

## NAG C Library Function Document

### **nag\_1d\_quad\_osc\_1 (d01skc)**

#### 1 Purpose

nag\_1d\_quad\_osc\_1 (d01skc) is an adaptive integrator, especially suited to oscillating, non-singular integrands, which calculates an approximation to the integral of a function  $f(x)$  over a finite interval  $[a, b]$ :

$$I = \int_a^b f(x)dx.$$

#### 2 Specification

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

void nag_1d_quad_osc_1 (double (*f)(double x, Nag_User *comm),
                        double a, double b, double epsabs, double epsrel,
                        Integer max_num_subint, double *result, double *abserr,
                        Nag_QuadProgress *qp, Nag_User *comm, NagError *fail)
```

#### 3 Description

This function is based upon the QUADPACK routine QAG (Piessens *et al.* (1983)). It is an adaptive function, using the Gauss 30-point and Kronrod 61-point rules. A ‘global’ acceptance criterion (as defined by Malcolm and Simpson (1976)) is used. The local error estimation is described by Piessens *et al.* (1983).

As this function is based on integration rules of high order, it is especially suitable for non-singular oscillating integrands.

This function requires the user to supply a function to evaluate the integrand at a single point.

#### 4 Parameters

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

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

The specification of **f** is:

double f(double x, Nag_User *comm)	
1: <b>x</b> – double	<i>Input</i>
<i>On entry:</i> the point at which the integrand $f$ must be evaluated.	
2: <b>comm</b> – Nag_User *	
<i>On entry/on exit:</i> pointer to a structure of type <b>Nag_User</b> with the following member:	
<b>p</b> – Pointer	<i>Input/Output</i>
<i>On entry/on exit:</i> the pointer <b>comm</b> – <b>p</b> should be cast to the required type, e.g., <b>struct user</b> * <b>s</b> = ( <b>struct user</b> *) <b>comm</b> – <b>p</b> , to obtain the original object’s address with appropriate type. (See the argument <b>comm</b> below.)	

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: **epsabs** – double *Input*

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

5: **epsrel** – double *Input*

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

6: **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**  $\geq 1$ .

7: **result** – double \* *Output*

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

8: **abserr** – double \* *Output*

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

9: **qp** – Nag\_QuadProgress \* *Output*

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\_osc\_1.

**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** 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\_osc\_1 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**.

10: **comm** – Nag\_User \*

*On entry/on exit:* pointer to a structure of type Nag\_User with the following member:

**p** – Pointer Input/Output

*On entry/on exit:* the pointer **p**, of type Pointer, allows the user to communicate information to and from the user-defined function **f()**. An object of the required type should be declared by the user, e.g., a structure, and its address assigned to the pointer **p** by means of a cast to Pointer in the calling program, e.g., **comm.p = (Pointer)&s**. The type Pointer is void \*.

11: **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\_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**.

## 6 Further Comments

The time taken by nag\_1d\_quad\_osc\_1 depends on the integrand and the accuracy required.

If the function fails with an error exit other than **NE\_INT\_ARG\_LT** 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\_osc\_1 along with the integral contributions and error estimates over these sub-intervals.

Specifically, for  $i = 1, 2, \dots, n$ , 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,  $\int_{a_i}^{b_i} f(x)dx \simeq r_i$  and **result** =  $\sum_{i=1}^n r_i$ . 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

$$\begin{aligned} a_i &= \text{sub\_int\_beg\_pts}[i - 1], \\ b_i &= \text{sub\_int\_end\_pts}[i - 1], \\ r_i &= \text{sub\_int\_result}[i - 1] \text{ and} \\ e_i &= \text{sub\_int\_error}[i - 1]. \end{aligned}$$

## 6.1 Accuracy

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

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

where

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

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

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

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

Piessens R (1973) An algorithm for automatic integration *Angew. Inf.* **15** 399–401

## 7 See Also

`nag_1d_quad_gen_1` (d01sjc)  
`nag_1d_quad_brkpts_1` (d01slc)

## 8 Example

To compute

$$\int_0^{2\pi} \sin(30x) \cos x \, dx.$$

### 8.1 Program Text

```
/* nag_1d_quad_osc_1(d01skc) Example Program
*
* Copyright 1998 Numerical Algorithms Group.
*
* Mark 5, 1998.
*
* Mark 6 revised, 2000.
*/
#include <nag.h>
#include <stdio.h>
#include <nag_stdl�.h>
```

```

#include <math.h>
#include <nagd01.h>
#include <nagx01.h>

static double f(double x, Nag_User *comm);

main()
{
    double a, b;
    double epsabs, abserr, epsrel, result;
    Nag_QuadProgress qp;
    Integer max_num_subint;
    static NagError fail;
    double pi = X01AAC;
    Nag_User comm;

    Vprintf("d01skc Example Program Results\n");
    epsabs = 0.0;
    epsrel = 0.001;
    a = 0.0;
    b = pi * 2.0;
    max_num_subint = 200;

    d01skc(f, a, b, epsabs, epsrel, max_num_subint, &result, &abserr, &qp,
            &comm, &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_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);
    }
    else
        exit(EXIT_FAILURE);
}

static double f(double x, Nag_User *comm)
{
    return x*sin(x*30.0)*cos(x);
}

```

## 8.2 Program Data

None.

### 8.3 Program Results

```
d01skc Example Program Results
a      - lower limit of integration =    0.0000
b      - upper limit of integration =   6.2832
epsabs - absolute accuracy requested = 0.00e+00
epsrel - relative accuracy requested = 1.00e-03

result - approximation to the integral = -0.20967
abserr - estimate of the absolute error = 4.49e-14
qp.fun_count - number of function evaluations = 427
qp.num_subint - number of subintervals used =     4
```

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