# NAG C Library Function Document

# nag_1d_quad_wt_trig (d01anc)

## 1 Purpose

nag_1d_quad_wt_trig (d01anc) calculates an approximation to the sine or the cosine transform of a function $g$ over $[a, b]$:

$$I = \int_a^b g(x) \sin(\omega x) \, dx \quad \text{or} \quad I = \int_a^b g(x) \cos(\omega x) \, dx$$

(for a user-specified value of $\omega$).

## 2 Specification

```
#include <nag.h>
#include <nagd01.h>
```

```
void nag_1d_quad_wt_trig (double (*g)(double x),
          double a, double b, double omega, Nag_TrigTransform wt_func,
          double epsabs, double epsrel, Integer max_num_subint,
          double *result, double *abserr, Nag_QuadProgress *qp, NagError *fail)
```

## 3 Description

This function is based upon the QUADPACK routine QFOUR (Piessens *et al.* (1983)). It is an adaptive routine, designed to integrate a function of the form $g(x)w(x)$, where $w(x)$ is either $\sin(\omega x)$ or $\cos(\omega x)$. If a sub-interval has length

$$L = |b - a| 2^{-l}$$

then the integration over this sub-interval is performed by means of a modified Clenshaw-Curtis procedure (Piessens and Branders (1975)) if $L\omega > 4$ and $l \leq 20$. In this case a Chebyshev-series approximation of degree 24 is used to approximate $g(x)$, while an error estimate is computed from this approximation together with that obtained using Chebyshev-series of degree 12. If the above conditions do not hold then Gauss 7-point and Kronrod 15-point rules are used. The algorithm, described in Piessens *et al.* (1983), incorporates a global acceptance criterion (as defined in Malcolm and Simpson (1976)) together with the $\epsilon$-algorithm (Wynn (1956)) to perform extrapolation. The local error estimation is described in Piessens *et al.* (1983).

## 4 Parameters

1: **g** – function supplied by user *Function*

The function **g**, supplied by the user, must return the value of the function $g$ at a given point.

The specification of **g** is:

```
double g(double x)
```

1: **x** – double *Input*

*On entry:* the point at which the function $g$ must be evaluated.

2: **a** – double *Input*

*On entry:* the lower limit of integration, $a$.

3: **b** – double *Input*

*On entry:* the upper limit of integration, $b$. It is not necessary that $a < b$.

4: **omega** – double *Input*

*On entry:* the parameter $\omega$ in the weight function of the transform.

5: **wt_func** – Nag_TrigTransform *Input*

*On entry:* indicates which integral is to be computed:

if **wt_func** $=$ **Nag_Cosine**, $w(x) = \cos(\omega x)$;

if **wt_func** $=$ **Nag_Sine**, $w(x) = \sin(\omega x)$.

*Constraint:* **wt_func** $=$ **Nag_Cosine** or **Nag_Sine**.

6: **epsabs** – double *Input*

*On entry:* the absolute accuracy required. If **epsabs** is negative, the absolute value is used. See Section 6.1.

7: **epsrel** – double *Input*

*On entry:* the relative accuracy required. If **epsrel** is negative, the absolute value is used. See Section 6.1.

8: **max_num_subint** – Integer *Input*

*On entry:* the upper bound on the number of sub-intervals into which the interval of integration may be divided by the function. The more difficult the integrand, the larger **max_num_subint** should be.

*Suggested values:* a value in the range 200 to 500 is adequate for most problems.

*Constraint:* **max_num_subint** $\geq 1$.

9: **result** – double * *Output*

*On exit:* the approximation to the integral $I$.

10: **abserr** – double * *Output*

*On exit:* an estimate of the modulus of the absolute error, which should be an upper bound for $|I -$ **result**$|$.

11: **qp** – Nag_QuadProgress * 

Pointer to structure of type **Nag_QuadProgress** with the following members:

**num_subint** – Integer *Output*

*On exit:* the actual number of sub-intervals used.

**fun_count** – Integer *Output*

*On exit:* the number of function evaluations performed by nag_1d_quad_wt_trig.

**sub_int_beg_pts** – double * *Output*
**sub_int_end_pts** – double * *Output*
**sub_int_result** – double * *Output*
**sub_int_error** – double * *Output*

*On exit:* these pointers are allocated memory internally with **max_num_subint** elements. If an error exit other than **NE_INT_ARG_LT**, **NE_BAD_PARAM** or **NE_ALLOC_FAIL** occurs, these arrays will contain information which may be useful. For details, see Section 6.

Before a subsequent call to nag_1d_quad_wt_trig is made, or when the information contained in these arrays is no longer useful, the user should free the storage allocated by these pointers using the NAG macro **NAG_FREE**.

12: **fail** – NagError * *Input/Output*

The NAG error parameter (see the Essential Introduction).

Users are recommended to declare and initialise **fail** and set **fail.print** = **TRUE** for this function.

## 5 Error Indicators and Warnings

**NE_INT_ARG_LT**

On entry, **max_num_subint** must not be less than 1: **max_num_subint** = <*value*>.

**NE_BAD_PARAM**

On entry, parameter **wt_func** had an illegal value.

**NE_ALLOC_FAIL**

Memory allocation failed.

**NE_QUAD_MAX_SUBDIV**

The maximum number of subdivisions has been reached: **max_num_subint** = <*value*>.
The maximum number of subdivisions has been reached without the accuracy requirements being achieved. Look at the integrand in order to determine the integration difficulties. If the position of a local difficulty within the interval can be determined (e.g., a singularity of the integrand or its derivative, a peak, a discontinuity, etc.) you will probably gain from splitting up the interval at this point and calling the integrator on the sub-intervals. If necessary, another integrator, which is designed for handling the type of difficulty involved, must be used. Alternatively, consider relaxing the accuracy requirements specified by **epsabs** and **epsrel**, or increasing the value of **max_num_subint**.

**NE_QUAD_ROUNDOFF_TOL**

Round-off error prevents the requested tolerance from being achieved: **epsabs** = <*value*>, **epsrel** = <*value*>.
The error may be underestimated. Consider relaxing the accuracy requirements specified by **epsabs** and **epsrel**.

**NE_QUAD_BAD_SUBDIV**

Extremely bad integrand behaviour occurs around the sub-interval (<*value*>, <*value*>).
The same advice applies as in the case of **NE_QUAD_MAX_SUBDIV**.

**NE_QUAD_ROUNDOFF_EXTRAPL**

Round-off error is detected during extrapolation.
The requested tolerance cannot be achieved, because the extrapolation does not increase the accuracy satisfactorily; the returned result is the best that can be obtained.
The same advice applies as in the case of **NE_QUAD_MAX_SUBDIV**.

**NE_QUAD_NO_CONV**

The integral is probably divergent or slowly convergent.
Please note that divergence can also occur with any error exit other than **NE_INT_ARG_LT**, **NE_BAD_PARAM** or **NE_ALLOC_FAIL**.

# 6 Further Comments

The time taken by nag_1d_quad_wt_trig depends on the integrand and the accuracy required.

If the function fails with an error exit other than **NE_INT_ARG_LT**, **NE_BAD_PARAM** or **NE_ALLOC_FAIL**, then the user may wish to examine the contents of the structure **qp**. These contain the end-points of the sub-intervals used by nag_1d_quad_wt_trig along with the integral contributions and error estimates over the sub-intervals.

Specifically, for $i = 1, 2, \ldots, n$, let $r_i$ denote the approximation to the value of the integral over the sub-interval $[a_i, b_i]$ in the partition of $[a, b]$ and $e_i$ be the corresponding absolute error estimate.

Then, $\int_{a_i}^{b_i} g(x)w(x)\,dx \simeq r_i$ and **result** $= \sum_{i=1}^{n} r_i$ unless the function terminates while testing for divergence of the integral (see Section 3.4.3 of Piessens *et al.* (1983)). In this case, **result** (and **abserr**) are taken to be the values returned from the extrapolation process. The value of $n$ is returned in **num_subint**, and the values $a_i$, $b_i$, $r_i$ and $e_i$ are stored in the structure **qp** as

$a_i$ = **sub_int_beg_pts**$[i-1]$,

$b_i$ = **sub_int_end_pts**$[i-1]$,

$r_i$ = **sub_int_result**$[i-1]$ and

$e_i$ = **sub_int_error**$[i-1]$.

## 6.1 Accuracy

The function cannot guarantee, but in practice usually achieves, the following accuracy:

$$|I - \textbf{result}| \leq tol$$

where

$$tol = \max\{|\textbf{epsabs}|, |\textbf{epsrel}| \times |I|\}$$

and **epsabs** and **epsrel** are user-specified absolute and relative error tolerances. Moreover it returns the quantity **abserr** which, in normal circumstances, satisfies

$$|I - \textbf{result}| \leq \textbf{abserr} \leq tol.$$

## 6.2 References

Malcolm M A and Simpson R B (1976) Local versus global strategies for adaptive quadrature *ACM Trans. Math. Software* **1** 129–146

Piessens R and Branders M (1975) Algorithm 002. Computation of oscillating integrals *J. Comput. Appl. Math.* **1** 153–164

Piessens R, De Doncker-Kapenga E, Überhuber C and Kahaner D (1983) *QUADPACK, A Subroutine Package for Automatic Integration* Springer-Verlag

Wynn P (1956) On a device for computing the $e_m(S_n)$ transformation *Math. Tables Aids Comput.* **10** 91–96

# 7 See Also

nag_1d_quad_gen (d01ajc)

# 8 Example

To compute

$$\int_0^1 \ln x \sin(10\pi x)\,dx.$$

## 8.1 Program Text

```
/* nag_1d_quad_wt_trig(d01anc) Example Program
 *
 * Copyright 1991 Numerical Algorithms Group.
 *
 * Mark 2, 1991.
 *
 * Mark 6 revised, 2000.
 */

#include <nag.h>
#include <stdio.h>
#include <nag_stdlib.h>
#include <math.h>
#include <nagd01.h>
#include <nagx01.h>

static double g(double x);

main()
{
  double a, b;
  double omega;
  double epsabs, abserr, epsrel, result;
  Nag_TrigTransform wt_func;
  Nag_QuadProgress qp;
  Integer max_num_subint;
  static NagError fail;

  Vprintf("d01anc Example Program Results\n");
  epsrel = 0.0001;
  epsabs = 0.0;
  a = 0.0;
  b = 1.0;
  omega = X01AAC * 10.0;
  wt_func = Nag_Sine;
  max_num_subint = 200;
  d01anc(g, a, b, omega, wt_func, epsabs, epsrel, max_num_subint, &result,
         &abserr, &qp, &fail);
  Vprintf("a      - lower limit of integration = %10.4f\n", a);
  Vprintf("b      - upper limit of integration = %10.4f\n", b);
  Vprintf("epsabs - absolute accuracy requested = %9.2e\n", epsabs);
  Vprintf("epsrel - relative accuracy requested = %9.2e\n\n", epsrel);
  if (fail.code != NE_NOERROR)
    Vprintf("%s\n", fail.message);
  if (fail.code != NE_INT_ARG_LT && fail.code != NE_BAD_PARAM &&
      fail.code != NE_ALLOC_FAIL)
    {
      Vprintf("result - approximation to the integral = %9.5f\n", result);
      Vprintf("abserr - estimate of the absolute error = %9.2e\n", abserr);
      Vprintf("qp.fun_count  - number of function evaluations = %4ld\n",
              qp.fun_count);
      Vprintf("qp.num_subint  - number of subintervals used = %4ld\n",
              qp.num_subint);
      /* Free memory used by qp */
      NAG_FREE(qp.sub_int_beg_pts);
      NAG_FREE(qp.sub_int_end_pts);
      NAG_FREE(qp.sub_int_result);
```

```
      NAG_FREE(qp.sub_int_error);
      exit(EXIT_SUCCESS);
    }
  exit(EXIT_FAILURE);
}

static double g(double x)
{
  return (x>0.0) ? log(x) : 0.0;
}
```

## 8.2 Program Data

None.

## 8.3 Program Results

```
d01anc Example Program Results
a      - lower limit of integration =     0.0000
b      - upper limit of integration =     1.0000
epsabs - absolute accuracy requested =  0.00e+00
epsrel - relative accuracy requested =  1.00e-04

result - approximation to the integral =  -0.12814
abserr - estimate of the absolute error =  3.58e-06
qp.fun_count  - number of function evaluations =  275
qp.num_subint  - number of subintervals used =    8
```