

# LAPACK Working Note 71

## IBM RS/6000-550 & -590 Performance for Selected Routines in ESSL\*/LAPACK /NAG<sup>†</sup>/IMSL<sup>‡§</sup>

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## 1 Overview

This document contains performance results for selected double-precision real and double-precision complex LAPACK routines and their equivalents in ESSL, NAG, and IMSL. The routines are listed in Figure 1.

## 2 Timing Environments

The experiments were conducted in two different timing environments: the IBM RS/6000-550 and the IBM RS/6000-590. In both cases the input matrices were identical for similar routines from different packages, thereby eliminating timing discrepancies resulting from pivoting, etc. Also, all timings were performed with no other users logged in to the machine.

### 2.1 IBM RS/6000 model 550

For the RS/6000 model 550 machine, routines were selected from the following four numerical algebra packages:

#### ESSL Version 2.2.1

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\*ESSL is a trademark of IBM.

<sup>†</sup>NAG is a trademark of The Numerical Algorithms Group Limited.

<sup>‡</sup>IMSL is a trademark of Visual Numerics, Inc.

<sup>§</sup>This work supported in part by the Office of Scientific Computing, U.S. Department of Energy, under Contract DE-AC05-84OR21400 and in part by IBM.

Figure 1: **The matched subroutines from each library and a brief description. Similar descriptions list the double-precision real routines before the double-precision complex.**

Description	LAPACK	ESSL	NAG	IMSL
General LU Factorization	DGETRF	DGEF	F07ADF	DLFTRG
General LU Factorization	ZGETRF	ZGEF	F07ARF	DLFTCG
Solve $Ax = b$ Using LU	DGETRS	DGESM	F07AEF	DLFSRG
Solve $Ax = b$ Using LU	ZGETRS	ZGESM	F07ASF	DLFSCG
Cholesky Factorization	DPOTRF	DPOF	F07FDF	DLFTDS
Cholesky Factorization	ZPOTRF	ZPOF	F07FRF	DLFTDH
Solve $Ax = b$ Using Cholesky	DPOTRS	DPOSM	F07FEF	DLFSDS
Solve $Ax = b$ Using Cholesky	ZPOTRS	ZPOSM	F07FSF	DLFSDH
Find Eigenvalues and Eigenvectors	DSPEV	DSLEV <sup>a</sup>	F02ABF	DEVSCF
Find Eigenvalues and Eigenvectors	ZHPEV	ZHLEV <sup>b</sup>	F02AXF	DEVSHF

<sup>a</sup>ESSL 2.2.1 accepts either DSPEV or DSLEV as the subroutine name for this routine; therefore, DSLEV has been used to prevent a name conflict with LAPACK's DSPEV. This is consistent throughout this report.

<sup>b</sup>ESSL 2.2.1 accepts either ZHPEV or ZHLEV as the subroutine name for this routine; therefore, ZHLEV has been used to prevent a name conflict with LAPACK's ZHPEV. This is consistent throughout this report.

## LAPACK 1.1

## NAG Mark 16

## IMSL Version 2.0

All of the timings were made under the following conditions:

- AIX 3.2.5 was the operating system.
- XLF 3.1 was the Fortran compiler.
- `xlf -O2 filename.f` was the compile command for **all** subroutines.
- `-lessl` was the ESSL library link for this architecture.
- The BLAS for all packages were supplied by the ESSL library. This gave all the packages an equal footing: that is to say, the algorithmic speed of different routines could be measured without an initial handicap of a slower or naive BLAS implementation.
- `READRTC` was the IBM-supplied utility subprogram for obtaining the timing data. It has a resolution of 1 microsecond.
- Blocksize selection routines were not modified for any of the blocking algorithms in any of the packages.

## 2.2 IBM RS/6000 model 590–256kByte data cache

For the IBM RS/6000 model 590 machine, routines were selected from the following two numerical algebra packages; IMSL and NAG have not yet been made available for the XLF 3.1 compiler on this architecture.

### ESSL Version 2.2.1

#### LAPACK 1.1

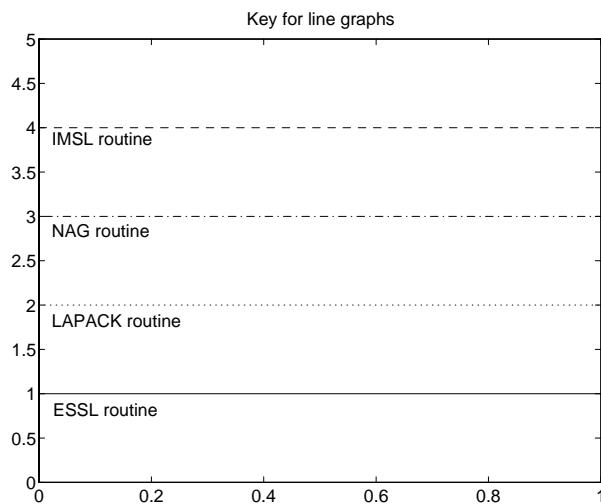
All of the timings were made under the following parameters:

- AIX 3.2.5 was the operating system.
- XLF 3.1 was the Fortran compiler.
- *xf -O2 -qarch=pwrx filename.f* was the compile command for **all** subroutines.
- *-lesslp2* was the ESSL library link for this architecture.
- The BLAS were supplied by the ESSL package. This gave all the packages an equal footing: that is to say, the algorithmic speed of different routines could be measured without an initial handicap of a slower or naive BLAS implementation.
- *READRTC* was the IBM-supplied utility subprogram for obtaining the timing data. It has a resolution of 1 microsecond.
- Blocksize selection routines were not modified for any of the blocking algorithms in any of the packages.

### 3 Results

In this section, we discuss the computational results for each routine. Also discussed are the tests that were performed to ensure the validity of the timing data, as well as any specifics to the implementation of the subroutine. The title of each subsection is the “4-tuple” of equivalent routines from ESSL, LAPACK, NAG, and IMSL, respectively.

All graphs utilize the following key:



Several points should be noted in reading the graphs:

- The data from both machines is graphed together; therefore, six lines appear on every graph (4 from the 550 and 2 from the 590). When two lines of the same type occur (only ESSL or LAPACK), the “faster” line always represents the IBM RS/6000-590. This format allows the comparison of all the numerical packages on the IBM RS/6000-550 as well as the contrast of ESSL and LAPACK on both machines.
- Some lines may overlap. In case of confusion, the timing data should be consulted.

### 3.1 *DGEF, DGETRF, F07ADF, DLFTRG*

The four routines *DGEF*, *DGETRF*, *F07ADF*, and *DLFTRG* compute the *LU* factorization of a general square *DOUBLE PRECISION* matrix. Note that NAG's implementation of *F07ADF* is LAPACK's *DGETRF*; consequently, the times are similar. Also, note that *DGEF* produces the same output format as *DGETRF*.

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

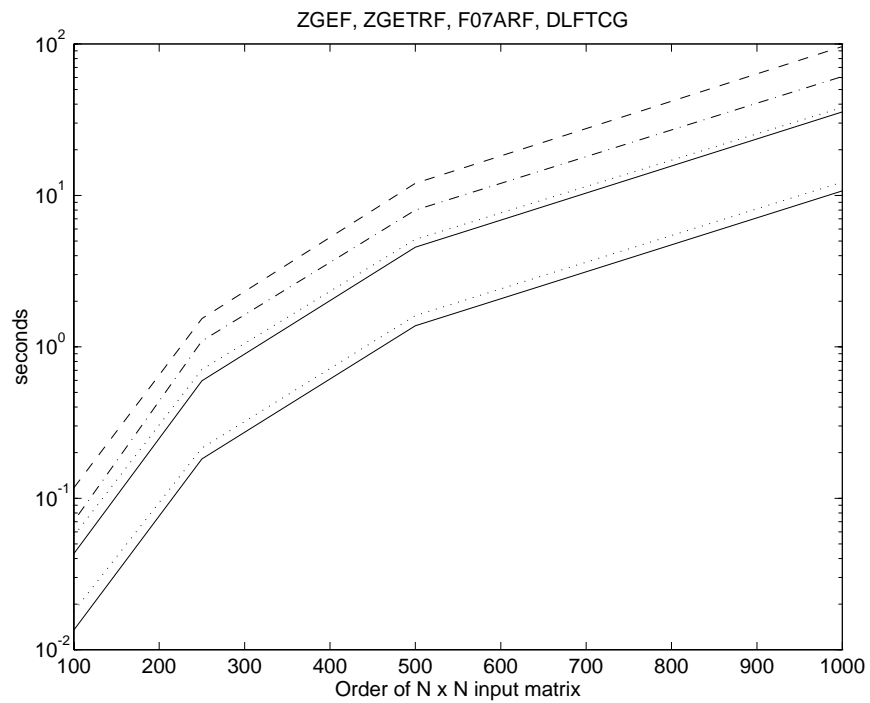
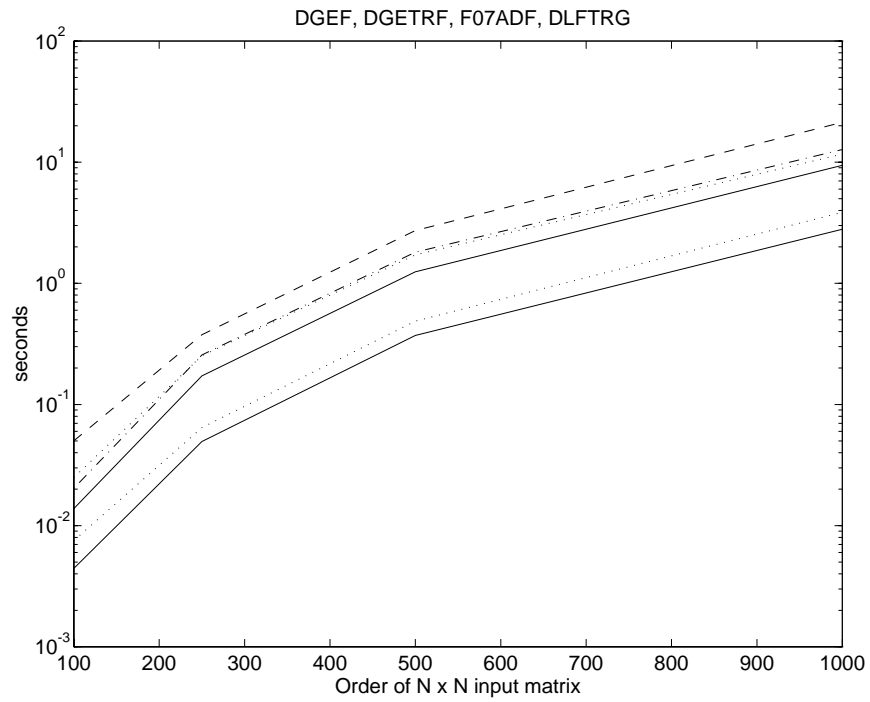
where  $\epsilon$  is the machine precision.

### 3.2 *ZGEF, ZGETRF, F07ARF, DLFTCG*

The routines *ZGEF*, *ZGETRF*, *F07ARF*, and *DLFTCG* compute the *LU* factorization of a general square *COMPLEX\*16* matrix. Note that NAG's implementation of *F07ARF* is LAPACK's *ZGETRF*; consequently, the times are similar. Also, note that *ZGEF* produces the same output format as *ZGETRF*. The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.



### 3.3 *DGESM, DGETRS, F07AE, DLFSRG*

The routines *DGESM*, *DGETRS*, *F07AEF*, and *DLFSRG* perform a DOUBLE PRECISION triangular solve, given a solution matrix and the factorization from Section 3.1. Note that NAG's implementation of *F07AEF*, ESSL's implementation of *DGESM*, and LAPACK's implementation of *DGETRS* are essentially the same; consequently, the times are similar. Also, IMSL's routine does not solve for multiple right-hand sides—rather, just a solution vector. Therefore, the following code was used to make IMSL's routine equivalent to the others:

```
DO 100 IRHS = 1, NRHS
    CALL DLFSRG(..., B( 1, IRHS ), ...)
100 CONTINUE
```

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.

### 3.4 *ZGESM, ZGETRS, F07ASF, DLFSCG*

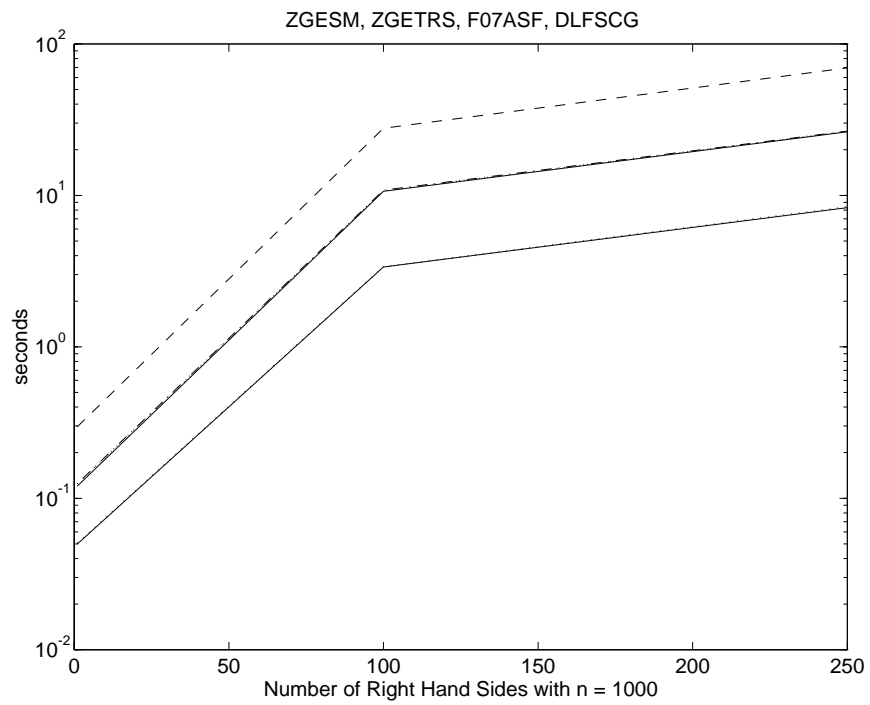
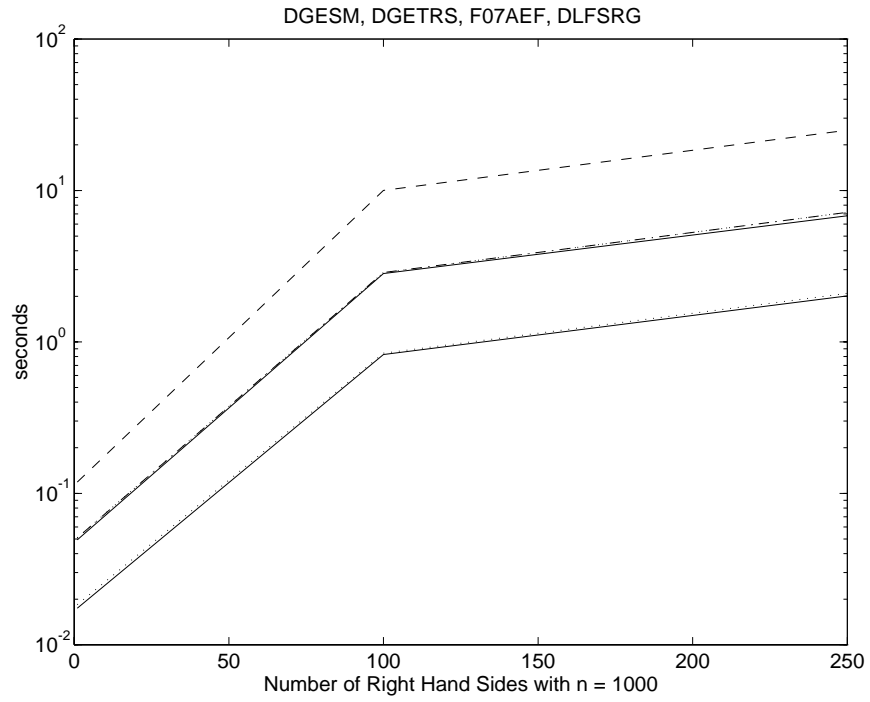
The routines *ZGESM*, *ZGETRS*, *F07ASF*, and *DLFSCG* perform a COMPLEX\*16 triangular solve, given a solution matrix and the factorization from Section 3.2. Note that NAG's implementation of *F07ASF*, ESSL's implementation of *ZGESM*, and LAPACK's implementation of *ZGETRS* are essentially the same; consequently, the times are similar. Also, IMSL's routine does not solve for multiple right-hand sides—rather, just a solution vector. Therefore, the following code was used to make IMSL's routine equivalent to the others:

```
DO 100 IRHS = 1, NRHS
    CALL DLFSCG(..., B( 1, IRHS ), ...)
100 CONTINUE
```

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.



### 3.5 *DPOF, DPOTRF, F07FDF, DLFTDS*

The routines *DPOF*, *DPOTRF*, *F07FDF*, and *DLFTDS* compute the Cholesky factorization of a symmetric positive definite **DOUBLE PRECISION** matrix. Note that NAG's implementation of *F07FDF* is LAPACK's *DPOTRF*; consequently, the times are similar. For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.

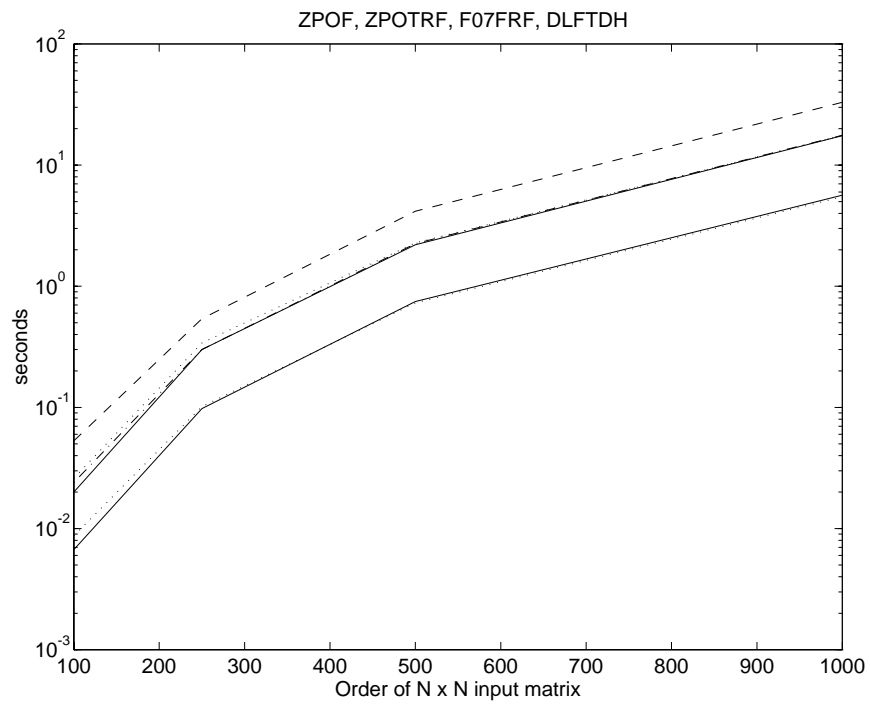
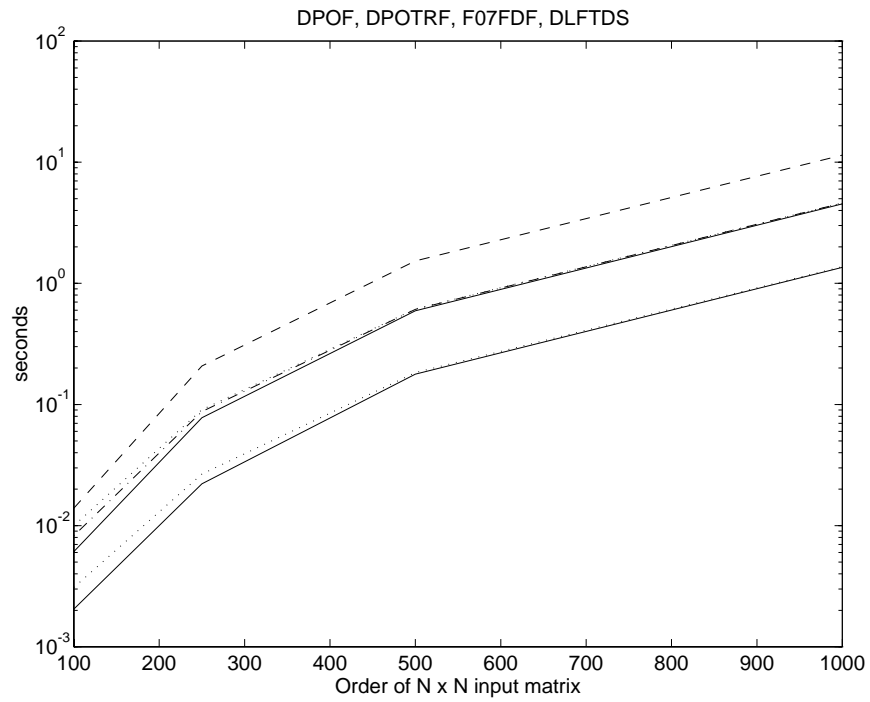
### 3.6 *ZPOF, ZPOTRF, F07FRF, DLFTDH*

These routines compute the Cholesky factorization of a Hermitian positive definite **COMPLEX\*16** matrix. Note that NAG's implementation of *F07FRF* is LAPACK's *ZPOTRF*; consequently, the times are similar. For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.



### 3.7 *DPOSM, DPOTRS, F07FEF, DLFSDS*

The routines *DPOSM*, *DPOTRS*, *F07FEF*, and *DLFSDS* perform a DOUBLE PRECISION triangular solve, given a solution matrix and the factorization from Section 3.5. Note that NAG's implementation of *F07FEF* is LAPACK's *DPOTRS*; consequently, the times are similar. Also, IMSL's routine does not solve for multiple right-hand sides—rather, just a solution vector. Therefore, the following code was used to make IMSL's routine equivalent to the others:

```
DO 100 IRHS = 1, NRHS
  CALL DLFSDS(..., B( 1, IRHS ), ...)
100 CONTINUE
```

For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.

### 3.8 *ZPOSM, ZPOTRS, F07FSF, DLFSDH*

The routines *ZPOSH*, *ZOTRS*, *F07FSF*, and *DLFSDH* do a COMPLEX\*16 triangular solve, given a solution matrix and the factorization from Section 3.6. Note that NAG's implementation of *F07FSF* is LAPACK's *ZPOTRS*; consequently, the times are similar. Also, IMSL's routine does not solve for multiple right-hand sides—rather, just a solution vector. Therefore, the following code was used to make IMSL's routine equivalent to the others:

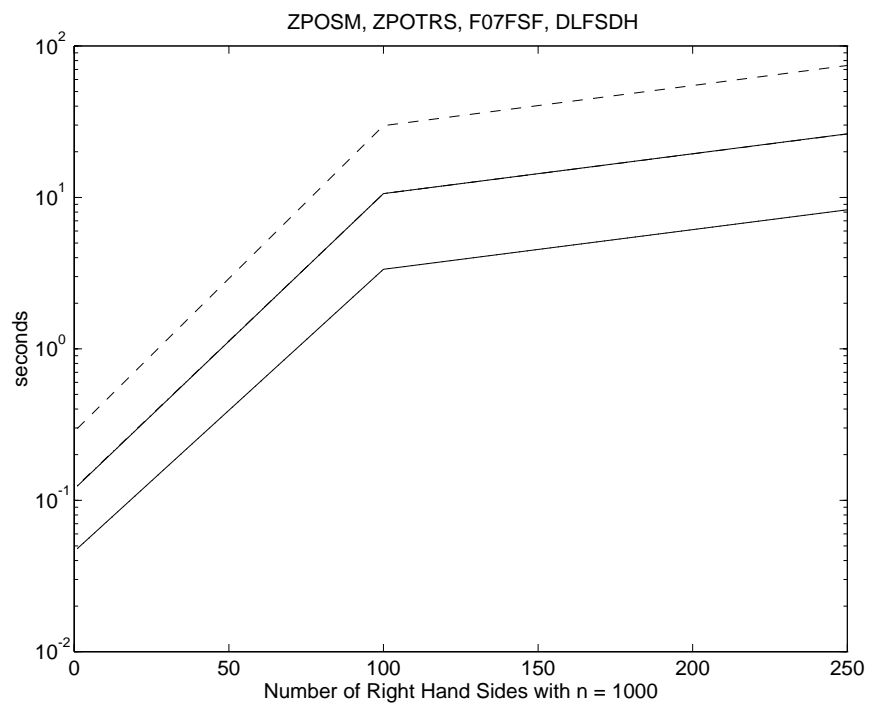
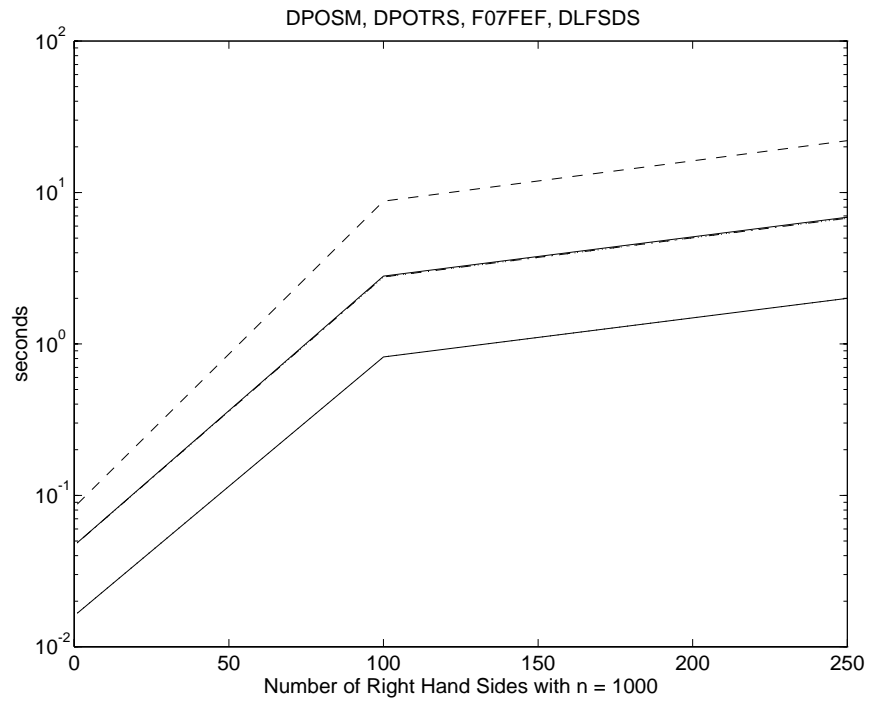
```
DO 100 IRHS = 1, NRHS
  CALL DLFSDH(..., B( 1, IRHS ), ...)
100 CONTINUE
```

For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|Ax-b\|}{\|A\|\|x\|}\epsilon$$

where  $\epsilon$  is the machine precision.



### 3.9 DSLEV, DSPEV, F02ABF, DEVSCF

The routines DSLEV, DSPEV, F02ABF, and DEVSCF compute the eigenvalues and eigenvectors of a DOUBLE PRECISION symmetric matrix. Unlike the first 8 routines, NAG's F02ABF is *not* equivalent to LAPACK's DSPEV. Also, LAPACK and ESSL use input matrices in *packed* form, whereas NAG and IMSL do not. For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|A - ZDZ^T\|}{\|A\| * n * \epsilon} \quad \text{and} \quad \frac{\|I - ZZ^T\|}{n * \epsilon}$$

where  $A$  is the symmetric input matrix of order  $n$ .  $Z$  contains the eigenvectors, and  $D$  contains the eigenvalues.  $I$  is the identity matrix, and  $\epsilon$  is the machine precision.

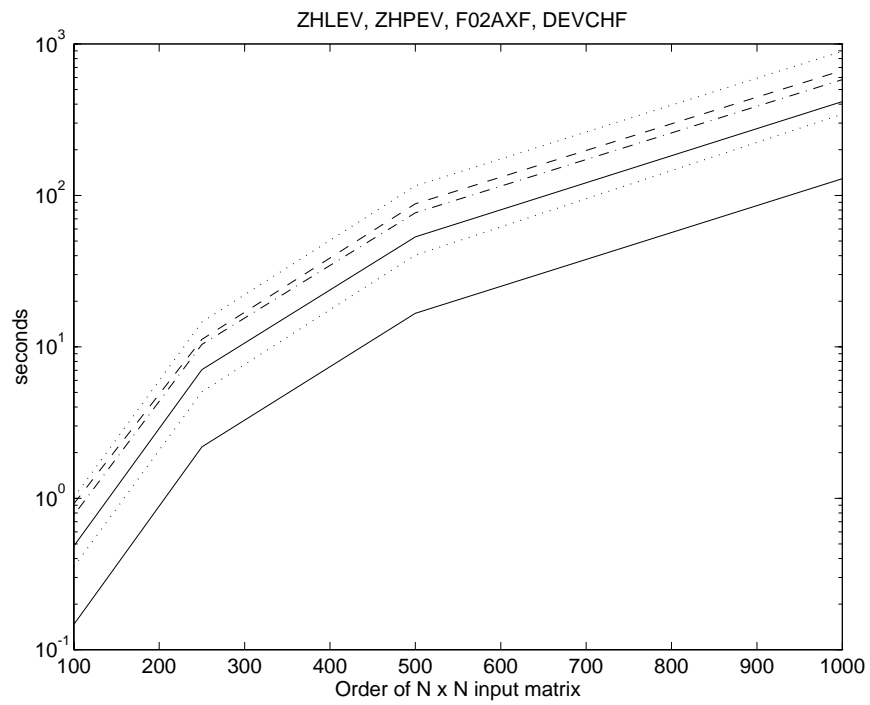
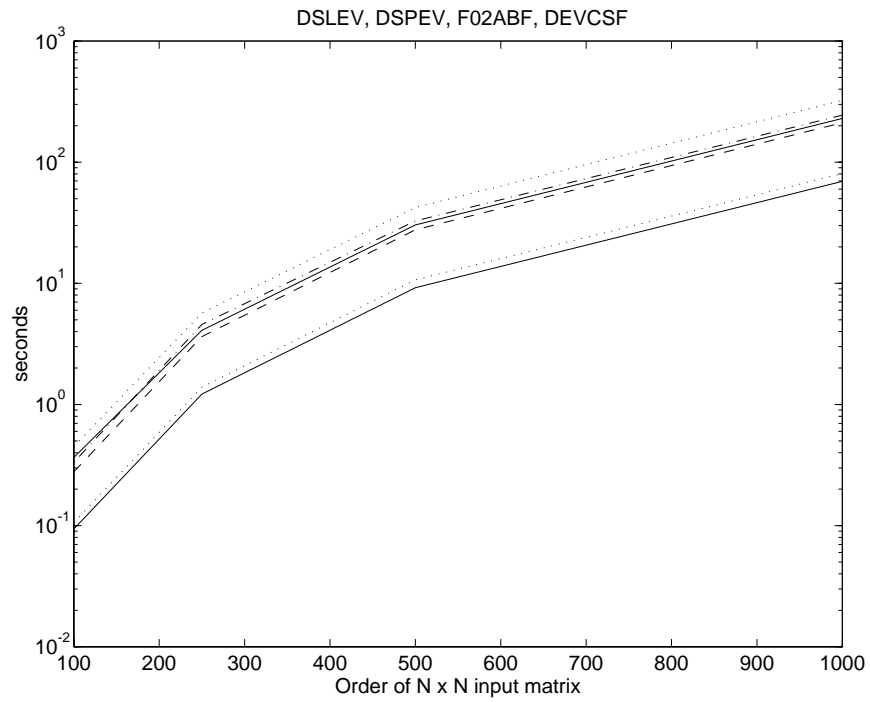
### 3.10 ZHLEV, ZHPEV, F02AXF, DEVCHF

These routines compute the eigenvalues and eigenvectors of a COMPLEX\*16 Hermitian matrix. Unlike the first 8 routines, NAG's F02AXF is NOT equivalent to LAPACK's ZHPEV. Also, LAPACK and ESSL use input matrices in *packed* form, whereas, NAG and IMSL do not. Further, NAG accepts its input matrix as two real matrices—one to hold the real values, and the other to hold the imaginary ones. ESSL, LAPACK, and IMSL accept one complex input matrix. For uniformity, the **upper** triangle is used for all timing data.

The following test was run to validate the results:

$$\frac{\|A - ZDZ^T\|}{\|A\| * n * \epsilon} \quad \text{and} \quad \frac{\|I - ZZ^T\|}{n * \epsilon}$$

where  $A$  is the symmetric input matrix of order  $n$ .  $Z$  contains the eigenvectors, and  $D$  contains the eigenvalues.  $I$  is the identity matrix, and  $\epsilon$  is the machine precision.



## 4 Discussion

All of the tested subroutines appear to be numerically correct on both the IBM RS/6000-550 and the new IBM RS/6000-590. Further, the ESSL subroutines achieve the overall best performance of all the packages used. Also, as a side note, the ESSL BLAS have been tested and appear error-free; better yet, they are optimized for both architectures (as most manufacturer's BLAS packages typically are). Consequently, it is recommended that the ESSL BLAS library be linked in front of the numerical analysis package of choice.

## A Timing Data

The following tables are output files of the times on the IBM RS/6000-550 and RS/6000-590, respectively. Counts for Megaflops are based upon the number of operations performed in the LAPACK routines.

### A.1 550.out

Numerical packages used in this timing set:

ESSL  
LAPACK  
NAG  
IMSL

The following parameter values will be used:

N : 100 250 500 1000  
NRHS : 1 100 250

Number of routine sets to be timed: 10

Start of Timings

\*\*\* Timing Set Separator \*\*\*

100 x	100		
DGEF	.01381	seconds	47.9 Mflops
DGETRF	.02494	seconds	26.5 Mflops
F07ADF	.02035	seconds	32.5 Mflops
DLFTRG	.05011	seconds	13.2 Mflops

250 x	250		
DGEF	.17203	seconds	60.4 Mflops
DGETRF	.25225	seconds	41.2 Mflops
F07ADF	.25609	seconds	40.6 Mflops
DLFTRG	.37602	seconds	27.6 Mflops

500 x	500		
DGEF	1.24526	seconds	66.8 Mflops
DGETRF	1.71697	seconds	48.5 Mflops
F07ADF	1.80797	seconds	46.0 Mflops
DLFTRG	2.73070	seconds	30.5 Mflops

1000 x	1000		
DGEF	9.42146	seconds	70.7 Mflops
DGETRF	11.64439	seconds	57.2 Mflops

F07ADF	12.71110	seconds	52.4 Mflops
DLFTRG	21.34845	seconds	31.2 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x	100		
ZGEF	.04310	seconds	61.6 Mflops
ZGETRF	.05652	seconds	47.0 Mflops
F07ARF	.07070	seconds	37.6 Mflops
DLFTCG	.11719	seconds	22.7 Mflops

250 x	250		
ZGEF	.59706	seconds	69.7 Mflops
ZGETRF	.70884	seconds	58.7 Mflops
F07ARF	1.09264	seconds	38.1 Mflops
DLFTCG	1.53696	seconds	27.1 Mflops

500 x	500		
ZGEF	4.55074	seconds	73.2 Mflops
ZGETRF	5.12570	seconds	65.0 Mflops
F07ARF	7.99196	seconds	41.7 Mflops
DLFTCG	12.03358	seconds	27.7 Mflops

1000 x	1000		
ZGEF	35.56992	seconds	74.9 Mflops
ZGETRF	38.09008	seconds	70.0 Mflops
F07ARF	60.93470	seconds	43.7 Mflops
DLFTCG	96.09003	seconds	27.7 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x	100		
Number of Right Hand Sides: 1			
DGESM	.00098	seconds	20.3 Mflops
DGETRS	.00095	seconds	21.0 Mflops
F07AEF	.00093	seconds	21.4 Mflops
DLFSRG	.00151	seconds	13.1 Mflops

Number of Right Hand Sides: 100			
DGESM	.03243	seconds	61.4 Mflops
DGETRS	.03545	seconds	56.1 Mflops
F07AEF	.03366	seconds	59.1 Mflops
DLFSRG	.13329	seconds	14.9 Mflops

Number of Right Hand Sides: 250			
DGESM	.07936	seconds	62.7 Mflops

DGETRS .10037 seconds 49.6 Mflops  
 F07AEF .09990 seconds 49.8 Mflops  
 DLFSRG .32836 seconds 15.2 Mflops

250 x 250

Number of Right Hand Sides: 1

DGESM .00416 seconds 30.0 Mflops  
 DGETRS .00454 seconds 27.5 Mflops  
 F07AEF .00452 seconds 27.6 Mflops  
 DLFSRG .00756 seconds 16.5 Mflops

Number of Right Hand Sides: 100

DGESM .18405 seconds 67.8 Mflops  
 DGETRS .19275 seconds 64.7 Mflops  
 F07AEF .20183 seconds 61.8 Mflops  
 DLFSRG .72633 seconds 17.2 Mflops

Number of Right Hand Sides: 250

DGESM .44774 seconds 69.7 Mflops  
 DGETRS .51719 seconds 60.3 Mflops  
 F07AEF .51731 seconds 60.3 Mflops  
 DLFSRG 1.85189 seconds 16.8 Mflops

500 x 500

Number of Right Hand Sides: 1

DGESM .01373 seconds 36.4 Mflops  
 DGETRS .01504 seconds 33.2 Mflops  
 F07AEF .01431 seconds 34.9 Mflops  
 DLFSRG .02635 seconds 19.0 Mflops

Number of Right Hand Sides: 100

DGESM .70717 seconds 70.6 Mflops  
 DGETRS .73682 seconds 67.8 Mflops  
 F07AEF .73388 seconds 68.1 Mflops  
 DLFSRG 2.65112 seconds 18.8 Mflops

Number of Right Hand Sides: 250

DGESM 1.72664 seconds 72.3 Mflops  
 DGETRS 1.88323 seconds 66.3 Mflops  
 F07AEF 1.88731 seconds 66.2 Mflops  
 DLFSRG 6.62045 seconds 18.9 Mflops

1000 x 1000

Number of Right Hand Sides: 1

DGESM .04934 seconds 40.5 Mflops  
 DGETRS .05089 seconds 39.3 Mflops  
 F07AEF .05084 seconds 39.3 Mflops  
 DLFSRG .11866 seconds 16.8 Mflops

Number of Right Hand Sides: 100

DGESM 2.82658 seconds 70.7 Mflops  
 DGETRS 2.87006 seconds 69.7 Mflops  
 F07AEF 2.87292 seconds 69.6 Mflops  
 DLFSRG 10.00971 seconds 20.0 Mflops

Number of Right Hand Sides: 250

DGESM 6.80839 seconds 73.4 Mflops  
 DGETRS 7.16865 seconds 69.7 Mflops  
 F07AEF 7.16805 seconds 69.7 Mflops  
 DLFSRG 24.98881 seconds 20.0 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

Number of Right Hand Sides: 1

ZGESM .00199 seconds 40.2 Mflops  
 ZGETRS .00186 seconds 42.8 Mflops  
 F07ASF .00185 seconds 43.1 Mflops  
 DLFSCG .00360 seconds 22.2 Mflops

Number of Right Hand Sides: 100

ZGESM .11402 seconds 70.0 Mflops  
 ZGETRS .11581 seconds 68.9 Mflops  
 F07ASF .11489 seconds 69.5 Mflops  
 DLFSCG .33419 seconds 23.9 Mflops

Number of Right Hand Sides: 250

ZGESM .27961 seconds 71.3 Mflops  
 ZGETRS .30154 seconds 66.2 Mflops  
 F07ASF .30331 seconds 65.8 Mflops  
 DLFSCG .83361 seconds 23.9 Mflops

250 x 250

Number of Right Hand Sides: 1

ZGESM .00908 seconds 55.0 Mflops  
 ZGETRS .00934 seconds 53.5 Mflops  
 F07ASF .00930 seconds 53.7 Mflops  
 DLFSCG .01874 seconds 26.7 Mflops

Number of Right Hand Sides: 100

ZGESM .67880 seconds 73.6 Mflops  
 ZGETRS .69327 seconds 72.0 Mflops  
 F07ASF .69315 seconds 72.1 Mflops  
 DLFSCG 1.87768 seconds 26.6 Mflops

Number of Right Hand Sides: 250

ZGESM 1.67864 seconds 74.4 Mflops  
 ZGETRS 1.75167 seconds 71.3 Mflops

F07ASF 1.75228 seconds 71.3 Mflops  
 DLFSCG 4.69669 seconds 26.6 Mflops

500 x 500

Number of Right Hand Sides: 1

ZGESM .03174 seconds 63.0 Mflops  
 ZGETRS .03260 seconds 61.3 Mflops  
 F07ASF .03256 seconds 61.4 Mflops  
 DLFSCG .07207 seconds 27.7 Mflops

Number of Right Hand Sides: 100

ZGESM 2.68238 seconds 74.5 Mflops  
 ZGETRS 2.74301 seconds 72.9 Mflops  
 F07ASF 2.71448 seconds 73.6 Mflops  
 DLFSCG 7.15520 seconds 27.9 Mflops

Number of Right Hand Sides: 250

ZGESM 6.60774 seconds 75.6 Mflops  
 ZGETRS 6.77147 seconds 73.8 Mflops  
 F07ASF 6.77807 seconds 73.7 Mflops  
 DLFSCG 17.91578 seconds 27.9 Mflops

1000 x 1000

Number of Right Hand Sides: 1

ZGESM .12028 seconds 66.5 Mflops  
 ZGETRS .12446 seconds 64.3 Mflops  
 F07ASF .12465 seconds 64.2 Mflops  
 DLFSCG .29612 seconds 27.0 Mflops

Number of Right Hand Sides: 100

ZGESM 10.64363 seconds 75.1 Mflops  
 ZGETRS 10.75328 seconds 74.4 Mflops  
 F07ASF 10.82651 seconds 73.9 Mflops  
 DLFSCG 27.78095 seconds 28.8 Mflops

Number of Right Hand Sides: 250

ZGESM 26.27937 seconds 76.1 Mflops  
 ZGETRS 26.60404 seconds 75.2 Mflops  
 F07ASF 26.60625 seconds 75.2 Mflops  
 DLFSCG 69.50199 seconds 28.8 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

DPOF .00610 seconds 55.5 Mflops  
 DPOTRF .01000 seconds 33.8 Mflops  
 F07FDF .00825 seconds 41.0 Mflops  
 DLFTDS .01395 seconds 24.2 Mflops

250 x 250

DPOF .07776 seconds 67.4 Mflops  
 DPOTRF .09048 seconds 57.9 Mflops  
 F07FDF .08737 seconds 60.0 Mflops  
 DLFTDS .20766 seconds 25.2 Mflops

500 x 500

DPOF .59384 seconds 70.4 Mflops  
 DPOTRF .61534 seconds 67.9 Mflops  
 F07FDF .60912 seconds 68.6 Mflops  
 DLFTDS 1.53247 seconds 27.3 Mflops

1000 x 1000

DPOF 4.52868 seconds 73.7 Mflops  
 DPOTRF 4.61709 seconds 72.3 Mflops  
 F07FDF 4.60352 seconds 72.5 Mflops  
 DLFTDS 11.43321 seconds 29.2 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

ZPOF .01926 seconds 70.8 Mflops  
 ZPOTRF .02563 seconds 53.2 Mflops  
 F07FRF .02449 seconds 55.7 Mflops  
 DLFTDH .05344 seconds 25.5 Mflops

250 x 250

ZPOF .28881 seconds 72.8 Mflops  
 ZPOTRF .33835 seconds 62.1 Mflops  
 F07FRF .30192 seconds 69.6 Mflops  
 DLFTDH .54172 seconds 38.8 Mflops

500 x 500

ZPOF 2.22075 seconds 75.4 Mflops  
 ZPOTRF 2.28085 seconds 73.4 Mflops  
 F07FRF 2.24692 seconds 74.5 Mflops  
 DLFTDH 4.15906 seconds 40.3 Mflops

1000 x 1000

ZPOF 17.47949 seconds 76.5 Mflops  
 ZPOTRF 17.60942 seconds 75.9 Mflops  
 F07FRF 17.63009 seconds 75.8 Mflops  
 DLFTDH 33.04114 seconds 40.4 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100  
 Number of Right Hand Sides: 1  
 DPOSM .00069 seconds 28.9 Mflops  
 DPOTRS .00071 seconds 28.3 Mflops  
 F07FEF .00067 seconds 29.7 Mflops  
 DLFSDS .00118 seconds 17.0 Mflops  
 Number of Right Hand Sides: 100  
 DPOSM .03128 seconds 63.9 Mflops  
 DPOTRS .03120 seconds 64.1 Mflops  
 F07FEF .03115 seconds 64.2 Mflops  
 DLFSDS .11143 seconds 17.9 Mflops  
 Number of Right Hand Sides: 250  
 DPOSM .07549 seconds 66.2 Mflops  
 DPOTRS .07571 seconds 66.0 Mflops  
 F07FEF .07523 seconds 66.5 Mflops  
 DLFSDS .27968 seconds 17.9 Mflops

250 x 250  
 Number of Right Hand Sides: 1  
 DPOSM .00380 seconds 32.9 Mflops  
 DPOTRS .00394 seconds 31.7 Mflops  
 F07FEF .00371 seconds 33.7 Mflops  
 DLFSDS .00656 seconds 19.0 Mflops  
 Number of Right Hand Sides: 100  
 DPOSM .17960 seconds 69.6 Mflops  
 DPOTRS .17742 seconds 70.5 Mflops  
 F07FEF .17874 seconds 69.9 Mflops  
 DLFSDS .65458 seconds 19.1 Mflops  
 Number of Right Hand Sides: 250  
 DPOSM .43529 seconds 71.8 Mflops  
 DPOTRS .43542 seconds 71.8 Mflops  
 F07FEF .43321 seconds 72.1 Mflops  
 DLFSDS 1.63897 seconds 19.1 Mflops

500 x 500  
 Number of Right Hand Sides: 1  
 DPOSM .01336 seconds 37.4 Mflops  
 DPOTRS .01334 seconds 37.5 Mflops  
 F07FEF .01315 seconds 38.0 Mflops  
 DLFSDS .02355 seconds 21.2 Mflops  
 Number of Right Hand Sides: 100

DPOSM .69936 seconds 71.5 Mflops  
 DPOTRS .69738 seconds 71.7 Mflops  
 F07FEF .69636 seconds 71.8 Mflops  
 DLFSDS 2.41227 seconds 20.7 Mflops  
 Number of Right Hand Sides: 250  
 DPOSM 1.70554 seconds 73.3 Mflops  
 DPOTRS 1.70593 seconds 73.3 Mflops  
 F07FEF 1.70174 seconds 73.5 Mflops  
 DLFSDS 5.93529 seconds 21.1 Mflops

1000 x 1000  
 Number of Right Hand Sides: 1  
 DPOSM .04870 seconds 41.1 Mflops  
 DPOTRS .04843 seconds 41.3 Mflops  
 F07FEF .04851 seconds 41.2 Mflops  
 DLFSDS .08741 seconds 22.9 Mflops  
 Number of Right Hand Sides: 100  
 DPOSM 2.80515 seconds 71.3 Mflops  
 DPOTRS 2.76205 seconds 72.4 Mflops  
 F07FEF 2.76806 seconds 72.3 Mflops  
 DLFSDS 8.77114 seconds 22.8 Mflops  
 Number of Right Hand Sides: 250  
 DPOSM 6.87006 seconds 72.8 Mflops  
 DPOTRS 6.75116 seconds 74.1 Mflops  
 F07FEF 6.75768 seconds 74.0 Mflops  
 DLFSDS 21.99848 seconds 22.7 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100  
 Number of Right Hand Sides: 1  
 ZPOSM .00171 seconds 47.1 Mflops  
 ZPOTRS .00188 seconds 42.7 Mflops  
 F07FSF .00167 seconds 48.2 Mflops  
 DLFS DH .00381 seconds 21.1 Mflops  
 Number of Right Hand Sides: 100  
 ZPOSM .11168 seconds 72.0 Mflops  
 ZPOTRS .11189 seconds 71.9 Mflops  
 F07FSF .11170 seconds 72.0 Mflops  
 DLFS DH .35981 seconds 22.3 Mflops  
 Number of Right Hand Sides: 250  
 ZPOSM .27350 seconds 73.5 Mflops  
 ZPOTRS .27320 seconds 73.6 Mflops  
 F07FSF .27353 seconds 73.5 Mflops

DLFSDH .90033 seconds 22.3 Mflops

250 x 250  
Number of Right Hand Sides: 1

ZPOSM .01001 seconds 50.1 Mflops  
ZPOTRS .00903 seconds 55.5 Mflops  
F07FSF .00900 seconds 55.7 Mflops  
DLFSDH .02047 seconds 24.5 Mflops

Number of Right Hand Sides: 100

ZPOSM .67220 seconds 74.5 Mflops  
ZPOTRS .67288 seconds 74.5 Mflops  
F07FSF .67110 seconds 74.7 Mflops  
DLFSDH 2.04851 seconds 24.5 Mflops

Number of Right Hand Sides: 250

ZPOSM 1.65947 seconds 75.5 Mflops  
ZPOTRS 1.66043 seconds 75.4 Mflops  
F07FSF 1.65710 seconds 75.6 Mflops  
DLFSDH 5.19694 seconds 24.1 Mflops

500 x 500  
Number of Right Hand Sides: 1

ZPOSM .03274 seconds 61.2 Mflops  
ZPOTRS .03290 seconds 60.9 Mflops  
F07FSF .03435 seconds 58.3 Mflops  
DLFSDH .07759 seconds 25.8 Mflops

Number of Right Hand Sides: 100

ZPOSM 2.67634 seconds 74.8 Mflops  
ZPOTRS 2.67118 seconds 74.9 Mflops  
F07FSF 2.66576 seconds 75.1 Mflops  
DLFSDH 8.20426 seconds 24.4 Mflops

Number of Right Hand Sides: 250

ZPOSM 6.64089 seconds 75.4 Mflops  
ZPOTRS 6.62695 seconds 75.5 Mflops  
F07FSF 6.57015 seconds 76.2 Mflops  
DLFSDH 19.32584 seconds 25.9 Mflops

1000 x 1000  
Number of Right Hand Sides: 1

ZPOSM .12407 seconds 64.5 Mflops  
ZPOTRS .12392 seconds 64.6 Mflops  
F07FSF .12514 seconds 64.0 Mflops  
DLFSDH .29777 seconds 26.9 Mflops

Number of Right Hand Sides: 100

ZPOSM 10.60525 seconds 75.5 Mflops

ZPOTRS 10.60409 seconds 75.5 Mflops  
F07FSF 10.59904 seconds 75.5 Mflops  
DLFSDH 29.74984 seconds 26.9 Mflops

Number of Right Hand Sides: 250

ZPOSM 26.29174 seconds 76.1 Mflops  
ZPOTRS 26.22856 seconds 76.3 Mflops  
F07FSF 26.25879 seconds 76.2 Mflops  
DLFSDH 74.42543 seconds 26.9 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

DSLEV .36523 seconds 21.7 Mflops  
DSPEV .44989 seconds 17.6 Mflops  
F02ABF .33433 seconds 23.7 Mflops  
DEVCSF .27842 seconds 28.5 Mflops

250 x 250

DSLEV 4.10146 seconds 28.7 Mflops  
DSPEV 5.70087 seconds 20.6 Mflops  
F02ABF 4.57444 seconds 25.7 Mflops  
DEVCSF 3.63383 seconds 32.4 Mflops

500 x 500

DSLEV 30.30769 seconds 30.1 Mflops  
DSPEV 42.34420 seconds 21.5 Mflops  
F02ABF 32.73366 seconds 27.9 Mflops  
DEVCSF 27.66989 seconds 33.0 Mflops

1000 x 1000

DSLEV 229.48141 seconds 31.1 Mflops  
DSPEV 323.34836 seconds 22.1 Mflops  
F02ABF 244.58197 seconds 29.2 Mflops  
DEVCSF 211.76927 seconds 33.8 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

ZHLEV .48390 seconds 37.4 Mflops  
ZHPEV 1.01247 seconds 17.9 Mflops  
F02AXF .77370 seconds 23.4 Mflops  
DEVCHF .91984 seconds 19.7 Mflops

250 x 250

ZHLEV	7.06681	seconds	38.5	Mflops
ZHPEV	14.56624	seconds	18.7	Mflops
FO2AXF	10.37188	seconds	26.3	Mflops
DEVCHF	11.19001	seconds	24.3	Mflops

500 x 500

ZHLEV	53.18078	seconds	41.4	Mflops
ZHPEV	115.52283	seconds	19.1	Mflops
FO2AXF	76.70922	seconds	28.7	Mflops
DEVCHF	87.96585	seconds	25.0	Mflops

1000 x 1000

ZHLEV	415.99728	seconds	41.4	Mflops
ZHPEV	895.60843	seconds	19.2	Mflops
FO2AXF	580.77693	seconds	29.7	Mflops
DEVCHF	668.79005	seconds	25.8	Mflops

End of Timings

## A.2 590.out

Numerical packages used in this timing set:

ESSL

LAPACK

The following parameter values will be used:

N : 100 250 500 1000

NRHS : 1 100 250

Number of routine sets to be timed: 10

Start of Timings

\*\*\* Timing Set Separator \*\*\*

100 x 100

DGEF .00444 seconds 148.9 Mflops

DGETRF .00753 seconds 87.9 Mflops

250 x 250

DGEF .04951 seconds 209.7 Mflops

DGETRF .06439 seconds 161.3 Mflops

500 x 500

DGEF .37139 seconds 224.0 Mflops

DGETRF .48771 seconds 170.6 Mflops

1000 x 1000

DGEF 2.79424 seconds 238.4 Mflops

DGETRF 3.85433 seconds 172.8 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

ZGEF .01348 seconds 197.1 Mflops

ZGETRF .01794 seconds 148.1 Mflops

250 x 250

ZGEF .18206 seconds 228.5 Mflops

ZGETRF .21470 seconds 193.8 Mflops

500 x 500

ZGEF 1.37634 seconds 242.0 Mflops

ZGETRF 1.60849 seconds 207.1 Mflops

1000 x 1000

ZGEF 10.70659 seconds 249.0 Mflops

ZGETRF 12.22530 seconds 218.0 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

Number of Right Hand Sides: 1

DGESM .00034 seconds 58.0 Mflops

DGETRS .00032 seconds 61.6 Mflops

Number of Right Hand Sides: 100

DGESM .00921 seconds 216.0 Mflops

DGETRS .00907 seconds 219.5 Mflops

Number of Right Hand Sides: 250

DGESM .02303 seconds 216.0 Mflops

DGETRS .02276 seconds 218.6 Mflops

250 x 250

Number of Right Hand Sides: 1

DGESM .00130 seconds 95.9 Mflops

DGETRS .00163 seconds 76.6 Mflops

Number of Right Hand Sides: 100

DGESM .05454 seconds 228.7 Mflops

DGETRS .05426 seconds 229.9 Mflops

Number of Right Hand Sides: 250

DGESM .13310 seconds 234.3 Mflops

DGETRS .13962 seconds 223.4 Mflops

500 x 500

Number of Right Hand Sides: 1

DGESM .00505 seconds 98.9 Mflops

DGETRS .00535 seconds 93.4 Mflops

Number of Right Hand Sides: 100

DGESM .20915 seconds 238.8 Mflops

DGETRS .21124 seconds 236.5 Mflops

Number of Right Hand Sides: 250

DGESM .51023 seconds 244.7 Mflops

DGETRS .53649 seconds 232.8 Mflops

1000 x 1000

Number of Right Hand Sides: 1

DGESM .01743 seconds 114.7 Mflops

DGETRS .01841 seconds 108.6 Mflops

Number of Right Hand Sides: 100

DGESM .82599 seconds 242.0 Mflops  
 DGETRS .84246 seconds 237.3 Mflops  
 Number of Right Hand Sides: 250  
 DGESM 2.01335 seconds 248.2 Mflops  
 DGETRS 2.09311 seconds 238.8 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100  
 Number of Right Hand Sides: 1  
 ZGESM .00075 seconds 105.8 Mflops  
 ZGETRS .00075 seconds 106.0 Mflops  
 Number of Right Hand Sides: 100  
 ZGESM .04781 seconds 166.9 Mflops  
 ZGETRS .04794 seconds 166.5 Mflops  
 Number of Right Hand Sides: 250  
 ZGESM .11915 seconds 167.4 Mflops  
 ZGETRS .11995 seconds 166.3 Mflops

250 x 250  
 Number of Right Hand Sides: 1  
 ZGESM .00368 seconds 135.7 Mflops  
 ZGETRS .00389 seconds 128.3 Mflops  
 Number of Right Hand Sides: 100  
 ZGESM .24832 seconds 201.2 Mflops  
 ZGETRS .24924 seconds 200.4 Mflops  
 Number of Right Hand Sides: 250  
 ZGESM .61376 seconds 203.5 Mflops  
 ZGETRS .62532 seconds 199.7 Mflops

500 x 500  
 Number of Right Hand Sides: 1  
 ZGESM .01323 seconds 151.1 Mflops  
 ZGETRS .01370 seconds 145.9 Mflops  
 Number of Right Hand Sides: 100  
 ZGESM .89052 seconds 224.5 Mflops  
 ZGETRS .94063 seconds 212.5 Mflops  
 Number of Right Hand Sides: 250  
 ZGESM 2.20119 seconds 227.0 Mflops  
 ZGETRS 2.23438 seconds 223.7 Mflops

1000 x 1000  
 Number of Right Hand Sides: 1  
 ZGESM .04983 seconds 160.5 Mflops

ZGETRS .05070 seconds 157.7 Mflops  
 Number of Right Hand Sides: 100  
 ZGESM 3.36467 seconds 237.7 Mflops  
 ZGETRS 3.38821 seconds 236.1 Mflops  
 Number of Right Hand Sides: 250  
 ZGESM 8.30722 seconds 240.7 Mflops  
 ZGETRS 8.43493 seconds 237.1 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100  
 DPOF .00205 seconds 164.8 Mflops  
 DPOTRF .00309 seconds 109.5 Mflops

250 x 250  
 DPOF .02216 seconds 236.4 Mflops  
 DPOTRF .02668 seconds 196.4 Mflops

500 x 500  
 DPOF .17797 seconds 234.8 Mflops  
 DPOTRF .18328 seconds 228.0 Mflops

1000 x 1000  
 DPOF 1.35571 seconds 246.2 Mflops  
 DPOTRF 1.37470 seconds 242.8 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100  
 ZPOF .00672 seconds 202.8 Mflops  
 ZPOTRF .00871 seconds 156.5 Mflops

250 x 250  
 ZPOF .09775 seconds 215.1 Mflops  
 ZPOTRF .10162 seconds 206.9 Mflops

500 x 500  
 ZPOF .74767 seconds 223.9 Mflops  
 ZPOTRF .72744 seconds 230.1 Mflops

1000 x 1000  
 ZPOF 5.63974 seconds 236.9 Mflops  
 ZPOTRF 5.47636 seconds 244.0 Mflops

\*\*\* Timing Set Separator \*\*\*

```

100 x 100
  Number of Right Hand Sides: 1
DPOSM .00023 seconds 85.9 Mflops
DPOTRS .00023 seconds 85.6 Mflops
  Number of Right Hand Sides: 100
DPOSM .00854 seconds 234.2 Mflops
DPOTRS .00851 seconds 235.1 Mflops
  Number of Right Hand Sides: 250
DPOSM .02121 seconds 235.8 Mflops
DPOTRS .02139 seconds 233.8 Mflops

250 x 250
  Number of Right Hand Sides: 1
DPOSM .00126 seconds 99.1 Mflops
DPOTRS .00125 seconds 99.8 Mflops
  Number of Right Hand Sides: 100
DPOSM .05260 seconds 237.7 Mflops
DPOTRS .05256 seconds 237.8 Mflops
  Number of Right Hand Sides: 250
DPOSM .12891 seconds 242.4 Mflops
DPOTRS .12849 seconds 243.2 Mflops

500 x 500
  Number of Right Hand Sides: 1
DPOSM .00469 seconds 106.6 Mflops
DPOTRS .00460 seconds 108.8 Mflops
  Number of Right Hand Sides: 100
DPOSM .20583 seconds 242.9 Mflops
DPOTRS .20610 seconds 242.6 Mflops
  Number of Right Hand Sides: 250
DPOSM .50275 seconds 248.6 Mflops
DPOTRS .50278 seconds 248.6 Mflops

1000 x 1000
  Number of Right Hand Sides: 1
DPOSM .01666 seconds 120.0 Mflops
DPOTRS .01669 seconds 119.8 Mflops
  Number of Right Hand Sides: 100
DPOSM .82002 seconds 243.9 Mflops
DPOTRS .82039 seconds 243.8 Mflops
  Number of Right Hand Sides: 250
DPOSM 2.00066 seconds 249.9 Mflops

```

DPOTRS 2.00077 seconds 249.9 Mflops

\*\*\* Timing Set Separator \*\*\*

```

100 x 100
  Number of Right Hand Sides: 1
ZPOSM .00068 seconds 118.9 Mflops
ZPOTRS .00068 seconds 118.4 Mflops
  Number of Right Hand Sides: 100
ZPOSM .04690 seconds 171.4 Mflops
ZPOTRS .04699 seconds 171.1 Mflops
  Number of Right Hand Sides: 250
ZPOSM .11626 seconds 172.9 Mflops
ZPOTRS .11628 seconds 172.9 Mflops

250 x 250
  Number of Right Hand Sides: 1
ZPOSM .00350 seconds 143.3 Mflops
ZPOTRS .00346 seconds 144.8 Mflops
  Number of Right Hand Sides: 100
ZPOSM .24578 seconds 203.8 Mflops
ZPOTRS .24638 seconds 203.3 Mflops
  Number of Right Hand Sides: 250
ZPOSM .60861 seconds 205.8 Mflops
ZPOTRS .60818 seconds 205.9 Mflops

500 x 500
  Number of Right Hand Sides: 1
ZPOSM .01284 seconds 155.9 Mflops
ZPOTRS .01286 seconds 155.7 Mflops
  Number of Right Hand Sides: 100
ZPOSM .88620 seconds 225.9 Mflops
ZPOTRS .88635 seconds 225.9 Mflops
  Number of Right Hand Sides: 250
ZPOSM 2.18976 seconds 228.6 Mflops
ZPOTRS 2.19077 seconds 228.5 Mflops

1000 x 1000
  Number of Right Hand Sides: 1
ZPOSM .04790 seconds 167.1 Mflops
ZPOTRS .04784 seconds 167.3 Mflops
  Number of Right Hand Sides: 100
ZPOSM 3.35386 seconds 238.7 Mflops
ZPOTRS 3.35393 seconds 238.6 Mflops

```

Number of Right Hand Sides: 250

ZPOSM 8.27809 seconds 241.7 Mflops  
ZPOTRS 8.28052 seconds 241.7 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

DSLEV .09377 seconds 84.7 Mflops  
DSPEV .10606 seconds 74.9 Mflops

250 x 250

DSLEV 1.21790 seconds 96.7 Mflops  
DSPEV 1.38857 seconds 84.8 Mflops

500 x 500

DSLEV 9.18926 seconds 99.3 Mflops  
DSPEV 10.68463 seconds 85.4 Mflops

1000 x 1000

DSLEV 69.46343 seconds 102.9 Mflops  
DSPEV 80.43700 seconds 88.9 Mflops

\*\*\* Timing Set Separator \*\*\*

100 x 100

ZHLEV .14683 seconds 123.2 Mflops  
ZHPEV .35243 seconds 51.3 Mflops

250 x 250

ZHLEV 2.18221 seconds 124.8 Mflops  
ZHPEV 5.04441 seconds 54.0 Mflops

500 x 500

ZHLEV 16.64748 seconds 132.3 Mflops  
ZHPEV 40.33818 seconds 54.6 Mflops

1000 x 1000

ZHLEV 128.84442 seconds 133.8 Mflops  
ZHPEV 343.85137 seconds 50.1 Mflops

End of Timings