

NAG Fortran Library Routine Document

F08WSF (CGGHRD/ZGGHRD)

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

F08WSF (CGGHRD/ZGGHRD) reduces a pair of complex matrices (A, B) , where B is upper triangular, to the generalized upper Hessenberg form using unitary transformations.

2 Specification

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SUBROUTINE F08WSF (COMPQ, COMPZ, N, ILO, IHI, A, LDA, B, LDB, Q, LDQ, Z,
1              LDZ, INFO)
ENTRY          cgghrd (COMPQ, COMPZ, N, ILO, IHI, A, LDA, B, LDB, Q, LDQ, Z,
1              LDZ, INFO)
INTEGER        N, ILO, IHI, LDA, LDB, LDQ, LDZ, INFO
complex      A(LDA,*), B(LDB,*), Q(LDQ,*), Z(LDZ,*)
CHARACTER*1    COMPQ, COMPZ

```

The ENTRY statement enables the routine to be called by its LAPACK name.

3 Description

F08WSF (CGGHRD/ZGGHRD) is usually the third step in the solution of the complex generalized eigenvalue problem

$$Ax = \lambda Bx.$$

The (optional) first step balances the two matrices using F08WVF (CGGBAL/ZGGBAL). In the second step, matrix B is reduced to upper triangular form using the QR factorization routine F08ASF (CGEQRF/ZGEQRF) and this unitary transformation Q is applied to matrix A by calling F08AUF (CUNMQR/ZUNMQR).

F08WSF (CGGHRD/ZGGHRD) reduces a pair of complex matrices (A, B) , where B is triangular, to the generalized upper Hessenberg form using unitary transformations. This two-sided transformation is of the form

$$\begin{aligned} Q^H AZ &= H \\ Q^H BZ &= T \end{aligned}$$

where H is an upper Hessenberg matrix, T is an upper triangular matrix and Q and Z are unitary matrices determined as products of Givens rotations. They may either be formed explicitly, or they may be postmultiplied into input matrices Q_1 and Z_1 , so that

$$\begin{aligned} Q_1 AZ_1^H &= (Q_1 Q) H (Z_1 Z)^H, \\ Q_1 BZ_1^H &= (Q_1 Q) T (Z_1 Z)^H. \end{aligned}$$

4 References

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

Moler C B and Stewart G W (1973) An algorithm for generalized matrix eigenproblems *SIAM J. Numer. Anal.* **10** 241–256

5 Parameters

- 1: COMPQ – CHARACTER*1 *Input*
On entry: specifies the form of the computed unitary matrix Q , as follows:
 if COMPQ = 'N', do not compute Q ;
 if COMPQ = 'T', the unitary matrix Q is returned;
 if COMPQ = 'V', Q must contain a unitary matrix Q_1 , and the product Q_1Q is returned.
Constraint: COMPQ = 'N', 'T' or 'V'.
- 2: COMPZ – CHARACTER*1 *Input*
On entry: specifies the form of the computed unitary matrix Z , as follows:
 if COMPZ = 'N', do not compute Z ;
 if COMPZ = 'T', the unitary matrix Z is returned;
 if COMPZ = 'V', Z must contain a unitary matrix Z_1 , and the product Z_1Z is returned.
Constraint: COMPZ = 'N', 'T' or 'V'.
- 3: N – INTEGER *Input*
On entry: n , the order of the matrices A and B .
Constraint: $N \geq 0$.
- 4: ILO – INTEGER *Input*
 5: IHI – INTEGER *Input*
On entry: i_{lo} and i_{hi} as determined by a previous call to F08WVF (CGGBAL/ZGGBAL). Otherwise, they should be set to 1 and n , respectively.
Constraints:
 $1 \leq ILO \leq IHI \leq N$ if $N > 0$;
 $ILO = 1$ and $IHI = 0$ if $N = 0$.
- 6: A(LDA,*) – **complex** array *Input/Output*
Note: the second dimension of the array A must be at least $\max(1, N)$.
On entry: the matrix A of the matrix pair (A, B) . Usually, this is the matrix A returned by F08AUF (CUNMQR/ZUNMQR).
On exit: A is overwritten by the upper Hessenberg matrix H .
- 7: LDA – INTEGER *Input*
On entry: the first dimension of the array A as declared in the (sub)program from which F08WSF (CGGHRD/ZGGHRD) is called.
Constraint: $LDA \geq \max(1, N)$.
- 8: B(LDB,*) – **complex** array *Input/Output*
Note: the second dimension of the array B must be at least $\max(1, N)$.
On entry: the upper triangular matrix B of the matrix pair (A, B) . Usually, this is the matrix B returned by the QR factorization routine F08ASF (CGEQRF/ZGEQRF).
On exit: B is overwritten by the upper triangular matrix T .

- 9: LDB – INTEGER *Input*
On entry: the first dimension of the array B as declared in the (sub)program from which F08WSF (CGGHRD/ZGGHRD) is called.
Constraint: $LDB \geq \max(1, N)$.
- 10: Q(LDQ,*) – **complex** array *Input/Output*
Note: the second dimension of the array Q must be at least $\max(1, N)$.
On entry: if COMPQ = 'N', Q is not referenced; if COMPQ = 'V', Q must contain a unitary matrix Q_1 .
On exit: if COMPQ = 'I', Q contains the unitary matrix Q ; if COMPQ = 'V', Q is overwritten by $Q_1 Q$.
- 11: LDQ – INTEGER *Input*
On entry: the first dimension of the array Q as declared in the (sub)program from which F08WSF (CGGHRD/ZGGHRD) is called.
Constraints:
 $LDQ \geq 1$ if COMPQ = 'N',
 $LDQ \geq \max(1, N)$ if COMPQ = 'I' or 'V'.
- 12: Z(LDZ,*) – **complex** array *Input/Output*
Note: the second dimension of the array Z must be at least $\max(1, N)$.
On entry: if COMPZ = 'N', Z is not referenced; if COMPZ = 'V', Z must contain a unitary matrix Z_1 .
On exit: if COMPZ = 'I', Z contains the unitary matrix Z ; if COMPZ = 'V', Z is overwritten by $Z_1 Z$.
- 13: LDZ – INTEGER *Input*
On entry: the first dimension of the array Z as declared in the (sub)program from which F08WSF (CGGHRD/ZGGHRD) is called.
Constraints:
 $LDZ \geq 1$ if COMPZ = 'N',
 $LDZ \geq \max(1, N)$ if COMPZ = 'V' or 'I'.
- 14: 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 i th parameter had an illegal value. An explanatory message is output, and execution of the program is terminated.

7 Accuracy

The reduction to the generalized Hessenberg form is implemented using unitary transformations which are backward stable.

8 Further Comments

This routine is usually followed by F08XSF (CHGEQZ/ZHGEQZ) which implements the *QZ* algorithm for computing generalized eigenvalues of a reduced pair of matrices.

The real analogue of this routine is F08WEF (SGGHRD/DGGHRD).

9 Example

See Section 9 of the documents for F08XSF (CHGEQZ/ZHGEQZ) and F08YXF (CTGEVC/ZTGEVC).
