NAG Library Routine Document

F08VSF (ZGGSVP)

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

F08VSF (ZGGSVP) uses unitary transformations to simultaneously reduce the m by n matrix A and the p by n matrix B to upper triangular form. This factorization is usually used as a preprocessing step for computing the generalized singular value decomposition (GSVD).

2 Specification

```
      SUBROUTINE F08VSF(JOBU, JOBV, JOBQ, M, P, N, A, LDA, B, LDB, TOLA, TOLB,
     1                  K, L, U, LDU, V, LDV, Q, LDQ, IWORK, RWORK, TAU, WORK,
     2                  INFO)
      INTEGER           M, P, N, LDA, LDB, K, L, LDU, LDV, LDQ, IWORK(N), INFO
      double precision  TOLA, TOLB, RWORK(2*N)
      complex*16        A(LDA,*), B(LDB,*), U(LDU,*), V(LDV,*), Q(LDQ,*),
     1                  TAU(N), WORK(max(3*N,M,P))
      CHARACTER*1       JOBU, JOBV, JOBQ
```

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

3 Description

F08VSF (ZGGSVP) computes unitary matrices U, V and Q such that

$$U^{\mathrm{H}}AQ = \begin{cases} \begin{array}{c c} & \begin{array}{ccc} n-k-l & k & l \end{array} \\ \begin{array}{r} k \\ l \\ m-k-l \end{array} & \begin{pmatrix} 0 & A_{12} & A_{13} \\ 0 & 0 & A_{23} \\ 0 & 0 & 0 \end{pmatrix} \end{array}, & \text{if } m-k-l \geq 0; \\ \begin{array}{c c} & \begin{array}{ccc} n-k-l & k & l \end{array} \\ \begin{array}{r} k \\ m-k \end{array} & \begin{pmatrix} 0 & A_{12} & A_{13} \\ 0 & 0 & A_{23} \end{pmatrix} \end{array}, & \text{if } m-k-l < 0; \end{cases}$$

$$V^{\mathrm{H}}BQ = \begin{array}{c c} & \begin{array}{ccc} n-k-l & k & l \end{array} \\ \begin{array}{r} l \\ p-l \end{array} & \begin{pmatrix} 0 & 0 & B_{13} \\ 0 & 0 & 0 \end{pmatrix} \end{array}$$

where the k by k matrix A_{12} and l by l matrix B_{13} are nonsingular upper triangular; A_{23} is l by l upper triangular if $m-k-l \geq 0$ and is $(m-k)$ by l upper trapezoidal otherwise. $(k+l)$ is the effective numerical rank of the $(m+p)$ by n matrix $\begin{pmatrix} A^{\mathrm{H}} & B^{\mathrm{H}} \end{pmatrix}^{\mathrm{H}}$.

This decomposition is usually used as the preprocessing step for computing the Generalized Singular Value Decomposition (GSVD), see routine F08VNF (ZGGSVD).

4 References

Anderson E, Bai Z, Bischof C, Blackford S, Demmel J, Dongarra J J, Du Croz J J, Greenbaum A, Hammarling S, McKenney A and Sorensen D (1999) *LAPACK Users' Guide* (3rd Edition) SIAM, Philadelphiahttp://www.netlib.org/lapack/lug

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

5 Parameters

1: JOBU – CHARACTER*1 *Input*

On entry: if JOBU = 'U', the orthogonal matrix U is computed.

If JOBU = 'N', U is not computed.

Constraint: JOBU = 'U' or 'N'.

2: JOBV – CHARACTER*1 *Input*

On entry: if JOBV = 'V', the unitary matrix V is computed.

If JOBV = 'N', V is not computed.

Constraint: JOBV = 'V' or 'N'.

3: JOBQ – CHARACTER*1 *Input*

On entry: if JOBQ = 'Q', the unitary matrix Q is computed.

If JOBQ = 'N', Q is not computed.

Constraint: JOBQ = 'Q' or 'N'.

4: M – INTEGER *Input*

On entry: m, the number of rows of the matrix A.

Constraint: M ≥ 0.

5: P – INTEGER *Input*

On entry: p, the number of rows of the matrix B.

Constraint: P ≥ 0.

6: N – INTEGER *Input*

On entry: n, the number of columns of the matrices A and B.

Constraint: N ≥ 0.

7: A(LDA,$*$) – ***complex*16*** array *Input/Output*

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

On entry: the m by n matrix A.

On exit: contains the triangular (or trapezoidal) matrix described in Section 3.

8: LDA – INTEGER *Input*

On entry: the first dimension of the array A as declared in the (sub)program from which F08VSF (ZGGSVP) is called.

Constraint: LDA $\geq \max(1, \mathrm{M})$.

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

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

On entry: the p by n matrix B.

On exit: contains the triangular matrix described in Section 3.

10: LDB – INTEGER *Input*

On entry: the first dimension of the array B as declared in the (sub)program from which F08VSF (ZGGSVP) is called.

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

11: TOLA – ***double precision*** *Input*
12: TOLB – ***double precision*** *Input*

On entry: TOLA and TOLB are the thresholds to determine the effective numerical rank of matrix B and a subblock of A. Generally, they are set to

$$\mathrm{TOLA} = \max(\mathrm{M}, \mathrm{N})\|A\|\epsilon,$$
$$\mathrm{TOLB} = \max(\mathrm{P}, \mathrm{N})\|B\|\epsilon,$$

where ϵ is the ***machine precision***.

The size of TOLA and TOLB may affect the size of backward errors of the decomposition.

13: K – INTEGER *Output*
14: L – INTEGER *Output*

On exit: K and L specify the dimension of the subblocks k and l as described in Section 3; $(k+l)$ is the effective numerical rank of $\begin{pmatrix} \mathrm{A}^{\mathrm{T}} & \mathrm{B}^{\mathrm{T}} \end{pmatrix}^{\mathrm{T}}$.

15: U(LDU,$*$) – ***complex*16*** array *Output*

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

On exit: if JOBU = 'U', U contains the unitary matrix U.

If JOBU = 'N', U is not referenced.

16: LDU – INTEGER *Input*

On entry: the first dimension of the array U as declared in the (sub)program from which F08VSF (ZGGSVP) is called.

Constraints:

if JOBU = 'U', LDU $\geq \max(1, \mathrm{M})$;
otherwise LDU ≥ 1.

17: V(LDV,$*$) – ***complex*16*** array *Output*

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

On exit: if JOBV = 'V', V contains the unitary matrix V.

If JOBV = 'N', V is not referenced.

18: LDV – INTEGER *Input*

On entry: the first dimension of the array V as declared in the (sub)program from which F08VSF (ZGGSVP) is called.

Constraints:

if JOBV = 'V', LDV $\geq \max(1, \mathrm{P})$;
otherwise LDV ≥ 1.

19: Q(LDQ,$*$) – ***complex*16*** array *Output*

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

On exit: if JOBQ = 'Q', Q contains the unitary matrix Q.

If JOBQ = 'N', Q is not referenced.

20: LDQ – INTEGER *Input*

On entry: the first dimension of the array Q as declared in the (sub)program from which F08VSF (ZGGSVP) is called.

Constraints:

if JOBQ = 'Q', LDQ $\geq \max(1, \mathrm{N})$;
otherwise LDQ ≥ 1.

21: IWORK(N) – INTEGER array *Workspace*

22: RWORK($2 \times \mathrm{N}$) – ***double precision*** array *Workspace*

23: TAU(N) – ***complex*16*** array *Workspace*

24: WORK($\max(3 \times \mathrm{N}, \mathrm{M}, \mathrm{P})$) – ***complex*16*** array *Workspace*

25: 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 $= -i$, argument i had an illegal value. An explanatory message is output, and execution of the program is terminated.

7 Accuracy

The computed factorization is nearly the exact factorization for nearby matrices $(A + E)$ and $(B + F)$, where

$$\|E\|_2 = O(\epsilon)\|A\|_2 \qquad \text{and} \qquad \|F\|_2 = O(\epsilon)\|B\|_2,$$

and ϵ is the ***machine precision***.

8 Further Comments

The real analogue of this routine is F08VEF (DGGSVP).

9 Example

This example finds the generalized factorization

$$A = U\Sigma_1(\,0 \quad S\,)Q^{\mathrm{H}}, \qquad B = V\Sigma_2(\,0 \quad T\,)Q^{\mathrm{H}},$$

of the matrix pair $(\,A \quad B\,)$, where

$$A = \begin{pmatrix} 0.96 - 0.81i & -0.03 + 0.96i & -0.91 + 2.06i & -0.05 + 0.41i \\ -0.98 + 1.98i & -1.20 + 0.19i & -0.66 + 0.42i & -0.81 + 0.56i \\ 0.62 - 0.46i & 1.01 + 0.02i & 0.63 - 0.17i & -1.11 + 0.60i \\ 0.37 + 0.38i & 0.19 - 0.54i & -0.98 - 0.36i & 0.22 - 0.20i \\ 0.83 + 0.51i & 0.20 + 0.01i & -0.17 - 0.46i & 1.47 + 1.59i \\ 1.08 - 0.28i & 0.20 - 0.12i & -0.07 + 1.23i & 0.26 + 0.26i \end{pmatrix}$$

and

$$B = \begin{pmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{pmatrix}.$$

9.1 Program Text

```
*     F08VSF Example Program Text
*     Mark 21 Release. NAG Copyright 2004.
*     .. Parameters ..
      INTEGER          NIN, NOUT
      PARAMETER        (NIN=5,NOUT=6)
      INTEGER          MMAX, NMAX, PMAX
      PARAMETER        (MMAX=10,NMAX=10,PMAX=10)
      INTEGER          LDA, LDB, LDQ, LDU, LDV
      PARAMETER        (LDA=MMAX,LDB=PMAX,LDQ=NMAX,LDU=MMAX,LDV=PMAX)
*     .. Local Scalars ..
      DOUBLE PRECISION EPS, TOLA, TOLB
      INTEGER          I, IFAIL, INFO, IRANK, J, K, L, M, N, P
*     .. Local Arrays ..
      COMPLEX *16      A(LDA,NMAX), B(LDB,NMAX), Q(LDQ,NMAX), TAU(NMAX),
     +                 U(LDU,MMAX), V(LDV,PMAX), WORK(MMAX+3*NMAX+PMAX)
      DOUBLE PRECISION RWORK(2*NMAX)
      INTEGER          IWORK(NMAX)
      CHARACTER        CLABS(1), RLABS(1)
*     .. External Functions ..
      DOUBLE PRECISION F06UAF, X02AJF
      EXTERNAL         F06UAF, X02AJF
*     .. External Subroutines ..
      EXTERNAL         X04DBF, ZGGSVP
*     .. Intrinsic Functions ..
      INTRINSIC        MAX
*     .. Executable Statements ..
      WRITE (NOUT,*) 'F08VSF Example Program Results'
      WRITE (NOUT,*)
*     Skip heading in data file
      READ (NIN,*)
      READ (NIN,*) M, N, P
      IF (M.LE.MMAX .AND. N.LE.NMAX .AND. P.LE.PMAX) THEN
*
*        Read the m by n matrix A and p by n matrix B from data file
*
         READ (NIN,*) ((A(I,J),J=1,N),I=1,M)
         READ (NIN,*) ((B(I,J),J=1,N),I=1,P)
*
*        Compute TOLA and TOLB as
*           TOLA = max(M,N)*norm(A)*macheps
*           TOLB = max(P,N)*norm(B)*macheps
*
         EPS = X02AJF()
         TOLA = MAX(M,N)*F06UAF('One-norm',M,N,A,LDA,RWORK)*EPS
         TOLB = MAX(P,N)*F06UAF('One-norm',P,N,B,LDB,RWORK)*EPS
*
*        Compute the factorization of (A, B)
*           (A = U*S*(Q**H), B = V*T*(Q**H))
*
         CALL ZGGSVP('U','V','Q',M,P,N,A,LDA,B,LDB,TOLA,TOLB,K,L,U,LDU,
     +               V,LDV,Q,LDQ,IWORK,RWORK,TAU,WORK,INFO)
*
*        Print solution
*
         IRANK = K + L
         WRITE (NOUT,*) 'Numerical rank of (A**T B**T)**T (K+L)'
         WRITE (NOUT,99999) IRANK
*
         WRITE (NOUT,*)
         IF (M.GE.IRANK) THEN
            IFAIL = 0
            CALL X04DBF('Upper','Non-unit',IRANK,IRANK,A(1,N-IRANK+1),
     +                  LDA,'Bracketed','1P,E12.4',
     +                  'Upper triangular matrix S','Integer',RLABS,
     +                  'Integer',CLABS,80,0,IFAIL)
         ELSE
            IFAIL = 0
            CALL X04DBF('Upper','Non-unit',M,IRANK,A(1,N-IRANK+1),LDA,
     +                  'Bracketed','1P,E12.4',
```

```
     +                 'Upper trapezoidal matrix S','Integer',RLABS,
     +                 'Integer',CLABS,80,0,IFAIL)
         END IF
         WRITE (NOUT,*)
         IFAIL = 0
         CALL X04DBF('Upper','Non-unit',L,L,B(1,N-L+1),LDB,'Bracketed',
     +               '1P,E12.4','Upper triangular matrix T','Integer',
     +               RLABS,'Integer',CLABS,80,0,IFAIL)
         WRITE (NOUT,*)
         IFAIL = 0
         CALL X04DBF('General',' ',M,M,U,LDU,'Bracketed','1P,E12.4',
     +               'Orthogonal matrix U','Integer',RLABS,'Integer',
     +               CLABS,80,0,IFAIL)
         WRITE (NOUT,*)
         IFAIL = 0
         CALL X04DBF('General',' ',P,P,V,LDV,'Bracketed','1P,E12.4',
     +               'Orthogonal matrix V','Integer',RLABS,'Integer',
     +               CLABS,80,0,IFAIL)
         WRITE (NOUT,*)
         IFAIL = 0
         CALL X04DBF('General',' ',N,N,Q,LDQ,'Bracketed','1P,E12.4',
     +               'Orthogonal matrix Q','Integer',RLABS,'Integer',
     +               CLABS,80,0,IFAIL)
      ELSE
         WRITE (NOUT,*) 'MMAX and/or NMAX too small'
      END IF
*
99999 FORMAT (1X,I5)
      END
```

9.2 Program Data

```
F08VSF Example Program Data

  6            4            2                          :Values of M, N and P

( 0.96,-0.81) (-0.03, 0.96) (-0.91, 2.06) (-0.05, 0.41)
(-0.98, 1.98) (-1.20, 0.19) (-0.66, 0.42) (-0.81, 0.56)
( 0.62,-0.46) ( 1.01, 0.02) ( 0.63,-0.17) (-1.11, 0.60)
( 0.37, 0.38) ( 0.19,-0.54) (-0.98,-0.36) ( 0.22,-0.20)
( 0.83, 0.51) ( 0.20, 0.01) (-0.17,-0.46) ( 1.47, 1.59)
( 1.08,-0.28) ( 0.20,-0.12) (-0.07, 1.23) ( 0.26, 0.26) :End of matrix A

( 1.00, 0.00) ( 0.00, 0.00) (-1.00, 0.00) ( 0.00, 0.00)
( 0.00, 0.00) ( 1.00, 0.00) ( 0.00, 0.00) (-1.00, 0.00) :End of matrix B
```

9.3 Program Results

```
 F08VSF Example Program Results

 Numerical rank of (A**T B**T)**T (K+L)
     4

 Upper triangular matrix S
                               1                            2
 1  ( -2.7118E+00,  0.0000E+00) ( -1.4390E+00, -1.0315E+00)
 2                              ( -1.8583E+00,  0.0000E+00)
 3
 4

                               3                            4
 1  ( -1.0543E-01,  1.3176E+00) ( -3.9240E-01, -1.9504E-01)
 2  ( -9.4529E-01,  1.9279E-01) (  1.4355E+00,  2.6313E-01)
 3  (  2.9079E+00,  0.0000E+00) ( -2.3946E-01,  1.8856E-01)
 4                              ( -1.5759E+00,  0.0000E+00)

 Upper triangular matrix T
                               1                            2
 1  (  1.4142E+00,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 2                              (  1.4142E+00,  0.0000E+00)
```

```
 Orthogonal matrix U
                                   1                              2
 1  ( -1.3038E-02, -3.2595E-01) ( -1.4039E-01, -2.6167E-01)
 2  (  4.2764E-01, -6.2582E-01) (  8.6298E-02, -3.8174E-02)
 3  ( -3.2595E-01,  1.6428E-01) (  3.8163E-01, -1.8219E-01)
 4  (  1.5906E-01, -5.2151E-03) ( -2.8207E-01,  1.9732E-01)
 5  ( -1.7210E-01, -1.3038E-02) ( -5.0942E-01, -5.0319E-01)
 6  ( -2.6336E-01, -2.4772E-01) ( -1.0861E-01,  2.8474E-01)

                                   3                              4
 1  (  2.4357E-01, -7.7956E-01) ( -7.4007E-02, -2.7823E-01)
 2  ( -3.2035E-01,  1.4475E-01) (  1.0740E-01,  1.8824E-01)
 3  (  1.7217E-01, -1.4009E-03) ( -4.9770E-01,  1.7826E-01)
 4  (  2.5307E-01,  1.9053E-01) ( -3.7794E-01,  2.6816E-01)
 5  (  3.2057E-02,  1.8358E-01) (  2.0422E-01,  1.6601E-01)
 6  (  1.4142E-01, -1.5707E-01) ( -8.7335E-02,  5.4683E-01)

                                   5                              6
 1  ( -4.5947E-02,  1.4052E-04) ( -5.2773E-02, -2.2492E-01)
 2  ( -8.0311E-02, -4.3605E-01) ( -3.8117E-02, -2.1907E-01)
 3  (  5.9714E-02, -5.8974E-01) ( -1.3850E-01, -9.0941E-02)
 4  ( -4.6443E-02,  3.0864E-01) ( -3.7354E-01, -5.5148E-01)
 5  (  5.7843E-01, -1.2439E-01) ( -1.8815E-02, -5.5686E-02)
 6  (  1.5763E-02,  4.7130E-02) (  6.5007E-01,  4.9173E-03)

 Orthogonal matrix V
                                   1                              2
 1  (  1.0000E+00,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 2  (  0.0000E+00,  0.0000E+00) (  1.0000E+00,  0.0000E+00)

 Orthogonal matrix Q
                                   1                              2
 1  (  7.0711E-01,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 2  (  0.0000E+00,  0.0000E+00) (  7.0711E-01,  0.0000E+00)
 3  (  7.0711E-01,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 4  (  0.0000E+00,  0.0000E+00) (  7.0711E-01,  0.0000E+00)

                                   3                              4
 1  (  7.0711E-01,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 2  (  0.0000E+00,  0.0000E+00) (  7.0711E-01,  0.0000E+00)
 3  ( -7.0711E-01,  0.0000E+00) (  0.0000E+00,  0.0000E+00)
 4  (  0.0000E+00,  0.0000E+00) ( -7.0711E-01,  0.0000E+00)
```