

# NAG Library Function Document

## nag\_zgemqrt (f08aqc)

### 1 Purpose

nag\_zgemqrt (f08aqc) multiplies an arbitrary complex matrix  $C$  by the complex unitary matrix  $Q$  from a  $QR$  factorization computed by nag\_zgeqrt (f08apc).

### 2 Specification

```
#include <nag.h>
#include <nagf08.h>

void nag_zgemqrt (Nag_OrderType order, Nag_SideType side,
                 Nag_TransType trans, Integer m, Integer n, Integer k, Integer nb,
                 const Complex v[], Integer pdv, const Complex t[], Integer pdt,
                 Complex c[], Integer pdc, NagError *fail)
```

### 3 Description

nag\_zgemqrt (f08aqc) is intended to be used after a call to nag\_zgeqrt (f08apc), which performs a  $QR$  factorization of a complex matrix  $A$ . The unitary matrix  $Q$  is represented as a product of elementary reflectors.

This function may be used to form one of the matrix products

$$QC, Q^H C, CQ \text{ or } CQ^H,$$

overwriting the result on  $C$  (which may be any complex rectangular matrix).

A common application of this function is in solving linear least squares problems, as described in the f08 Chapter Introduction and illustrated in Section 10 in nag\_zgeqrt (f08apc).

### 4 References

Golub G H and Van Loan C F (2012) *Matrix Computations* (4th Edition) Johns Hopkins University Press, Baltimore

### 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: **side** – Nag\_SideType *Input*

*On entry:* indicates how  $Q$  or  $Q^H$  is to be applied to  $C$ .

**side** = Nag\_LeftSide

$Q$  or  $Q^H$  is applied to  $C$  from the left.

**side** = Nag\_RightSide

$Q$  or  $Q^H$  is applied to  $C$  from the right.

*Constraint:* **side** = Nag\_LeftSide or Nag\_RightSide.

- 3: **trans** – Nag\_TransType *Input*  
*On entry:* indicates whether  $Q$  or  $Q^H$  is to be applied to  $C$ .  
**trans** = Nag\_NoTrans  
 $Q$  is applied to  $C$ .  
**trans** = Nag\_ConjTrans  
 $Q^H$  is applied to  $C$ .  
*Constraint:* **trans** = Nag\_NoTrans or Nag\_ConjTrans.
- 4: **m** – Integer *Input*  
*On entry:*  $m$ , the number of rows of the matrix  $C$ .  
*Constraint:* **m**  $\geq$  0.
- 5: **n** – Integer *Input*  
*On entry:*  $n$ , the number of columns of the matrix  $C$ .  
*Constraint:* **n**  $\geq$  0.
- 6: **k** – Integer *Input*  
*On entry:*  $k$ , the number of elementary reflectors whose product defines the matrix  $Q$ . Usually **k** =  $\min(m_A, n_A)$  where  $m_A, n_A$  are the dimensions of the matrix  $A$  supplied in a previous call to nag\_zgeqrt (f08apc).  
*Constraints:*  
if **side** = Nag\_LeftSide, **m**  $\geq$  **k**  $\geq$  0;  
if **side** = Nag\_RightSide, **n**  $\geq$  **k**  $\geq$  0.
- 7: **nb** – Integer *Input*  
*On entry:* the block size used in the  $QR$  factorization performed in a previous call to nag\_zgeqrt (f08apc); this value must remain unchanged from that call.  
*Constraints:*  
**nb**  $\geq$  1;  
if **k** > 0, **nb**  $\leq$  **k**.
- 8: **v[dim]** – const Complex *Input*  
**Note:** the dimension,  $dim$ , of the array **v** must be at least  
 $\max(1, \mathbf{pdv} \times \mathbf{k})$  when **order** = Nag\_ColMajor;  
 $\max(1, \mathbf{m} \times \mathbf{pdv})$  when **order** = Nag\_RowMajor and **side** = Nag\_LeftSide;  
 $\max(1, \mathbf{n} \times \mathbf{pdv})$  when **order** = Nag\_RowMajor and **side** = Nag\_RightSide.  
*On entry:* details of the vectors which define the elementary reflectors, as returned by nag\_zgeqrt (f08apc) in the first  $k$  columns of its array argument **a**.
- 9: **pdv** – Integer *Input*  
*On entry:* the stride separating row or column elements (depending on the value of **order**) in the array **v**.  
*Constraints:*  
if **order** = Nag\_ColMajor,  
if **side** = Nag\_LeftSide, **pdv**  $\geq$   $\max(1, \mathbf{m})$ ;  
if **side** = Nag\_RightSide, **pdv**  $\geq$   $\max(1, \mathbf{n})$ .;  
if **order** = Nag\_RowMajor, **pdv**  $\geq$   $\max(1, \mathbf{k})$ .

10: **t**[*dim*] – const Complex *Input*

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

$$\begin{aligned} &\max(1, \mathbf{pdt} \times \mathbf{k}) \text{ when } \mathbf{order} = \text{Nag\_ColMajor}; \\ &\max(1, \mathbf{nb} \times \mathbf{pdt}) \text{ when } \mathbf{order} = \text{Nag\_RowMajor}. \end{aligned}$$

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

$$\begin{aligned} &\mathbf{t}[(j-1) \times \mathbf{pdt} + i - 1] \text{ when } \mathbf{order} = \text{Nag\_ColMajor}; \\ &\mathbf{t}[(i-1) \times \mathbf{pdt} + j - 1] \text{ when } \mathbf{order} = \text{Nag\_RowMajor}. \end{aligned}$$

*On entry:* further details of the unitary matrix *Q* as returned by nag\_zgeqrt (f08apc). The number of blocks is  $b = \lceil \frac{k}{\mathbf{nb}} \rceil$ , where  $k = \min(m, n)$  and each block is of order **nb** except for the last block, which is of order  $k - (b - 1) \times \mathbf{nb}$ . For the *b* blocks the upper triangular block reflector factors  $\mathbf{T}_1, \mathbf{T}_2, \dots, \mathbf{T}_b$  are stored in the **nb** by *n* matrix *T* as  $\mathbf{T} = [\mathbf{T}_1 | \mathbf{T}_2 | \dots | \mathbf{T}_b]$ .

11: **pdt** – Integer *Input*

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

*Constraints:*

$$\begin{aligned} &\text{if } \mathbf{order} = \text{Nag\_ColMajor}, \mathbf{pdt} \geq \mathbf{nb}; \\ &\text{if } \mathbf{order} = \text{Nag\_RowMajor}, \mathbf{pdt} \geq \max(1, \mathbf{k}). \end{aligned}$$

12: **c**[*dim*] – Complex *Input/Output*

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

$$\begin{aligned} &\max(1, \mathbf{pdc} \times \mathbf{n}) \text{ when } \mathbf{order} = \text{Nag\_ColMajor}; \\ &\max(1, \mathbf{m} \times \mathbf{pdc}) \text{ when } \mathbf{order} = \text{Nag\_RowMajor}. \end{aligned}$$

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

$$\begin{aligned} &\mathbf{c}[(j-1) \times \mathbf{pdc} + i - 1] \text{ when } \mathbf{order} = \text{Nag\_ColMajor}; \\ &\mathbf{c}[(i-1) \times \mathbf{pdc} + j - 1] \text{ when } \mathbf{order} = \text{Nag\_RowMajor}. \end{aligned}$$

*On entry:* the *m* by *n* matrix *C*.

*On exit:* **c** is overwritten by *QC* or  $Q^H C$  or *CQ* or  $CQ^H$  as specified by **side** and **trans**.

13: **pdc** – Integer *Input*

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

*Constraints:*

$$\begin{aligned} &\text{if } \mathbf{order} = \text{Nag\_ColMajor}, \mathbf{pdc} \geq \max(1, \mathbf{m}); \\ &\text{if } \mathbf{order} = \text{Nag\_RowMajor}, \mathbf{pdc} \geq \max(1, \mathbf{n}). \end{aligned}$$

14: **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\_ENUM\_INT\_3**

On entry, **side** =  $\langle value \rangle$ , **m** =  $\langle value \rangle$ , **n** =  $\langle value \rangle$  and **k** =  $\langle value \rangle$ .

Constraint: if **side** = Nag\_LeftSide, **m**  $\geq$  **k**  $\geq$  0;

if **side** = Nag\_RightSide, **n**  $\geq$  **k**  $\geq$  0.

On entry, **side** =  $\langle value \rangle$ , **m** =  $\langle value \rangle$ , **n** =  $\langle value \rangle$  and **pdv** =  $\langle value \rangle$ .

Constraint: if **side** = Nag\_LeftSide, **pdv**  $\geq$  max(1, **m**);

if **side** = Nag\_RightSide, **pdv**  $\geq$  max(1, **n**).

**NE\_INT**

On entry, **m** =  $\langle value \rangle$ .

Constraint: **m**  $\geq$  0.

On entry, **n** =  $\langle value \rangle$ .

Constraint: **n**  $\geq$  0.

**NE\_INT\_2**

On entry, **nb** =  $\langle value \rangle$  and **k** =  $\langle value \rangle$ .

Constraint: **nb**  $\geq$  1 and

if **k** > 0, **nb**  $\leq$  **k**.

On entry, **pdv** =  $\langle value \rangle$  and **m** =  $\langle value \rangle$ .

Constraint: **pdv**  $\geq$  max(1, **m**).

On entry, **pdv** =  $\langle value \rangle$  and **n** =  $\langle value \rangle$ .

Constraint: **pdv**  $\geq$  max(1, **n**).

On entry, **pdv** =  $\langle value \rangle$  and **k** =  $\langle value \rangle$ .

Constraint: **pdv**  $\geq$  max(1, **k**).

On entry, **pdv** =  $\langle value \rangle$  and **nb** =  $\langle value \rangle$ .

Constraint: **pdv**  $\geq$  **nb**.

On entry, **pdv** =  $\langle value \rangle$  and **k** =  $\langle value \rangle$ .

Constraint: **pdv**  $\geq$  max(1, **k**).

**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\_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.

**7 Accuracy**

The computed result differs from the exact result by a matrix  $E$  such that

$$\|E\|_2 = O(\epsilon)\|C\|_2,$$

where  $\epsilon$  is the *machine precision*.

## **8 Parallelism and Performance**

nag\_zgemqrt (f08aqc) 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 real floating-point operations is approximately  $8nk(2m - k)$  if **side** = Nag\_LeftSide and  $8mk(2n - k)$  if **side** = Nag\_RightSide.

The real analogue of this function is nag\_dgemqrt (f08acc).

## **10 Example**

See Section 10 in nag\_zgeqrt (f08apc).

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