IMPACT OF PARALLEL COMPUTING ON LARGE SCALE AEROELASTIC COMPUTATIONS

PRESENTED BY

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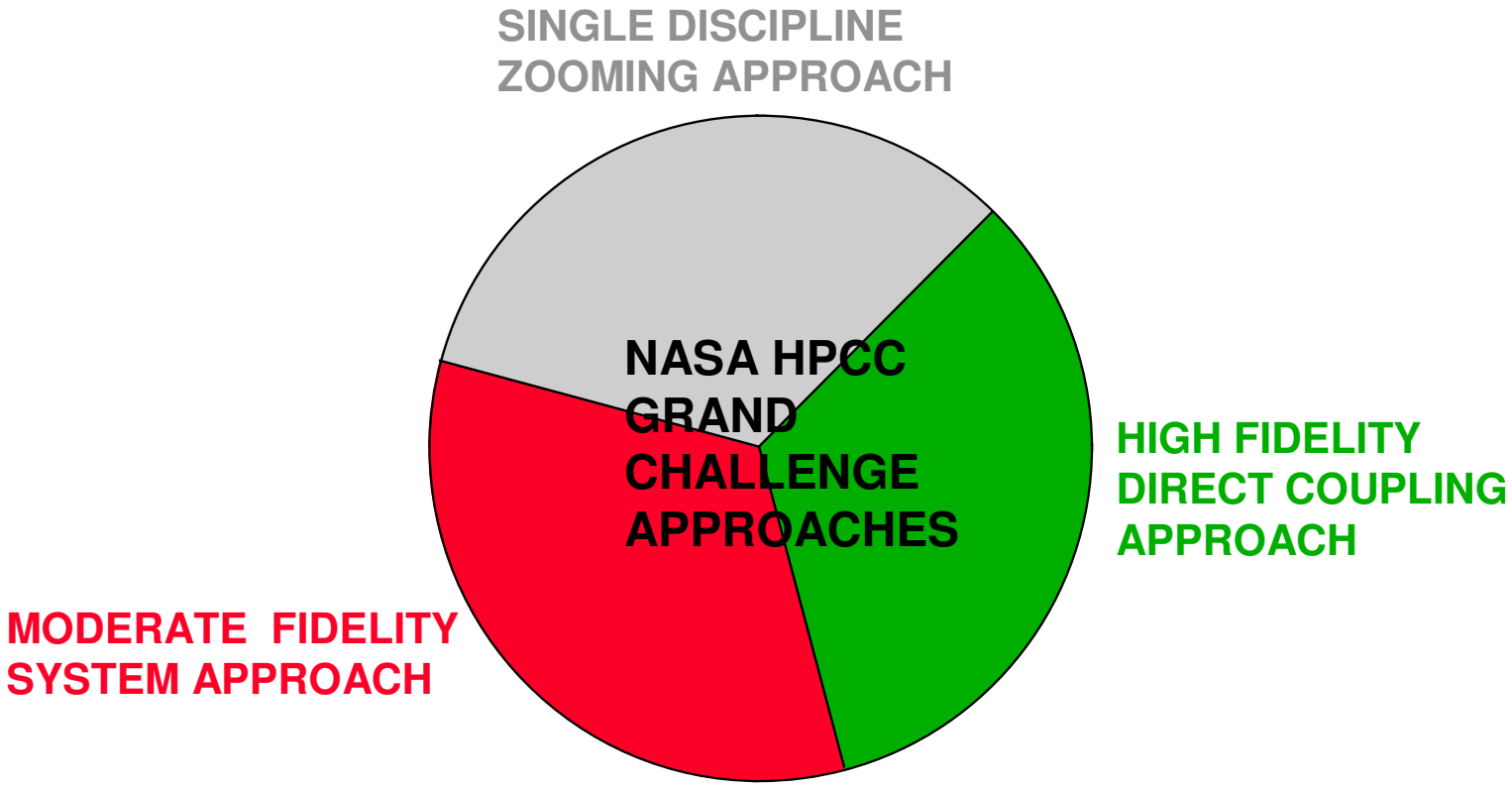
OBJECTIVE

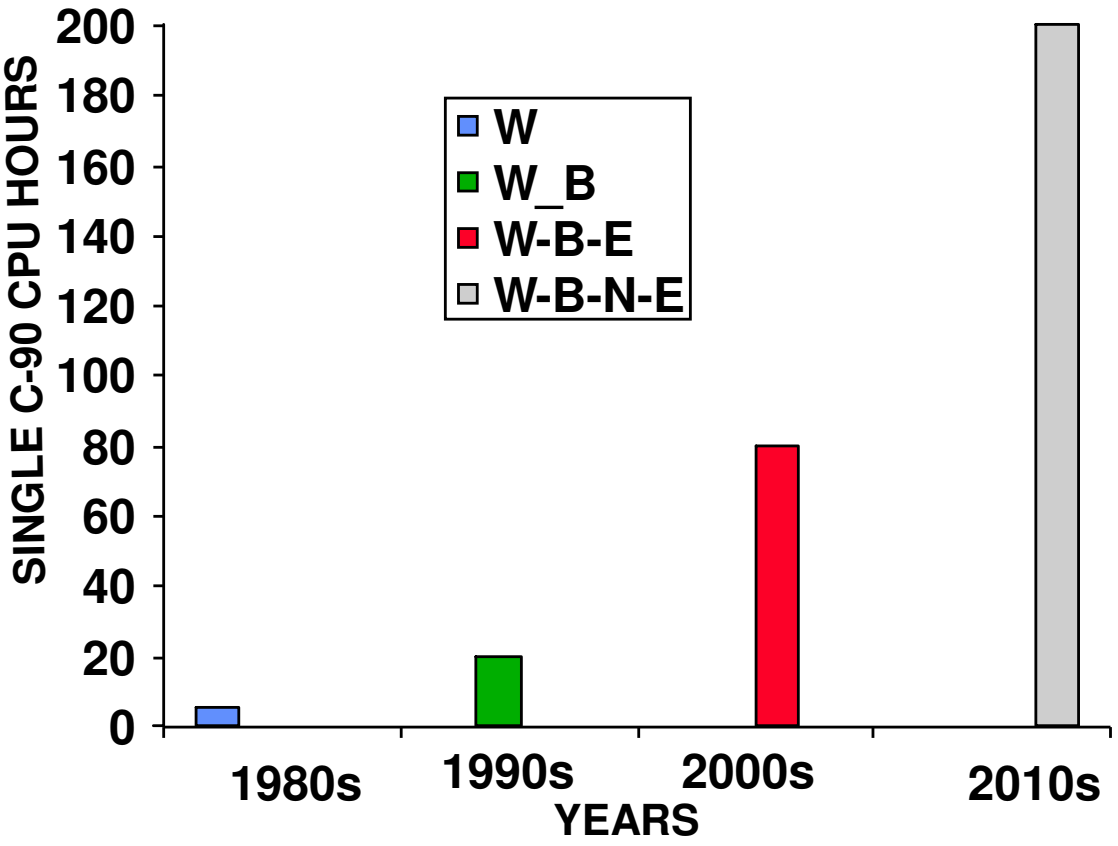
SUMMARIZE THE IMPACT OF NASA HPCCP SUPPORTED PARALLEL COMPUTERS ON THE DEVELOPMENT FULLY COUPLED AEROELASTIC ANALYSIS PROCESS THAT USES HIGH FIDELITY EQUATIONS



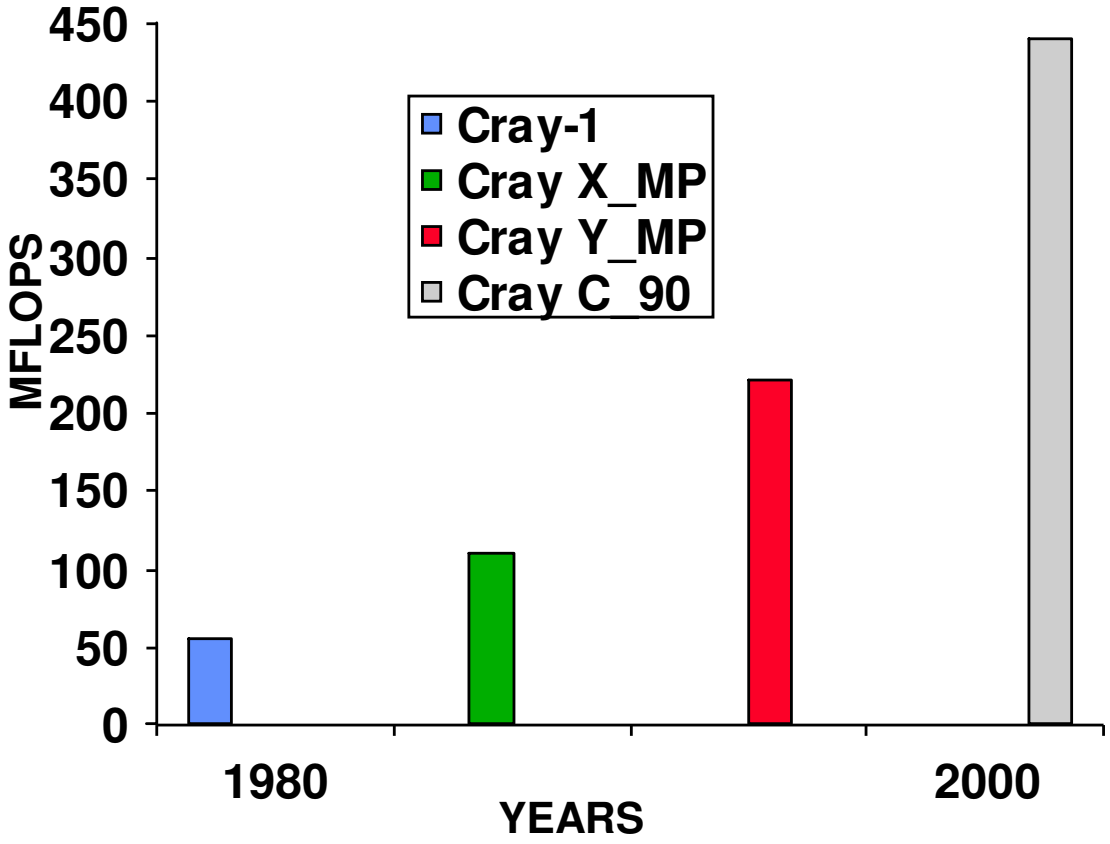
BACKGROUND

- MAIN FRAME TYPE SUPERCOMPUTERS SUCH AS CRAY C-90 ARE BECOMING EXTINCT
  - PROCESSOR SPEED HAS ALMOST REACHED SATURATION
  - LACK OF MASS MARKET
  - ADVANCES IN WORKSTATION TECHNOLOGY
  - COST OF PROCUREMENT AND MAINTAINENCE
- CONTINIOUS INCREASE IN NEED FOR SUPERCOMPUTING RESOURCES BY US AEROSPACE INDUSTRY
- MAINTAIN US LEADERSHIP IN SUPERCOMPUTING
- SUPERCOMPUTING USING MASSIVELY PARALLEL PROCESSORS (MPP) IS BECOMING A REALITY
  - SCALABLE PROCESSOR SPEED
  - BUILT OUT OF COMMODITY TYPE WORKSTATIONS
  - MANY VENDORS (IBM, SGI, SUN, HP Etc.)

GROWTH IN NEED CPU HOURS FOR AEROELASTICITY

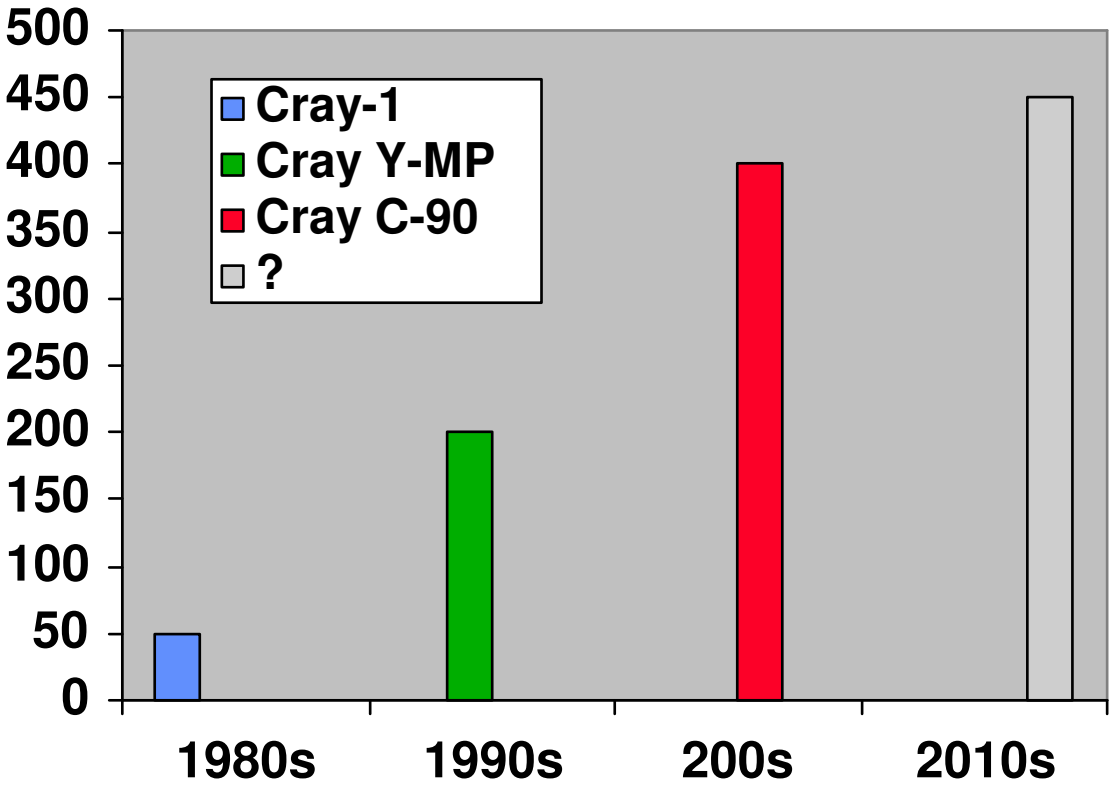


NOTE : TO SIMULATE ABOUT 5 SEC DYNAMIC RESPONSE



NOTE : PRACTICAL MFLOP BASED ON ENSAERO COMPUTATIONS ON SINGLE CPU

GROWTH OF MAIN FRAME SUPERCOMPUTERS



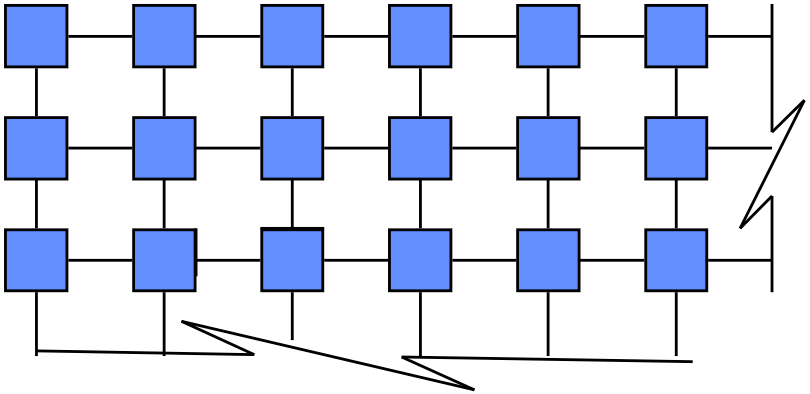
NOTE : PRACTICAL MFLOP ON SINGLE CPU BASED ON NAVIER-STOKES BASEDFLUIDS/STRUCTURES CODE

NASA HPCCP TESTBED 1

- **IN 1991 NASA HPCCP INSTALLED 128 NODE INTEL iPSC/860**

  - MULTIPLE INSTRUCTION AND MULTIPLE DATA (MIMD) ARCHITECTURE
  - 40 MHz RISC CHIP, 8 MB MEMORY PER NODE
  - 60 MFLOP , 64-BIT FLOATING POINT PERFORMANCE

- **USED INTEL'S OPERATING SYSTEM NX DEPENDENT MESSAGE PASSING PROTOCOL**



INTEL's
860 PROCESSOR
40 MHz, 8MB

DEVELOPMENT AND APPLICATIONS OF ENSAERO ON TESTBED-1

- PIPE LINE GAUSS ELIMINATION PARALLEL FLOW SOLVER BASED ON SERIAL EULER/NAVIER STOKES(ENS) SOLVER ARC3D (WEERATUNGA)

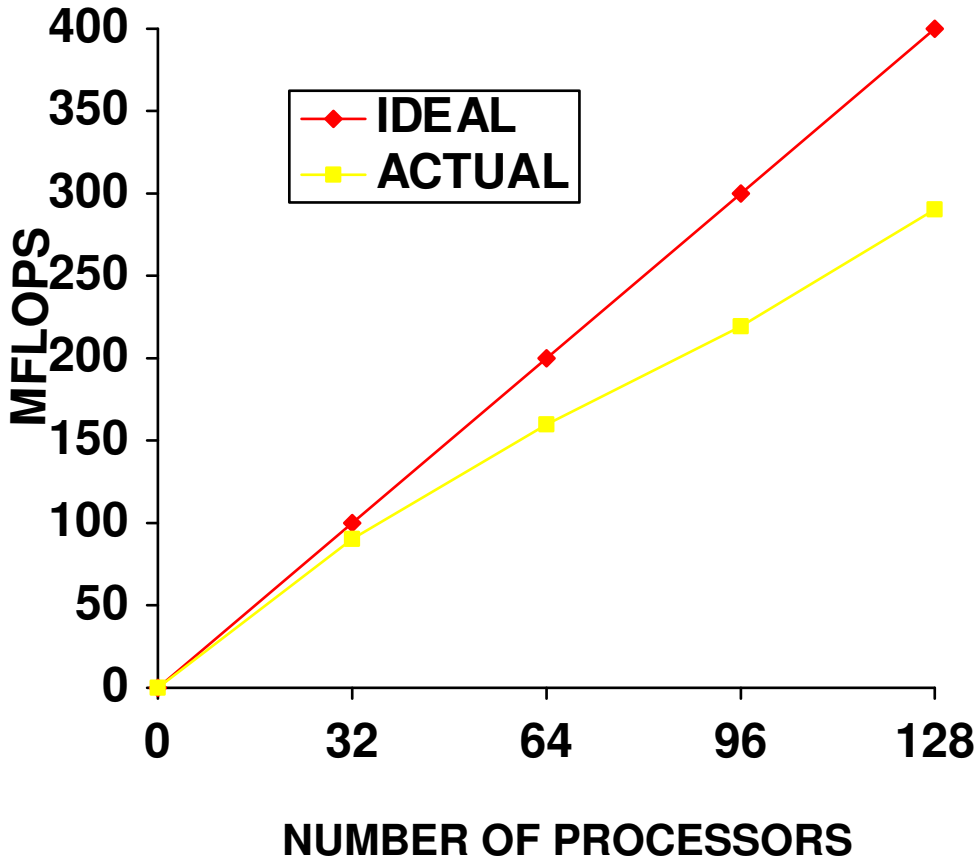
- A COMMUNICATION PROTOCOL TO SEND DATA AMONG GROUP OF PROCESSORS BASED ON NX MESSAGE PASSING (BARSZCZ)

- FIRST EVER PARALLEL AEROELASTIC ANALYSIS PROCESS ENSAERO_MODAL BASED ON ENS EQUATIONS (GURUSWAMY, PROMONO AND WEERATUNGA)

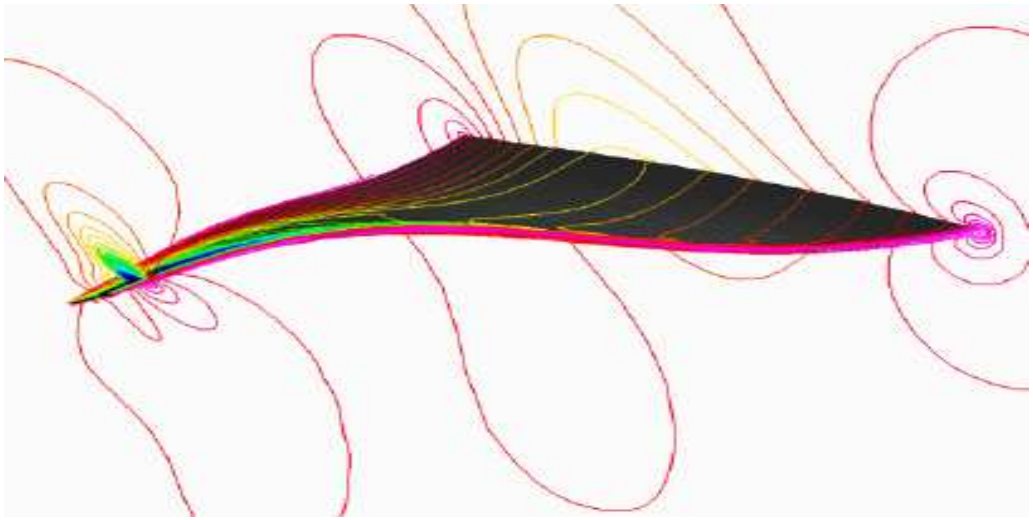
- ENSAERO_FE (FINITE ELEMENTS) FROM ENSAERO_MODAL (BYUN AND GURUSWAMY)

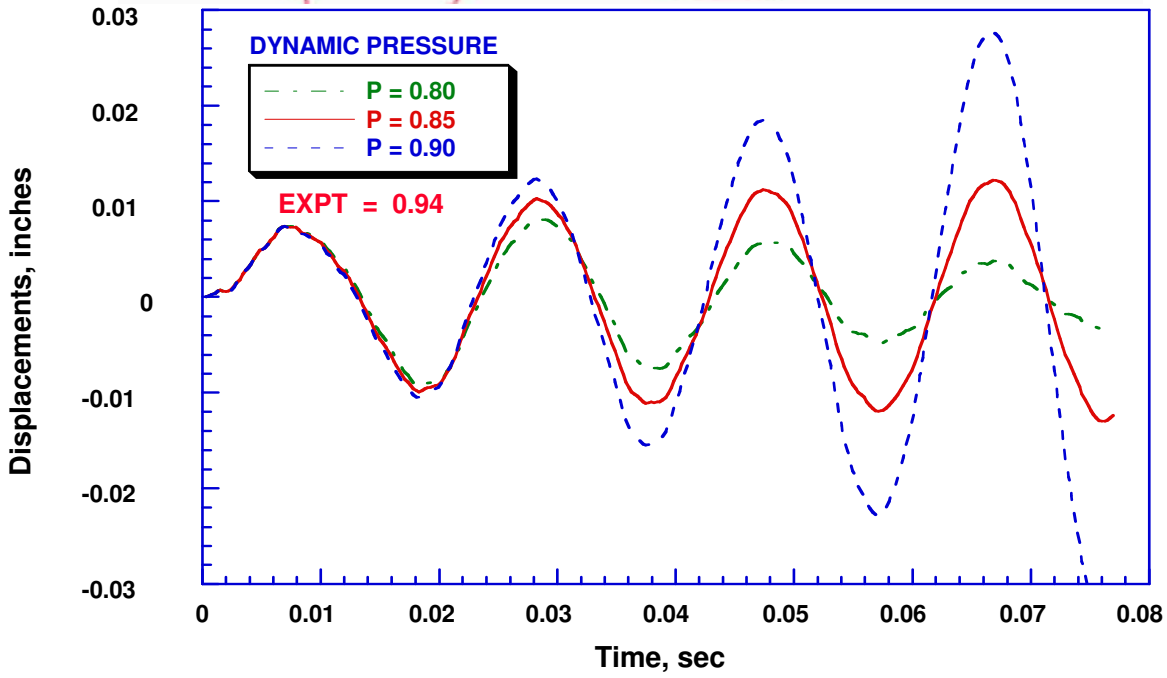
- DEMONSTRATION OF AEROELASTIC RESULTS FOR WING AND WINGBODY CONFIGURATIONS USING EULER FLOW EQUATIONS

PERFORMANCE OF ARC3D ON iPSC/860

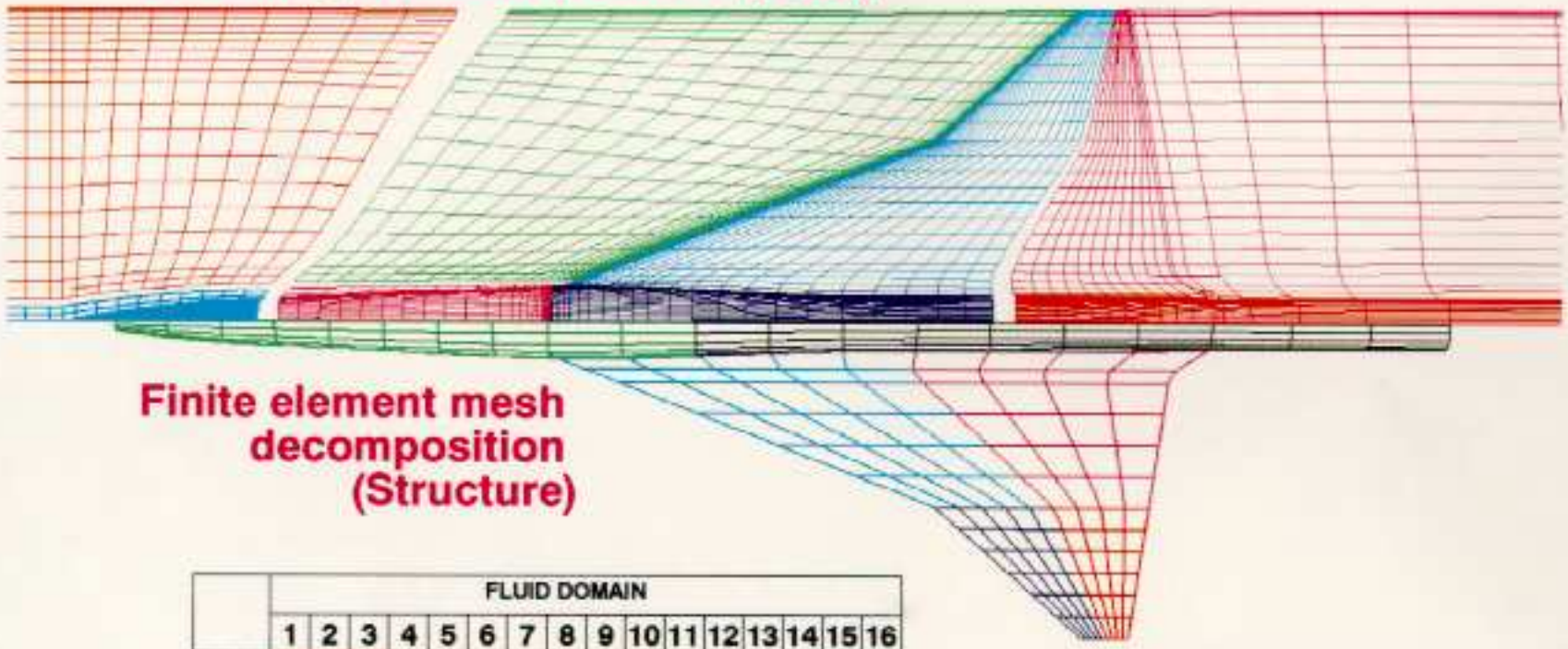


FLUTTER BOUNDARY USING ENSAERO-MODAL ON INTEL iPSC/860
M = 0.85, ALTITUDE = 30K FEET, EULER EQUATIONS





An Intercube Communication Between Fluid and Structural Domains



STRUCTURAL DOMAIN \ FLUID DOMAIN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	■	■	■													
2			■	■												
3	■	■	■			■	■			■	■		■	■	■	
4			■	■			■	■		■	■				■	■
5		■	■			■	■			■	■			■	■	
6			■	■			■	■			■	■			■	■
7						■	■			■	■					
8							■	■			■	■				

■ active communication

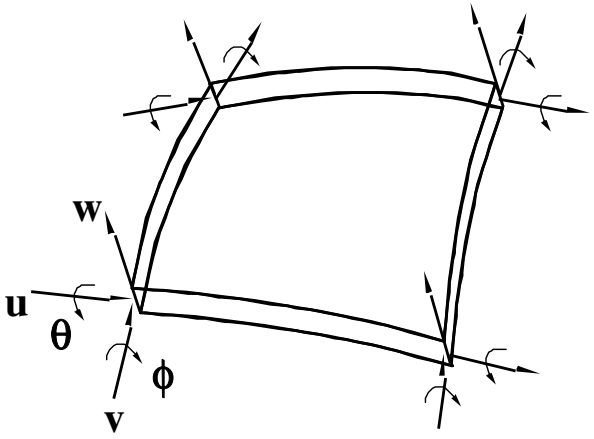
□ no communication

1 – 16 : processor numbers

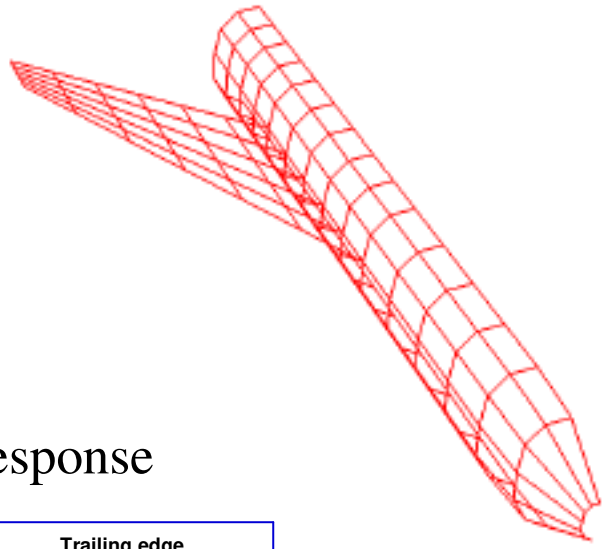
COMPUTATIONS ON WING-BODY CONFIGURATION

COUPLED NAVIER-STOKES FLUIDS/ SHELL FINITE ELEMENT STRUCTURES

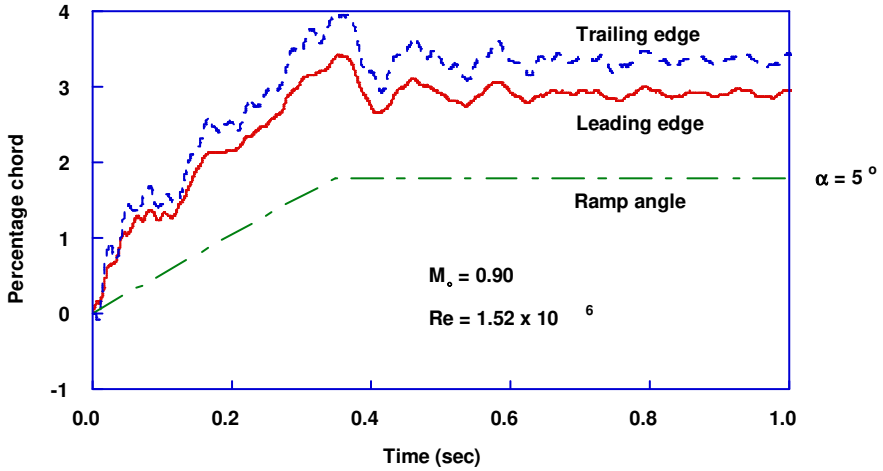
20 DOF Plate/Shell Element



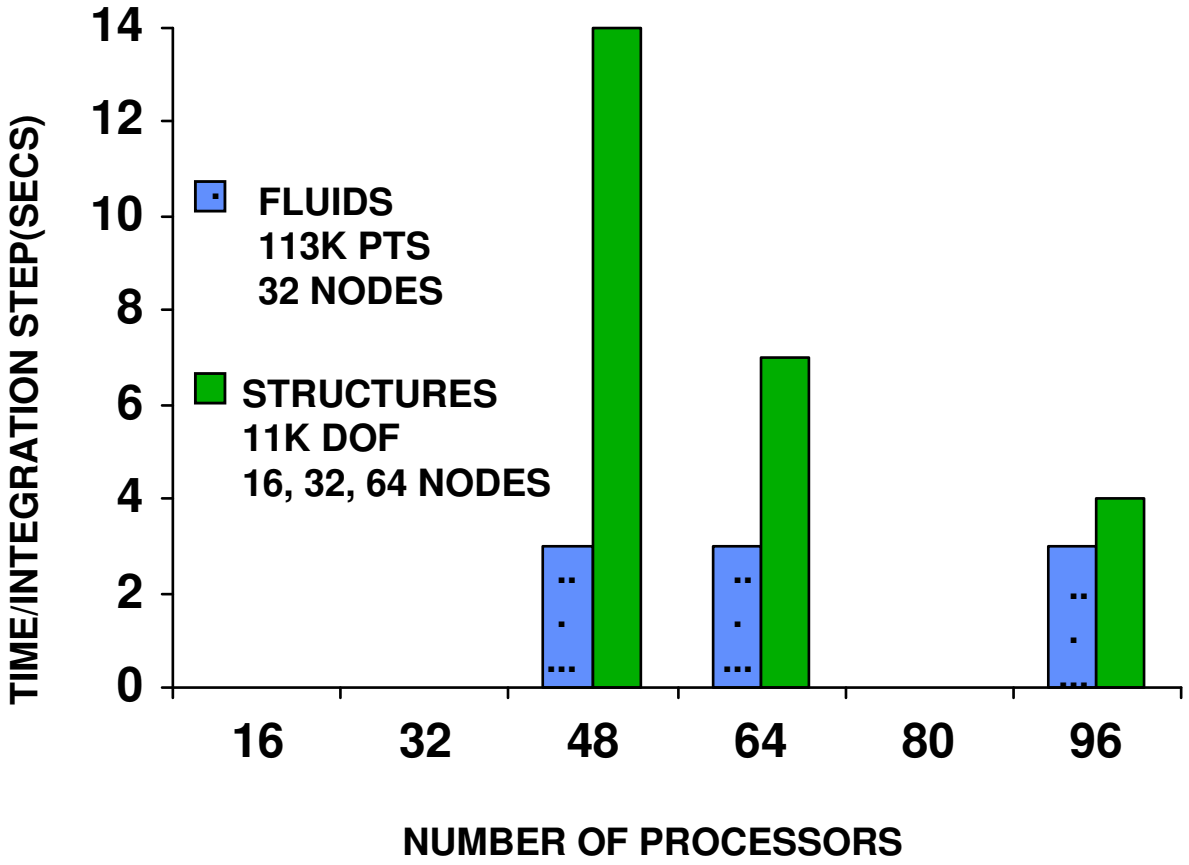
646 DOF Wing-Body FE Model



Aeroelastic Response



PERFORMANCE OF ENSAERO ON iPSC/860



LESSONS LEARNED DURING TESTBED-1

- FOR HIGH FIDELITY BASED MULTIDISCIPLINE COMPUTATIONS MULTI INSTRUCTION MULTI DATA (MIMD) ARCHITECTURES ARE MORE SUITABLE THAN SINGLE INSTRUCTION MULTI DATA (SIMD) ARCHITECTURES

- TIGHLTLY KNITTED MULTIPLE PROCESSOR PARALLEL (MPP) ARE MORE RELIABLE AND COST EFFECTIVE THAN CLUSTER OF WORKSTATIONS

- COMPUTER POWER OF 128 NODE iPSC/860 IS NOT ADEQUATE FOR PRACTICAL AEROSPACE APPLICATIONS (1 GFLOP, LIMITED MEMORY)

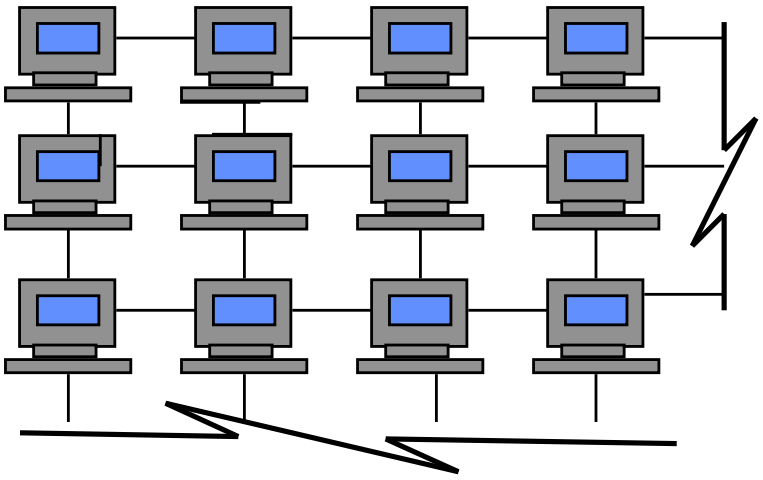
- VENDOR INDEPENDENT MESSAGE PASSING PROTOCOL IS NEEDED
  - PARALLEL VIRTUAL MACHINE (PVM) APPEARED AS A POSSIBLE SOLUTION

NASA HPCCP TESTBED 2

- IN 1993 NASA HPCCP INSTALLED 160 NODE IBM SP2

  - MULTIPLE INSTRUCTION AND MULTIPLE DATA (MIMD) ARCHITECTURE
  - 66.7 MHz R6000 RISC CHIP, 128 MB MEMORY PER NODE
  - 250 MFLOP , 64-BIT FLOATING POINT PERFORMANCE

- BUILT OUT OF MASS COMMODITY TYPE WORKSTATION
- IBM's OS DEPENDENT MESSAGE PASSING PROTOCOL, MPL

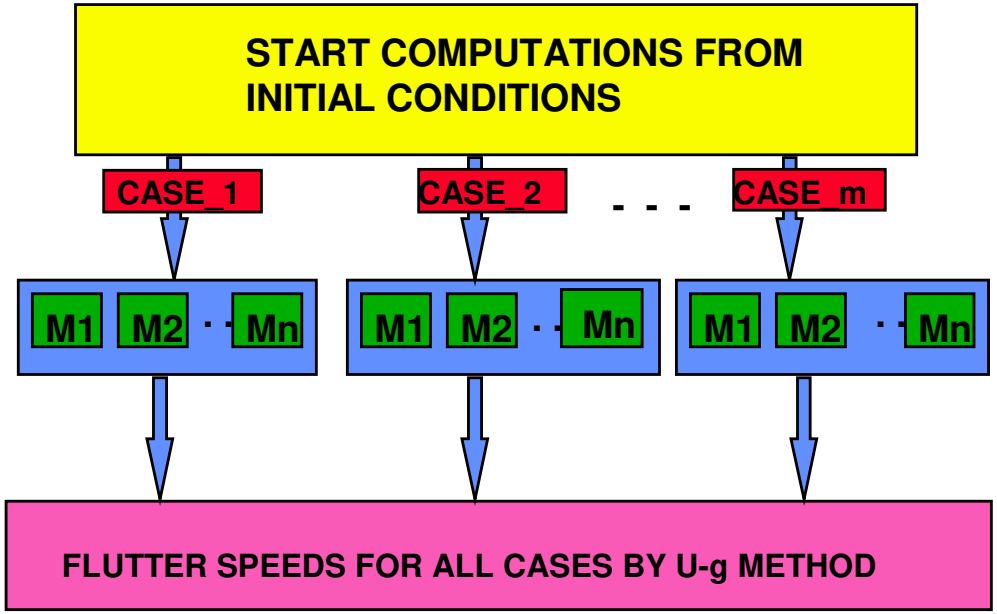


IBM 590 WORK STATION
66.7 MHz, 128MB

DEVELOPMENT AND APPLICATIONS ON TESTBED-2

- SINGLE NODE VERSION OF ENSAERO ON IBM SP2 (40 MFLOPS/ NODE)
- IEEE STANDARD MESSAGE PASSING INTERFACE (MPI) IN ENSAERO
- A LOADER FOR MULTIDISCIPLINARY APPLICATIONS MPIRUN BASED ON MPI and C++ (FINBERG & BYUN)
- MIDDLEWARE ENSAERO_MPI, AN EARLIER VERSION OF 3-LEVEL COARSE GRAIN PARALLEL, SUPER MODULAR, PORTABLE MULTIDISCIPLINARY ANALYSIS PROCESS HiMAP (BYUN & GURUSWAMY)
- IMPLEMENTATION OF FINE GRAIN PARALLEL CAPABILITY (HATAY)
- A PARALLEL INTERFACE TO NASTRAN (ELDRED AND GURUSWAMY)
- APPLICATIONS TO AEROELASTICITY OF WING-BODY-CONTROL-ENGINE CONFIGURATIONS USING NS EQUATIONS (FARHANGNIA AND BYUN)
- UNCOUPLED AND COUPLED AEROELASTIC COMPUTATIONS AT 7 AND 4 GFLOPS, RESPECTIVELY

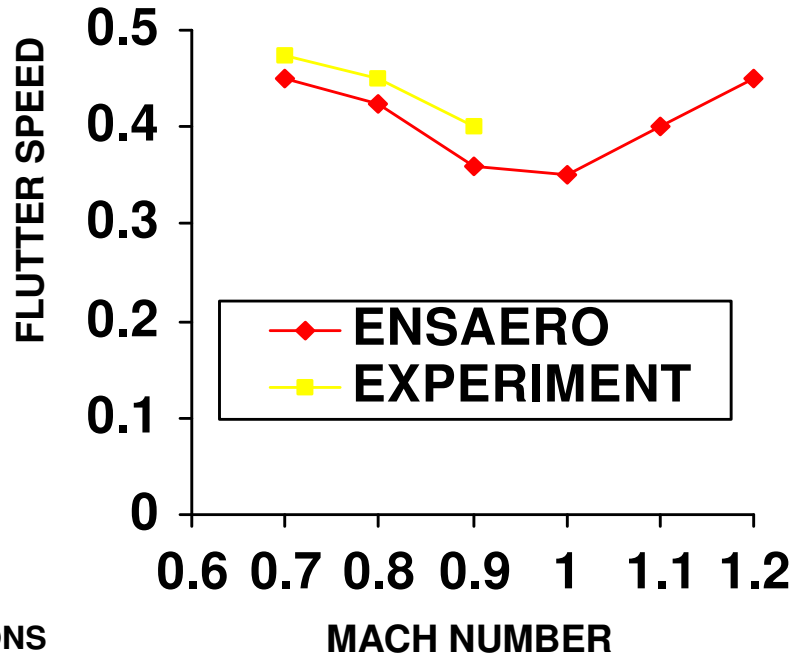
PARALLEL MODAL APPROACH FOR AEROELASTICITY



Mn N MODES = NUMBER OF MODES X
NUMBER OF FREQUENCIES SELECTED

CASE_m EACH CASE MAY HAVE DIFFERENT FLOW CONDITIONS

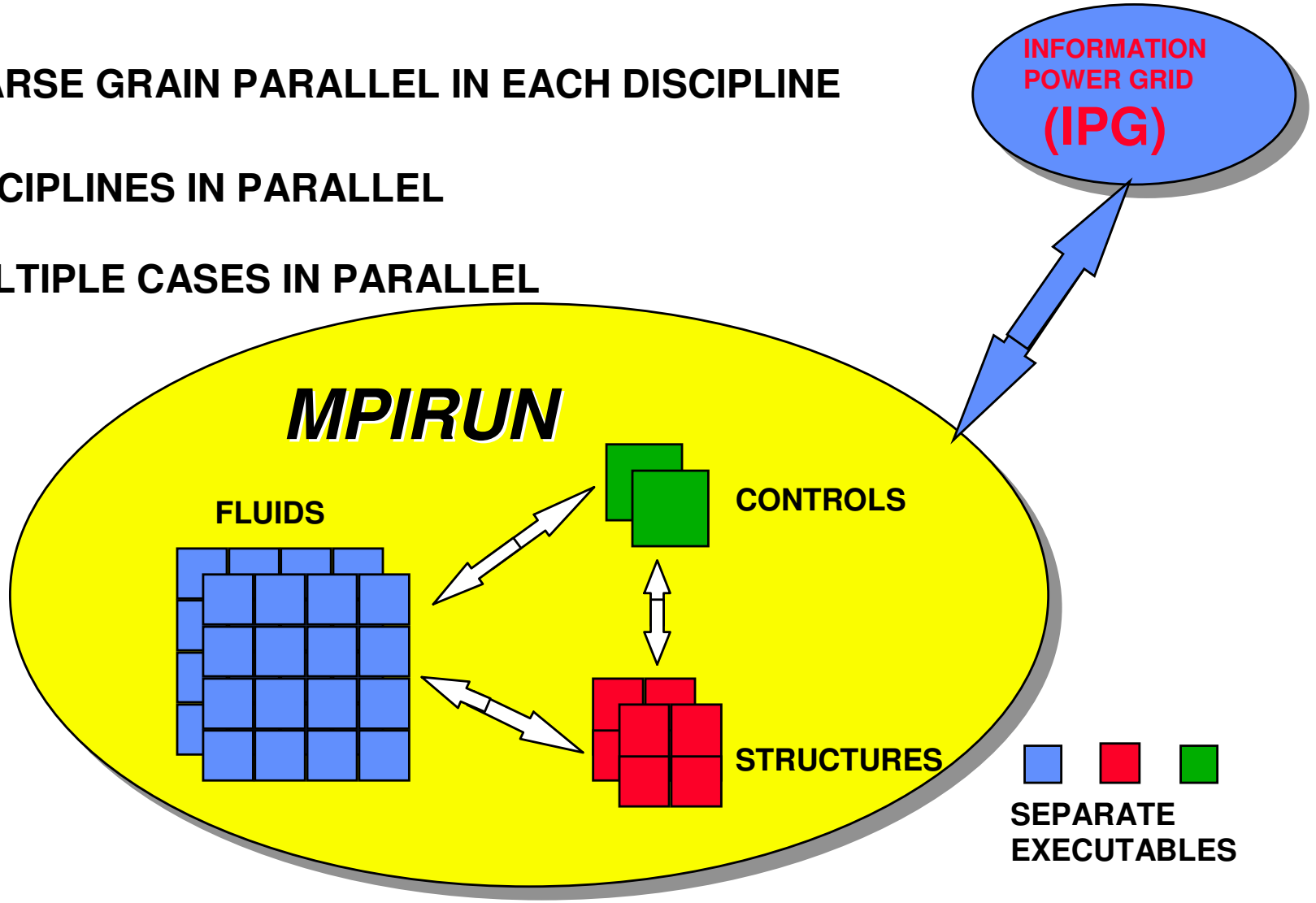
FLUTTER BOUNDARY
OF A TYPICAL WING



NOTE : 7 GFLOP PERFORMANCE ON 160 NODES

THREE LEVEL PARALLEL PROCESS HiMAP USING MPIRUN

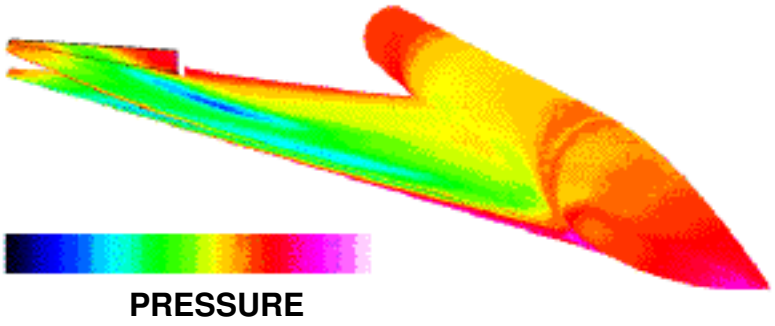
- COARSE GRAIN PARALLEL IN EACH DISCIPLINE
- DISCIPLINES IN PARALLEL
- MULTIPLE CASES IN PARALLEL

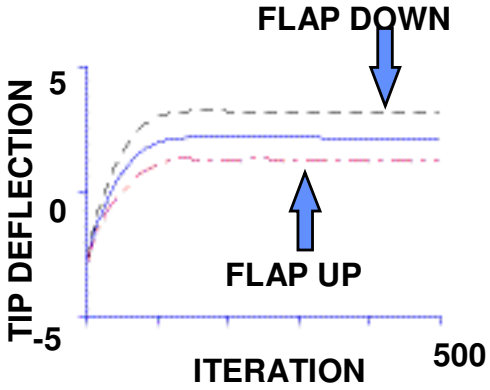


DEMONSTRATION OF HiMAP FOR WING-BODY-CONTROL AEROELASTICITY ON IBM SP2

PROCESSORS

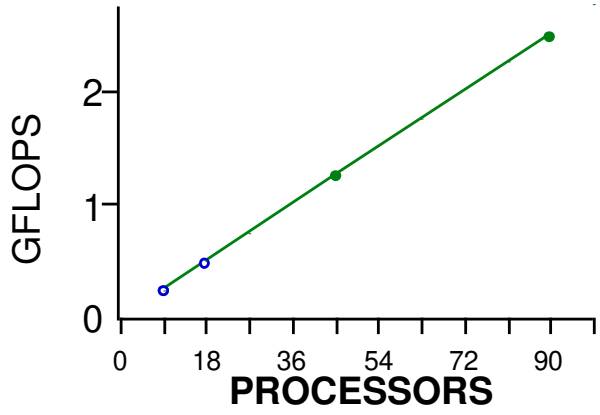
- **FLUID - 8**
- **STRUCTURES -1**
- **CONTROLS -1**





STATIC AEROELASTIC COMPUTATIONS ON HSCT WING-BODY-EMPENNAGE MODEL ON IBM SP2 USING HiMAP

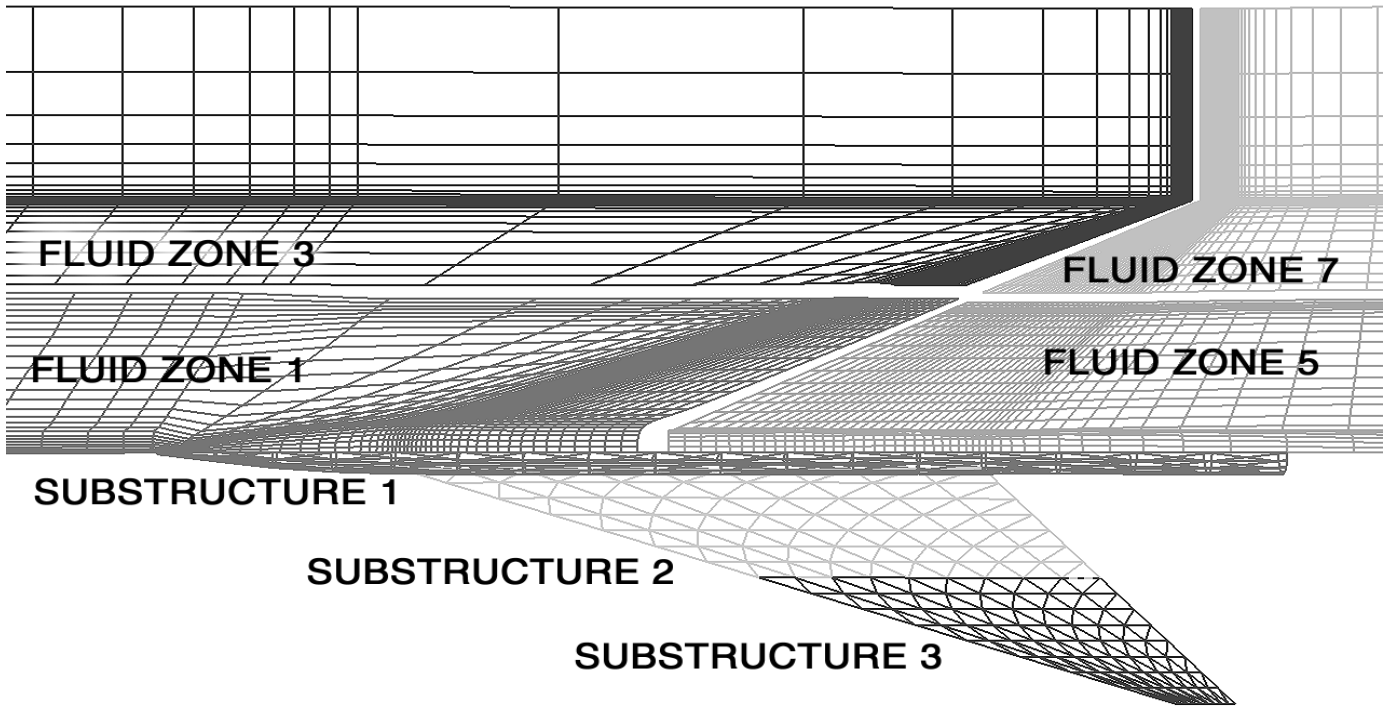
FLUIDS : 1.2M PTS, 8 PROCESSORS
STRUCTURES : 120MODES, 1 PROCESSOR



NOTE : 4 GFLOP PERFORMANCE ON 160 NODE SP2

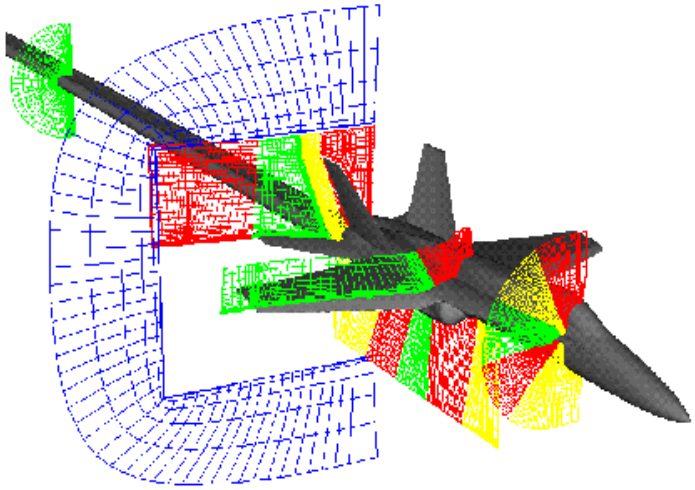
CFD COUPLED WITH NASTRAN BASED PARALLEL STRUCTURES SOLVER

- CREATE SUB-STRUCTURE DATA BASE USING NASTRAN
- SOLVE SUB-STRUCTURES IN PARALLEL USING HiMAP_FE AND COUPLE WITH ENSAERO USING MPIRUN



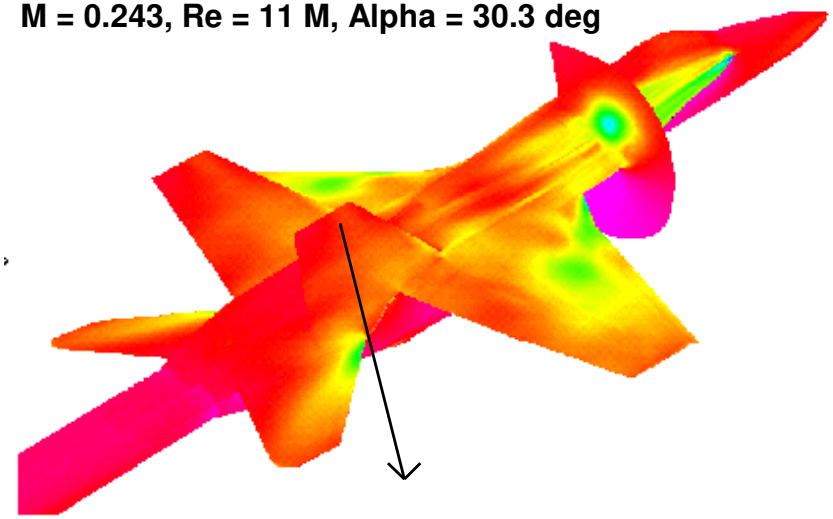
VERTICAL TAIL AEROELASTIC RESPONSES OF F-18

1.8M, 18 BLOCK GRID

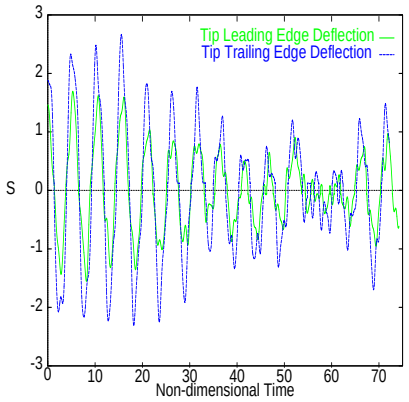


SURFACE PRESSURES

M = 0.243, Re = 11 M, Alpha = 30.3 deg



COMPUTATIONS ON SP2 BY FINDLAY & FARHANGNIA



LESSONS LEARNT DURING TESTBED-2

- MPP TYPE PARALLEL SUPERCOMPUTERS ARE MORE RELIABLE AND COST EFFECTIVE THAN WORKSTATION CLUSTERS

- COMPUTATION ON PARALLEL COMPUTER USING HOMOGENEOUS NODES IS MORE REALISTIC THAN HETROGENEOUS NODES

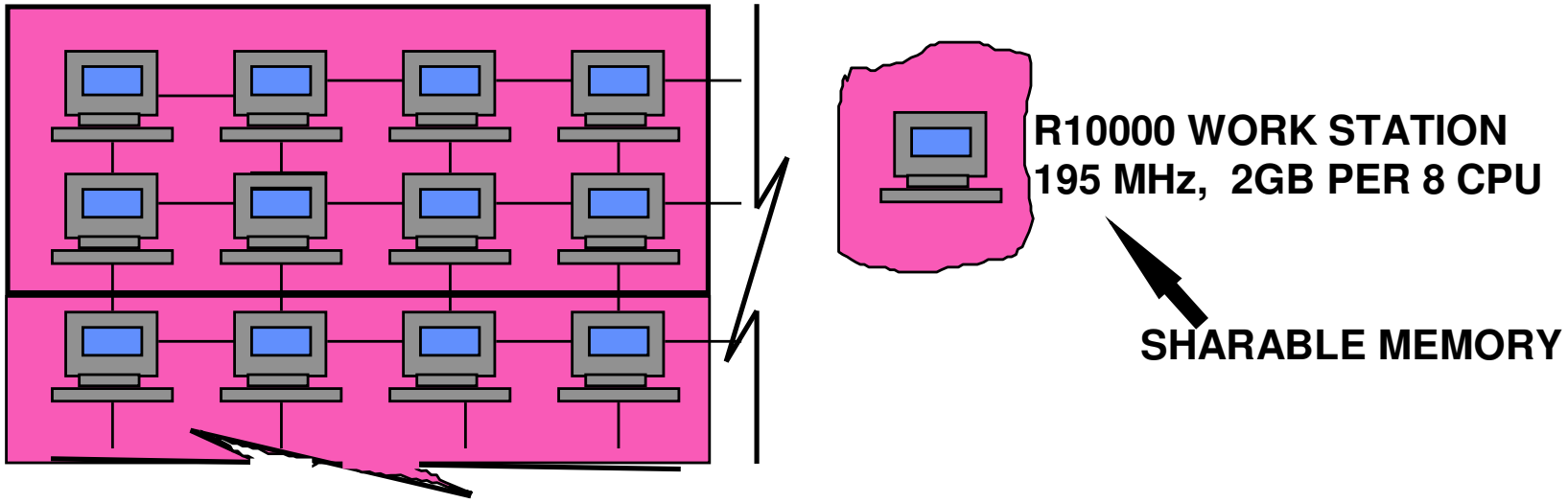
- MPI MESSAGE PASSING ON MPP IS MORE ROBUST THAN PVM

- FINE GRAIN PARALLEL APPROACH CAN IMPROVE PERFORMANCE FOR MULTIBLOCK GRIDS WITH LARGE DIFFERENCES IN SIZES
  - COMMUNICATION OVERHEAD IS MORE THAN COARSE GRAIN APPROACH

- MPP BUILT OUT OF COMMODITY TYPE WORK STATIONS SHOWED GOOD SCALABLE PERFORMANCE

NASA HPCCP TESTBED 3

- IN 1998 NASA HPCCP INSTALLED 64 PROCESSOR SGI O-2000
  - MULTIPLE INSTRUCTION AND MULTIPLE DATA (MIMD) ARCHITECTURE
  - 195 MHz R10000 RISC 64 BIT CPU, 2GB MEMORY SHARED BY 8 CPUS
  - 300 MFLOP, 64-BIT FLOATING POINT PERFORMANCE
- BUILT OUT OF MASS COMMODITY WORKSTATIONS
- SHARED SCALABLE MEMORY ARCHITECTURE ALLOWING MULTITASKING USING HARDWARE DEPENDENT MULTI-LEVEL-PROGRAMMING (MLP)

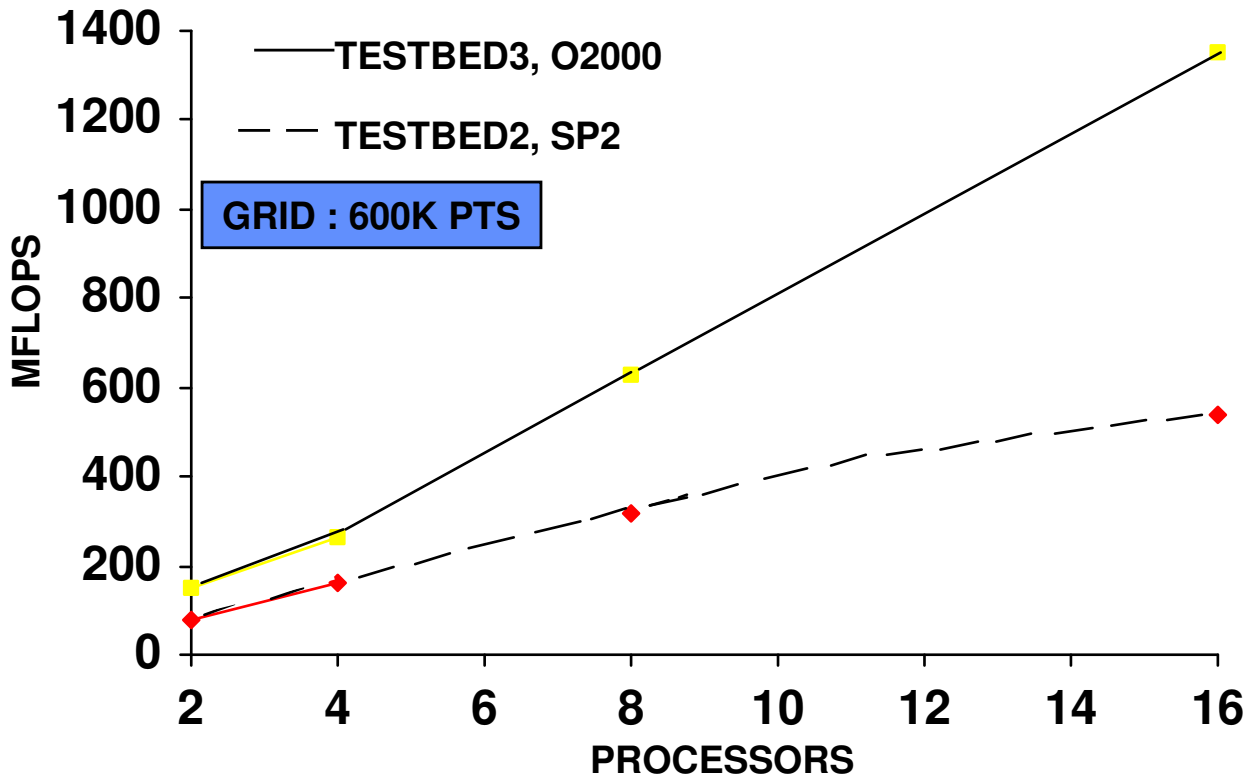


DEVELOPMENST AND APPLICATIONS ON TESTBED-3

- HiMAP SUCCESSFULLY PORTED TO O-2000
  - MPIRUN WAS MODIFIED TO MATCH 64 BIT MEMORY
  - UP TO 100 MFLOP PER NODE ACHIEVED

- 30 GFLOPS DEMONSTRATED USING 256 NODES

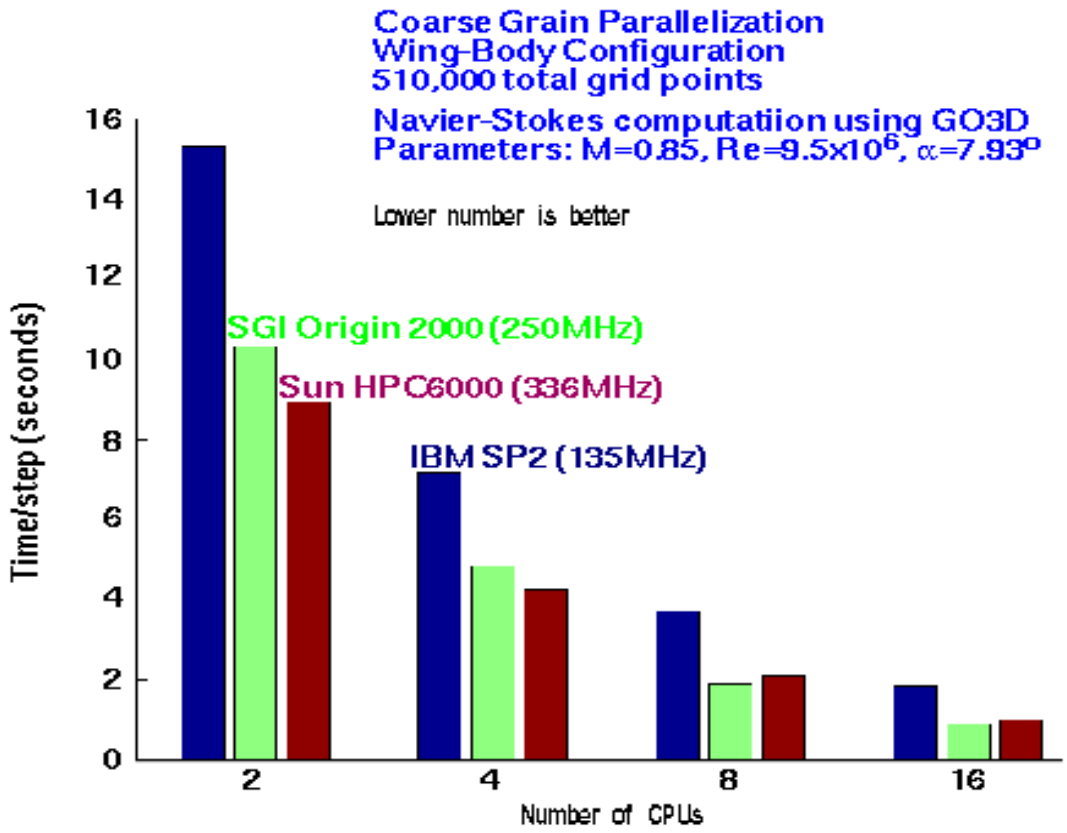
PERFORMANCE COMPARISONS OF HiMAP ON HPCC TESTBEDS



LARGE AEROELASTIC APPLICATIONS ON TESTBED 3

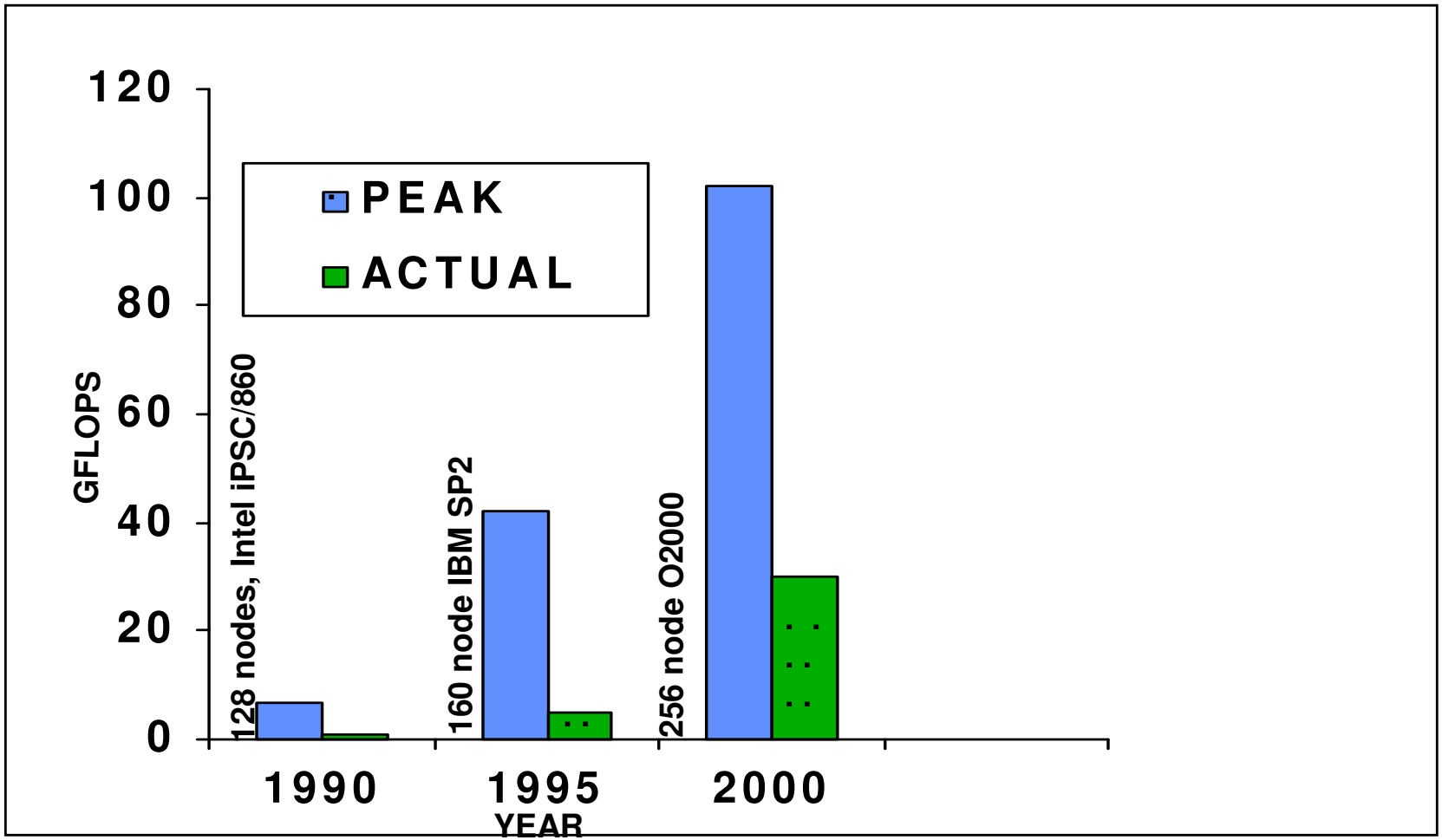
- **W-B-N-E MODEL OF HSCT CONFIGURATION WITH 10 M GRID POINTS (FLUIDS) AND 10,000 FINITE ELEMENTS (STRUCTURES) MODEL MAPPED ON TO 256 O-2000 PROCESSORS .**
- **30 GFLOP PERFORMANCE AND ABOUT 2HRS OF WALL CLOCK TIME FOR STATIC AEROELASTIC RESPONSE**
- **HPCC GRAND CHALLENGE**

PORTABILITY AND PERFORMANCE OF HiMAP



NOTE : BASED ON INDEPENDENT STUDY SPONSORED (SEPT 98)

GROWTH IN MPP TYPE PARALLEL COMPUTERS



CONCLUSIONS AND FUTURE DIRECTIONS

- OVER A DECADE COMPUTATIONAL SPEED HAS INCREASED BY FACTOR OF 50 (INTEL TO O-2000/TESTBED- 3)
  - FACTOR OF 8 FOR SERIAL COMPUTERS (Cray XMP - C-90)
- MPP TYPE PARALLEL COMPUTERS USING MPI/IEEE HAS LEAD TO COST EFFECTIVE ANALYSIS PROCESS SUCH AS HIMAP
  - 1/4 COST OF CURRENT OF MAINFRAME SUPERCOMPUTER
- IN-ADDITION TO HARDWARE SPEED-UP, EFFORT TO SPEED-UP APPLICATION ALGORITHMS ARE NEEDED
  - FAST UNSTEADY ALGORITHMS
  - ROBUST MULTIBLOCK MOVING GRIDS
  - ADVANCED TURBULENCE MODELS
- PARALLEL COMPUTERS STILL NEED TO IMPROVE RELIABILITY COMPARED TO MAINFRAME TYPE SUPERCOMPUTERS
  - INTERNAL NETWORK COMMUNICATION NEED IMPROVEMENTS
  - BETTER DEBUG AND PERFORMANCE TOOLS ARE REQUIRED
- APPLICATIONS FOR LARGE SCALE REAL AEROELASTIC PROBLEMS NEED TO BE FURTHER DEMONSTRATED
- HIMAP TYPE MIIDDLEWARE NEED TO BE MAPPED ON TO PROBLEM SOLVING ENVIRONMENTS SUITABLE FOR INFORMATION POWER GRID PROJECT OF NASA