DOCUMENTATION FOR THREE WAKE VORTEX MODEL DATA SETS FROM SIMULATION OF FLIGHT 587 WAKE VORTEX ENCOUNTER ACCIDENT CASE

FINAL REPORT

Prepared for

**National Aeronautics and Space Administration
Langley Research Center
Hampton, VA   23681**

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ABSTRACT

This document contains a general description for data sets of a wake vortex system in a turbulent environment. The turbulence and thermal stratification of the environment are representative of the conditions on November 12, 2001 near John F. Kennedy International Airport.   The simulation assumes no ambient winds. The full three dimensional simulation of the wake vortex system from a Boeing 747 predicts vortex circulation levels at 80% of their initial value at the time of the proposed vortex encounter. The linked vortex oval orientation showed no twisting, and the oval elevations at the widest point were about 20 meters higher than where the vortex pair joined. Fred Proctor of NASA's Langley Research Center presented the results from this work at the NTSB public hearing that started 29 October 2002. This document contains a description of each data set including: variables, coordinate system, data format, and sample plots. Also included are instructions on how to read the data.

1.0 INTRODUCTION

On November 12, 2001, Flight 587 departed from John F. Kennedy International Airport en route to Santo Domingo. Shortly after take-off the plane crashed into Belle Harbor, New York, killing all 260 persons aboard and 5 on the ground. The National Transportation and Safety Board (NTSB) asked NASA to assist with the accident investigation. One aspect of the accident investigation was to determine the possibliity that flight 587 encountered the wake vortex system from the previous Japan Air Lines flight 47. RTI International supported the vortex encounter study by creating a three-dimensional simulation of the environment and the wake vortex from the Boeing 747 of flight 47. The Terminal Area Simulation System (TASS) was the numerical model used to perform the simulation. Fred Proctor of NASA's Langley Research Center presented the results from this simulation at the NTSB public hearing held 29 October through 01 November 2002. The results from the simulation are available at the NTSB web site at www.ntsb.gov as appendix B of the exhibit "Aircraft Performance 13 - Factual Report of Group Chairman."   The two key results from the numerical simulations are that the vortex system circulation was about 80% of its initial value and the vortex rings do not exhibit any tilting. However, the vortex height does vary about 20 meters with the lowest point being where the vortex pair joined.

RTI International received the thermal stratification and turbulence intensity parameters from NASA. The first step was to create a simulated three-dimensional domain with the desired turbulence intensity level. With the proper ambient turbulence intensity level, the simulation then began by adding the thermal stratification and vortex system to the domain. Switzer and Proctor[1], gives the details of this procedure and a description of the TASS model. Data sets consist of the chosen variables for the entire domain at a given simulation time. The times chosen for the three data sets from this simulation supported the investigation. The first two times are near the proposed vortex encounter time and the third is at a time after the vortex system has linked.

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[1] Switzer, G. F, and F. H. Proctor 2000: Numerical Study of Wake Vortex Behavior in Turbulent Domains with Ambient Stratification. *38th Aerospace Sciences Meeting & Exhibit*, Reno Nevada, AIAA paper 2000-0755, January 10-13, 14 pp.

2.0 DATA SET INFORMATION

The model domain is a fully periodic right-handed Cartesian coordinate system. The domain size is 960 by 648 by 360 meters in the along-track (x), cross-track (y), and vertical directions (z), respectively. The resolution is 1.5 meters in y and z with 2 meters in x. The domain consists of 484 by 436 by 244 points in the x, y, and z directions, respectively. There are 2 boundary planes at each end of each coordinate direction, which result in an effective domain of 480 by 432 by 240.

The parameters for flight 47 are as follows: initial vortex separation (b_0) is 50.5 meters, initial vortex core radius is 3 meters, and the initial vortex circulation (Γ_0) is 547 m^2/s. The normalized turbulence intensity is defined as follows:

$$\varepsilon^* = \frac{\left(\varepsilon \, b_0\right)^{1/3}}{V_0}$$

where ε is the eddy dissipation rate and V_0 is the initial vortex descent velocity given by $\Gamma_0/(2\pi b_0)$, which is 1.72 m/s. The normalized thermal stratification is:

$$N^* = \frac{2\pi N b_0}{\Gamma_0}$$

where N is the Brunt-Vaisala frequency, and π is the ratio of a circle's circumference to its diameter. The values assumed for ε^* and N* are 0.065 and 0.257, respectively. These values correspond to a light turbulence intensity level and a slightly stable thermal stratification. The initial position of the vortex system was in the center of the cross-track direction at a constant elevation of 232.5 meters. The domain coordinates do not correspond to the actual aircraft position.

The extracted data sets are at model times of 97.5, 99.0, and 115.5 seconds. At the last time, the vortex system has linked. This is the stage where the two parallel vortex lines have transformed into oval rings.

2.1 Data fields

Table 2.1 lists each of the variables available in the database. Each variable is represented by an array of data in three-dimensional space taken at the respective output time of either 97.5, 99.0 or 115.5 seconds simulation time. Each variable of the data set is located in a separate data file and compressed to conserve disk space.

Table 2.1. Variables contained in data set

VARIABLE	DESCRIPTION	UNITS
U	Horizontal component of wind velocity along the flight path	m/s
V	Horizontal component of wind velocity perpendicular to the flight path	m/s
W	Vertical Component of Wind Velocity (positive upwards)	m/s

2.2 How to read the data field format

The file is in ASCII format. The following is a FORTRAN example of how to read the data. Each variable of the data set has a header followed by the raw data for the variable.

```
      read(1,1000) title
 1000  format(a80)
      read(1,2000) var,ix,iy,iz,time,xstart,ystart,zstart,dx,dy,dz,
    1    (((q(i,j,k),i=1,ix),j=1,iy),k=1,iz)
 2000  format(a4,/,3i4,/,4e12.4),/,3e12.4),/,(6e13.6))
```

Although the example above is in FORTRAN, the user can use any desired software that can read ASCII data. Shown in the first column of Table 2.1 are the codes (4-character name in **var**) for the variables. For each data file all but **var**, **time**, and **q** are constant and Table 2.2 contains the values for the remaining parameters.

Table 2.2. Parameter values for the data set.

VARIABLE	VALUE
ix	484
iy	436
iz	244
xstart	-484 meters
ystart	-327 meters
zstart	-1.5 meters
dy and dz	1.5 meters
dx	2.0 meters

2.3   How to reconstruct the three-dimensional domain

The following logic shows how to construct the TASS domain grid (in FORTRAN).

Horizontal direction in the along-track direction (x):

```
do i = 1, ix
  x(i) = xstart + (i-1)*dx
enddo
```

Horizontal direction in the cross-track direction (y):

```
do j = 1, iy
  y(j) = ystart + (j-1)*dy
enddo
```

Vertical direction up (z):

```
do k = 1, iz
  z(k) = zstart + (k-1)*dz
enddo
```

For example, the physical location of a variable at I=34, j=12, and k=23 or q(34,12,23) would be (x(34), y(12), z(23)).

2.4   Details About the Archive Files and Data CDs

Each file of the 99.0 or 115.5 second archive is 677,949,942 bytes in size and each file of the 97.5 second archive is 677,949,941 bytes. Each data set is composed of three files at approximately 2.0 gigabytes. Table 2.3 shows the names, sizes, and locations of the compressed data files. The data files on the CD are compressed and most decompression software packages will recognize and properly expand them.

Table 2.3. Details of the data set files

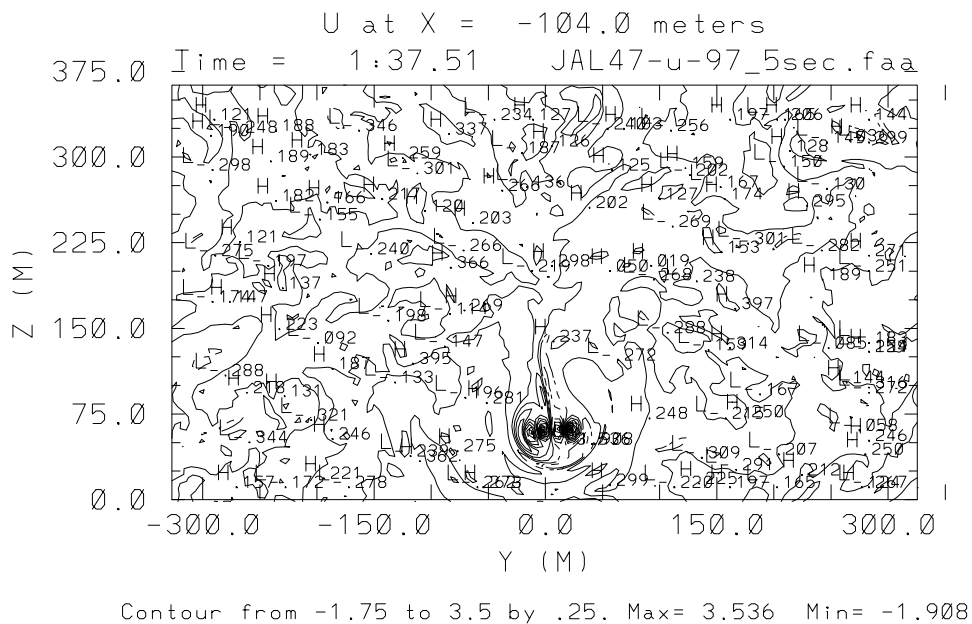| FILE NAME	VARIABLE	CD NUMBER	COMPRESSED FILE SIZE (BYTES)
JAL47-u-97_5sec.faa.gz	U	1	250,053,471
JAL47-v-97_5sec.faa.gz	V	1	246,461,563
JAL47-w-97_5sec.faa.gz	W	2	244,192,054
JAL47-u-99sec.faa.gz	U	2	250,058,827
JAL47-v-99sec.faa.gz	V	3	246,526,027
JAL47-w-99sec.faa.gz	W	3	244,321,217
JAL47-u-115_5sec.faa.gz	U	4	250,082,194
JAL47-v-115_5sec.faa.gz	V	4	247,321,059
JAL47-w-115_5sec.faa.gz	W	5	245,582,343
README.pdf	-	5	-
Aircraft Performance 13.pdf	-	5	-
AIAA-2000-0755.pdf	-	5	-

2.5   Data set verification

The comparison of plots from original TASS output and the data set verified the data set integrity. Plots at the along-track plane corresponding to the minimum vortex separation (I=191) showed each data set to be essentially identical to the TASS data. The criteria used were the agreement of the contour lines and the plot minimum and maximums.   Because of this excellent

agreement the plots contained in this document are only from the data set.
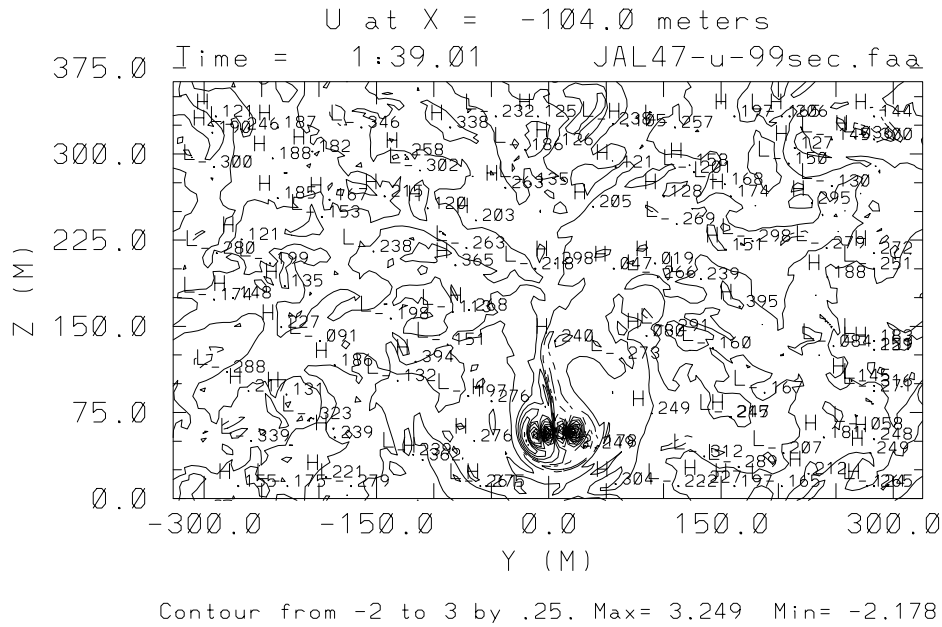
2.6   Data set plots

There are nine plots shown to provide a means for the user to verify the reading of the data set – one of each variable at each output time. Figures 1 through 3 display the variables in the order listed in table 2.1 for the output time of 97.5 seconds. Likewise, figures 4 through 6 are for the output time of 99.0 seconds, and figures 7 through 9 are for 115.5 seconds output time.

Figure 1. Data at 97.5 seconds for the U component of velocity at I = 191.
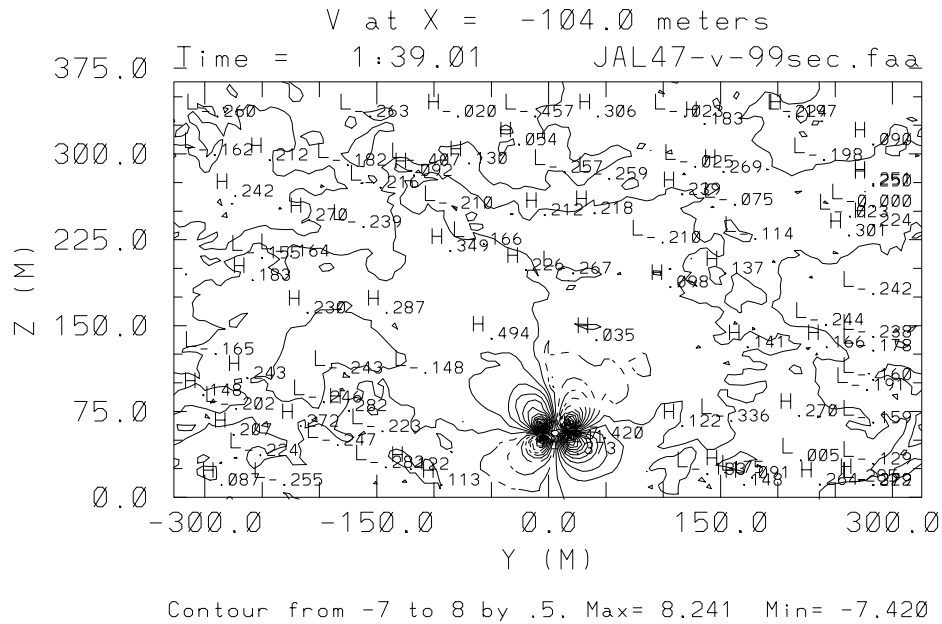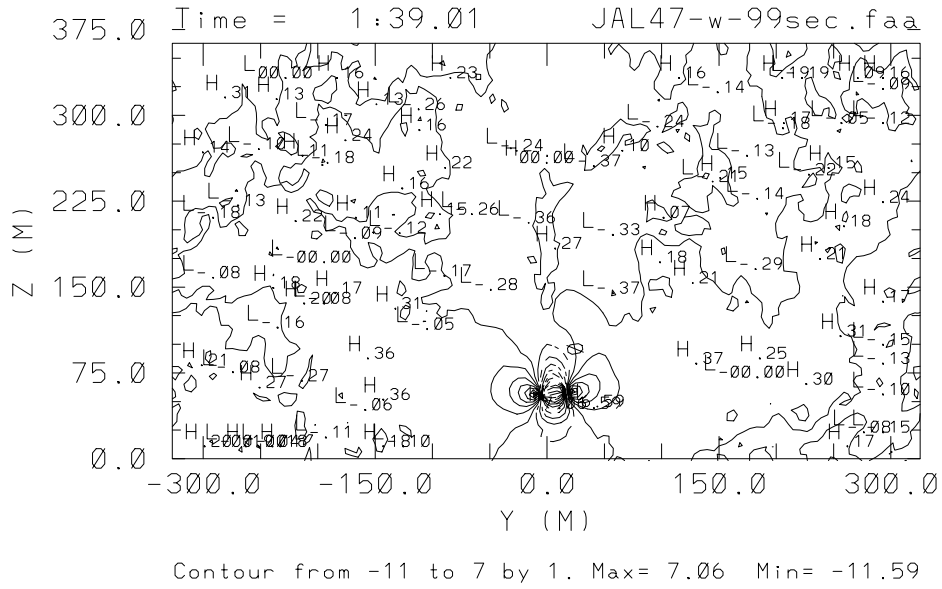
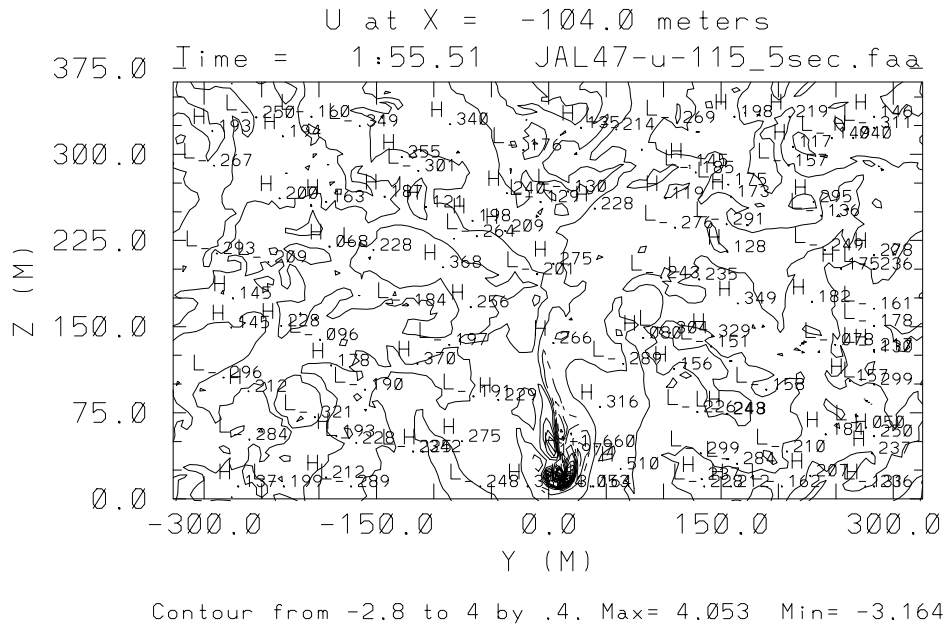**Figure 2. Data at 97.5 seconds for the V component of velocity at I = 191.**

Contour from -7 to 8 by 1. Max= 8.438   Min= -7.686

Figure 3. Data at 97.5 seconds for the W component of velocity at I = 191.

Contour from -11 to 7 by 1. Max= 7.17   Min= -11.39

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Figure 4. Data at 99.0 seconds for the U component of velocity at I = 191.

Contour from −2 to 3 by .25. Max= 3.249 Min= −2.178

Figure 5. Data at 99.0 seconds for the V component of velocity at I = 191.

Contour from −7 to 8 by .5. Max= 8.241 Min= −7.420

Figure 6. Data at 99.0 seconds for the W component of velocity at I = 191.

Contour from −11 to 7 by 1. Max= 7.06 Min= −11.59

Figure 7. Data at 115.5 seconds for the U component of velocity at I = 191.

Contour from −2.8 to 4 by .4. Max= 4.053 Min= −3.164

Figure 8. Data at 115.5 seconds for the V component of velocity at I = 191.

Contour from −5.5 to 8 by .5. Max= 8.204 Min= −5.659
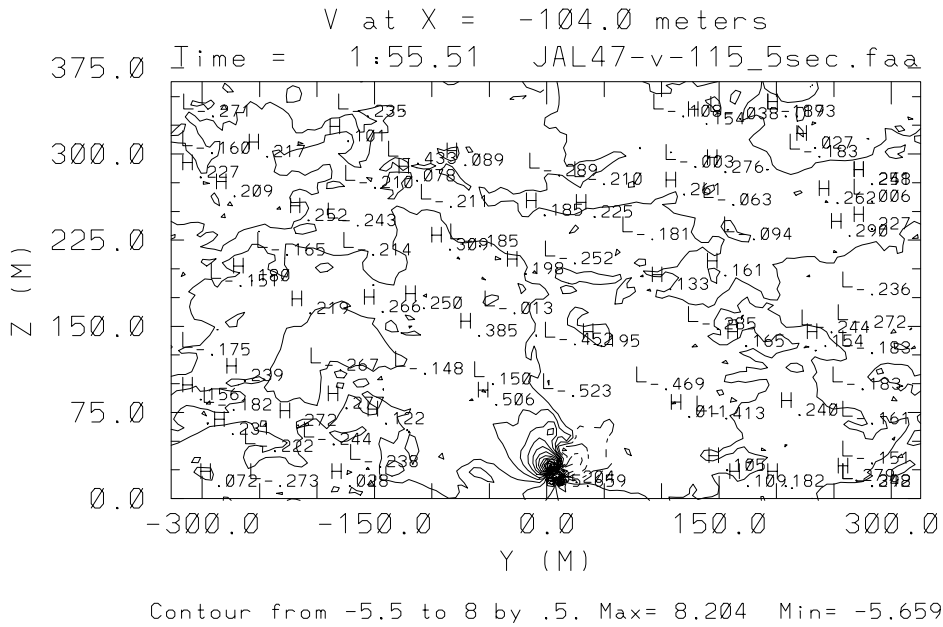
Figure 9. Data at 115.5 seconds for the W component of velocity at I = 191.

Contour from −12 to 7 by 1. Max= 7.40 Min= −12.55

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