

NAG Library Function Document

nag_airy_ai (s17agc)

1 Purpose

nag_airy_ai (s17agc) returns a value for the Airy function, $\text{Ai}(x)$.

2 Specification

```
#include <nag.h>
#include <nags.h>
double nag_airy_ai (double x, NagError *fail)
```

3 Description

nag_airy_ai (s17agc) evaluates an approximation to the Airy function, $\text{Ai}(x)$. It is based on a number of Chebyshev expansions:

For $x < -5$,

$$\text{Ai}(x) = \frac{a(t) \sin z - b(t) \cos z}{(-x)^{1/4}}$$

where $z = \frac{\pi}{4} + \frac{2}{3}\sqrt{-x^3}$, and $a(t)$ and $b(t)$ are expansions in the variable $t = -2\left(\frac{5}{x}\right)^3 - 1$.

For $-5 \leq x \leq 0$,

$$\text{Ai}(x) = f(t) - xg(t),$$

where f and g are expansions in $t = -2\left(\frac{x}{5}\right)^3 - 1$.

For $0 < x < 4.5$,

$$\text{Ai}(x) = e^{-3x/2}y(t),$$

where y is an expansion in $t = 4x/9 - 1$.

For $4.5 \leq x < 9$,

$$\text{Ai}(x) = e^{-5x/2}u(t),$$

where u is an expansion in $t = 4x/9 - 3$.

For $x \geq 9$,

$$\text{Ai}(x) = \frac{e^{-z}v(t)}{x^{1/4}},$$

where $z = \frac{2}{3}\sqrt{x^3}$ and v is an expansion in $t = 2\left(\frac{18}{z}\right) - 1$.

For $|x| < \mathbf{machine\ precision}$, the result is set directly to $\text{Ai}(0)$. This both saves time and guards against underflow in intermediate calculations.

For large negative arguments, it becomes impossible to calculate the phase of the oscillatory function with any precision and so the function must fail. This occurs if $x < -\left(\frac{3}{2\epsilon}\right)^{2/3}$, where ϵ is the **machine precision**.

For large positive arguments, where Ai decays in an essentially exponential manner, there is a danger of underflow so the function must fail.

4 References

Abramowitz M and Stegun I A (1972) *Handbook of Mathematical Functions* (3rd Edition) Dover Publications

5 Arguments

- 1: **x** – double *Input*
On entry: the argument x of the function.
- 2: **fail** – NagError * *Input/Output*
 The NAG error argument (see Section 3.6 in the Essential Introduction).

6 Error Indicators and Warnings

NE_ALLOC_FAIL

Dynamic memory allocation failed.
 See Section 3.2.1.2 in the Essential Introduction for further information.

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 the Essential Introduction for further information.

NE_NO_LICENCE

Your licence key may have expired or may not have been installed correctly.
 See Section 3.6.5 in the Essential Introduction for further information.

NE_REAL_ARG_GT

On entry, $x = \langle \text{value} \rangle$.
 Constraint: $x \leq \langle \text{value} \rangle$.
 x is too large and positive. The function returns zero.

NE_REAL_ARG_LT

On entry, $x = \langle \text{value} \rangle$.
 Constraint: $x \geq \langle \text{value} \rangle$.
 x is too large and negative. The function returns zero.

7 Accuracy

For negative arguments the function is oscillatory and hence absolute error is the appropriate measure. In the positive region the function is essentially exponential-like and here relative error is appropriate. The absolute error, E , and the relative error, ϵ , are related in principle to the relative error in the argument, δ , by

$$E \simeq |xAi'(x)|\delta, \epsilon \simeq \left| \frac{xAi'(x)}{Ai(x)} \right| \delta.$$

In practice, approximate equality is the best that can be expected. When δ , ϵ or E is of the order of the *machine precision*, the errors in the result will be somewhat larger.

For small x , errors are strongly damped by the function and hence will be bounded by the *machine precision*.

For moderate negative x , the error behaviour is oscillatory but the amplitude of the error grows like

$$\text{amplitude}\left(\frac{E}{\delta}\right) \sim \frac{|x|^{5/4}}{\sqrt{\pi}}.$$

However the phase error will be growing roughly like $\frac{2}{3}\sqrt{|x|^3}$ and hence all accuracy will be lost for large negative arguments due to the impossibility of calculating sin and cos to any accuracy if $\frac{2}{3}\sqrt{|x|^3} > \frac{1}{\delta}$.

For large positive arguments, the relative error amplification is considerable:

$$\frac{\epsilon}{\delta} \sim \sqrt{x^3}.$$

This means a loss of roughly two decimal places accuracy for arguments in the region of 20. However very large arguments are not possible due to the danger of setting underflow and so the errors are limited in practice.

8 Parallelism and Performance

Not applicable.

9 Further Comments

None.

10 Example

This example reads values of the argument x from a file, evaluates the function at each value of x and prints the results.

10.1 Program Text

```
/* nag_airy_ai (s17agc) Example Program.
 *
 * Copyright 2014 Numerical Algorithms Group.
 *
 * Mark 2 revised, 1992.
 */

#include <nag.h>
#include <stdio.h>
#include <nag_stdlib.h>
#include <nags.h>

int main(void)
{
    Integer  exit_status = 0;
    double   x, y;
    NagError fail;

    INIT_FAIL(fail);

    /* Skip heading in data file */
#ifdef _WIN32
    scanf_s("%*[\n]");
#else
    scanf("%*[\n]");
#endif
    printf("nag_airy_ai (s17agc) Example Program Results\n");
```

```

    printf("      x          y\n");
#ifdef _WIN32
    while (scanf_s("%lf", &x) != EOF)
#else
    while (scanf("%lf", &x) != EOF)
#endif
    {
        /* nag_airy_ai (s17agc).
         * Airy function Ai(x)
         */
        y = nag_airy_ai(x, &fail);
        if (fail.code != NE_NOERROR)
        {
            printf("Error from nag_airy_ai (s17agc).\n%s\n",
                fail.message);
            exit_status = 1;
            goto END;
        }
        printf("%12.3e%12.3e\n", x, y);
    }

END:
    return exit_status;
}

```

10.2 Program Data

```

nag_airy_ai (s17agc) Example Program Data
      -10.0
       -1.0
        0.0
         1.0
         5.0
        10.0
        20.0

```

10.3 Program Results

```

nag_airy_ai (s17agc) Example Program Results
      x          y
-1.000e+01  4.024e-02
-1.000e+00  5.356e-01
 0.000e+00  3.550e-01
 1.000e+00  1.353e-01
 5.000e+00  1.083e-04
 1.000e+01  1.105e-10
 2.000e+01  1.692e-27

```

Example Program
Returns a Value for the Airy Function $Ai(x)$

