NAG Library Routine Document

F07GSF (ZPPTRS)

Note: before using this routine, please read the Users' Note for your implementation to check the interpretation of ***bold italicised*** terms and other implementation-dependent details.

1 Purpose

F07GSF (ZPPTRS) solves a complex Hermitian positive-definite system of linear equations with multiple right-hand sides,

$$AX = B,$$

where A has been factorized by F07GRF (ZPPTRF), using packed storage.

2 Specification

```
SUBROUTINE F07GSF(UPLO, N, NRHS, AP, B, LDB, INFO)
INTEGER           N, NRHS, LDB, INFO
complex*16        AP(*), B(LDB,*)
CHARACTER*1       UPLO
```

The routine may be called by its LAPACK name ***zpptrs***.

3 Description

F07GSF (ZPPTRS) is used to solve a complex Hermitian positive-definite system of linear equations $AX = B$, the routine must be preceded by a call to F07GRF (ZPPTRF) which computes the Cholesky factorization of A, using packed storage. The solution X is computed by forward and backward substitution.

If UPLO = 'U', $A = U^{\mathrm{H}}U$, where U is upper triangular; the solution X is computed by solving $U^{\mathrm{H}}Y = B$ and then $UX = Y$.

If UPLO = 'L', $A = LL^{\mathrm{H}}$, where L is lower triangular; the solution X is computed by solving $LY = B$ and then $L^{\mathrm{H}}X = Y$.

4 References

Golub G H and Van Loan C F (1996) *Matrix Computations* (3rd Edition) Johns Hopkins University Press, Baltimore

5 Parameters

1: UPLO – CHARACTER*1 *Input*

On entry: indicates how A has been factorized.

UPLO = 'U'
$A = U^{\mathrm{H}}U$, where U is upper triangular.

UPLO = 'L'
$A = LL^{\mathrm{H}}$, where L is lower triangular.

Constraint: UPLO = 'U' or 'L'.

2: N – INTEGER *Input*

On entry: n, the order of the matrix A.

Constraint: $\mathrm{N} \geq 0$.

3: NRHS – INTEGER *Input*

On entry: r, the number of right-hand sides.

Constraint: $\mathrm{NRHS} \geq 0$.

4: AP$(*)$ – ***complex*16*** array *Input*

Note: the dimension of the array AP must be at least $\max(1, \mathrm{N} \times (\mathrm{N}+1)/2)$.

On entry: the Cholesky factor of A stored in packed form, as returned by F07GRF (ZPPTRF).

5: B(LDB,$*$) – ***complex*16*** array *Input/Output*

Note: the second dimension of the array B must be at least $\max(1, \mathrm{NRHS})$.

On entry: the n by r right-hand side matrix B.

On exit: the n by r solution matrix X.

6: LDB – INTEGER *Input*

On entry: the first dimension of the array B as declared in the (sub)program from which F07GSF (ZPPTRS) is called.

Constraint: $\mathrm{LDB} \geq \max(1, \mathrm{N})$.

7: INFO – INTEGER *Output*

On exit: INFO $= 0$ unless the routine detects an error (see Section 6).

6 Error Indicators and Warnings

Errors or warnings detected by the routine:

INFO < 0

If INFO $= -i$, the ith parameter had an illegal value. An explanatory message is output, and execution of the program is terminated.

7 Accuracy

For each right-hand side vector b, the computed solution x is the exact solution of a perturbed system of equations $(A+E)x = b$, where

if UPLO = 'U', $|E| \leq c(n)\epsilon \left|U^{\mathrm{H}}\right||U|$;

if UPLO = 'L', $|E| \leq c(n)\epsilon |L|\left|L^{\mathrm{H}}\right|$,

$c(n)$ is a modest linear function of n, and ϵ is the ***machine precision***.

If $\hat{x}$ is the true solution, then the computed solution x satisfies a forward error bound of the form

$$\frac{\|x-\hat{x}\|_\infty}{\|x\|_\infty} \leq c(n)\,\mathrm{cond}(A,x)\epsilon$$

where $\mathrm{cond}(A,x) = \left\|\left|A^{-1}\right||A||x|\right\|_\infty / \|x\|_\infty \leq \mathrm{cond}(A) = \left\|\left|A^{-1}\right||A|\right\|_\infty \leq \kappa_\infty(A)$.

Note that $\mathrm{cond}(A,x)$ can be much smaller than $\mathrm{cond}(A)$.

Forward and backward error bounds can be computed by calling F07GVF (ZPPRFS), and an estimate for $\kappa_\infty(A)$ ($= \kappa_1(A)$) can be obtained by calling F07GUF (ZPPCON).

8 Further Comments

The total number of real floating-point operations is approximately $8n^2r$.

This routine may be followed by a call to F07GVF (ZPPRFS) to refine the solution and return an error estimate.

The real analogue of this routine is F07GEF (DPPTRS).

9 Example

This example solves the system of equations $AX = B$, where

$$A = \begin{pmatrix} 3.23 + 0.00i & 1.51 - 1.92i & 1.90 + 0.84i & 0.42 + 2.50i \\ 1.51 + 1.92i & 3.58 + 0.00i & -0.23 + 1.11i & -1.18 + 1.37i \\ 1.90 - 0.84i & -0.23 - 1.11i & 4.09 + 0.00i & 2.33 - 0.14i \\ 0.42 - 2.50i & -1.18 - 1.37i & 2.33 + 0.14i & 4.29 + 0.00i \end{pmatrix}$$

and

$$B = \begin{pmatrix} 3.93 - 6.14i & 1.48 + 6.58i \\ 6.17 + 9.42i & 4.65 - 4.75i \\ -7.17 - 21.83i & -4.91 + 2.29i \\ 1.99 - 14.38i & 7.64 - 10.79i \end{pmatrix}.$$

Here A is Hermitian positive-definite, stored in packed form, and must first be factorized by F07GRF (ZPPTRF).

9.1 Program Text

```
*     F07GSF Example Program Text
*     Mark 15 Release. NAG Copyright 1991.
*     .. Parameters ..
      INTEGER          NIN, NOUT
      PARAMETER        (NIN=5,NOUT=6)
      INTEGER          NMAX, NRHMAX, LDB
      PARAMETER        (NMAX=8,NRHMAX=NMAX,LDB=NMAX)
*     .. Local Scalars ..
      INTEGER          I, IFAIL, INFO, J, N, NRHS
      CHARACTER        UPLO
*     .. Local Arrays ..
      COMPLEX *16      AP(NMAX*(NMAX+1)/2), B(LDB,NRHMAX)
      CHARACTER        CLABS(1), RLABS(1)
*     .. External Subroutines ..
      EXTERNAL         X04DBF, ZPPTRF, ZPPTRS
*     .. Executable Statements ..
      WRITE (NOUT,*) 'F07GSF Example Program Results'
*     Skip heading in data file
      READ (NIN,*)
      READ (NIN,*) N, NRHS
      IF (N.LE.NMAX .AND. NRHS.LE.NRHMAX) THEN
*
*        Read A and B from data file
*
         READ (NIN,*) UPLO
         IF (UPLO.EQ.'U') THEN
            READ (NIN,*) ((AP(I+J*(J-1)/2),J=I,N),I=1,N)
         ELSE IF (UPLO.EQ.'L') THEN
            READ (NIN,*) ((AP(I+(2*N-J)*(J-1)/2),J=1,I),I=1,N)
         END IF
         READ (NIN,*) ((B(I,J),J=1,NRHS),I=1,N)
*
*        Factorize A
*
         CALL ZPPTRF(UPLO,N,AP,INFO)
*
         WRITE (NOUT,*)
```

```
         IF (INFO.EQ.0) THEN
*
*           Compute solution
*
            CALL ZPPTRS(UPLO,N,NRHS,AP,B,LDB,INFO)
*
*           Print solution
*
            IFAIL = 0
            CALL X04DBF('General',' ',N,NRHS,B,LDB,'Bracketed','F7.4',
     +                  'Solution(s)','Integer',RLABS,'Integer',CLABS,
     +                  80,0,IFAIL)
         ELSE
            WRITE (NOUT,*) 'A is not positive-definite'
         END IF
      END IF
*
      END
```

9.2 Program Data

```
F07GSF Example Program Data
  4  2                                                    :Values of N and NRHS
  'L'                                                     :Value of UPLO
 (3.23, 0.00)
 (1.51, 1.92) ( 3.58, 0.00)
 (1.90,-0.84) (-0.23,-1.11) ( 4.09, 0.00)
 (0.42,-2.50) (-1.18,-1.37) ( 2.33, 0.14) ( 4.29, 0.00)  :End of matrix A
 ( 3.93, -6.14) ( 1.48,  6.58)
 ( 6.17,  9.42) ( 4.65, -4.75)
 (-7.17,-21.83) (-4.91,  2.29)
 ( 1.99,-14.38) ( 7.64,-10.79)                           :End of matrix B
```

9.3 Program Results

```
 F07GSF Example Program Results

 Solution(s)
                      1                   2
 1  ( 1.0000,-1.0000) (-1.0000, 2.0000)
 2  ( 0.0000, 3.0000) ( 3.0000,-4.0000)
 3  (-4.0000,-5.0000) (-2.0000, 3.0000)
 4  ( 2.0000, 1.0000) ( 4.0000,-5.0000)
```