# NAG Library Function Document

# nag_dppequ (f07gfc)

## 1 Purpose

nag_dppequ (f07gfc) computes a diagonal scaling matrix $S$ intended to equilibrate a real $n$ by $n$ symmetric positive definite matrix $A$, stored in packed format, and reduce its condition number.

## 2 Specification

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

```
void nag_dppequ (Nag_OrderType order, Nag_UploType uplo, Integer n,
     const double ap[], double s[], double *scond, double *amax,
     NagError *fail)
```

## 3 Description

nag_dppequ (f07gfc) computes a diagonal scaling matrix $S$ chosen so that

$$s_j = 1/\sqrt{a_{jj}}.$$

This means that the matrix $B$ given by

$$B = SAS,$$

has diagonal elements equal to unity. This in turn means that the condition number of $B$, $\kappa_2(B)$, is within a factor $n$ of the matrix of smallest possible condition number over all possible choices of diagonal scalings (see Corollary 7.6 of Higham (2002)).

## 4 References

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*: indicates whether the upper or lower triangular part of $A$ is stored in the array **ap**, as follows:

**uplo** = Nag_Upper
The upper triangle of $A$ is stored.

**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 order of the matrix $A$.

*Constraint*: $\mathbf{n} \geq 0$.

4: **ap**[$dim$] – const double *Input*

**Note**: the dimension, *dim*, of the array **ap** must be at least $\max(1, \mathbf{n} \times (\mathbf{n}+1)/2)$.

*On entry*: the $n$ by $n$ symmetric matrix $A$, packed by rows or columns.

The storage of elements $A_{ij}$ depends on the **order** and **uplo** arguments as follows:

if **order** = Nag_ColMajor and **uplo** = Nag_Upper,
$A_{ij}$ is stored in **ap**$[(j-1) \times j/2 + i - 1]$, for $i \leq j$;
if **order** = Nag_ColMajor and **uplo** = Nag_Lower,
$A_{ij}$ is stored in **ap**$[(2n-j) \times (j-1)/2 + i - 1]$, for $i \geq j$;
if **order** = Nag_RowMajor and **uplo** = Nag_Upper,
$A_{ij}$ is stored in **ap**$[(2n-i) \times (i-1)/2 + j - 1]$, for $i \leq j$;
if **order** = Nag_RowMajor and **uplo** = Nag_Lower,
$A_{ij}$ is stored in **ap**$[(i-1) \times i/2 + j - 1]$, for $i \geq j$.

Only the elements of **ap** corresponding to the diagonal elements $A$ are referenced.

5: **s**[**n**] – double *Output*

*On exit*: if **fail.code** = NE_NOERROR, **s** contains the diagonal elements of the scaling matrix $S$.

6: **scond** – double * *Output*

*On exit*: if **fail.code** = NE_NOERROR, **scond** contains the ratio of the smallest value of **s** to the largest value of **s**. If **scond** $\geq 0.1$ and **amax** is neither too large nor too small, it is not worth scaling by $S$.

7: **amax** – double * *Output*

*On exit*: $\max|a_{ij}|$. If **amax** is very close to overflow or underflow, the matrix $A$ should be scaled.

8: **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** $\geq 0$.

**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_MAT_NOT_POS_DEF**

The ⟨*value*⟩th diagonal element of $A$ is not positive (and hence $A$ cannot be positive definite).

**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.

## 7 Accuracy

The computed scale factors will be close to the exact scale factors.

## 8 Parallelism and Performance

nag_dppequ (f07gfc) is not threaded in any implementation.

## 9 Further Comments

The complex analogue of this function is nag_zppequ (f07gtc).

## 10 Example

This example equilibrates the symmetric positive definite matrix $A$ given by

$$A = \begin{pmatrix} 4.16 & -3.12 \times 10^5 & 0.56 & -0.10 \\ -3.12 \times 10^5 & 5.03 \times 10^{10} & -0.83 \times 10^5 & 1.18 \times 10^5 \\ 0.56 & -0.83 \times 10^5 & 0.76 & 0.34 \\ -0.10 & 1.18 \times 10^5 & 0.34 & 1.18 \end{pmatrix}.$$

Details of the scaling factors and the scaled matrix are output.

### 10.1 Program Text

```
/* nag_dppequ (f07gfc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */
#include <stdio.h>
#include <nag.h>
#include <nagx04.h>
#include <nag_stdlib.h>
#include <nagf07.h>
#include <nagx02.h>

int main(void)
{

  /* Scalars */
  double amax, big, scond, small;
  Integer exit_status = 0, i, j, n;

  /* Arrays */
  double *ap = 0, *s = 0;
  char nag_enum_arg[40];

  /* Nag Types */
```

```
  NagError fail;
  Nag_OrderType order;
  Nag_UploType uplo;

#ifdef NAG_COLUMN_MAJOR
#define A_UPPER(I, J) ap[J*(J-1)/2 + I - 1]
#define A_LOWER(I, J) ap[(2*n-J)*(J-1)/2 + I - 1]
  order = Nag_ColMajor;
#else
#define A_LOWER(I, J) ap[I*(I-1)/2 + J - 1]
#define A_UPPER(I, J) ap[(2*n-I)*(I-1)/2 + J - 1]
  order = Nag_RowMajor;
#endif
  INIT_FAIL(fail);

  printf("nag_dppequ (f07gfc) 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 "%*[^\n]", &n);
#else
  scanf("%" NAG_IFMT "%*[^\n]", &n);
#endif
  if (n < 0) {
    printf("Invalid n\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 (!(ap = NAG_ALLOC(n * (n + 1) / 2, double)) ||
      !(s = NAG_ALLOC(n, double)))
  {
    printf("Allocation failure\n");
    exit_status = -1;
    goto END;
  }

  /* Read the upper or lower triangular part of the matrix A from data file */
  if (uplo == Nag_Upper)
    for (i = 1; i <= n; ++i)
#ifdef _WIN32
      for (j = i; j <= n; ++j)
        scanf_s("%lf", &A_UPPER(i, j));
#else
      for (j = i; j <= n; ++j)
        scanf("%lf", &A_UPPER(i, j));
#endif
  else if (uplo == Nag_Lower)
    for (i = 1; i <= n; ++i)
#ifdef _WIN32
      for (j = 1; j <= i; ++j)
        scanf_s("%lf", &A_LOWER(i, j));
#else
      for (j = 1; j <= i; ++j)
        scanf("%lf", &A_LOWER(i, j));
```

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

  /* Print the matrix A using nag_pack_real_mat_print (x04ccc). */
  fflush(stdout);
  nag_pack_real_mat_print(order, uplo, Nag_NonUnitDiag, n, ap,
                          "Matrix A", 0, &fail);
  if (fail.code != NE_NOERROR) {
    printf("Error from nag_pack_real_mat_print (x04ccc).\n%s\n",
           fail.message);
    exit_status = 1;
    goto END;
  }
  printf("\n");

  /* Compute diagonal scaling factors using nag_dppequ (f07gfc). */
  nag_dppequ(order, uplo, n, ap, s, &scond, &amax, &fail);
  if (fail.code != NE_NOERROR) {
    printf("Error from nag_dppequ (f07gfc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
  }

  /* Print scond, amax and the scale factors */
  printf("scond = %10.1e, amax = %10.1e\n\n", scond, amax);
  printf("Diagonal scaling factors\n");
  for (i = 0; i < n; ++i)
    printf("%11.1e%s", s[i], i % 7 == 6 ? "\n" : " ");
  printf("\n\n");

  /* Compute values close to underflow and overflow using
   * nag_real_safe_small_number (x02amc), nag_machine_precision (x02ajc) and
   * nag_real_base (x02bhc)
   */
  small = nag_real_safe_small_number / (nag_machine_precision *
                                        nag_real_base);
  big = 1. / small;
  if (scond < 0.1 || amax < small || amax > big) {
    /* Scale A */
    if (uplo == Nag_Upper)
      for (j = 1; j <= n; ++j)
        for (i = 1; i <= j; ++i)
          A_UPPER(i, j) *= s[i - 1] * s[j - 1];
    else
      for (j = 1; j <= n; ++j)
        for (i = j; i <= n; ++i)
          A_LOWER(i, j) *= s[i - 1] * s[j - 1];

    /* Print the scaled matrix using nag_pack_real_mat_print (x04ccc). */
    fflush(stdout);
    nag_pack_real_mat_print(order, uplo, Nag_NonUnitDiag, n, ap,
                            "Scaled matrix", 0, &fail);
    if (fail.code != NE_NOERROR) {
      printf("Error from nag_pack_real_mat_print (x04ccc).\n%s\n",
             fail.message);
      exit_status = 1;
      goto END;
    }
  }
END:
  NAG_FREE(ap);
  NAG_FREE(s);
```

```
  return exit_status;
}

#undef A_UPPER
#undef A_LOWER
```

## 10.2 Program Data

```
nag_dppequ (f07gfc) Example Program Data
  4                                         : n
  Nag_Upper                                 : uplo
  4.16      -3.12e+05   0.56      -0.10
             5.03e+10  -0.83e+05   1.18e+05
                        0.76       0.34
                                   1.18     : matrix A
```

## 10.3 Program Results

```
nag_dppequ (f07gfc) Example Program Results

 Matrix A
             1            2            3            4
 1    4.1600e+00  -3.1200e+05   5.6000e-01  -1.0000e-01
 2                 5.0300e+10  -8.3000e+04   1.1800e+05
 3                              7.6000e-01   3.4000e-01
 4                                           1.1800e+00

scond =    3.9e-06, amax =    5.0e+10

Diagonal scaling factors
    4.9e-01     4.5e-06     1.1e+00     9.2e-01

 Scaled matrix
           1          2          3          4
 1      1.0000    -0.6821     0.3149    -0.0451
 2                 1.0000    -0.4245     0.4843
 3                            1.0000     0.3590
 4                                       1.0000
```