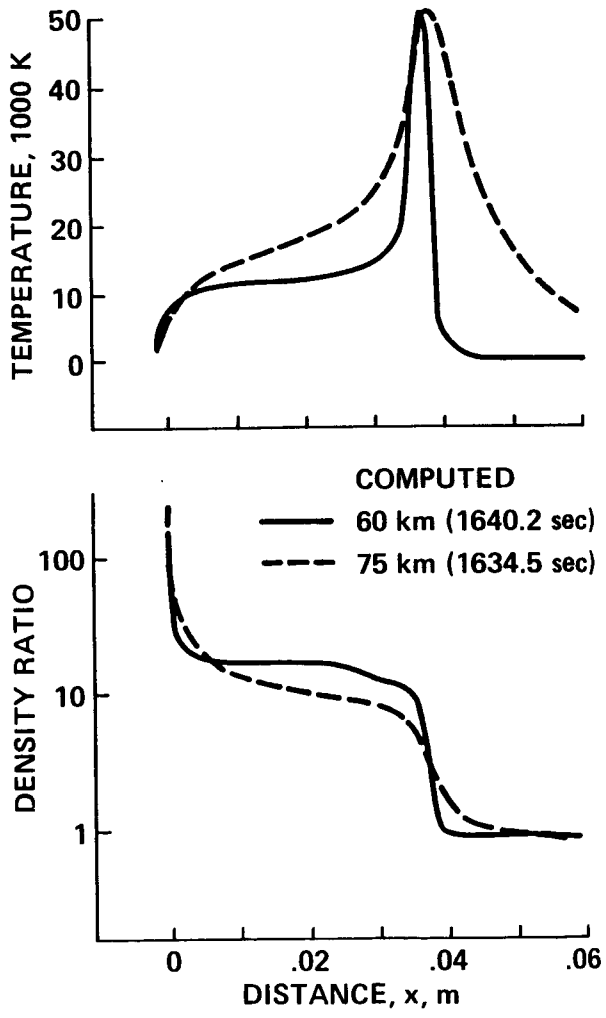


EQUILIBRIUM



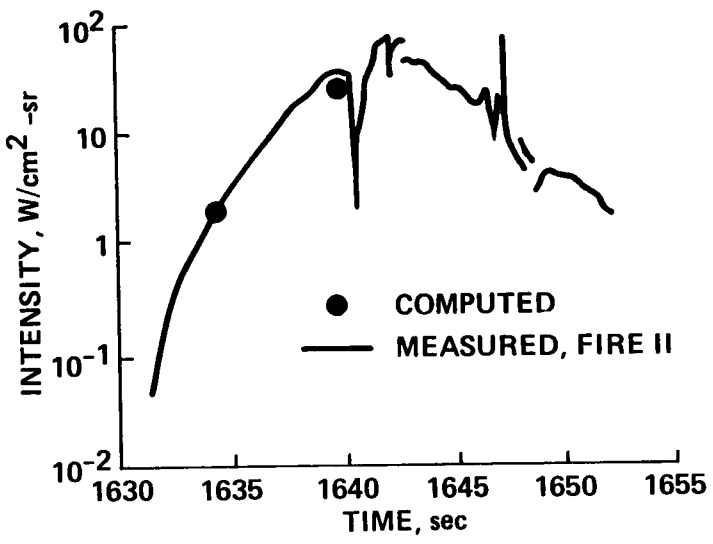
RAREFIED HYPERSONIC FLOWS

STAGNATION STREAMLINE CALCULATIONS AND FLIGHT MEASUREMENTS



FLIGHT EXPERIMENT

FIRE II (APRIL, 1964)
ENTRY VELOCITY 11.3 km/sec
AIR
MEASURED SPECTRUM: 0.2 TO 4.0 μ



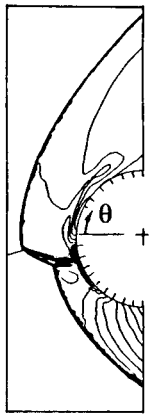
INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYSIS

OBJECTIVE

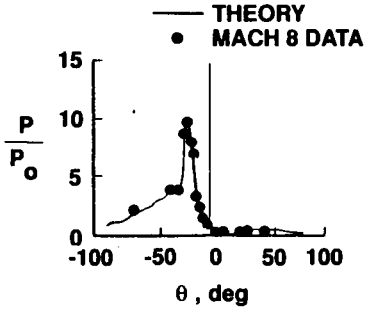
- DEVELOP CAPABILITY TO COMPLETE FULLY COUPLED FLUID-THERMAL-STRUCTURAL PHENOMENA FOR HYPERSONIC VEHICLES WHERE AEROTHERMAL LOADS PRODUCE ATTENDANT STRUCTURAL TEMPERATURE GRADIENTS, DEFORMATION AND STRESSES

SCHLIEREN PHOTOGRAPH

PREDICTED DENSITY CONTOURS



PREDICTED SURFACE PRESSURE DISTRIBUTION



CURRENT APPROACH

- SOLVE ALL THREE DISCIPLINES WITH SINGLE FINITE-ELEMENT MODEL AND ALGORITHM
- USE IDEAL GAS AND EQUILIBRIUM CHEMISTRY ASSUMPTIONS TO TREAT 2-D AND AXISYMMETRIC PROBLEMS

FUTURE DIRECTIONS

- EXTEND TO THREE DIMENSIONS, VISCOUS FLOWS AND NONEQUILIBRIUM CHEMISTRY
- DEVELOP IMPROVED ALGORITHMS AND STRUCTURAL MODELS

PAYOFF

- REDUCED STRUCTURAL DESIGN MARGINS
- REDUCED DESIGN TIME
- MORE EFFICIENT HYPERSONIC VEHICLES

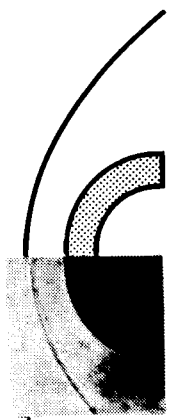
INTEGRATED FLUID-STRUCTURAL-THERMAL ANALYSIS

EXAMPLE RESULT FOR BLUNT LEADING EDGE

$M_\infty = 8.0$

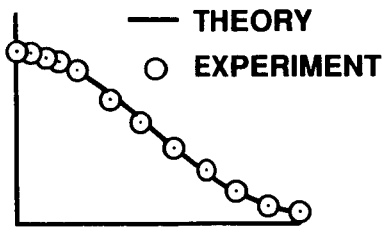
FLOW

SHOCK SHAPE

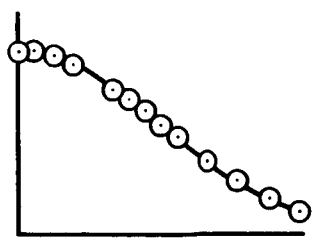


SCHLIEREN

AEROTHERMAL LOADS



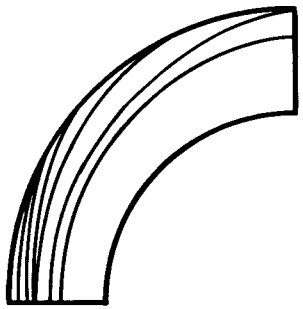
PRESSURE



HEAT FLUX

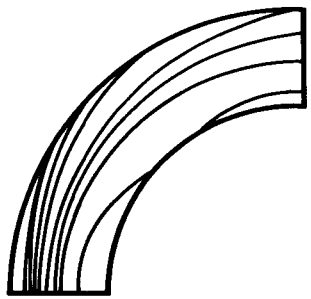
THERMAL

TEMPERATURE CONTOURS



STRUCTURAL

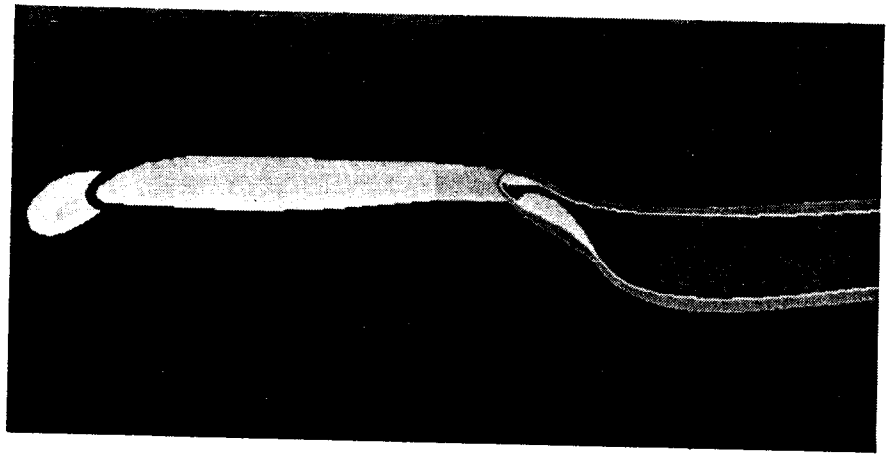
STRESS CONTOURS



EXPERT SYSTEMS TO ENHANCE RESEARCH CONDUCTED COMPUTATIONALLY

OBJECTIVE

- REDUCE THE TIME AND EXPERTISE REQUIRED TO CONDUCT CALCULATIONS AND INCREASE THE QUALITY AND UNIFORMITY OF COMPUTED RESULTS



CURRENT APPROACH

- DEVELOP INTERACTIVE KNOWLEDGE-BASED SYSTEM FOR TWO-DIMENSIONAL FLOW-FIELD ZONING
- INCORPORATE EXISTING GRID-GENERATION CODES
- INCREASE LEVEL OF SYSTEM AUTOMATION INCREMENTALLY

FUTURE DIRECTIONS

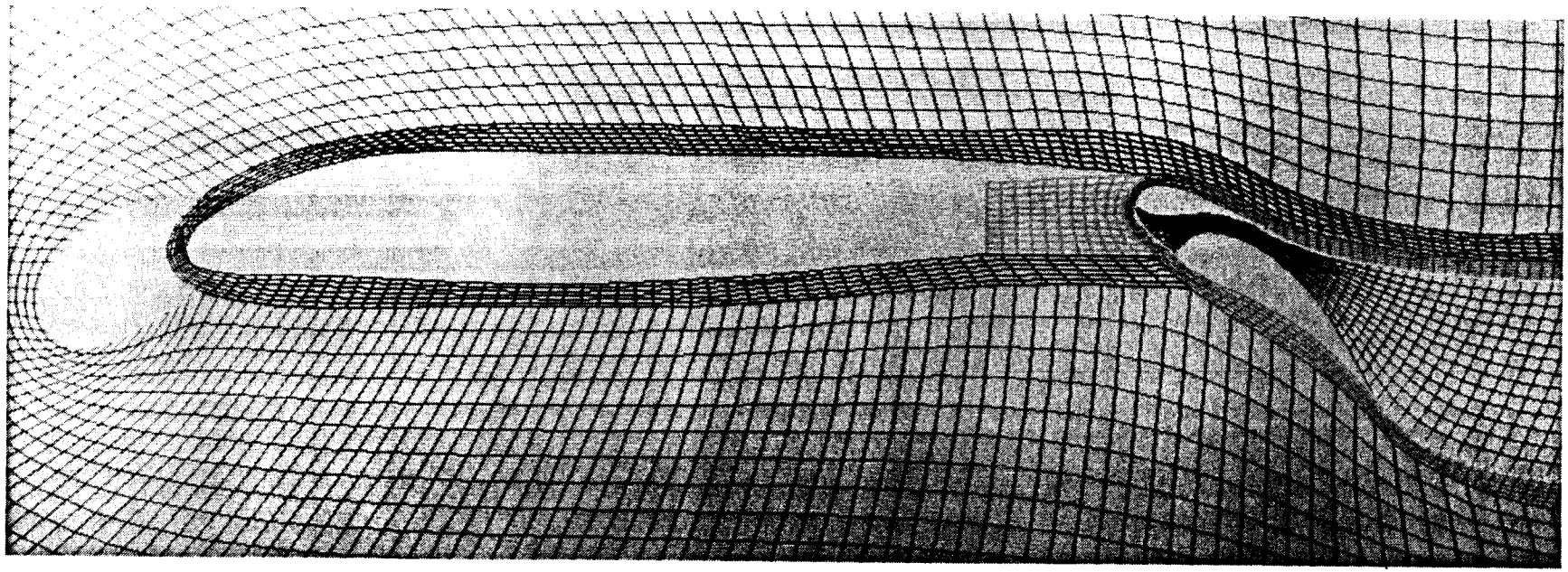
- EXPLORE EXTENSIONS TO THREE DIMENSIONS

PAYOFF

- REDUCED LABOR AND SKILL REQUIRED FOR PREPARING COMPUTATIONAL GRIDS
- INCREASED QUALITY AND UNIFORMITY OF COMPUTED RESULTS

EXPERT SYSTEMS TO ENHANCE RESEARCH

ZONAL GRIDS FOR FOUR-ELEMENT AIRFOIL



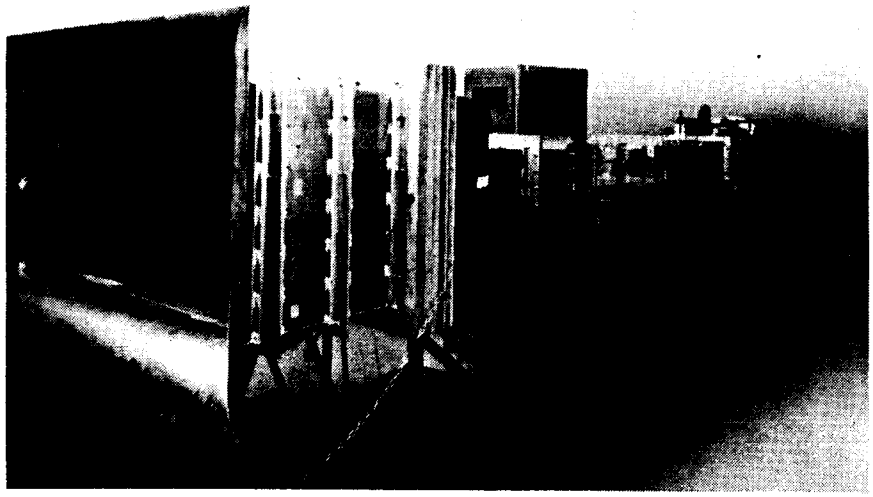
FINDINGS FOR THIS EXAMPLE

- MENU-BASED INTERACTIVE SYSTEM HAVING ABOUT 180 RULES REDUCED THE TIME REQUIRED TO ZONE AND GRID THIS EXAMPLE BY A FACTOR OF ABOUT 4

EXPERT SYSTEMS TO ENHANCE RESEARCH CONDUCTED EXPERIMENTALLY

OBJECTIVE

- REDUCE THE TIME REQUIRED TO CONDUCT EXPERIMENTS AND INCREASE THE QUALITY OF MEASURED RESULTS



CURRENT APPROACH

- DEVELOP A RULE-BASED EXPERT SYSTEM FOR AUTOMATING THE INTELLIGENT POSITIONING OF WIND-TUNNEL PROBES
- VALIDATE SYSTEM IN SMALL-SCALE RESEARCH FACILITY

FUTURE DIRECTIONS

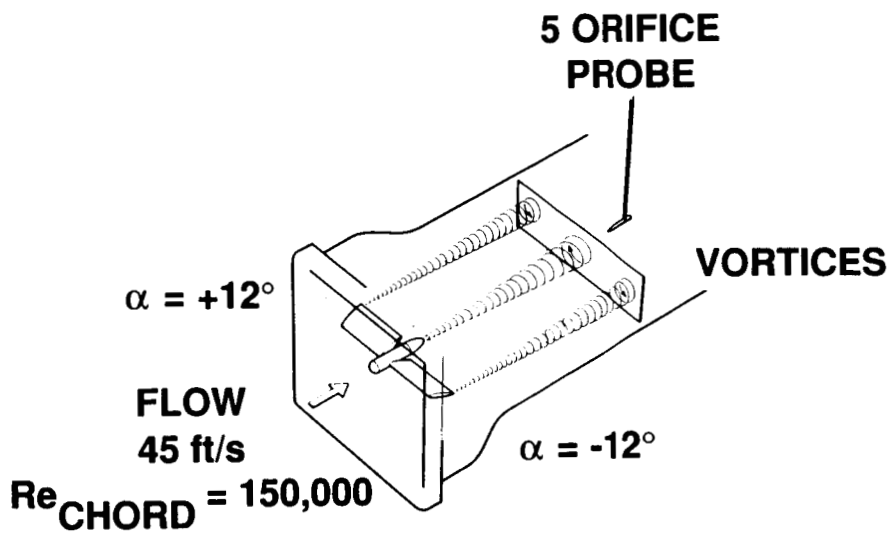
- INVESTIGATE ALTERNATIVE SEARCH STRATEGIES
- APPLY VALIDATED TECHNOLOGY IN OTHER RESEARCH- AND PRODUCTION-FACILITIES
- EXTEND CONCEPTS TO OTHER KINDS OF MEASUREMENTS

PAYOFF

- REDUCTIONS IN LABOR AND IN FACILITY OPERATING TIME FOR MEETING TESTING OBJECTIVES
- INCREASED QUALITY OF MEASUREMENTS
- POTENTIAL FOR UNCOVERING UNFORESEEN FLUID DYNAMIC PHENOMENA

EXPERT SYSTEMS TO ENHANCE RESEARCH

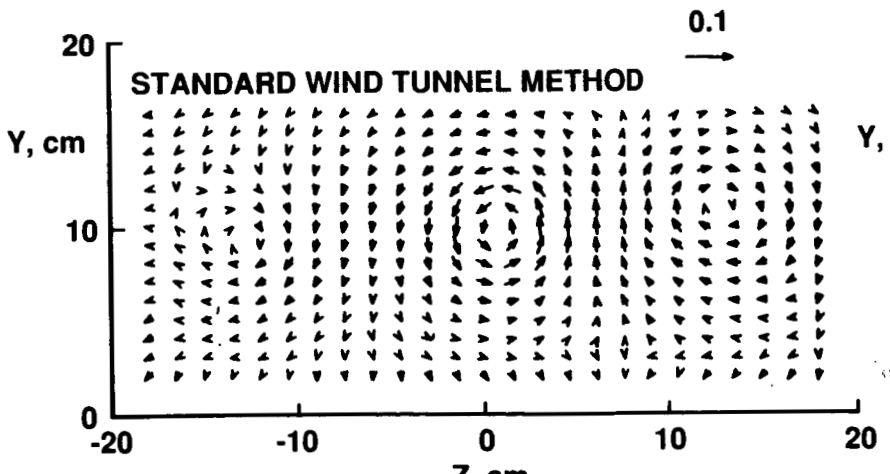
TEST OF SMART PROBE



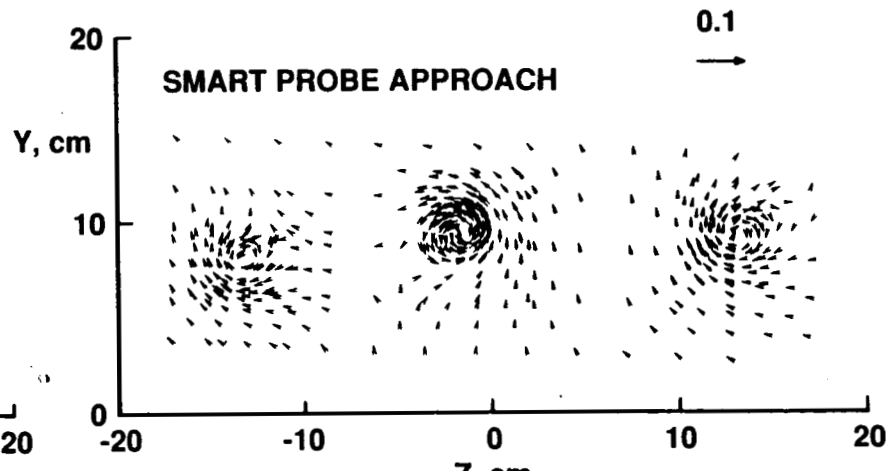
FINDINGS FOR THIS EXAMPLE

- DRAMATICALLY IMPROVED RESULTS
- EXPERT SYSTEM IMPOSES 7-PERCENT INCREASE IN MEASUREMENT TIME AT EACH PROBE LOCATION (SOFTWARE OVERHEAD)

VELOCITY FIELDS DEDUCED FROM PRESSURE MEASUREMENTS



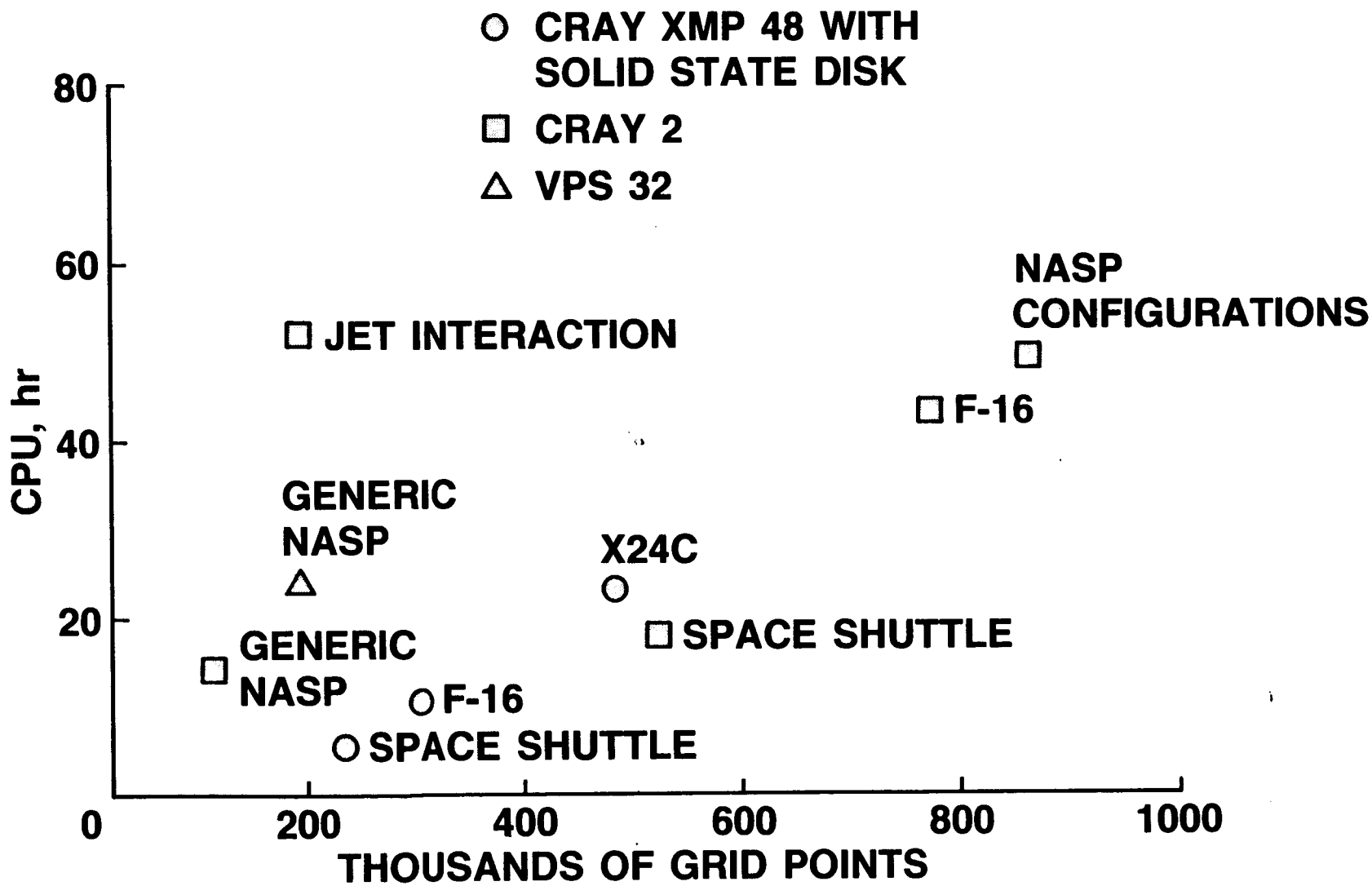
CONVENTIONAL APPROACH 375 EQUALLY SPACED MEASUREMENT LOCATIONS



AUTOMATED APPROACH 500 STRATEGICALLY SPACED MEASUREMENT LOCATIONS

COMPUTER PERFORMANCE RELATED TO PROBLEM SOLVING

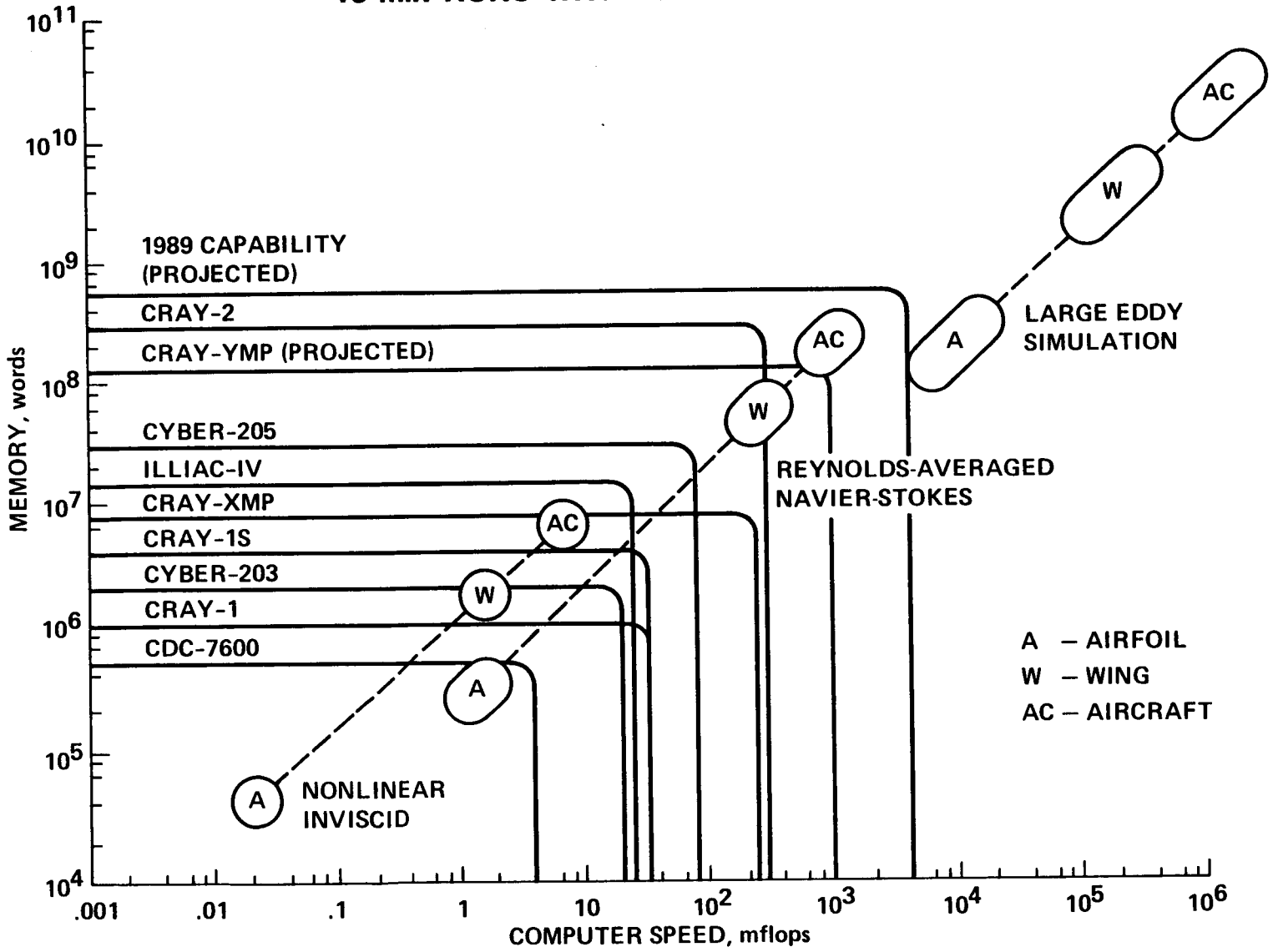
EXAMPLES OF COMPUTER TIME REQUIRED TO SOLVE VARIOUS PROBLEMS



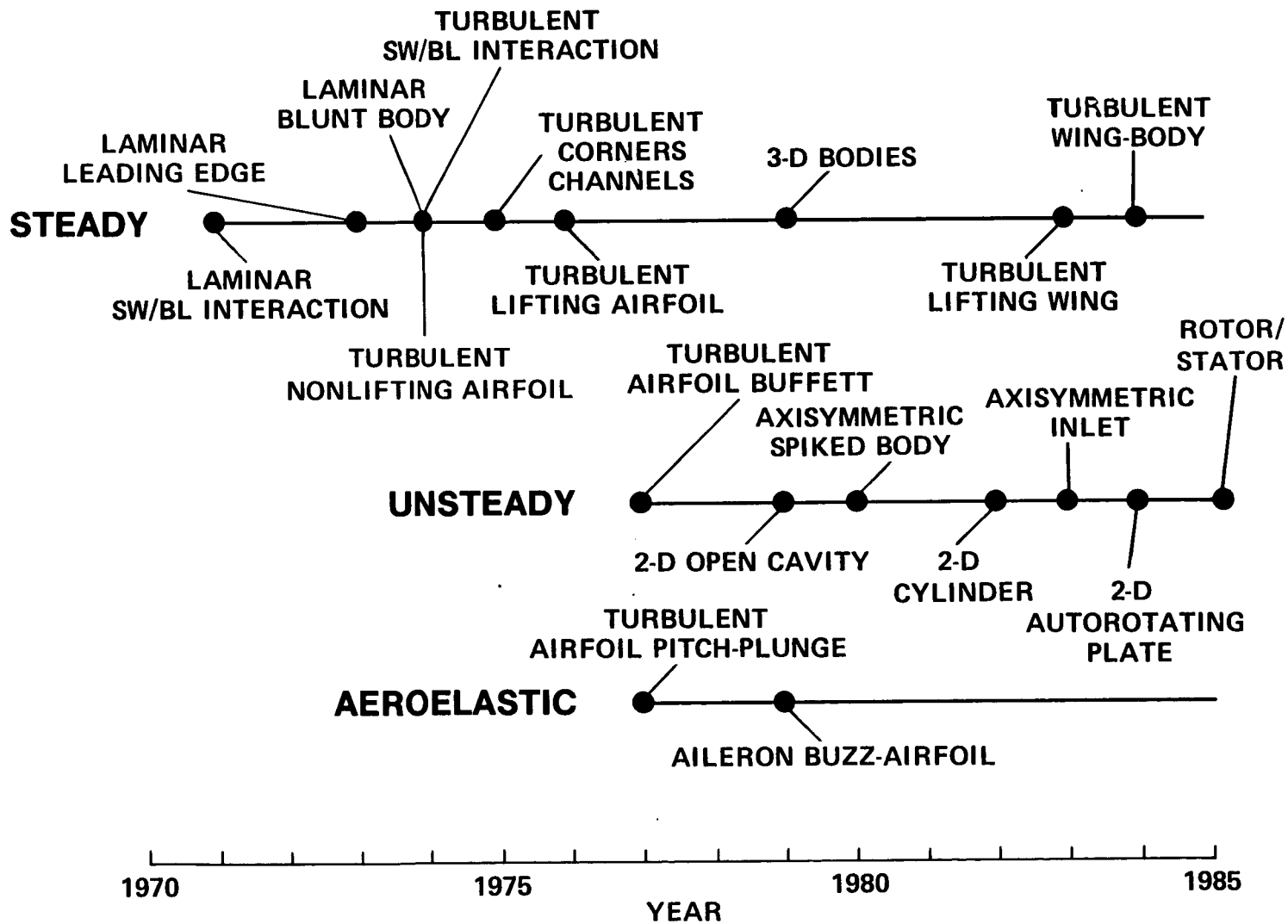
COMPUTER SPEED AND MEMORY REQUIREMENTS COMPARED WITH COMPUTER CAPABILITIES

STEADY FLOW — PERFECT GAS

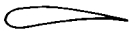
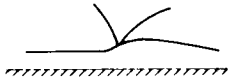
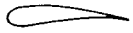
15-min RUNS WITH 1985 ALGORITHMS



MILESTONES IN THE DEVELOPMENT OF COMPUTATIONAL FLUID DYNAMICS FOR COMPRESSIBLE VISCOUS FLOWS



IMPACT OF INCREASING COMPUTER PERFORMANCE ON COMPUTATIONAL AERODYNAMICS

	IBM 360/67	CDC 7600	CRAY 1S/ CYBER 205	NAS
INVISCID LINEARIZED EQUATIONS	WING-BODY	COMPLETE CONFIGURATION	COMPLETE CONFIGURATION INCLUDING PROPULSION AND VORTEX EFFECTS	MATURE TECHNOLOGY
INVISCID NONLINEAR EQUATIONS	 AIRFOIL	WING-BODY	COMPLETE CONFIGURATION	COMPLETE CONFIGURATION OPTIMIZATION
VISCOUS N-S EQUATIONS	NONE	 FLAT PLATE	 AIRFOIL	COMPLETE CONFIGURATION

NAS, OTHER MAJOR COMPUTER FACILITIES AND SUPPORTING INSTITUTIONS

SUPERCOMPUTER RESOURCES PROVIDED BY NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

- NUMERICAL AERODYNAMIC SIMULATION (NAS) FACILITY (NATIONAL FACILITY LOCATED AT AMES RESEARCH CENTER)
  - 2 CRAY-2'S EACH WITH 268 MW OF MAIN MEMORY
  - EXPECT DELIVERY OF HSP-2 (4-TIMES CRAY-2 PERFORMANCE) IN 1988
- AMES RESEARCH CENTER
  - CRAY-XMP/48 WITH 128 MW SSD
  - CDC CYBER-205 WITH 4 PIPES AND 8 MW OF MAIN MEMORY
- LANGLEY RESEARCH CENTER
  - CDC VPS-32 WITH 2 PIPES AND 32 MW OF MAIN MEMORY
  - PROCUREMENT UNDERWAY FOR HIGHER PERFORMANCE SUPERCOMPUTER (3Q 1988 DELIVERY)
- LEWIS RESEARCH CENTER
  - CRAY-XMP/24 WITH 256 MW SSD

NAS PROGRAM OBJECTIVES

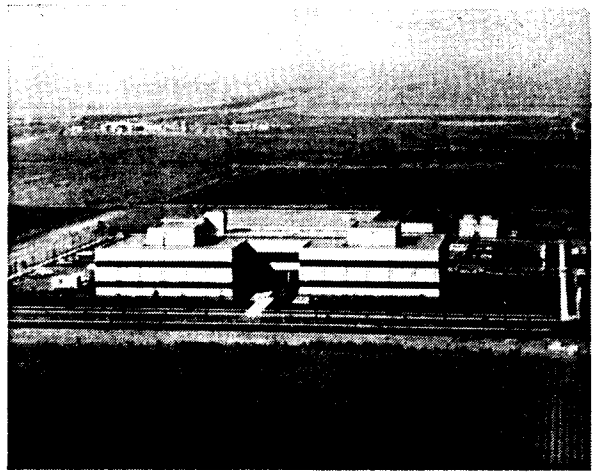
- PROVIDE A NATIONAL COMPUTATIONAL CAPABILITY AVAILABLE TO NASA, DoD, INDUSTRY, OTHER GOVERNMENT AGENCIES, AND UNIVERSITIES, AS A NECESSARY ELEMENT IN ENSURING CONTINUING LEADERSHIP IN COMPUTATIONAL FLUID DYNAMICS AND RELATED DISCIPLINES

- ACT AS A PATHFINDER IN ADVANCED, LARGE-SCALE COMPUTER SYSTEM CAPABILITY THROUGH SYSTEMATIC INCORPORATION OF STATE-OF-THE-ART IMPROVEMENTS IN COMPUTER HARDWARE AND SOFTWARE TECHNOLOGIES

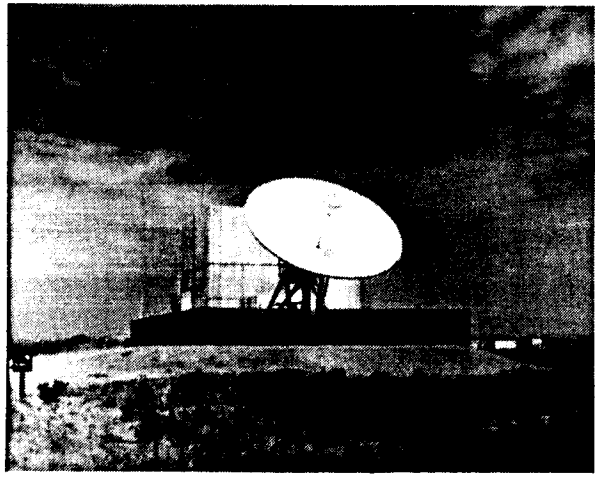
- PROVIDE A STRONG RESEARCH TOOL FOR THE NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

NUMERICAL AERODYNAMIC SIMULATION PROGRAM
(NAS)

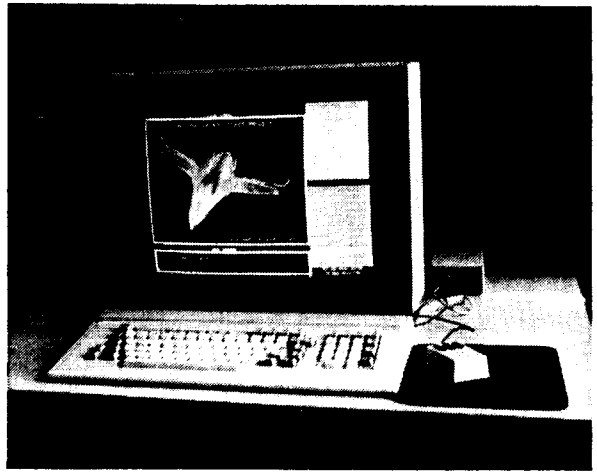
HIGH SPEED
PROCESSOR–ONE



NAS FACILITY



REMOTE COMMUNICATION
GATEWAY



WORKSTATION

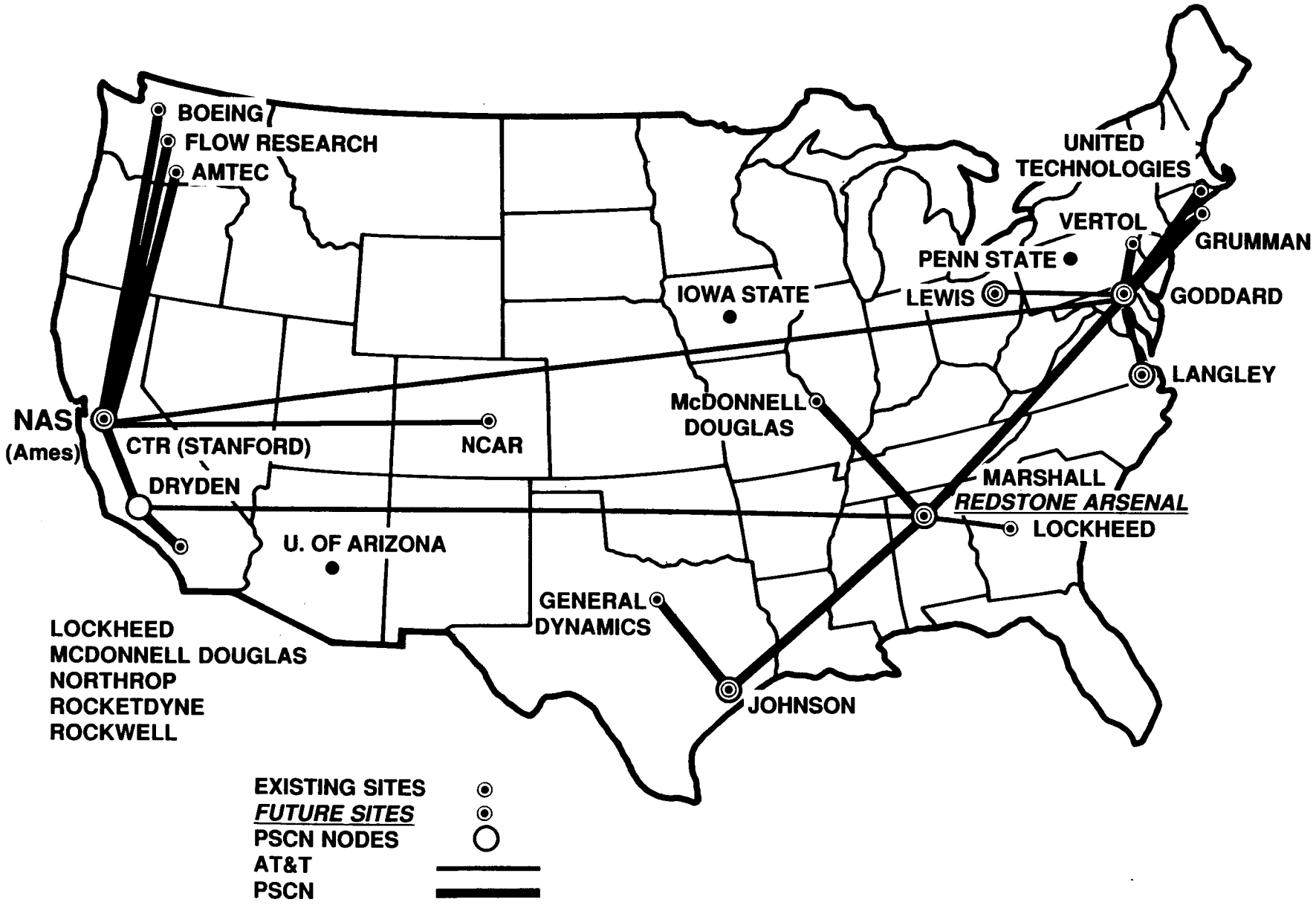
NAS PROGRAM DESCRIPTION

- NATIONAL SUPERCOMPUTING CENTER
  - 2 CRAY-2 SUPERCOMPUTERS, 6 SUPPORT COMPUTERS, 35 WORKSTATIONS
  - OPERATIONAL 24 HOURS/DAY AND 7 DAYS/WEEK
  - 672 USERS FROM 70 SITES ACROSS THE COUNTRY
- DEVELOPMENT CENTER FOR SUPERCOMPUTING TECHNOLOGIES
  - INTERACTIVE AND DISTRIBUTED OPERATING SYSTEMS
  - WORKSTATIONS
  - GRAPHICS
  - NETWORKING
  - REMOTE ACCESS
  - COMPUTER ARCHITECTURES
  - SOFTWARE TOOLS AND ENVIRONMENTS
  - SUPERCOMPUTING APPLICATIONS

NAS REMOTE ACCESS

- NAS PROVIDES ACCESS TO NASA, UNIVERSITIES, GOVERNMENT LABORATORIES AND THE AEROSPACE INDUSTRY VIA:
  - NASnet: DIRECT 1544 TO 9.600 KBIT/SEC TERRESTRIAL SERVICE TO 24 NASA, INDUSTRY, AND UNIVERSITY SITES (PSCN PROVIDED CIRCUITS)
  - NASA SCIENCE INTERNET: INTERCONNECTS NASA SCIENCE COMMUNITY
  - SPAN: INTERCONNECTS SPACE PHYSICS COMMUNITY (ACCESS VIA SEVERAL HOSTS AT ARC)
  - NSFnet: INTERCONNECTS NSF SUPERCOMPUTER CENTERS AND REGIONAL NETWORKS OF OVER 60 MAJOR UNIVERSITIES
  - BARRnet: NF REGIONAL NETWORK INTERCONNECTING NAS AND BAY AREA UNIVERSITIES
  - ARPAnet: INTERCONNECTS OVER 150 UNIVERSITIES, GOVERNMENT AND GOVERNMENT-FUNDED RESEARCH INSTITUTES
  - MILnet: INTERCONNECTS DoD LABS AND DoD CONTRACTORS
  - NPSS/Telenet: NATIONAWIDE TERMINAL ACCESS

NASnet USER SITES



NAS COMPUTER RESOURCE ALLOCATION GUIDELINES

- **DISCIPLINE USAGE**
  - AERONAUTICS/AEROSPACE – 90%
  - OTHER DISCIPLINES OF NASA INTEREST – 10%
- **ORGANIZATIONAL USAGE**
  - NASA (IN-HOUSE, GRANTS, CONTRACTS, JOINT EFFORTS) – 55%
  - DoD (IN-HOUSE, GRANTS, CONTRACTS, JOINT EFFORTS) – 20%
  - AEROSPACE INDUSTRY – 15%
  - OTHER GOVERNMENT AGENCIES – 5%
  - UNIVERSITIES – 5%
- **SCREENING CRITERIA**
  - TECHNICAL QUALITY
  - NATIONAL NEED
  - TIMELINESS

IOC PROJECTS AND USERS

	TOTAL NUMBER OF PROJECTS	TOTAL NUMBER OF USERS
NASA OAST CENTERS	107	409
– Ames	45	197
– Langley	52	194
– Lewis	10	18
OTHER NASA CENTERS	8	22
COMMERCIAL	21	71
DoD	30	92
UNIVERSITY	35	51
OTHER GOVERNMENT	2	3
TOTAL	203	648

PLANNED CAPABILITIES FOR THE NAS SYSTEM

- SECOND HALF 1988
  - UPGRADE ONE CRAY-2 SYSTEM TO 4 TIMES CRAY-2 PERFORMANCE (HSP-2)
- 1990?
  - INSTALL HSP-3 WITH 16 TIMES PERFORMANCE OF CRAY-2
  - KEEP HSP-2
  - REMOVE HSP-1
- CONTINUE TO UPGRADE SUPPORT PROCESSORS, MASS STORAGE, NETWORK BANDWIDTHS, AND WORKSTATION PERFORMANCE TO MAINTAIN SYSTEM BALANCE

PATHFINDING ACCOMPLISHMENTS

- FIRST UNIX BASED SUPERCOMPUTING ENVIRONMENT
- FIRST VENDOR-INDEPENDENT SUPERCOMPUTER-SYSTEM OPEN ARCHITECTURE
- NASNET, A NATIONWIDE LOCAL AREA NETWORK
- ADVANCED TECHNOLOGY INITIATIVES IN:
  - HIGH-PERFORMANCE DISTRIBUTED GRAPHICS PROCESSING
  - SCIENTIST'S "WORKBENCH"
  - ADVANCED ALGORITHMS AND ARCHITECTURES
  - PARALLEL COMPUTING

SUPPORTING INSTITUTES

- AMES RESEARCH CENTER
  - RESEARCH INSTITUTE FOR ADVANCED COMPUTER SCIENCE (RIACS)
    - — EMPHASIS ON COMPUTER SCIENCE RESEARCH RELATED TO LARGE-SCALE SCIENTIFIC COMPUTING, NETWORKING, TELESCIENCE AND AUTONOMOUS SYSTEMS
  - CENTER FOR TURBULENCE RESEARCH (CTR)
    - — EMPHASIS ON ADVANCING THE PHYSICAL UNDERSTANDING OF TURBULENCE LEADING TO IMPROVED CAPABILITIES FOR CONTROL OF TURBULENCE AND TURBULENCE MODELING
- LANGLEY RESEARCH CENTER
  - INSTITUTE FOR COMPUTER APPLICATIONS IN SCIENCE AND ENGINEERING (ICASE)
    - — EMPHASIS ON BASIC RESEARCH IN THE COMPUTATIONAL SCIENCES
- LEWIS RESEARCH CENTER
  - INSTITUTE FOR COMPUTATIONAL MECHANICS IN PROPULSION (ICOMP)
    - — EMPHASIS ON RESEARCH DIRECTED TOWARD IMPROVING COMPUTATIONAL CAPABILITIES IN FLUID MECHANICS AND STRUCTURES AS RELATED TO AEROSPACE PROPULSION

DEFENSE ORGANIZATIONS DIRECTLY INVOLVED WITH NASA'S COMPUTATIONAL FLUID DYNAMICS PROGRAM

- U.S. AIR FORCE
  - ARMAMENT LABORATORY
  - ARNOLD ENGINEERING CENTER
  - FLIGHT DYNAMICS LABORATORY
  - OFFICE OF SCIENTIFIC RESEARCH
  - PROPULSION LABORATORY
  - WEAPONS LABORATORY
- U.S. ARMY
  - AVIATION RESEARCH AND TECHNOLOGY ACTIVITY
    - — AEROFLIGHTDYNAMICS DIRECTORATE
    - — AEROSTRUCTURES DIRECTORATE
    - — APPLIED TECHNOLOGY DIRECTORATE
    - — PROPULSION DIRECTORATE
  - BALLISTIC RESEARCH LABORATORY
  - MISSILE COMMAND
  - RESEARCH OFFICE
  - STRATEGIC DEFENSE COMMAND

DEFENSE ORGANIZATIONS DIRECTLY INVOLVED WITH NASA'S COMPUTATIONAL FLUID DYNAMICS PROGRAM

(CONCLUDED)

- U.S. NAVY
  - AIR SYSTEMS COMMAND
  - AIR TURBINE TEST STATION
  - DAVID TAYLOR NAVAL SHIP R&D CENTER
  - ENGINEERING LOGISTICS OFFICE
  - OFFICE OF NAVAL RESEARCH
  - POST GRADUATE SCHOOL
  - RESEARCH LABORATORY
  - SEA SYSTEMS COMMAND
  - SURFACE WEAPONS CENTER
  - UNDERWATER SYSTEMS CENTER
  - WEAPONS CENTER
- DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)
- SPACE DEFENSE INITIATIVE ORGANIZATION (SDIO)
- DEFENSE NUCLEAR AGENCY

PRINCIPAL CURRENT LIMITATIONS AND FUTURE DIRECTIONS

PRINCIPAL CURRENT LIMITATIONS

PHYSICAL MODELING

- BOUNDARY LAYER TRANSITION MODELS
- TURBULENCE MODELS FOR SEPARATING AND REATTACHING FLOWS AND FOR REAL-GAS FLOWS
- REAL-GAS VALIDATION DATA

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

RESOURCES

AERONAUTICS RESOURCES APPLIED TO COMPUTATIONAL METHODS AND EXPERIMENTAL VALIDATION

FY 1987

ACTIVITY	CIVIL SERVANT WORKYEARS	GRANTS/CONTRACTS $K
FUNDAMENTAL DEVELOPMENTS	87	1,627
PHYSICAL MODELING	40	1,362
TURBULENCE SIMULATION	14	802
APPLICATIONS	133	3,137
EXPERIMENTAL VALIDATION	60	2,056
TOTALS	334	8,984

DOES NOT INCLUDE COST OF COMPUTER AND TEST FACILITIES AND THEIR OPERATION

SUMMARY AND SPECIAL ISSUES

SUMMARY

- DEVELOPMENT OF AEROSPACE TECHNOLOGY IS IMPORTANT TO THE COUNTRY'S ECONOMIC AND MILITARY POSTURE
- COMPUTATIONAL FLUID DYNAMICS IS A NECESSARY ELEMENT OF NASA'S CHARTER TO DEVELOP AEROSPACE TECHNOLOGY
- NASA IS MAKING A CONSIDERABLE INVESTMENT IN THE DEVELOPMENT AND APPLICATION OF COMPUTATIONAL FLUID DYNAMICS
- NASA'S COMPUTATIONAL FLUID DYNAMICS PROGRAM IS SUPPORTING BOTH CIVILIAN AND MILITARY NEAR AND FAR-TERM NEEDS

SPECIAL ISSUES

- INCREASED NEED FOR CLASSIFIED PROCESSING LEADING TO SPECIAL OPERATING SYSTEMS, COMMUNICATIONS LINKS AND FACILITIES
- NEW ALGORITHMS AND PROGRAMMING TOOLS TO EXPLOIT MULTIPLE-PROCESSOR COMPUTER ARCHITECTURES
- INCREASING COMPETITIVENESS OF JAPANESE SUPERCOMPUTERS