

# NAG Library Function Document

## nag\_zsysv (f07nnc)

### 1 Purpose

nag\_zsysv (f07nnc) computes the solution to a complex system of linear equations

$$AX = B,$$

where  $A$  is an  $n$  by  $n$  symmetric matrix and  $X$  and  $B$  are  $n$  by  $r$  matrices.

### 2 Specification

```
#include <nag.h>
#include <nagf07.h>

void nag_zsysv (Nag_OrderType order, Nag_UploType uplo, Integer n,
               Integer nrhs, Complex a[], Integer pda, Integer ipiv[], Complex b[],
               Integer pdb, NagError *fail)
```

### 3 Description

nag\_zsysv (f07nnc) uses the diagonal pivoting method to factor  $A$  as

	<b>order</b>	<b>uplo</b>	<b><math>A</math></b>
	Nag_ColMajor	Nag_Upper	$UDU^T$
	Nag_ColMajor	Nag_Lower	$LDL^T$
	Nag_RowMajor	Nag_Upper	$U^T DU$
	Nag_RowMajor	Nag_Lower	$L^T DL$

where  $U$  (or  $L$ ) is a product of permutation and unit upper (lower) triangular matrices, and  $D$  is symmetric and block diagonal with 1 by 1 and 2 by 2 diagonal blocks. The factored form of  $A$  is then used to solve the system of equations  $AX = B$ .

### 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, Philadelphia <http://www.netlib.org/lapack/lug>

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

Higham N J (2002) *Accuracy and Stability of Numerical Algorithms* (2nd Edition) SIAM, Philadelphia

### 5 Arguments

1: **order** – Nag\_OrderType *Input*

*On entry:* the **order** argument specifies the two-dimensional storage scheme being used, i.e., row-major ordering or column-major ordering. C language defined storage is specified by **order** = Nag\_RowMajor. See Section 2.3.1.3 in How to Use the NAG Library and its Documentation for a more detailed explanation of the use of this argument.

*Constraint:* **order** = Nag\_RowMajor or Nag\_ColMajor.

- 2: **uplo** – Nag\_UploType Input  
*On entry:* if **uplo** = Nag\_Upper, the upper triangle of  $A$  is stored.  
 If **uplo** = Nag\_Lower, the lower triangle of  $A$  is stored.  
*Constraint:* **uplo** = Nag\_Upper or Nag\_Lower.
- 3: **n** – Integer Input  
*On entry:*  $n$ , the number of linear equations, i.e., the order of the matrix  $A$ .  
*Constraint:*  $n \geq 0$ .
- 4: **nrhs** – Integer Input  
*On entry:*  $r$ , the number of right-hand sides, i.e., the number of columns of the matrix  $B$ .  
*Constraint:* **nrhs**  $\geq 0$ .
- 5: **a**[*dim*] – Complex Input/Output  
**Note:** the dimension, *dim*, of the array **a** must be at least  $\max(1, \mathbf{pda} \times \mathbf{n})$ .  
*On entry:* the  $n$  by  $n$  symmetric matrix  $A$ .  
 If **order** = Nag\_ColMajor,  $A_{ij}$  is stored in **a**[( $j - 1$ )  $\times$  **pda** +  $i - 1$ ].  
 If **order** = Nag\_RowMajor,  $A_{ij}$  is stored in **a**[( $i - 1$ )  $\times$  **pda** +  $j - 1$ ].  
 If **uplo** = Nag\_Upper, the upper triangular part of  $A$  must be stored and the elements of the array below the diagonal are not referenced.  
 If **uplo** = Nag\_Lower, the lower triangular part of  $A$  must be stored and the elements of the array above the diagonal are not referenced.  
*On exit:* if **fail.code** = NE\_NOERROR, the block diagonal matrix  $D$  and the multipliers used to obtain the factor  $U$  or  $L$  from the factorization  $A = UDU^T$ ,  $A = LDL^T$ ,  $A = U^T D U$  or  $A = L^T D L$  as computed by nag\_zsytrf (f07nrc).
- 6: **pda** – Integer Input  
*On entry:* the stride separating row or column elements (depending on the value of **order**) of the matrix  $A$  in the array **a**.  
*Constraint:* **pda**  $\geq \max(1, \mathbf{n})$ .
- 7: **ipiv**[*dim*] – Integer Output  
**Note:** the dimension, *dim*, of the array **ipiv** must be at least  $\max(1, \mathbf{n})$ .  
*On exit:* details of the interchanges and the block structure of  $D$ . More precisely,  
 if **ipiv**[ $i - 1$ ] =  $k > 0$ ,  $d_{ii}$  is a 1 by 1 pivot block and the  $i$ th row and column of  $A$  were interchanged with the  $k$ th row and column;  
 if **uplo** = Nag\_Upper and **ipiv**[ $i - 2$ ] = **ipiv**[ $i - 1$ ] =  $-l < 0$ ,  $\begin{pmatrix} d_{i-1,i-1} & \bar{d}_{i,i-1} \\ \bar{d}_{i,i-1} & d_{ii} \end{pmatrix}$  is a 2 by 2 pivot block and the ( $i - 1$ )th row and column of  $A$  were interchanged with the  $l$ th row and column;  
 if **uplo** = Nag\_Lower and **ipiv**[ $i - 1$ ] = **ipiv**[ $i$ ] =  $-m < 0$ ,  $\begin{pmatrix} d_{ii} & d_{i+1,i} \\ d_{i+1,i} & d_{i+1,i+1} \end{pmatrix}$  is a 2 by 2 pivot block and the ( $i + 1$ )th row and column of  $A$  were interchanged with the  $m$ th row and column.

8: **b**[*dim*] – Complex *Input/Output*

**Note:** the dimension, *dim*, of the array **b** must be at least

$\max(1, \mathbf{pdb} \times \mathbf{nrhs})$  when **order** = Nag\_ColMajor;

$\max(1, \mathbf{n} \times \mathbf{pdb})$  when **order** = Nag\_RowMajor.

The (*i*, *j*)th element of the matrix *B* is stored in

**b**[(*j* – 1) × **pdb** + *i* – 1] when **order** = Nag\_ColMajor;

**b**[(*i* – 1) × **pdb** + *j* – 1] when **order** = Nag\_RowMajor.

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

*On exit:* if **fail.code** = NE\_NOERROR, the *n* by *r* solution matrix *X*.

9: **pdb** – Integer *Input*

*On entry:* the stride separating row or column elements (depending on the value of **order**) in the array **b**.

*Constraints:*

if **order** = Nag\_ColMajor, **pdb** ≥ max(1, **n**);

if **order** = Nag\_RowMajor, **pdb** ≥ max(1, **nrhs**).

10: **fail** – NagError \* *Input/Output*

The NAG error argument (see Section 2.7 in How to Use the NAG Library and its Documentation).

## 6 Error Indicators and Warnings

### NE\_ALLOC\_FAIL

Dynamic memory allocation failed.

See Section 3.2.1.2 in How to Use the NAG Library and its Documentation for further information.

### NE\_BAD\_PARAM

On entry, argument *<value>* had an illegal value.

### NE\_INT

On entry, **n** = *<value>*.

Constraint: **n** ≥ 0.

On entry, **nrhs** = *<value>*.

Constraint: **nrhs** ≥ 0.

On entry, **pda** = *<value>*.

Constraint: **pda** > 0.

On entry, **pdb** = *<value>*.

Constraint: **pdb** > 0.

### NE\_INT\_2

On entry, **pda** = *<value>* and **n** = *<value>*.

Constraint: **pda** ≥ max(1, **n**).

On entry, **pdb** = *<value>* and **n** = *<value>*.

Constraint: **pdb** ≥ max(1, **n**).

On entry, **pdb** = *<value>* and **nrhs** = *<value>*.

Constraint: **pdb** ≥ max(1, **nrhs**).

**NE\_INTERNAL\_ERROR**

An internal error has occurred in this function. Check the function call and any array sizes. If the call is correct then please contact NAG for assistance.

An unexpected error has been triggered by this function. Please contact NAG.  
See Section 3.6.6 in How to Use the NAG Library and its Documentation for further information.

**NE\_NO\_LICENCE**

Your licence key may have expired or may not have been installed correctly.  
See Section 3.6.5 in How to Use the NAG Library and its Documentation for further information.

**NE\_SINGULAR**

Element  $\langle value \rangle$  of the diagonal is exactly zero. The factorization has been completed, but the block diagonal matrix  $D$  is exactly singular, so the solution could not be computed.

**7 Accuracy**

The computed solution for a single right-hand side,  $\hat{x}$ , satisfies an equation of the form

$$(A + E)\hat{x} = b,$$

where

$$\|E\|_1 = O(\epsilon)\|A\|_1$$

and  $\epsilon$  is the *machine precision*. An approximate error bound for the computed solution is given by

$$\frac{\|\hat{x} - x\|_1}{\|x\|_1} \leq \kappa(A) \frac{\|E\|_1}{\|A\|_1},$$

where  $\kappa(A) = \|A^{-1}\|_1 \|A\|_1$ , the condition number of  $A$  with respect to the solution of the linear equations. See Section 4.4 of Anderson *et al.* (1999) and Chapter 11 of Higham (2002) for further details.

nag\_zsysvx (f07npc) is a comprehensive LAPACK driver that returns forward and backward error bounds and an estimate of the condition number. Alternatively, nag\_complex\_sym\_lin\_solve (f04dhc) solves  $Ax = b$  and returns a forward error bound and condition estimate. nag\_complex\_sym\_lin\_solve (f04dhc) calls nag\_zsysv (f07nnc) to solve the equations.

**8 Parallelism and Performance**

nag\_zsysv (f07nnc) makes calls to BLAS and/or LAPACK routines, which may be threaded within the vendor library used by this implementation. Consult the documentation for the vendor library for further information.

Please consult the x06 Chapter Introduction for information on how to control and interrogate the OpenMP environment used within this function. Please also consult the Users' Note for your implementation for any additional implementation-specific information.

**9 Further Comments**

The total number of floating-point operations is approximately  $\frac{4}{3}n^3 + 8n^2r$ , where  $r$  is the number of right-hand sides.

The real analogue of this function is nag\_dsystv (f07mac). The complex Hermitian analogue of this function is nag\_zhesv (f07mnc).

## 10 Example

This example solves the equations

$$Ax = b,$$

where  $A$  is the complex symmetric matrix

$$A = \begin{pmatrix} -0.56 + 0.12i & -1.54 - 2.86i & 5.32 - 1.59i & 3.80 + 0.92i \\ -1.54 - 2.86i & -2.83 - 0.03i & -3.52 + 0.58i & -7.86 - 2.96i \\ 5.32 - 1.59i & -3.52 + 0.58i & 8.86 + 1.81i & 5.14 - 0.64i \\ 3.80 + 0.92i & -7.86 - 2.96i & 5.14 - 0.64i & -0.39 - 0.71i \end{pmatrix}$$

and

$$b = \begin{pmatrix} -6.43 + 19.24i \\ -0.49 - 1.47i \\ -48.18 + 66.00i \\ -55.64 + 41.22i \end{pmatrix}.$$

Details of the factorization of  $A$  are also output.

### 10.1 Program Text

```

/* nag_zsysv (f07nnc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */

#include <stdio.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nagf07.h>

int main(void)
{
    /* Scalars */
    Integer exit_status = 0, i, j, n, nrhs, pda, pdb;

    /* Arrays */
    Complex *a = 0, *b = 0;
    Integer *ipiv = 0;
    char nag_enum_arg[40];

    /* Nag Types */
    NagError fail;
    Nag_UploType uplo;
    Nag_OrderType order;

#ifdef NAG_COLUMN_MAJOR
#define A(I, J) a[(J-1)*pda + I - 1]
#define B(I, J) b[(J-1)*pdb + I - 1]
    order = Nag_ColMajor;
#else
#define A(I, J) a[(I-1)*pda + J - 1]
#define B(I, J) b[(I-1)*pdb + J - 1]
    order = Nag_RowMajor;
#endif

    INIT_FAIL(fail);

    printf("nag_zsysv (f07nnc) Example Program Results\n\n");

    /* Skip heading in data file */

```

```

#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif

#ifdef _WIN32
    scanf_s("%" NAG_IFMT "%" NAG_IFMT "%*[\n]", &n, &nrhs);
#else
    scanf("%" NAG_IFMT "%" NAG_IFMT "%*[\n]", &n, &nrhs);
#endif
    if (n < 0 || nrhs < 0) {
        printf("Invalid n or nrhs\n");
        exit_status = 1;
        goto END;
    }
#ifdef _WIN32
    scanf_s(" %39s%*[\n]", nag_enum_arg, (unsigned)_countof(nag_enum_arg));
#else
    scanf(" %39s%*[\n]", nag_enum_arg);
#endif
    /* nag_enum_name_to_value (x04nac).
     * Converts NAG enum member name to value
     */
    uplo = (Nag_UploType) nag_enum_name_to_value(nag_enum_arg);

    /* Allocate memory */
    if (!(a = NAG_ALLOC(n * n, Complex)) ||
        !(b = NAG_ALLOC(n * nrhs, Complex)) || !(ipiv = NAG_ALLOC(n, Integer)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
        goto END;
    }

    pda = n;
#ifdef NAG_COLUMN_MAJOR
    pdb = n;
#else
    pdb = nrhs;
#endif

    /* Read the triangular part of the matrix A from data file */
    if (uplo == Nag_Upper)
        for (i = 1; i <= n; ++i)
            for (j = i; j <= n; ++j)
#ifdef _WIN32
                scanf_s(" ( %lf , %lf )", &A(i, j).re, &A(i, j).im);
#else
                scanf(" ( %lf , %lf )", &A(i, j).re, &A(i, j).im);
#endif
    else
        for (i = 1; i <= n; ++i)
            for (j = 1; j <= i; ++j)
#ifdef _WIN32
                scanf_s(" ( %lf , %lf )", &A(i, j).re, &A(i, j).im);
#else
                scanf(" ( %lf , %lf )", &A(i, j).re, &A(i, j).im);
#endif
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif

    /* Read b from data file */
    for (i = 1; i <= n; ++i)
        for (j = 1; j <= nrhs; ++j)
#ifdef _WIN32
            scanf_s(" ( %lf , %lf )", &B(i, j).re, &B(i, j).im);
#else

```

```

        scanf(" (%lf , %lf )", &B(i, j).re, &B(i, j).im);
#endif
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif

/* Solve the equations Ax = b for x using nag_zsysv (f07nnc). */
nag_zsysv(order, uplo, n, nrhs, a, pda, ipiv, b, pdb, &fail);
if (fail.code != NE_NOERROR) {
    printf("Error from nag_zsysv (f07nnc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}

/* Print solution */
printf("      Solution\n");
for (i = 1; i <= n; ++i) {
    for (j = 1; j <= nrhs; ++j)
        printf(" (%7.4f, %7.4f)%s", B(i, j).re, B(i, j).im,
            j % 4 == 0 ? "\n" : "");
    printf("\n");
}

END:
    NAG_FREE(a);
    NAG_FREE(b);
    NAG_FREE(ipiv);

    return exit_status;
}

#undef A
#undef B

```

## 10.2 Program Data

```

nag_zsysv (f07nnc) Example Program Data
    4          1          : n, nrhs
    Nag_Lower          : uplo
    (-0.56,  0.12)
    (-1.54, -2.86) (-2.83 , -0.03)
    ( 5.32, -1.59) (-3.52,  0.58) ( 8.86,  1.81)
    ( 3.80,  0.92) (-7.86, -2.96) ( 5.14, -0.64) (-0.39 , -0.71) : matrix A
    (-6.43, 19.24) (-0.49, -1.47) (-48.18, 66.00) (-55.64, 41.22) : vector b

```

## 10.3 Program Results

```

nag_zsysv (f07nnc) Example Program Results

      Solution
(-4.0000,  3.0000)
( 3.0000, -2.0000)
(-2.0000,  5.0000)
( 1.0000, -1.0000)

```

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