Ansys equation solvers: usage and guidelines

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Ansys Solvers Team, April, 2002

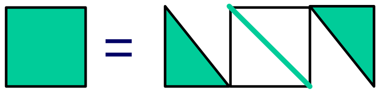
Outline

- Basic solver descriptions
  - Direct and iterative methods
  - *Why so many choices?*
- Solver usage in ANSYS
  - Available choices and defaults
  - *How do I chose a solver?*
- Practical usage considerations
  - Performance issues
  - Usage rules of thumb
  - Usage examples
  - *How do I chose the fastest solver??*

Solver Basics: Ax = b

Direct Methods

Factor: $A = LDL^T$

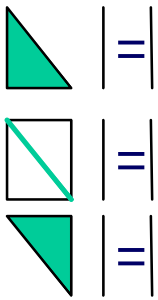


Solve:

$L\ z = b$

$z = D^{-1}z$

$L^T\ x = z$



Compute matrix L

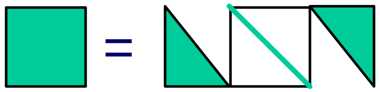
Solve triangular systems

Solver Basics: Ax = b

Direct Methods	**Iterative Methods**	
	Stationary Methods (Guess and Go)	Projection Methods (project and minimize)

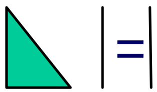
Direct Methods

Factor: $A = LDL^T$

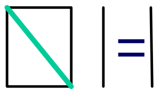


Solve:

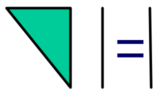
$L\,z = b$



$z = D^{-1}z$



$L^T x = z$



Iterative Methods

Stationary Methods
(Guess and Go)

Choose x^0

Iterate:
$x^{K+1} = Gx^k + c$
Until
$\| x^{k+1} - x^k \| < e$

Projection Methods
(project and minimize)

Choose x^0; $r^0 = Ax^0 - b$; $p^0 = r^0$

Iterate:
Compute Ap^k;
Update $x^k = x^{k-1} + \alpha^k p^{k-1}$
$r^k = r^{k-1} - \alpha^k Ap^k$
$p^k = r^k + \beta^k p^{k-1}$
Until $\| r^k \| < \varepsilon$

Compute matrix L

Solve triangular systems

Compute sparse Ax product

Vector updates

Solver Basics: Limitations

Direct Methods

- Factor is expensive
  - Memory & lots of flops
  - huge file to store L
- Solve I/O intensive
  - forward/backward read of huge L file

Iterative Methods

- Sparse Ax multiply cheap but slow
  - Memory bandwidth and cache limited
  - Harder to parallelize
- Preconditioners are not always robust
- Convergence is not guaranteed

ANSYS Direct Advantage

- Enhanced BCSLIB version 4.0
  - Parallel factorization
  - Reduced memory requirements for equation reordering
  - Support for U/P formulation
- Sparse solver interface improvements
  - Dynamic memory uses feedback for optimal I/O performance
  - Sparse assembly including direct elimination of CEs

Multi-Point Constraints

Direct elimination method

$$\mathbf{x_1 = G^T x_2 + g}$$

$$\begin{bmatrix} A_{11} & A_{12} \\ A^T_{12} & A_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

solve :

$$\mathbf{(GA_{11}G^T + GA_{12} + A^T_{12}\, G^T + A_{22})\, x_2 = b_2 + Gb_1 - A^T_{12}g - GA_{11}g}$$

ANSYS Iterative Advantage

- Powersolver has a proprietary and robust preconditioner
  - Parallel matrix/vector multiply
  - Wide usage, robust
- Many additional iterative solvers for complex systems, non-symmetric, etc.
- New high performance parallel solvers
  - AMG Algebraic Multigrid
  - DDS Domain Decomposition Solver
- Ongoing efforts to utilize and enhance AMG and DDS solvers when applicable

Solver Usage

- Sparse, PCG and ICCG solvers cover 95% of all ANSYS applications
- Sparse solver is now default in most cases for robustness and efficiency reasons

Solver Usage: Choices

- Sparse direct solver (BCSLIB)
- PCG solver (PowerSolver)
- Frontal solver
- ICCG
- JCG

Listed by order of usage popularity

ANSYS now chooses sparse direct in nearly all applications for robustness and efficiency

Solver Usage: -pp Choices

- AMG – Algebraic Multigrid
  - Good for ill-conditioned problems
  - Best ANSYS shared memory parallel performance iterative solver
  - Good for nonlinear problems – can solve indefinite matrix
- DDS – Domain Decomposition Solver
  - Exploits MPP cluster computing for solver portion of analysis
  - Solver time scales even on many processors

Still under intensive developments

Solver Usage: Sparse Solver

- Real and complex, symmetric and non-symmetric
- Positive definite and indefinite(occurs in nonlinear and eigensolver)
- Supports block Lanczos
- Supports substructural USE pass
- Substructure Generation pass (Beta in 6.1)
- Supports ALL physics including some CFD
- Large numbers of CEs
- Support for mixed U-P formulation with Lagrange multipliers (efficient methods are used to support this)
- Pivoting and partial pivoting (EQSLV,sparse,0.01,-1)

Solver Usage: PCG Solver

- Real symmetric matrices
- Positive definite and indefinite matrices. Supporting indefinite matrices is a unique feature in our industry.
- Power Dynamics modal analyses based on PCG + subspace
- Substructure USE pass and expansion pass
- All structural analyses and some other field problems
- Large numbers of CEs
- NOT for mixed U-P formulation Lagrange multiplier elements
- NO pivoting or partial pivoting capability

Solver Usage: ICCG Suite

- Collection of iterative solvers for special cases
- Complex symmetric and non-symmetric systems
- Good for multiphysics, i.e. EMAG
- Not good for general usage

Usage Guidelines: Sparse

- **Capabilities**
  - Adapts to memory available
  - ANSYS interface strives for optimal I/O memory allocation
  - Uses machine tuned BLAS kernels that operate at near peak speed
  - Uses ANSYS file splitting for very large files
  - Parallel performance 2X to 3.5X faster on 4 to 8 processor systems
  - 3X to 6X speedup possible on high end server systems (IBM, HP, SGI ..)

Usage Guidelines:Sparse

- **Resource requirements**
  - Total factorization time depends on model geometry and element type
    - Shell models best
    - Bulky 3-D models with higher order elements more expensive
  - System requirements
    - 1 Gbyte per million dofs
    - 10 Gbyte disk per million dofs
  - Eventually runs out of resource
    - 10 million dofs = 100 Gbyte file
    - 100 Gbytes X 3 = 300 Gbytes I/O
    - 300 Gbytes @ 30 Mbytes/sec = approx. 10,000 seconds I/O wait time

Usage Guidelines: PCG

- **Capabilities**
  - Runs in-core, supports out-of-core (you don’t need to do this)
  - Parallel matrix/vector multiply achieves 2X on 4 to 8 processor system
  - Memory saving element-by-element technology for solid92 (and solid95 beta in 6.1)

Usage Guidelines:PCG

- **Resource requirements**
  - 1 Gbyte per million dofs
  - Memory grows automatically for large problems
  - I/O requirement is minimal
  - Convergence is best for meshes with good aspect ratios
  - 3-D cube elements converge better than thin shells or high aspect solids
  - Over 500k dofs shows best performance compared to sparse

Usage Guidelines: Substructuring

- Eqslv,spar in generation pass
  - Requires pcg or sparse in expansion pass
- Use pass uses sparse solver by default
  - May fail in symbolic assembly (try asso,,front)
- Pcg or sparse in expansion pass
  - Avoids large tri files

This is Beta feature only in 6.1, no unsymmetric, no damping

Performance Summary

- **Where to look**
  - PCG solver; file.PCS
  - Sparse solver; output file
    - Add Bcsopt ,,, ,,, -5 (undocu. Option)
- **What to look for**
  - Degrees of freedom
  - Memory usage
  - Total iterations (iterative only)

Usage Guidelines

- Tuning sparse solver performance
  - Bcsopt command (undocumented)
  - Optimal I/O for largest jobs
  - In-core for large memory systems and small to medium jobs (< 250,000 dofs)
  - Use parallel processing

User Control of Sparse Solver Options

Sparse solver control using undocumented command:

bcsopt, ropt, mopt, msiz ,,, dbg

mmd
metis
sgi
wave

Set equation reordering method

forc
limit

Force or limit solver memory space in Mbytes

nnnn - Mbytes up to 2048

-5

Print performance stats

Solvers and Modal Analyses

- **Modal analyses most demanding in ANSYS**
  - Block Lanczos is most robust
    - Requires all of sparse solver resources plus additional space for eigenvectors
    - Requires multiple solves during Lanczos iterations
  - Subspace good for very large jobs and few eigenvalues
    - Uses PCG solver
    - Or uses the frontal solver
    - Not as robust as block Lanczos

Some Solver Examples

- Some benchmarks 5.7 vs 6.0
- Typical large sparse solver jobs
- Sparse solver memory problem
- PCG solver example
- AMG solver examples

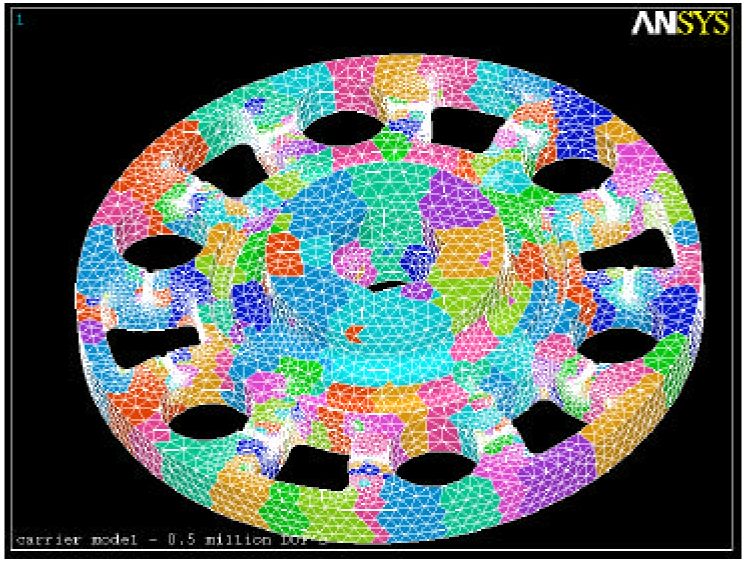
Benchmark study; Static analysis

	DOF	Total Solution Time		Peak Memory	
		5.7	6	5.7	6
Sparse Solver					
Beam	110838	320	289	58	124
Car	421677	1149	789	1124	940
Joint	502851	2123	1146	480	312
Carrier2	502851	3113	1893	1115	1115
Carrier1	980484	4662	2736	1665	1196
RailCar	1470915	4257	3531	1084	1084
Engine	1676660	x	7967	x	1466
Assembly	3388179	x	18091	x	2873
PCG					
Car	421677	4215	4215	268	269
Joint	502851	1014	1014	294	294
Carrier2	502851	763	763	349	349
Carrier1	980484	1167	1147	677	677
RailCar	1470915	7488	7488	862	862
Engine	1676660	13770	13770	1235	1235
Assembly	3388179	x	x	x	x

Benchmark study:ModalAnalysis

	DOF	Total Solution Time		Peak Memory	
		5.7	6	5.7	6
		Sparse Solver			
Beam	110838	320	289	58	124
Car	421677	1149	789	1124	940
Joint	502851	2123	1146	480	312
Carrier2	502851	3113	1893	1115	1115

Sparse Solver Memory Usage Example 1



2 Million DOF Sparse solver job
SGI O2000 16 CPU system

```
MultiSolution: Sparse Assembly Option .... Call No. 1
     ANSYS largest memory block available     10268444 :      9.79 Mbytes
                     ANSYS memory in use    1323917280 :   1262.59 Mbytes

End of PcgEnd
     ANSYS largest memory block available    588214172 :    560.96 Mbytes
                     ANSYS memory in use     256482560 :    244.60 Mbytes
  Total Time (sec) for Sparse Assembly     63.53 cpu    69.02 wall

 Heap space available at start of BCSSL4: nHeap=     75619667 D.P. words    576.93 Mbytes
```

577 Mbytes available for sparse solver

Sparse Solver Memory Usage Example 1 (cont.)

Carrier 2M dof Model

ANSYS 6.0 memory allocation

```
                SPARSE MATRIX DIRECT SOLVER.
  Number of equations =2090946,    Maximum wavefront =    275

      Heap space available at start of bcs_mem0: nHeap=
           61665329 D.P. words   470.47 Mbytes

      Estimated work space needed for solver: min_siz=
          256932078 D.P. words  1960.24 Mbytes

      Start_siz Work space needed for solver: start_siz=
          110399416 D.P. words   842.28 Mbytes

       Heap space setting at start of bcs_mem0: nHeap=
          110399416 D.P. words   842.28 Mbytes
 Initial BCS workspace memory =   110399416 D.P. words  842.28 Mbytes


      Total Reordering Time (cpu,wall) =   537.670  542.897

Increasing memory request for BCS work to     67802738 D.P. words   517.29 Mbytes
                     Initial BCS workspace is sufficient
       Memory available for solver =              842.28 MB
       Memory required for in-core =                0.00 MB
       Optimal memory required for out-of-core =  517.29 MB
       Minimum memory required for out-of-core =  162.39 MB
```

Initial memory increased to 800 Mbytes

800 Mbytes exceeds Optimal I/O setting

Initial guess easily runs in optimal I/O mode

Sparse Solver Memory Usage Example 1 (cont.)

Carrier2 2M dof Model

```
number of equations                          =        2090946
no. of nonzeroes in lower triangle of a =           84553633
no. of nonzeroes in the factor l             =     2434337580
maximum order of a front matrix              =           9645
maximum size of a front matrix               =       46517835
no. of floating point ops for factor         =     7.4048E+12

time (cpu & wall) for structure input        =     193.810000      223.923436
time (cpu & wall) for ordering               =     456.970000      461.192527
time (cpu & wall) for symbolic factor        =       7.400000        7.471412
time (cpu & wall) for value input            =     287.240000      384.408332
time (cpu & wall) for numeric factor         =   12671.900000    13367.557193
computational rate (mflops) for factor       =     584.351978      553.941885
time (cpu & wall) for numeric solve          =     765.760000     1411.694416
computational rate (mflops) for solve        =      12.729582        6.905039

     i/o statistics:   unit number        length         amount
                       -----------        ------         ------

                               20.    138591505.    288939194.
                               25.      9310592.     32587072.
                                9.   2434337580.   7894888171.
                               11.    169107266.    507331541.
  Freeing BCS workspace
  Sparse Matrix Solver CP Time (sec) =       14468.280
  Sparse Matrix Solver ELAPSED Time (sec) =       15982.407
```

2.1M Dofs
84M Nzeros in K (40/1)
2.4B Nzeros in L (1142/29)
7.4 Trillion F.P. ops

Factored Matrix file LN09
2.4 Billion D.P words, 18 Gbytes
59 Gbytes transferred

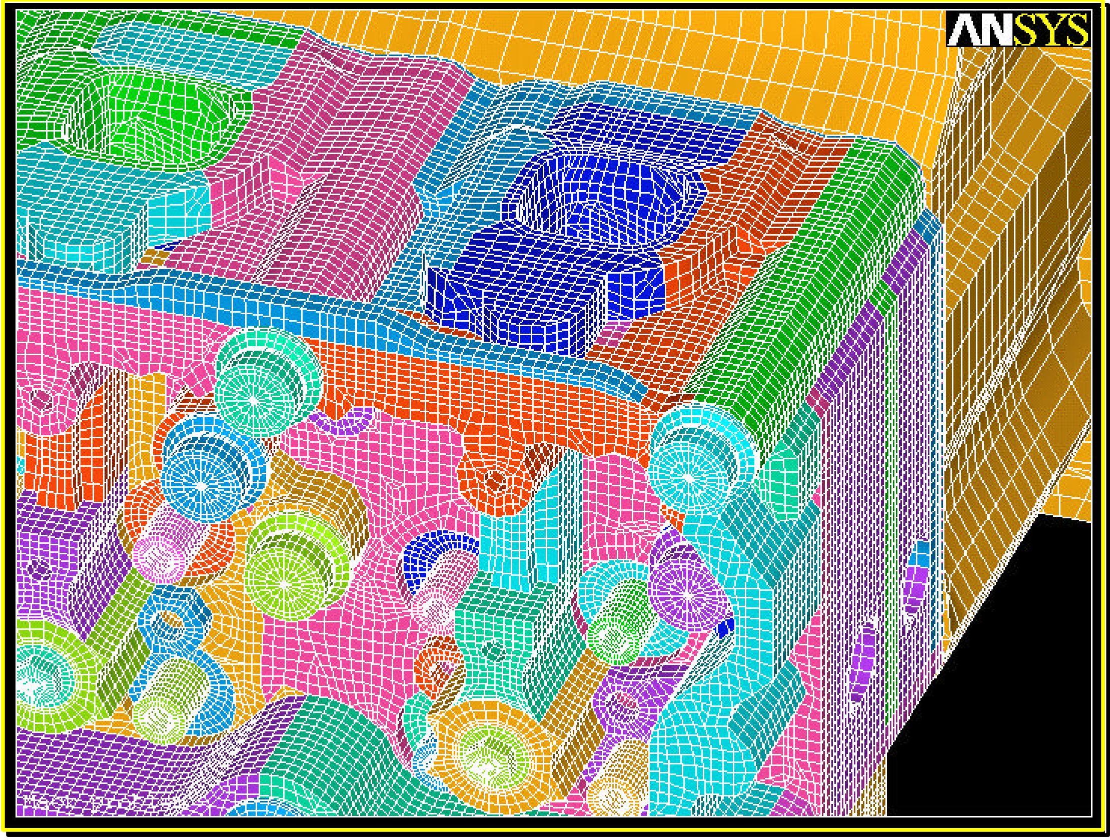
File LN32 not used

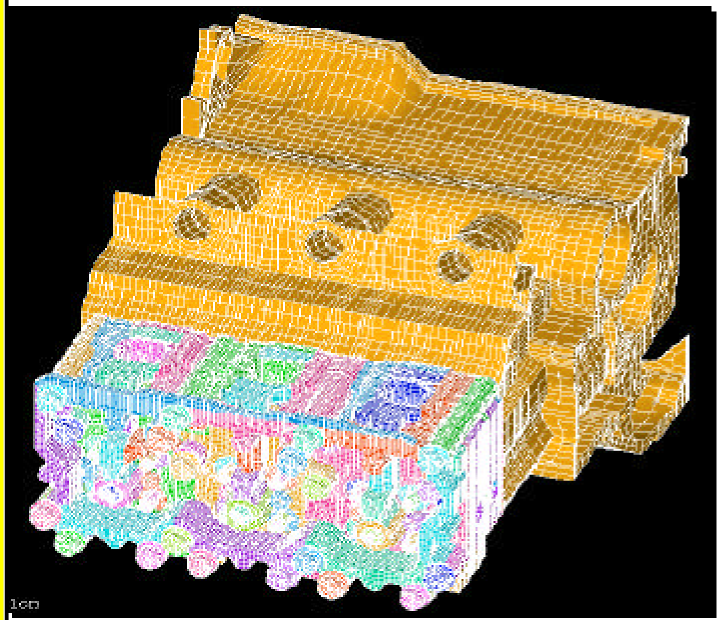
Elapsed time close to CPU time (4.5 Hours)
Good processor utilization, reasonable I/O performance

Engine Block Analysis

410,977 Solid45 Elements
16,304 Combin40 Elements

1,698,525 Equations
20,299 Multi-Point CEs





Engine Block Analysis

Sparse Solver Interface Statistics

Sparse CE interface Matrix	dim	coefs	mxcolmlth
-------------------------	*******	*********	*********
Original A22	1698525	55419678	209
Constraints G	20299	58147	6
H = G*A11 + A12T	20299	860830	99
HGT	1698525	865275	381
Modified A22	1698525	58304862	404

# of columns modified by direct elimination of CEs:132849

Over 20,000 CEs processed with minimal additional memory required

```
Memory available for solver =                 547.22 MB
Memory required for in-core =                9417.10 MB
Optimal memory required for out-of-core =   527.29 MB
Minimum memory required for out-of-core =   127.25 MB
```

Memory available is sufficient to run in Optimal I/O mode

Engine Block Analysis

Sparse Solver Performance Summary

SGI O2000 16-300Mhz Processors, 3 CPU run

```
time (cpu & wall) for structure input  =   162.05     172.82
time (cpu & wall) for ordering         =   340.37     342.63
time (cpu & wall) for symbolic factor  =     7.93       7.96
time (cpu & wall) for value input      =   225.89     267.12
time (cpu & wall) for numeric factor   =  4812.04    5086.30
computational rate (mflops) for factor =   592.55     560.60
time (cpu & wall) for numeric solve    =   365.90     663.77
computational rate (mflops) for solve  =    12.54       6.91

     i/o statistics:   unit number        length         amount
                       -----------        ------         ------

                               20     91464700    192879558
                               25      5319910     18619685
                                9   1145424928   3816657199
                               11    108680690    615455923
```

I/O always shows up in solve

Good sustained rate on factorization – nearly 600 mflops

Sparse Solver Example 2

What can go wrong

Customer example: excessive elapsed time

High Performance HP 2 CPU desktop system

```
|-----------------------------------------------------------------------|
|                                                                       |
|            Release 6.0          UP20010919        HPPA 8000-64        |
|                                                                       |
|-----------------------------------------------------------------------|
|                                                                       |
|   Maximum Scratch Memory Used      =   252053628 Words     961.508 MB |
|                                                                       |
|-----------------------------------------------------------------------|
|                                                                       |
|        CP Time      (sec) =        6323.090       Time  =  23:36:41   |
|        Elapsed Time (sec) =       27575.000       Date  =  01/10/2002 |
|                                                                       |
*-----------------------------------------------------------------------*
```

Sparse Solver Example 2 (cont.)

FEM model of large radiator

650k Degrees of Freedom

68,000 Solid95 Elements
2089 Surf154 Elements
3400 Constraint Equations

Initial memory setting –m 1000 –db 300

Sparse Solver Example 2 (cont.)

```
MultiSolution: Sparse Assembly Option .... Call No. 1
    ANSYS largest memory block available     73741452 :    70.33 Mbytes
                    ANSYS memory in use     612110368 :   583.75 Mbytes

Sparse Solver Interface Adding CEs.... Call No. 1
    ANSYS largest memory block available     73741164 :    70.33 Mbytes
                    ANSYS memory in use     612110656 :   583.75 Mbytes

 Sparse CE interface Matrix     dim      coefs  mxcolmlth
 -------------------------- ******* ********* *********
             Original A22    648234  41415993       461
            Constraints G      3471     23222         8
          H = G*A11 + A12T     3471    409194       219
                       HGT   648234    781339       668

The initial memory allocation (-m) has been exceeded.
  Supplemental memory allocations are being used.

No. of columns modified by direct elimination of CEs:     42558
             Modified A22    648234  43974225       692
    ANSYS largest memory block available    288465472 :   275.10 Mbytes
                    ANSYS memory in use     179570288 :   171.25 Mbytes
 Total Time (sec) for processing CEs    38.33 cpu    61.73 wall
End of PcgEnd
    ANSYS largest memory block available    575083952 :   548.44 Mbytes
                    ANSYS memory in use     133219536 :   127.05 Mbytes
 Total Time (sec) for Sparse Assembly     38.36 cpu    61.77 wall
```

584 Mbytes in use during sparse Assembly

Needs more memory to process CEs

548 Mbytes available after sparse Assembly

Sparse Solver Example 2 (cont)

Minimum core memory run: 650k dofs

```
Memory available for solver =                 488.21 MB
Memory required for in-core =                7348.80 MB
Optimal memory required for out-of-core =     651.66 MB
Minimum memory required for out-of-core =      63.18 MB

   time (cpu & wall) for structure input    =       40.130000       62.959089
   time (cpu & wall) for ordering           =      269.940000      296.114490
   time (cpu & wall) for symbolic factor    =        6.780000        8.303449
   time (cpu & wall) for value input        =      127.230000      624.087842
   time (cpu & wall) for numeric factor     =     5312.130000    25199.576871
   computational rate (mflops) for factor   =      740.325416      156.062337
   condition number estimate                =      0.0000D+00
   time (cpu & wall) for numeric solve      =      117.400000      890.047902
   computational rate (mflops) for solve    =       28.598027        3.772166

   i/o statistics:   unit number        length          amount
                     -----------        ------          ------

                            20.      77728422.      173599480.
                            25.       3414388.       11950358.
                             9.     838554505.     2753998119.
                            11.      84582582.      723248228.
                            32.      77134410.    11000063203.


Sparse Matrix Solver CP Time (sec) =          5956.170
Sparse Matrix Solver ELAPSED Time (sec) =        27177.617
```

488 Mbytes available is less than optimal I/O memory

Factored Matrix file LN09
838M D.P words, 6.4 Gbytes
21 Gbytes transferred

Elapsed time 5X larger than CPU time!

Large front spillover file I/O is culprit
77M D.P. words, 110 Billion transferred!
Over ¾ of a Terabyte transferred!!!

Sparse Solver Example 2 (cont)

Optimal out-of-core memory run: 650k dofs

```
 Memory available for solver =             660.21 MB
Memory required for in-core =            7348.80 MB
Optimal memory required for out-of-core =  651.66 MB
Minimum memory required for out-of-core =   63.18 MB

    time (cpu & wall) for structure input   =       40.170000       62.870488
    time (cpu & wall) for ordering          =      270.470000      294.560051
    time (cpu & wall) for symbolic factor   =        6.770000        8.156075
    time (cpu & wall) for value input       =      116.300000      360.649415
    time (cpu & wall) for numeric factor    =     4773.720000     3418.024528
    computational rate (mflops) for factor  =      823.823853     1150.578169
    condition number estimate               =      0.0000D+00
    time (cpu & wall) for numeric solve     =      115.450000      880.488530
    computational rate (mflops) for solve   =       29.081060        3.813120

    i/o statistics:   unit number        length        amount
                      -----------        ------        ------

                              20.      77728422.    173599480.
                              25.       3414388.     11950358.
                               9.     838554505.   2674553251.
                              11.      80694876.    470460286.

 Sparse Matrix Solver CP Time (sec) =       5405.520
 Sparse Matrix Solver ELAPSED Time (sec) =       5122.035
```

660 Mbytes available is achieves optimal I/O memory

1 Gflop sustained

Factored Matrix file LN09

838M D.P words, 6.4 Gbytes

21 Gbytes transferred

File LN32 not used

Elapsed time 5X faster than minimum memory run

Sparse Solver NT system Example

What can go wrong

Customer example: NT memory problems

Dell system, 2 P4 processors, 2 Gbytes memory

- default memory run failed
- -m 925 –db 100 failed before solver
- -m 1100 –db 100 interactive failed
- -m 1100 –db 100 batch mode worked

Why so memory sensitive???

Sparse Solver NT system example (cont.)

FEM model of turbine blade

772k Degrees of Freedom

114,000	Solid45 Elements
4662	Solid 95 Elements
76173	Solid 92 Elements
18118	Surf154 Elements
3400	Constraint Equations

Lots of CEs used to impose cyclic symmetry conditions

Sparse Solver NT system (cont.)

NT system run, 770k dofs turbine blade

```
MultiSolution: Sparse Assembly Option .... Call No. 1
     ANSYS largest memory block available    288061264 :    274.72 Mbytes
                     ANSYS memory in use     562923008 :    536.85 Mbytes

 Sparse Solver Interface Adding CEs.... Call No. 1
     ANSYS largest memory block available    288061024 :    274.72 Mbytes
                     ANSYS memory in use     562923248 :    536.85 Mbytes

  Sparse CE interface Matrix    dim     coefs   mxcolmlth
  -------------------------- ******* ********* *********
               Original A22   772125  28566123         0
              Constraints G    16533     71706         0
            H = G*A11 + A12T   16533    895685         0
                        HGT   772125   8364601         0

   The initial memory allocation (-m) has been exceeded.
      Supplemental memory allocations are being used.

    No. of columns modified by direct elimination of CEs:     51678
     Sparse CE interface Matrix    dim     coefs   mxcolmlth
     -------------------------- ******* ********* *********
                  Modified A22   772125  61587249         0

   ANSYS largest memory block available      4971036 :      4.74 Mbytes
                   ANSYS memory in use    1502114112 :   1432.53 Mbytes

   ANSYS largest memory block available    804449536 :    767.18 Mbytes
                   ANSYS memory in use     185689952 :    177.09 Mbytes
     Total Time (sec) for Sparse Assembly     79.95 cpu     80.48 wall
```

537 Mbytes in use Before CEs

Needs more memory to process CEs

1432 Mbytes in use after CEs

1400 Mbytes is well over initial allocation !

Sparse Solver NT example (cont)

Optimal I/O run on fast NT system: 770k dofs

```
 Using opt out of core memory setting
  Initial BCS workspace is sufficient
  Memory available for solver =              719.93 MB
  Memory required for in-core =             6944.94 MB
  Optimal memory required for out-of-core =  623.68 MB
  Minimum memory required for out-of-core =   77.61 MB

time (cpu & wall) for structure input   =      25.484000       25.643644
time (cpu & wall) for ordering          =     108.000000      108.698163
time (cpu & wall) for symbolic factor   =       4.531000        4.555646
time (cpu & wall) for value input       =     217.094000      218.496403
time (cpu & wall) for numeric factor    =    2224.359000     2238.762857
computational rate (mflops) for factor  =    1335.468214     1326.876016
condition number estimate               =     0.0000D+00
time (cpu & wall) for numeric solve     =     824.610000      829.907434
computational rate (mflops) for solve   =       3.759268        3.735272
i/o statistics:   unit number        length         amount
                  -----------        ------         ------

                           20.     55724809.    118615367.
                           25.      3780444.     13231554.
                            9.    774037991.   2451597713.

Sparse Matrix Solver       CP Time (sec) =       3432.969
Sparse Matrix Solver ELAPSED Time (sec) =       3455.119
```

720 Mbytes available
achieves optimal I/O memory

1.3 Gflops sustained

Factored Matrix file LN09
774M D.P words, 5.7 Gbytes
18 Gbytes transferred

File LN32 not used

Excellent performance once memory issue is resolved!!

Usage Guidelines: Substructuring

- Eqslv,spar in generation pass
  - Requires pcg or sparse in expansion pass
- Use pass uses sparse solver by default
  - May fail in symbolic assembly (try asso,,front)
- Pcg or sparse in expansion pass
  - Avoids large tri files

This is Beta feature only in 6.1, no unsymettric, no damping

Solving NT memory issues

- Try default memory management
- Maximize solver memory
  - Use larger db for prep and post only
  - Reduce db memory for solve
  - Run in batch mode
- Read output file memory messages
  - Leave room for supplemental memory allocations
  - Try bcsopt,,forc,msiz as a last resort

How to get Optimal I/OMemory

- Prior to 6.1
  - Increase –m, decrease –db
  - Force sparse memory with bcsopt
- Version 6.1
  - Automatic in most cases
  - Tuning possible using bcsopt
- WINTEL 32 bit limitations
  - Total process space 2Gbytes
  - Keep db space small to maximize sparse solver memory
  - Don’t start –m too small for large jobs
  - Use msave,on for PCG solver

Sparse Solver Example 3

ANSYS 6.1 example – 2 Million DOF engine block

```
 Start of BCS_MEM1: msglvl= 2
   need_in=              0 D.P. words      0.00 Mbytes
  need_opt=      221585885 D.P. words   1690.57 Mbytes
  need_ooc=       20333932 D.P. words    155.14 Mbytes
    nHold0=      202309239 D.P. words   1543.50 Mbytes
     nHeap=       11789065 D.P. words     89.94 Mbytes
    navail=      202309239 D.P. words   1543.50 Mbytes
   mem_siz=              0 D.P. words      0.00 Mbytes
```

Sparse solver memory is just below optimal setting

Grow memory to optimal setting

```
Increasing memory request for BCS work to    221585885 D.P. words  1690.57 Mbytes

The initial memory allocation (-m) has been exceeded.
   Supplemental memory allocations are being used.

 After Realloc: pdHold= -1575830551 hHold0=   324 nHold=   221585885
  Memory available for solver =              1690.57 MB
  Memory required for in-core =                 0.00 MB
  Optimal memory required for out-of-core = 1690.57 MB
  Minimum memory required for out-of-core =  155.14 MB
```

Sparse Solver Example 3 (cont.)

ANSYS 6.1 Engine Block example: SGI O2000 system

```
number of equations                       =       2149066
no. of nonzeroes in lower triangle of a   =      78007632
no. of nonzeroes in the factor l          =    2698281519.
maximum order of a front matrix           =         20062
maximum size of a front matrix            =     201251953
no. of floating point ops for factor      =    1.9072E+13
no. of floating point ops for solve       =    1.0804E+10
time (cpu & wall) for structure input     =    181.640000      191.469832
time (cpu & wall) for ordering            =    800.110000      807.598554
time (cpu & wall) for symbolic factor     =     10.520000       10.572956
time (cpu & wall) for value input         =    259.820000      345.327975
time (cpu & wall) for numeric factor      =  30088.200000    31027.369107
computational rate (mflops) for factor    =    633.883809      614.696745
time (cpu & wall) for numeric solve       =    768.060000     1634.010750
computational rate (mflops) for solve     =     14.066442        6.611873

i/o statistics:    unit number        length        amount
                   -----------        ------        ------

                           20.    129721091.    272147055.
                           25.      7964778.     27876723.
                            9.   2698281519.   8406875085.
                           11.    250835024.   1964282370.
Freeing BCS workspace
Dealloc ptr_Diag= 683102464
Sparse Matrix Solver CP Time (sec) =       32283.010
Sparse Matrix Solver ELAPSED Time (sec) =       34199.480
```

2.1M Dofs
78M Nzeros in K (37/1)
2.7B Nzeros in L (1286/35)
19 Trillion F.P. ops

Factored Matrix file LN09
2.7 Billion D.P words, 20 Gbytes
63 Gbytes transferred

File LN32 not used

Elapsed time close to CPU time (10 Hours)

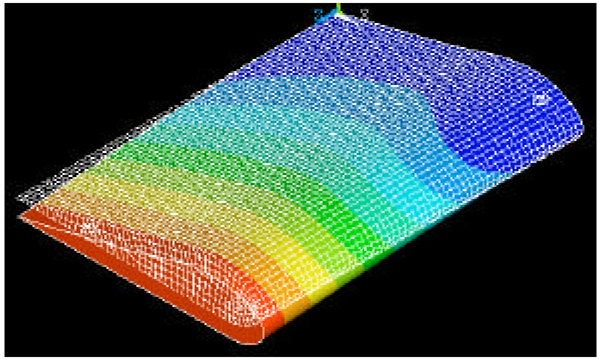
PCG Solver Example

- PCG memory grows dynamically in non-contiguous blocks
- Msave,on skips global assembly of stiffness matrix for SOLID 92, 95 elements.
- PCG solver can do largest problems in the least memory

PCG Solver Example (cont.)

Wing job example, 500k dofs, SOLID45 elements

File.PCS output



```
 Degrees of Freedom: 477792
        DOF Constraints: 4424
        Elements: 144144
                Assembled: 144144
                Implicit: 0
        Nodes: 159264
        Number of Load Cases: 1

        Nonzeros in Upper Triangular part of
                     Global Stiffness Matrix : 18350496
        Nonzeros in Preconditioner: 7017045

        Total Operation Count: 3.71503e+10
        Total Iterations In PCG: 343
        Average Iterations Per Load Case: 343
        Input PCG Error Tolerance: 1e-06
        Achieved PCG Error Tolerance: 9.90796e-07

        DETAILS OF SOLVER CP TIME(secs)          User      System
                Assembly                         23.9      3.6
                Preconditioner Construction      8.7       1.8
                Preconditioner Factoring         0.9       0
                Preconditioned CG                273.9     0.3
******************************************************************************
        Total PCG Solver CP Time: User: 320.9 secs: System: 9.9 secs
******************************************************************************
        Estimate of Memory Usage In CG : 240.191 MB
        Estimate of Disk Usage    : 247.919 MB
        CG Working Set Size with matrix outofcore : 65.0977 MB
******************************************************************************
        Multiply with A MFLOP Rate:168.24 MFlops
        Solve With Precond MFLOP Rate:111.946 MFlops

******************************************************************************
```

Good convergence
(1000 or more is bad)

Memory usage and disk I/O low

Mflops performance always
Lower than sparse solver

PCG Solver Example (cont.)

Wing job example, 228k dofs, SOLID95 elements

Msave,on

```
Degrees of Freedom: 228030
      DOF Constraints: 3832
      Elements: 16646
              Assembled: 0
              Implicit: 16646

Nonzeros in Upper Triangular part of
         Global Stiffness Matrix : 0
      Nonzeros in Preconditioner: 4412553

      Total Operation Count: 1.06317e+10
      Total Iterations In PCG: 488
****************************************************
      Total PCG Solver CP Time: User: 809.6 secs:
****************************************************
      Estimate of Memory Usage In CG : 30.6945 MB
      Estimate of Disk Usage    : 36.5936 MB
      *** Implicit Matrix Multiplication Activated
*****************************************************
      Multiply with A MFLOP Rate:0 MFlops
      Solve With Precond MFLOP Rate:81.7201 MFlops
*****************************************************
```

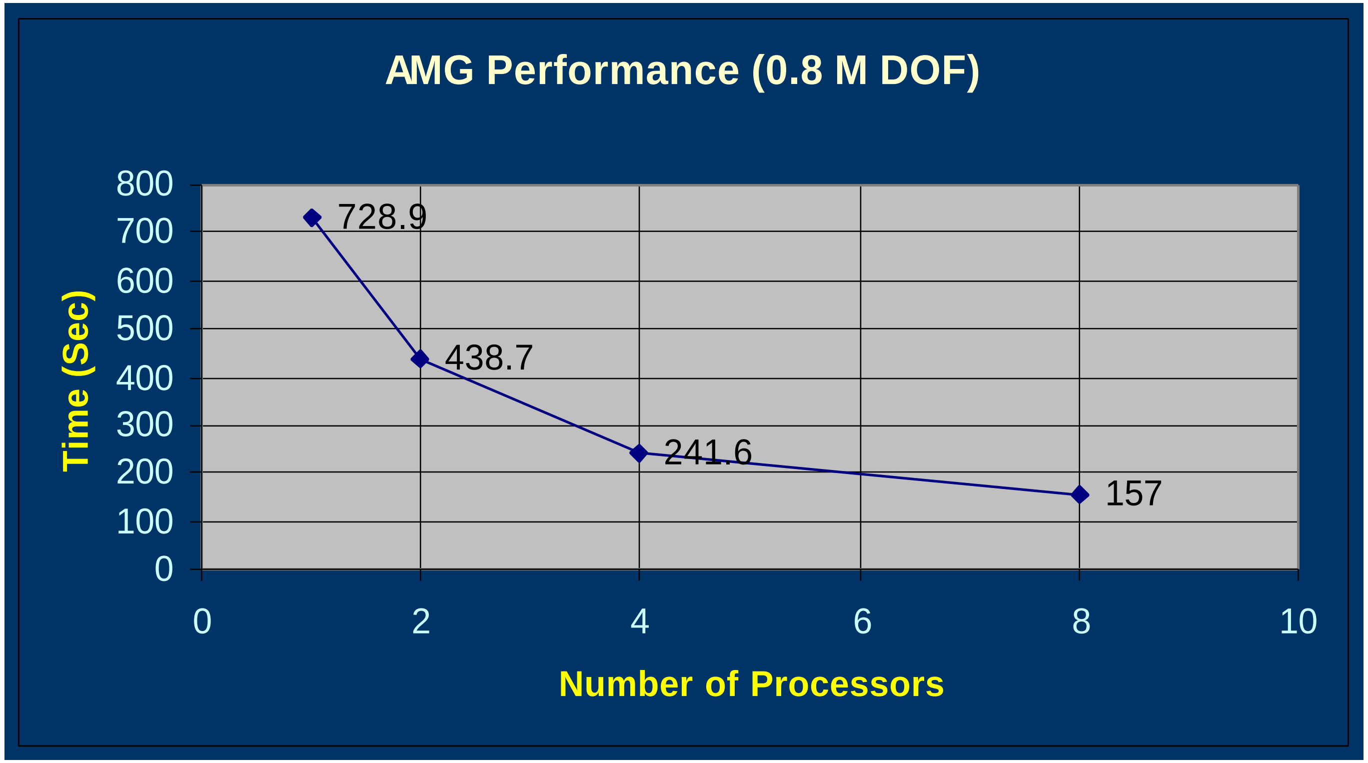
Default

```
Degrees of Freedom: 228030
      DOF Constraints: 3832
      Elements: 16646
              Assembled: 16646
              Implicit: 0

Nonzeros in Upper Triangular part of
       Global Stiffness Matrix : 18243210
      Nonzeros in Preconditioner: 4412553

      Total Operation Count: 4.60199e+10
      Total Iterations In PCG: 488
****************************************************
      Total PCG Solver CP Time: User: 850.2 secs:
****************************************************
      Estimate of Memory Usage In CG : 208.261 MB
      Estimate of Disk Usage    : 215.985 MB

****************************************************
      Multiply with A MFLOP Rate:62.3031 MFlops
      Solve With Precond MFLOP Rate:53.5653 MFlops
*****************************************************
```

Msave,on saves 170 Mbytes out of 200 Mbytes
Solve time is comparable to assembled run
Works only for SOLID 92s and SOLID95s in 6.1

AMG Performance

Solver time (sec) vs number of processors



AMG vs PowerSolver

Advantages:

- Insensitive to matrix ill-conditioning. Performance doesn’t deteriorate for high aspect ratio elements, rigid links, etc
- 5x faster than the PowerSolver for difficult problems on a single processor
- Scalable up to 8 processors (shared- memory only), 5 times faster with 8 processors

AMG vs PowerSolver

Disadvantages:

- 30% more memory required than PowerSolver
- 20% slower than PowerSolver for well conditioned problems on a single processor
- Doesn’t work for Distributed-Memory architecture (neither does PowerSolver).
- Scalability is limited by memory bandwidth (so is PowerSolver)

AMG vs Sparse Solver

ANSYS 6.1 example – 2 Million DOF engine block

```
 AMG ITERATIVE SOLVER:
  Number of equations =   2157241
  Number of processors used =        8

  Reading parameters from file amg_params.dat
  anis_hard=4
  anis_hard                          4
  hard=1
  hard                               1
  end reading parameters

AMG NO.OF ITER = 102 ACHIEVED RESIDUAL NORM = 0.90170E-05

  AMG ITERATIVE SOLVER ELAPSED TIME =   1758.000


  Sparse Matrix Solver CP Time (sec)      = 32283.010
  Sparse Matrix Solver ELAPSED Time (sec) = 34199.480
```

AMG parameters tuned for Ill-conditioned problem

AMG 19 times faster than sparse in this example

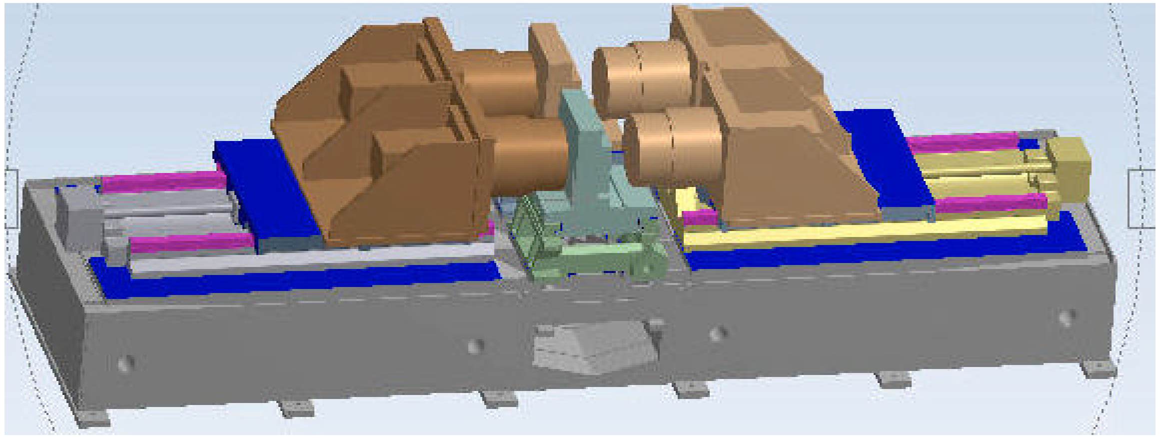
Comparative Performance may Vary

But,…

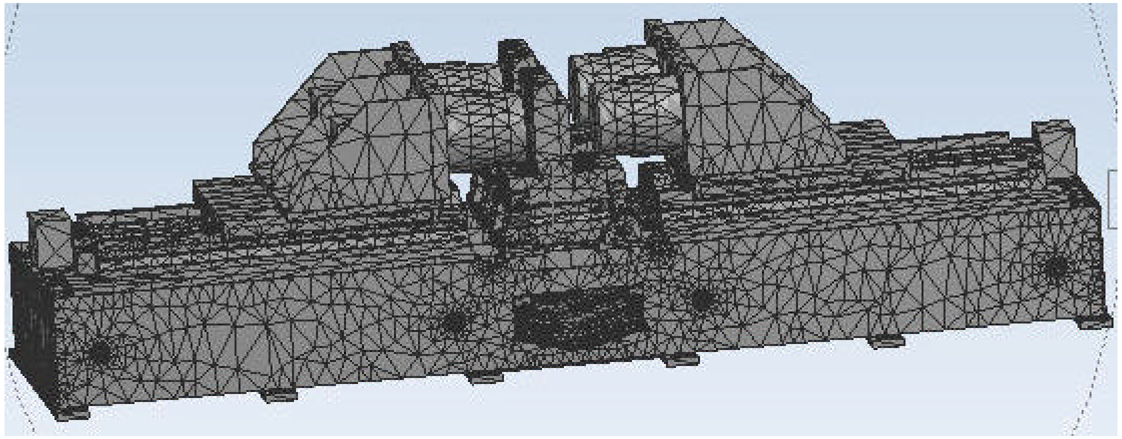
Your results may vary…

Large Industrial Example

Linear Static Analysis with Nonlinear Contact



ANSYS DesignSpace
Detailed Solid Model



Finite Element Model
119,000 Elements
590,000 DOFs

Large Industrial Example

Linear Static Analysis with Nonlinear Contact

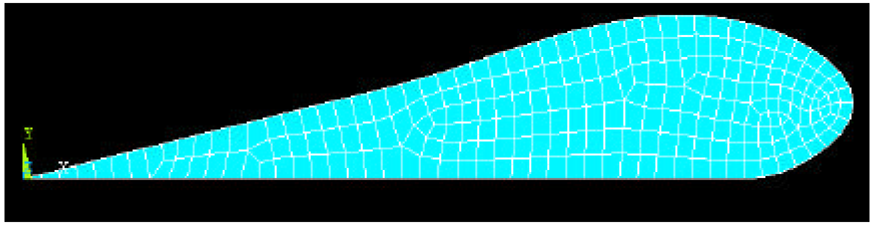
SGI O2000 16 300Mhz Processors, 16 Gbytes

Method	Memory Mbytes	Iter 10^{-6}	Solver Elapsed Time (sec) NP=1	NP=2	NP=3	NP=4
PCG	300	5301	8679	7745	6636	6909
AMG	722	200	5265	3831	2638	1884
SPAR	290		881			

AMG shows superior convergence and scaling for this problem

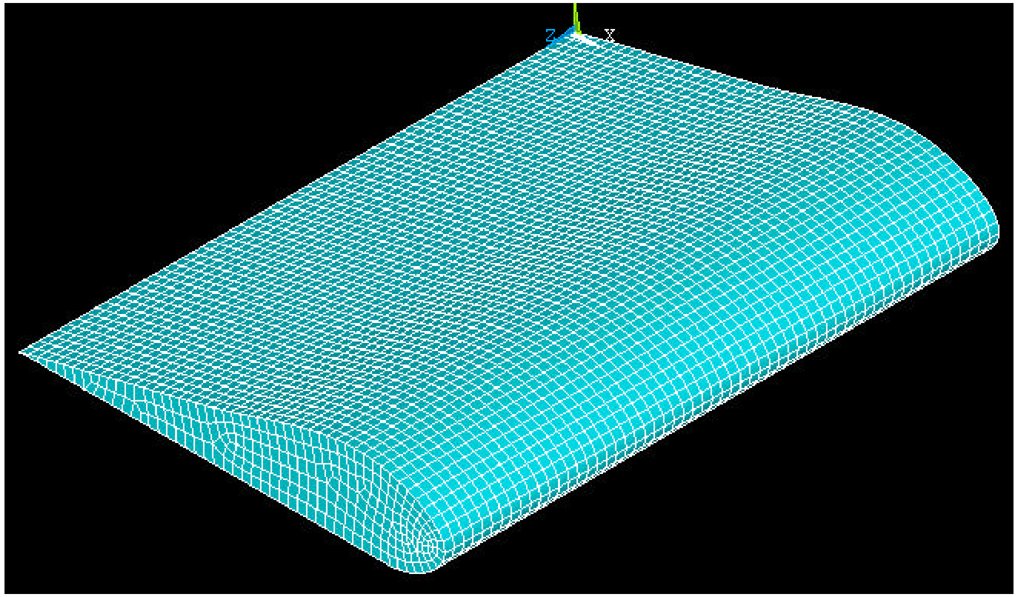
BUT…Sparse Direct solver best for this problem

Wing Example Job



2-D mesh

282 nodes, 233 elements, 646 DOFs



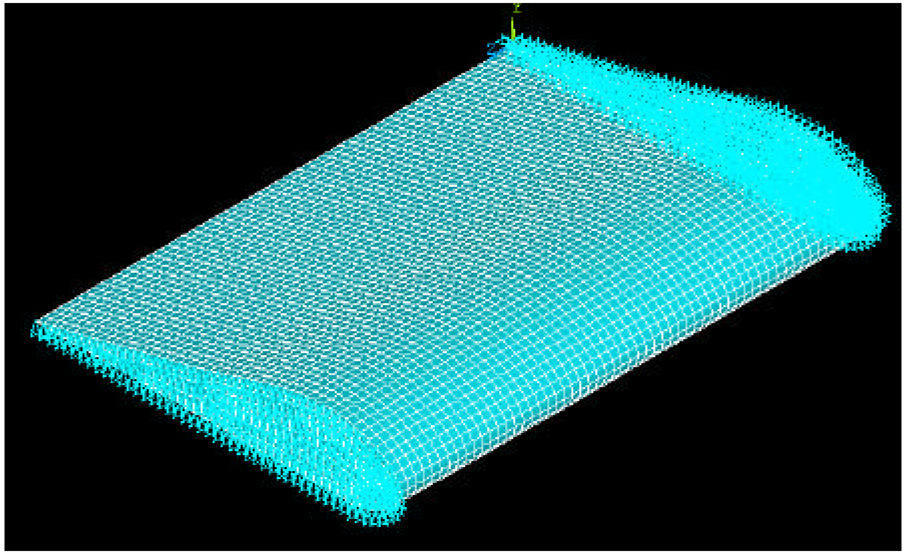
-dofs 50

Extrude 2-D mesh to obtain 50,000 Dofs

Elements sized to maintain nice aspect ratios

Wing Static Analyses

stype pcg, frontal, spar



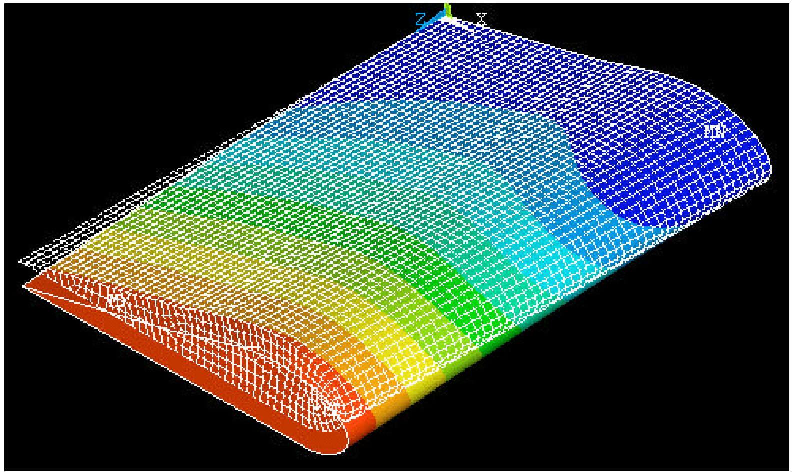
Fixed B.C.s at z=0.0

small negative y displacement at opposite end

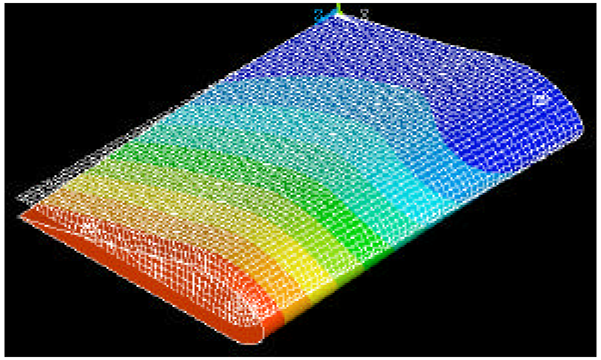
PowerSolver (pcg)

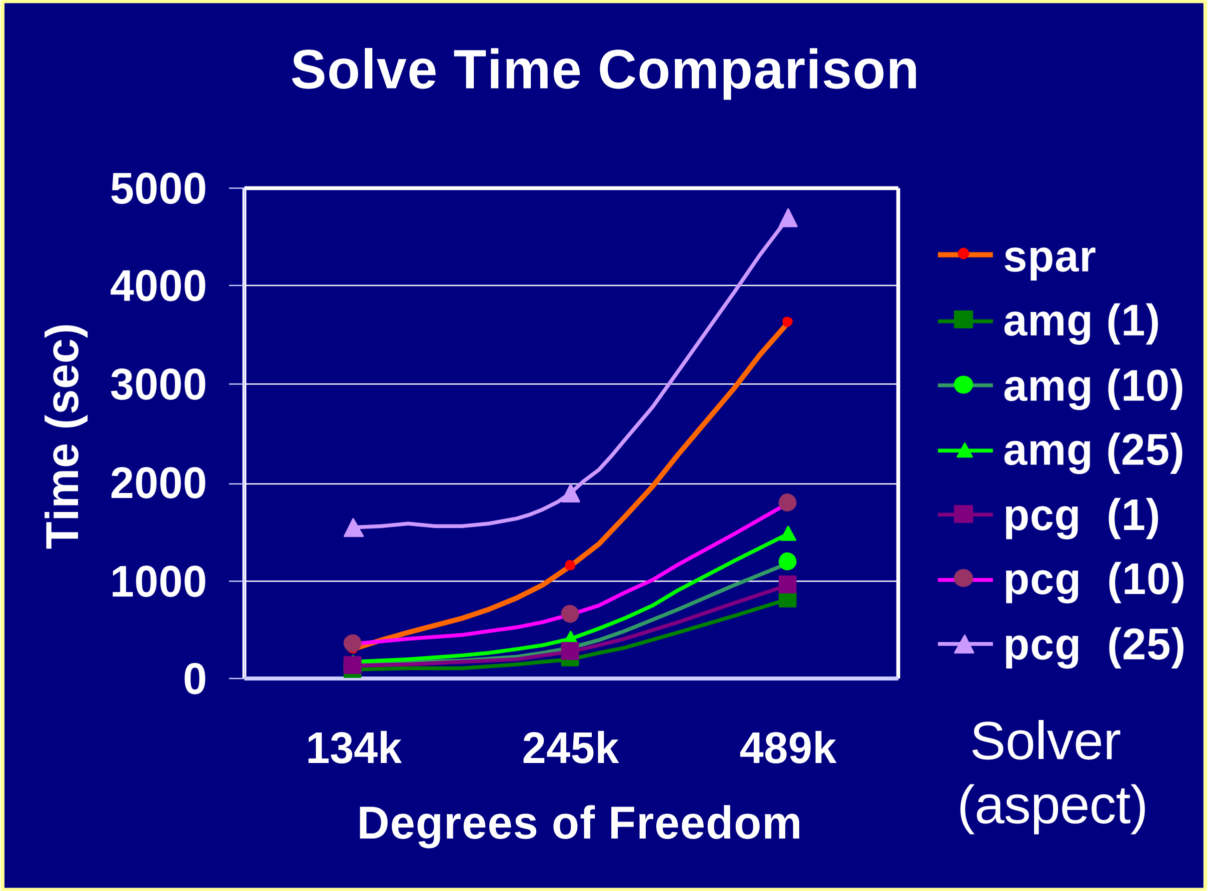
Frontal direct solver (frontal)

Sparse direct solver (spar)



Sparse Solvers Comparison





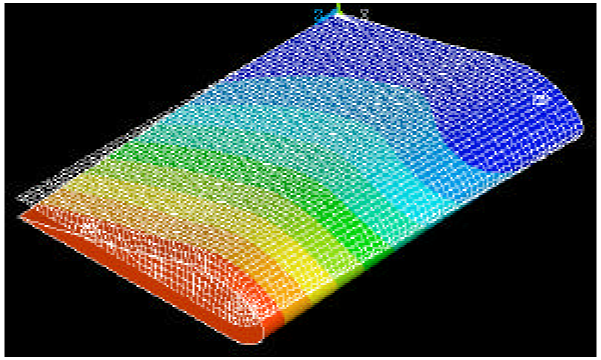
Static Analysis

HP L-Class

Four 550 Mhz CPUs

4 Gbytes Memory

Sparse Solvers Comparison



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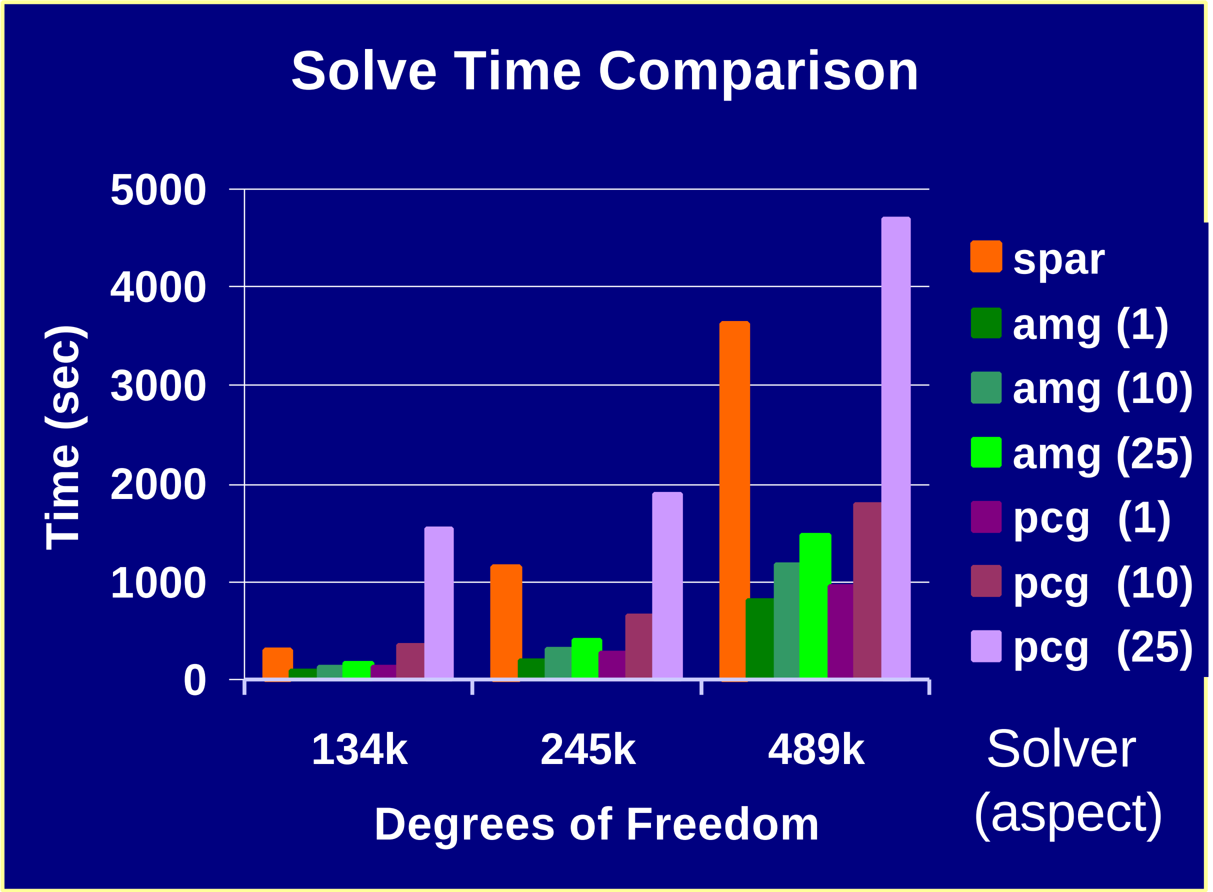
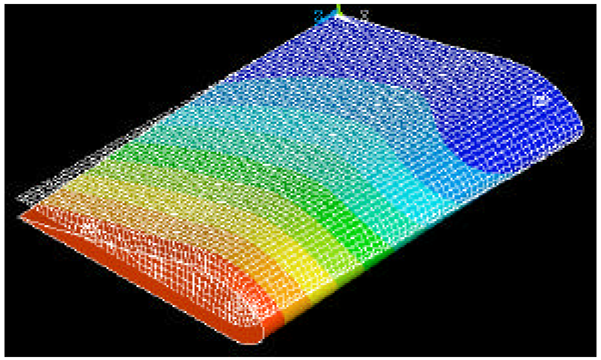


Increasing aspect ratio makes matrices Ill-conditioned

Sparse Solvers Comparison



Static Analysis

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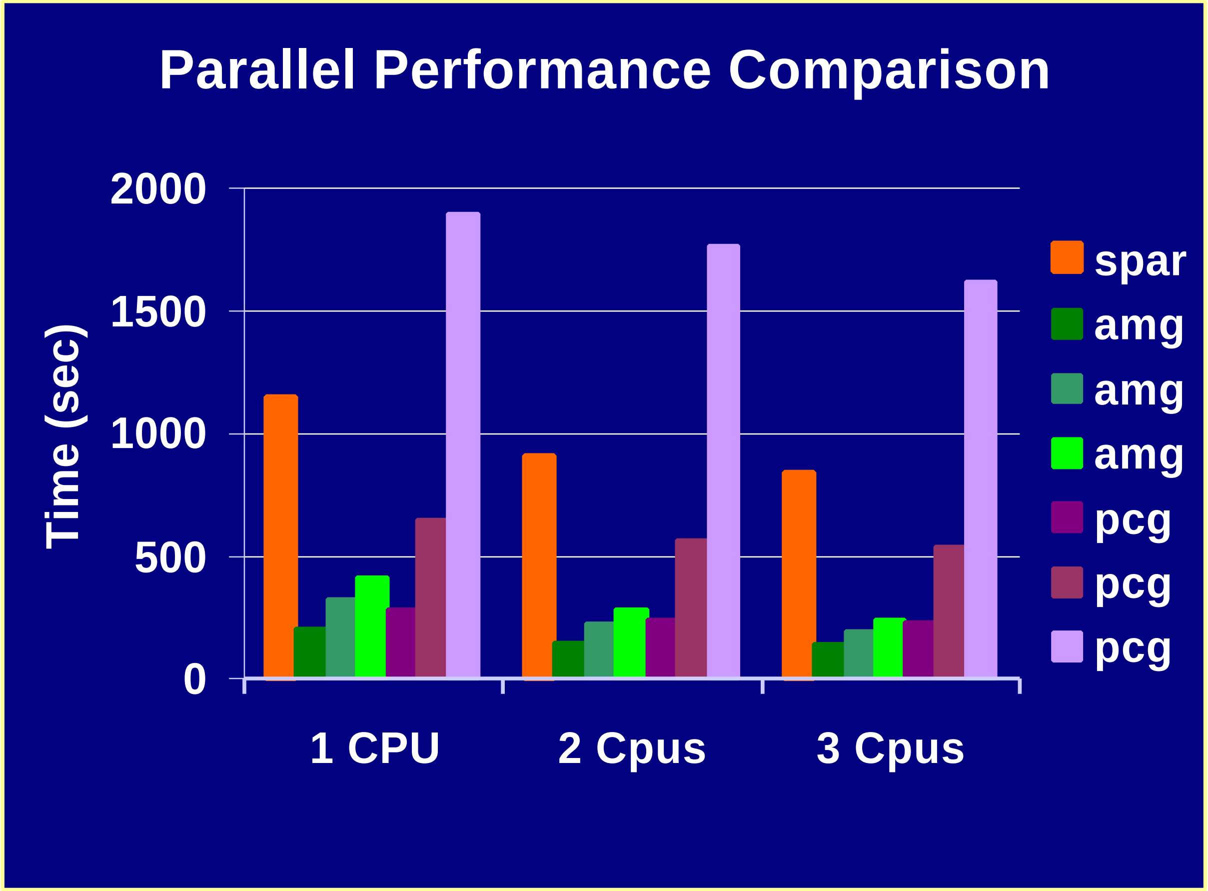
4 Gbytes Memory



Summary

- ANSYS has industry leading solver technology to support robust and comprehensive simulation capability
- Attention to solver capabilities and performance characteristics will extend analysis capabilities
- Future improvements will include increasing parallel processing capabilities and new breakthrough solver technologies