

## NAG Library Function Document

### nag\_complex\_sparse\_eigensystem\_sol (f12aqc)

**Note:** this function uses **optional parameters** to define choices in the problem specification. If you wish to use default settings for all of the optional parameters, then the option setting function `nag_complex_sparse_eigensystem_option (f12arc)` need not be called. If, however, you wish to reset some or all of the settings please refer to Section 11 in `nag_complex_sparse_eigensystem_option (f12arc)` for a detailed description of the specification of the optional parameters.

## 1 Purpose

`nag_complex_sparse_eigensystem_sol (f12aqc)` is a post-processing function in a suite of functions consisting of `nag_complex_sparse_eigensystem_init (f12anc)`, `nag_complex_sparse_eigensystem_iter (f12apc)`, `nag_complex_sparse_eigensystem_sol (f12aqc)`, `nag_complex_sparse_eigensystem_option (f12arc)` and `nag_complex_sparse_eigensystem_monit (f12asc)`, that must be called following a final exit from `nag_complex_sparse_eigensystem_sol (f12aqc)`.

## 2 Specification

```
#include <nag.h>
#include <nagf12.h>

void nag_complex_sparse_eigensystem_sol (Integer *nconv, Complex d[],
    Complex z[], Complex sigma, const Complex resid[], Complex v[],
    Complex comm[], Integer icomm[], NagError *fail)
```

## 3 Description

The suite of functions is designed to calculate some of the eigenvalues,  $\lambda$ , (and optionally the corresponding eigenvectors,  $x$ ) of a standard eigenvalue problem  $Ax = \lambda x$ , or of a generalized eigenvalue problem  $Ax = \lambda Bx$  of order  $n$ , where  $n$  is large and the coefficient matrices  $A$  and  $B$  are sparse, complex and nonsymmetric. The suite can also be used to find selected eigenvalues/eigenvectors of smaller scale dense, complex and nonsymmetric problems.

Following a call to `nag_complex_sparse_eigensystem_iter (f12apc)`, `nag_complex_sparse_eigensystem_sol (f12aqc)` returns the converged approximations to eigenvalues and (optionally) the corresponding approximate eigenvectors and/or an orthonormal basis for the associated approximate invariant subspace. The eigenvalues (and eigenvectors) are selected from those of a standard or generalized eigenvalue problem defined by complex nonsymmetric matrices. There is negligible additional cost to obtain eigenvectors; an orthonormal basis is always computed, but there is an additional storage cost if both are requested.

`nag_complex_sparse_eigensystem_sol (f12aqc)` is based on the function **zneupd** from the ARPACK package, which uses the Implicitly Restarted Arnoldi iteration method. The method is described in Lehoucq and Sorensen (1996) and Lehoucq (2001) while its use within the ARPACK software is described in great detail in Lehoucq *et al.* (1998). An evaluation of software for computing eigenvalues of sparse nonsymmetric matrices is provided in Lehoucq and Scott (1996). This suite of functions offers the same functionality as the ARPACK software for complex nonsymmetric problems, but the interface design is quite different in order to make the option setting clearer and to simplify some of the interfaces.

`nag_complex_sparse_eigensystem_sol (f12aqc)` is a post-processing function that must be called following a successful final exit from `nag_complex_sparse_eigensystem_iter (f12apc)`. `nag_complex_sparse_eigensystem_sol (f12aqc)` uses data returned from `nag_complex_sparse_eigensystem_iter (f12apc)` and options set either by default or explicitly by calling `nag_complex_sparse_eigensystem_option (f12arc)`, to return the converged approximations to selected eigenvalues and (optionally):

- the corresponding approximate eigenvectors;
- an orthonormal basis for the associated approximate invariant subspace;
- both.

## 4 References

Lehoucq R B (2001) Implicitly restarted Arnoldi methods and subspace iteration *SIAM Journal on Matrix Analysis and Applications* **23** 551–562

Lehoucq R B and Scott J A (1996) An evaluation of software for computing eigenvalues of sparse nonsymmetric matrices *Preprint MCS-P547-1195* Argonne National Laboratory

Lehoucq R B and Sorensen D C (1996) Deflation techniques for an implicitly restarted Arnoldi iteration *SIAM Journal on Matrix Analysis and Applications* **17** 789–821

Lehoucq R B, Sorensen D C and Yang C (1998) *ARPACK Users' Guide: Solution of Large-scale Eigenvalue Problems with Implicitly Restarted Arnoldi Methods* SIAM, Philadelphia

## 5 Arguments

- 1: **nconv** – Integer \* *Output*  
*On exit:* the number of converged eigenvalues as found by nag\_complex\_sparse\_eigensystem\_option (f12arc).
- 2: **d**[*dim*] – Complex *Output*  
**Note:** the dimension, *dim*, of the array **d** must be at least **ncv** (see nag\_complex\_sparse\_eigensystem\_init (f12anc)).  
*On exit:* the first **nconv** locations of the array **d** contain the converged approximate eigenvalues.
- 3: **z**[**n** × **ncv**] – Complex *Output*  
*On exit:* if the default option **Vectors** = RITZ (see nag\_real\_sparse\_eigensystem\_option (f12adc)) has been selected then **z** contains the final set of eigenvectors corresponding to the eigenvalues held in **d**. The complex eigenvector associated with an eigenvalue is stored in the corresponding array section of **z**.
- 4: **sigma** – Complex *Input*  
*On entry:* if one of the **Shifted Inverse** (see nag\_complex\_sparse\_eigensystem\_option (f12arc)) modes has been selected then **sigma** contains the shift used; otherwise **sigma** is not referenced.
- 5: **resid**[*dim*] – const Complex *Input*  
**Note:** the dimension, *dim*, of the array **resid** must be at least **n** (see nag\_complex\_sparse\_eigensystem\_init (f12anc)).  
*On entry:* must not be modified following a call to nag\_complex\_sparse\_eigensystem\_iter (f12apc) since it contains data required by nag\_complex\_sparse\_eigensystem\_sol (f12aqc).
- 6: **v**[**n** × **ncv**] – Complex *Input/Output*  
The *i*th element of the *j*th basis vector is stored in location **v**[**n** × (*j* – 1) + *i* – 1], for *i* = 1, 2, ..., **n** and *j* = 1, 2, ..., **ncv**.  
*On entry:* the **ncv** sections of **v**, of length *n*, contain the Arnoldi basis vectors for OP as constructed by nag\_complex\_sparse\_eigensystem\_iter (f12apc).  
*On exit:* if the option **Vectors** = SCHUR or RITZ has been set and a separate array **z** has been passed (i.e., **z** does not equal **v**), then the first **nconv** sections of **v**, of length *n*, will contain approximate Schur vectors that span the desired invariant subspace.

- 7: **comm**[*dim*] – Complex *Communication Array*  
**Note:** the dimension, *dim*, of the array **comm** must be at least  $\max(1, \mathbf{lcomm})$  (see `nag_complex_sparse_eigensystem_init` (f12anc)).  
*On initial entry:* must remain unchanged from the prior call to `nag_complex_sparse_eigensystem_init` (f12anc).  
*On exit:* contains data on the current state of the solution.
- 8: **icomm**[*dim*] – Integer *Communication Array*  
**Note:** the dimension, *dim*, of the array **icomm** must be at least  $\max(1, \mathbf{licomm})$  (see `nag_complex_sparse_eigensystem_init` (f12anc)).  
*On initial entry:* must remain unchanged from the prior call to `nag_complex_sparse_eigensystem_init` (f12anc).  
*On exit:* contains data on the current state of the solution.
- 9: **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 2.3.1.2 in How to Use the NAG Library and its Documentation for further information.

### NE\_BAD\_PARAM

On entry, argument  $\langle value \rangle$  had an illegal value.

### NE\_INTERNAL\_EIGVEC\_FAIL

In calculating eigenvectors, an internal call returned with an error. The function returned with **fail.code** =  $\langle value \rangle$ . Please contact NAG.

### 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 2.7.6 in How to Use the NAG Library and its Documentation for further information.

### NE\_INVALID\_OPTION

On entry, **Vectors** = Select, but this is not yet implemented.

### NE\_NO\_LICENCE

Your licence key may have expired or may not have been installed correctly.

See Section 2.7.5 in How to Use the NAG Library and its Documentation for further information.

### NE\_RITZ\_COUNT

Got a different count of the number of converged Ritz values than the value passed to it through the argument **icomm**: number counted =  $\langle value \rangle$ , number expected =  $\langle value \rangle$ . This usually indicates that a communication array has been altered or has become corrupted between calls to

nag\_complex\_sparse\_eigensystem\_iter (f12apc) and nag\_complex\_sparse\_eigensystem\_sol (f12aqc).

### NE\_SCHUR\_EIG\_FAIL

During calculation of a Schur form, there was a failure to compute  $\langle value \rangle$  eigenvalues in a total of  $\langle value \rangle$  iterations.

### NE\_SCHUR\_REORDER

The computed Schur form could not be reordered by an internal call. This function returned with **fail.code** =  $\langle value \rangle$ . Please contact NAG.

### NE\_ZERO\_EIGS\_FOUND

The number of eigenvalues found to sufficient accuracy, as communicated through the argument **icomm**, is zero. You should experiment with different values of **nev** and **ncv**, or select a different computational mode or increase the maximum number of iterations prior to calling nag\_complex\_sparse\_eigensystem\_iter (f12apc).

## 7 Accuracy

The relative accuracy of a Ritz value,  $\lambda$ , is considered acceptable if its Ritz estimate  $\leq \mathbf{Tolerance} \times |\lambda|$ . The default **Tolerance** used is the *machine precision* given by nag\_machine\_precision (X02AJC).

## 8 Parallelism and Performance

nag\_complex\_sparse\_eigensystem\_sol (f12aqc) 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

None.

## 10 Example

This example solves  $Ax = \lambda Bx$  in regular-invert mode, where  $A$  and  $B$  are derived from the standard central difference discretization of the one-dimensional convection-diffusion operator  $\frac{d^2u}{dx^2} + \rho \frac{du}{dx}$  on  $[0, 1]$ , with zero Dirichlet boundary conditions.

### 10.1 Program Text

```

/* nag_complex_sparse_eigensystem_sol (f12aqc) Example Program.
 *
 * NAGPRODCODE Version.
 *
 * Copyright 2016 Numerical Algorithms Group.
 *
 * Mark 26, 2016.
 */

#include <math.h>
#include <nag.h>
#include <nag_stdlib.h>
#include <nag_string.h>
#include <stdio.h>
#include <naga02.h>

```

```

#include <nagf12.h>
#include <nagf16.h>

/* Table of constant values */
static Complex rho = { 10., 0. };

static void av(Integer, Complex *, Complex *);
static void mv(Integer, Complex *, Complex *);
static void my_zgttrf(Integer, Complex *, Complex *, Complex *,
                    Complex *, Integer *, Integer *);
static void my_zgttrs(Integer, Complex *, Complex *, Complex *,
                    Complex *, Integer *, Complex *);

int main(void)
{
    /* Constants */
    Integer licomm = 140, imon = 0;

    /* Scalars */
    Complex h, h4, sigma;
    double estnrm, hr;
    Integer exit_status, info, irevcm, j, lcomm, n, nconv, ncv;
    Integer nev, niter, nshift, nx;
    /* Nag types */
    NagError fail;

    /* Arrays */
    Complex *comm = 0, *eigv = 0, *eigest = 0, *dd = 0, *dl = 0, *du = 0;
    Complex *du2 = 0, *resid = 0, *v = 0;
    Integer *icomm = 0, *ipiv = 0;

    /* Ponters */
    Complex *mx = 0, *x = 0, *y = 0;

    /* Assign to Complex type using nag_complex (a02bac) */
    sigma = nag_complex(0.0, 0.0);
    exit_status = 0;
    INIT_FAIL(fail);

    printf("nag_complex_sparse_eigensystem_sol (f12aqc) Example "
           "Program Results\n");
    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n] ");
#else
    scanf("%*[\n] ");
#endif

#ifdef _WIN32
    scanf_s("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &nx, &nev, &ncv);
#else
    scanf("%" NAG_IFMT "%" NAG_IFMT "%" NAG_IFMT "%*[\n] ", &nx, &nev, &ncv);
#endif
    n = nx * nx;
    lcomm = 3 * n + 3 * ncv * ncv + 5 * ncv + 60;
    /* Allocate memory */
    if (!(comm = NAG_ALLOC(lcomm, Complex)) ||
        !(eigv = NAG_ALLOC(ncv, Complex)) ||
        !(eigest = NAG_ALLOC(ncv, Complex)) ||
        !(dd = NAG_ALLOC(n, Complex)) ||
        !(dl = NAG_ALLOC(n, Complex)) ||
        !(du = NAG_ALLOC(n, Complex)) ||
        !(du2 = NAG_ALLOC(n, Complex)) ||
        !(resid = NAG_ALLOC(n, Complex)) ||
        !(v = NAG_ALLOC(n * ncv, Complex)) ||
        !(icomm = NAG_ALLOC(licomm, Integer)) ||
        !(ipiv = NAG_ALLOC(n, Integer)))
    {
        printf("Allocation failure\n");
        exit_status = -1;
    }
}

```

```

    goto END;
}
/* Initialize communication arrays for problem using
   nag_complex_sparse_eigensystem_init (f12anc). */
nag_complex_sparse_eigensystem_init(n, nev, ncv, icomm,
                                     licomm, comm, lcomm, &fail);
if (fail.code != NE_NOERROR) {
    printf("nag_complex_sparse_eigensystem_init (f12anc).\n%s\n",
          fail.message);
    exit_status = 1;
    goto END;
}

/* Select the required mode using
   nag_complex_sparse_eigensystem_option (f12arc). */
nag_complex_sparse_eigensystem_option("REGULAR INVERSE",
                                       icomm, comm, &fail);

/* Select the problem type using
   nag_complex_sparse_eigensystem_option (f12arc). */
nag_complex_sparse_eigensystem_option("GENERALIZED", icomm, comm, &fail);
hr = 1.0 / (double) (n + 1);
/* Assign to Complex type using nag_complex (a02bac) */
h = nag_complex(hr, 0.0);
h4 = nag_complex(4.0 * hr, 0.0);

for (j = 0; j <= n - 2; ++j) {
    dl[j] = h;
    dd[j] = h4;
    du[j] = h;
}
dd[n - 1] = h4;

my_zgtrf(n, dl, dd, du, du2, ipiv, &info);
if (fail.code != NE_NOERROR) {
    printf(" Error from nag_zgtrf.\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}
irevcm = 0;
REVCOMLOOP:
/* repeated calls to reverse communication routine
   nag_complex_sparse_eigensystem_iter (f12apc). */
nag_complex_sparse_eigensystem_iter(&irevcm, resid, v, &x,
                                     &y, &mx, &nshift, comm, icomm, &fail);
if (irevcm != 5) {
    if (irevcm == -1 || irevcm == 1) {
        /* Perform y <--- OP*x = inv[M]*A*x      | */
        av(nx, x, y);
        my_zgttrs(n, dl, dd, du, du2, ipiv, y);
        if (fail.code != NE_NOERROR) {
            printf(" Error from nag_zgttrs.\n%s\n", fail.message);
            exit_status = 1;
            goto END;
        }
    }
    else if (irevcm == 2) {
        /* Perform y <--- M*x */
        mv(nx, x, y);
    }
    else if (irevcm == 4 && imon == 1) {
        /* If imon=1, get monitoring information using
           nag_complex_sparse_eigensystem_monit (f12asc). */
        nag_complex_sparse_eigensystem_monit(&niter, &nconv, eigv,
                                             eigest, icomm, comm);

        /* Compute 2-norm of Ritz estimates using
           nag_zge_norm (f16uac). */
        nag_zge_norm(Nag_ColMajor, Nag_FrobeniusNorm, nev, 1,
                    eigest, nev, &estnrm, &fail);
        printf(" Iteration %3" NAG_IFMT " ", niter);
        printf(" No. converged = %3" NAG_IFMT " ", nconv);
        printf(" norm of estimates = %17.8e\n", estnrm);
    }
}

```

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    }
    goto REVCOMLOOP;
}
if (fail.code == NE_NOERROR) {
    /* Post-Process using nag_complex_sparse_eigensystem_sol (f12aqc)
       to compute eigenvalues. */
    nag_complex_sparse_eigensystem_sol(&nconv, eigv, v, sigma,
                                       resid, v, comm, icomm, &fail);

    printf("\n");
    printf(" The %4" NAG_IFMT " ", nconv);
    printf(" Ritz values of largest magnitude are:\n\n");
    for (j = 0; j <= nconv - 1; ++j) {
        printf("%8" NAG_IFMT "%5s( %12.4f , %12.4f )\n", j + 1, "",
              eigv[j].re, eigv[j].im);
    }
}
else {
    printf(" Error from nag_complex_sparse_eigensystem_iter "
          "(f12aqc).\n%s\n", fail.message);
    exit_status = 1;
    goto END;
}
END:
    NAG_FREE(comm);
    NAG_FREE(eigv);
    NAG_FREE(eigest);
    NAG_FREE(dd);
    NAG_FREE(dl);
    NAG_FREE(du);
    NAG_FREE(du2);
    NAG_FREE(resid);
    NAG_FREE(v);
    NAG_FREE(icomm);
    NAG_FREE(ipiv);
    return exit_status;
}

static void av(Integer nx, Complex *v, Complex *y)
{
    /* Scalars */
    Complex dd, dl, du, z1, z2, z3;
    double hr1, sr;
    Integer j, n;

    /* Function Body */
    n = nx * nx;
    hr1 = (double) (n + 1);
    sr = 0.5 * rho.re;
    /* Assign to Complex type using nag_complex (a02bac) */
    dd = nag_complex(2.0 * hr1, 0.0); /* dd = 2.0/h */
    dl = nag_complex(-hr1 - sr, 0.0); /* dl = -1.0/h - rho/2 */
    du = nag_complex(-hr1 + sr, 0.0); /* du = -1.0/h + rho/2 */
    /* w[0] = dd*v[0] + du*v[1] */
    /* Compute Complex multiply using nag_complex_multiply (a02ccc). */
    z1 = nag_complex_multiply(dd, v[0]);
    z2 = nag_complex_multiply(du, v[1]);
    /* Compute Complex addition using nag_complex_add (a02cac). */
    y[0] = nag_complex_add(z1, z2);
    for (j = 1; j <= n - 2; ++j) {
        /* y[j] = dl*v[j-1] + dd*v[j] + du*v[j+1] */
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        z1 = nag_complex_multiply(dl, v[j - 1]);
        z2 = nag_complex_multiply(dd, v[j]);
        z3 = nag_complex_multiply(du, v[j + 1]);
        /* Compute Complex addition using nag_complex_add
           (a02cac). */
        z1 = nag_complex_add(z1, z2);
        y[j] = nag_complex_add(z1, z3);
    }
}

```

```

/* y[n-1] = dl*v[n-2] + dd*v[n-1] */
/* Compute Complex multiply using nag_complex_multiply (a02ccc). */
z1 = nag_complex_multiply(dl, v[n - 2]);
z2 = nag_complex_multiply(dd, v[n - 1]);
/* Compute Complex addition using nag_complex_add (a02cac). */
y[n - 1] = nag_complex_add(z1, z2);
return;
} /* av */

static void mv(Integer nx, Complex *v, Complex *y)
{
/* Scalars */
Complex oneh, fourh, z1, z2;
double hr;
Integer j, n;

/* Function Body */
n = nx * nx;
hr = 1.0 / (double) (n + 1);
/* Assign to Complex type using nag_complex (a02bac) */
oneh = nag_complex(hr, 0.0);
fourh = nag_complex(4.0 * hr, 0.0);
/* y[0] = h*(four*v[0] + one*v[1]) */
/* Compute Complex multiply using nag_complex_multiply
(a02ccc). */
z1 = nag_complex_multiply(fourh, v[0]);
z2 = nag_complex_multiply(oneh, v[1]);
/* Compute Complex addition using nag_complex_add (a02cac). */
y[0] = nag_complex_add(z1, z2);
for (j = 1; j <= n - 2; ++j) {
/* y[j] = h*(one*v[j-1] + four*v[j] + one*v[j+1]) */
/* Compute Complex multiply using nag_complex_multiply
(a02ccc). */
z1 = nag_complex_multiply(fourh, v[j]);
/* Compute Complex addition using nag_complex_add
(a02cac). */
z2 = nag_complex_add(v[j - 1], v[j + 1]);
z2 = nag_complex_multiply(oneh, z2);
y[j] = nag_complex_add(z1, z2);
}
/* y[n-1] = h*(one*v[n-2] + four*v[n-1]) */
/* Compute Complex multiply using nag_complex_multiply
(a02ccc). */
z1 = nag_complex_multiply(fourh, v[n - 1]);
z2 = nag_complex_multiply(oneh, v[n - 2]);
/* Compute Complex addition using nag_complex_add (a02cac). */
y[n - 1] = nag_complex_add(z1, z2);
return;
} /* mv */

static void my_zgttrf(Integer n, Complex dl[], Complex d[],
Complex du[], Complex du2[], Integer ipiv[],
Integer *info)
{
/* A simple C version of the Lapack routine zgttrf with argument
checking removed */
/* Scalars */
Complex temp, fact, z1;
Integer i;
/* Function Body */
*info = 0;
for (i = 0; i < n; ++i) {
ipiv[i] = i;
}
for (i = 0; i < n - 2; ++i) {
du2[i] = nag_complex(0.0, 0.0);
}
for (i = 0; i < n - 2; ++i) {
if (fabs(d[i].re) + fabs(d[i].im) >= fabs(dl[i].re) + fabs(dl[i].im)) {
/* No row interchange required, eliminate dl[i]. */
if (fabs(d[i].re) + fabs(d[i].im) != 0.0) {

```

```

    /* Compute Complex division using nag_complex_divide
       (a02cdc). */
    fact = nag_complex_divide(dl[i], d[i]);
    dl[i] = fact;
    /* Compute Complex multiply using nag_complex_multiply
       (a02ccc). */
    fact = nag_complex_multiply(fact, du[i]);
    /* Compute Complex subtraction using
       nag_complex_subtract (a02cbc). */
    d[i + 1] = nag_complex_subtract(d[i + 1], fact);
}
}
else {
    /* Interchange rows I and I+1, eliminate dl[I] */
    /* Compute Complex division using nag_complex_divide
       (a02cdc). */
    fact = nag_complex_divide(d[i], dl[i]);
    d[i] = dl[i];
    dl[i] = fact;
    temp = du[i];
    du[i] = d[i + 1];
    /* Compute Complex multiply using nag_complex_multiply
       (a02ccc). */
    z1 = nag_complex_multiply(fact, d[i + 1]);
    /* Compute Complex subtraction using nag_complex_subtract
       (a02cbc). */
    d[i + 1] = nag_complex_subtract(temp, z1);
    du2[i] = du[i + 1];
    /* Compute Complex multiply using nag_complex_multiply
       (a02ccc). */
    du[i + 1] = nag_complex_multiply(fact, du[i + 1]);
    /* Perform Complex negation using nag_complex_negate
       (a02cec). */
    du[i + 1] = nag_complex_negate(du[i + 1]);
    ipiv[i] = i + 1;
}
}
if (n > 1) {
    i = n - 2;
    if (fabs(d[i].re) + fabs(d[i].im) >= fabs(dl[i].re) + fabs(dl[i].im)) {
        if (fabs(d[i].re) + fabs(d[i].im) != 0.0) {
            /* Compute Complex division using nag_complex_divide
               (a02cdc). */
            fact = nag_complex_divide(dl[i], d[i]);
            dl[i] = fact;
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            fact = nag_complex_multiply(fact, du[i]);
            /* Compute Complex subtraction using
               nag_complex_subtract (a02cbc). */
            d[i + 1] = nag_complex_subtract(d[i + 1], fact);
        }
    }
    else {
        /* Compute Complex division using nag_complex_divide
           (a02cdc). */
        fact = nag_complex_divide(d[i], dl[i]);
        d[i] = dl[i];
        dl[i] = fact;
        temp = du[i];
        du[i] = d[i + 1];
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        z1 = nag_complex_multiply(fact, d[i + 1]);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        d[i + 1] = nag_complex_subtract(temp, z1);
        ipiv[i] = i + 1;
    }
}
}
/* Check for a zero on the diagonal of U. */

```

```

for (i = 0; i < n; ++i) {
    if (fabs(d[i].re) + fabs(d[i].im) == 0.0) {
        *info = i;
        goto END;
    }
}
END:
return;
}

static void my_zgttrs(Integer n, Complex dl[], Complex d[],
                    Complex du[], Complex du2[], Integer ipiv[],
                    Complex b[])
{
    /* A simple C version of the Lapack routine zgttrs with argument
       checking removed, the number of right-hand-sides=1, Trans='N' */
    /* Scalars */
    Complex temp, z1;
    Integer i;
    /* Solve L*x = b. */
    for (i = 0; i < n - 1; ++i) {
        if (ipiv[i] == i) {
            /* b[i+1] = b[i+1] - dl[i]*b[i] */
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            temp = nag_complex_multiply(dl[i], b[i]);
            /* Compute Complex subtraction using nag_complex_subtract
               (a02cbc). */
            b[i + 1] = nag_complex_subtract(b[i + 1], temp);
        }
        else {
            temp = b[i];
            b[i] = b[i + 1];
            /* Compute Complex multiply using nag_complex_multiply
               (a02ccc). */
            z1 = nag_complex_multiply(dl[i], b[i]);
            /* Compute Complex subtraction using nag_complex_subtract
               (a02cbc). */
            b[i + 1] = nag_complex_subtract(temp, z1);
        }
    }
    /* Solve U*x = b. */
    /* Compute Complex division using nag_complex_divide (a02cdc). */
    b[n - 1] = nag_complex_divide(b[n - 1], d[n - 1]);
    if (n > 1) {
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        temp = nag_complex_multiply(du[n - 2], b[n - 1]);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        z1 = nag_complex_subtract(b[n - 2], temp);
        /* Compute Complex division using nag_complex_divide (a02cdc). */
        b[n - 2] = nag_complex_divide(z1, d[n - 2]);
    }
    for (i = n - 3; i >= 0; --i) {
        /* b[i] = (b[i]-du[i]*b[i+1]-du2[i]*b[i+2])/d[i]; */
        /* Compute Complex multiply using nag_complex_multiply
           (a02ccc). */
        temp = nag_complex_multiply(du[i], b[i + 1]);
        z1 = nag_complex_multiply(du2[i], b[i + 2]);
        /* Compute Complex addition using nag_complex_add
           (a02cac). */
        temp = nag_complex_add(temp, z1);
        /* Compute Complex subtraction using nag_complex_subtract
           (a02cbc). */
        z1 = nag_complex_subtract(b[i], temp);
        /* Compute Complex division using nag_complex_divide

```

```
        (a02cdc). */
    b[i] = nag_complex_divide(z1, d[i]);
}
return;
}
```

## 10.2 Program Data

nag\_complex\_sparse\_eigensystem\_sol (f12aqc) Example Program Data  
10 4 20 : Vaues for nx, nev and ncv

## 10.3 Program Results

nag\_complex\_sparse\_eigensystem\_sol (f12aqc) Example Program Results

The 4 Ritz values of largest magnitude are:

1	(	20383.0384	,	-0.0000	)
2	(	20338.7563	,	0.0000	)
3	(	20265.2844	,	-0.0000	)
4	(	20163.1142	,	0.0000	)

---