**Coordinate Transformations for Unsteady Frames**

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Indented abstract here!

# Nomenclature

= tangent vector of Frenet frame

= binormal vector of Frenet frame

= normal vector of Frenet frame

= position vector of Micro Aerial Vehicle (MAV)

= velocity vector of MAV

= acceleration vector of MAV

t = time of measurement

# Introduction

T

HE Frenet frame is a useful set of coordinates centered on a particle. The basis vectors describe the motion of the particle, showing the instantaneous direction of motion and the instatntaneous radius of curvature of the path. (SOURCE)This project focuses on the use of the Frenet frame on the paths of a unmanned aerial vehicle (UAV) mothership (MS) and Micro Aerial Vehicles (MAVs) deployed by the MS to act as sensory equipment. (SOURCE). The MAV motion with respect to the MS are a known quantity. Sensory data is then relayed from the MS to a ground station (GS), so coordinate transformations must be applied to obtain the MAV motion with respect to the GS.

The Frenet frame for a particle on a path is obtained by defining the tanget vector as

One can see that the tangent vector is solely in the direction of motion. The binormal vector is defined as

Thus, the binormal vector is normal to both the direction of motion and the particle acceleration. WHAT ABOUT WHEN they are collinear?? Finally, the normal vector is found to complete the three-dimensional coordinate frame by

This normal vector is normal to the curve of the path, and so it is useful to find the normal component of a particle’s acceleration.

To find the Frenet basis vectors for a given instant, the first and second derivatives of the position vector must be known. An analytic expression for the position vector will easily yield an analytic expression for these derivatives, but it is not the case when only time-stamped position data profided. In the latter case, one can forward-differentiate the *n*th data point by

This method will reduce the amount of data points by one for each derivative taken. For example, given five position vectors in time, one will end up with four velocity vectors and three acceleration vectors.

# Simulation of Known Analytical Path

Consider the path of the MS, with respect to the GS and expressed in a Cartesian frame:

And the path of an MAV in the MS Frenet frame:

Figures Figure 1 and Figure 2 show the positions of the mothership and MAV, with their Frenet basis vectors.

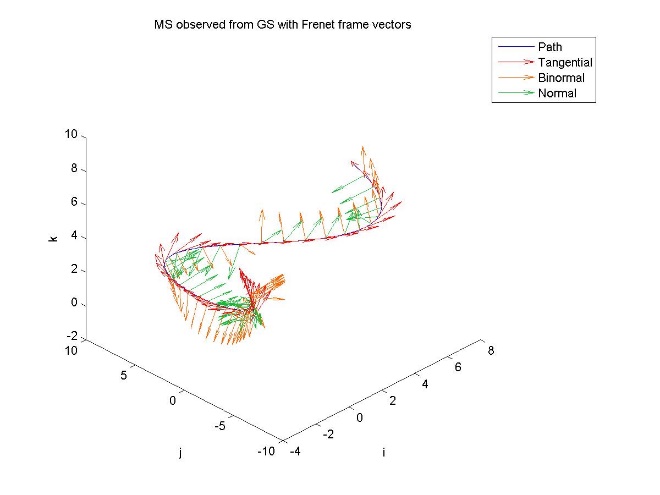


Figure :Mothership position wrt GS Cartesian, with its Frenet basis vectors

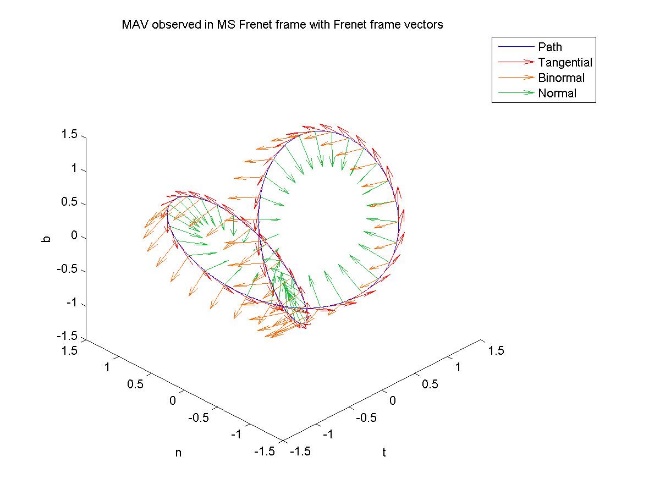


Figure : MAV position wrt MS Frenet frame, with its Frenet basis vectors

The mothership’s motion experiences an inflection in its path curvature, causing the normal and binormal Frenet vectors to change substantially. The MAV experiences a path with no inflections, so the change in the Frenet vectors is continuous.

The mothership’s speed and accelerations with respect to the GS Cartesian frame is shown in Figure 3 and Figure 4 below:

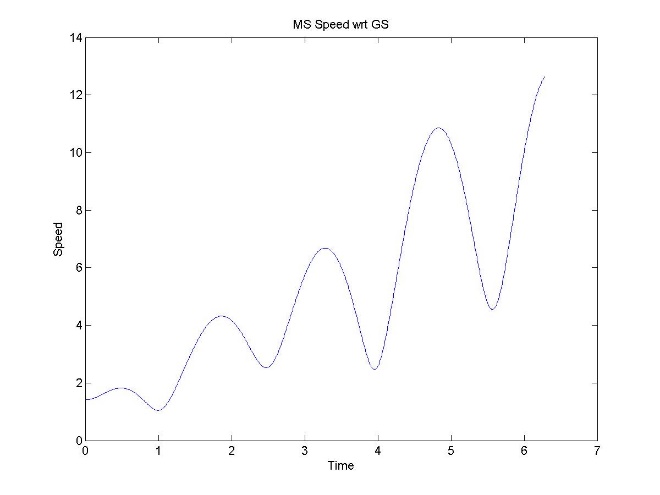


Figure : MS speed wrt GS

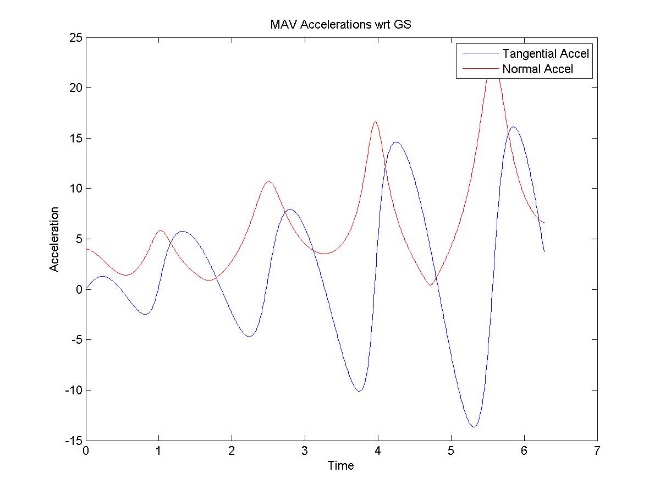


Figure : MS normal and tangential accelerations wrt GS

The MAV speed and accelerations with respect to the MS Frenet frame is shown in

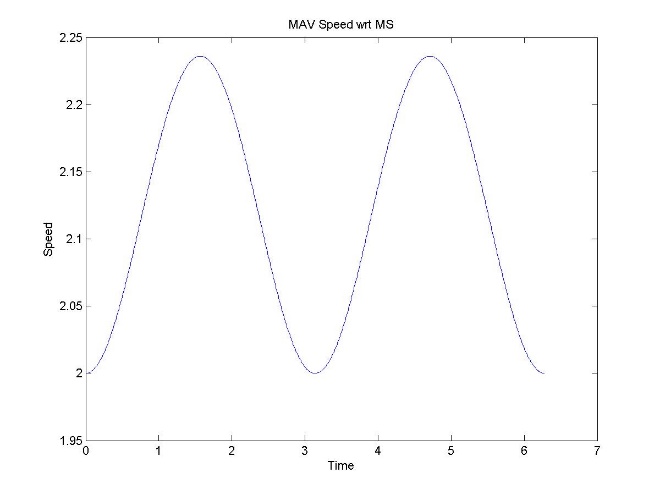


Figure : MAV speed wrt MS

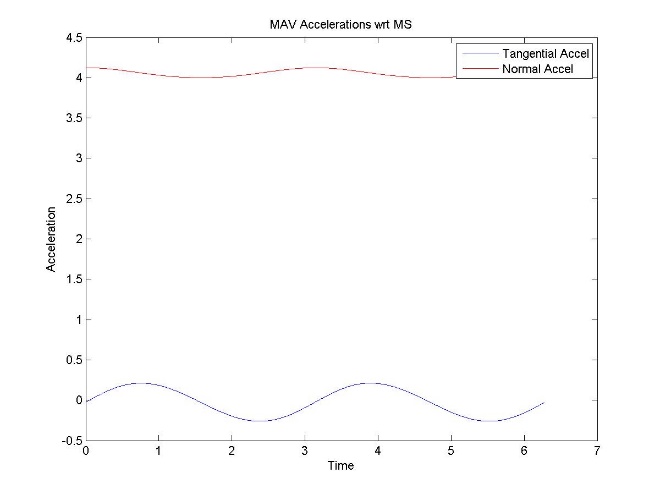


Figure : MAV accelerations wrt MS

Asdf

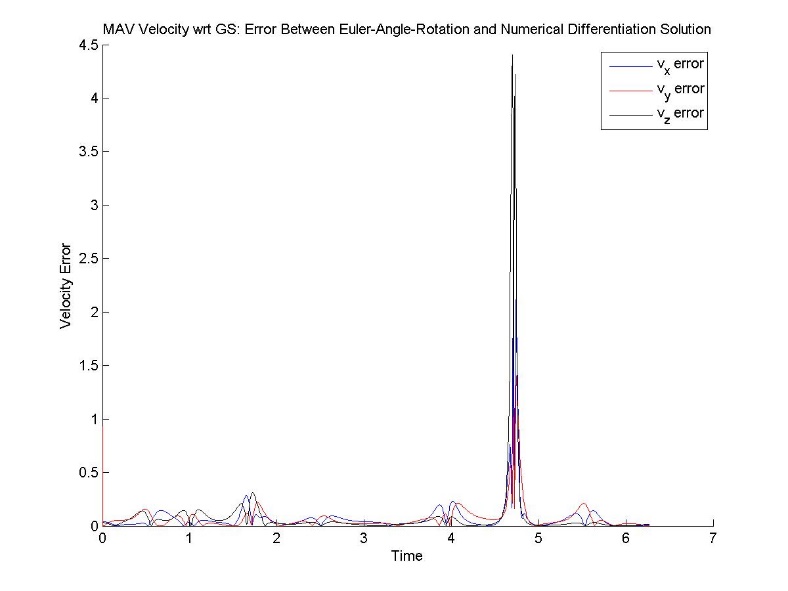
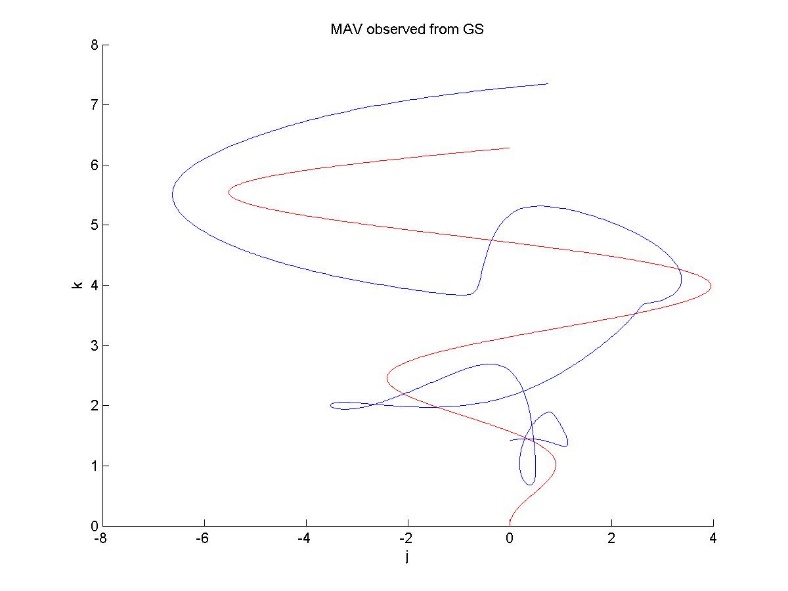
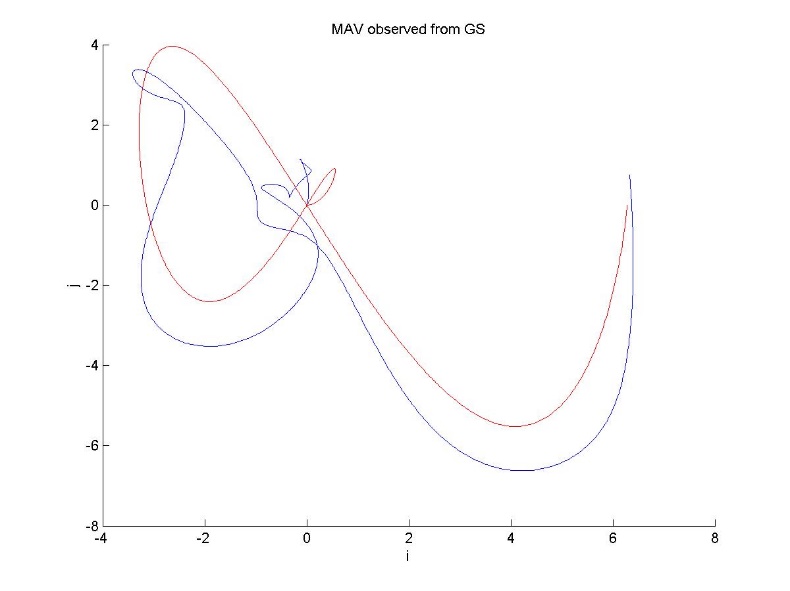
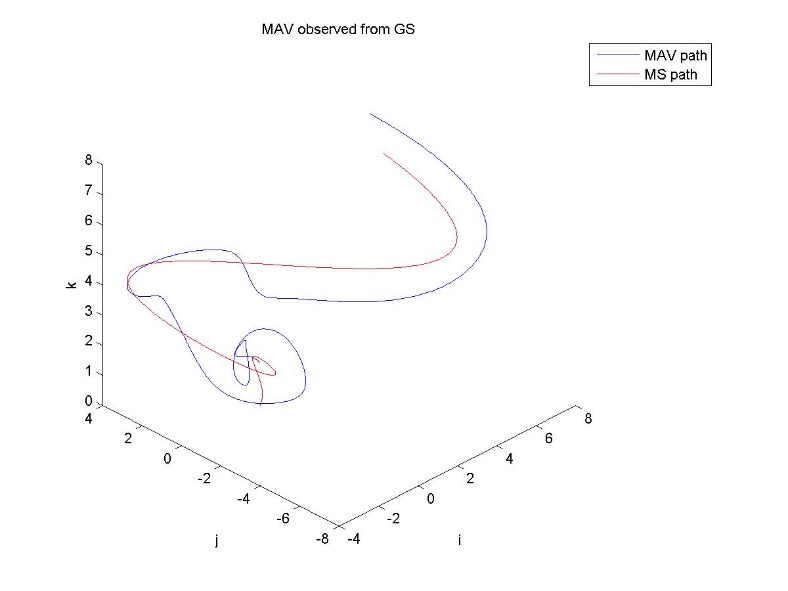


Figure : Error in velocity between Euler-angle frame rotation and numerical differentiation

Figure : MAV path wrt GS, in Cartesian frame



# Discrete Data for MAV Position

Figure : MAV speed and accelerations wrt MS, obtained from discrete data

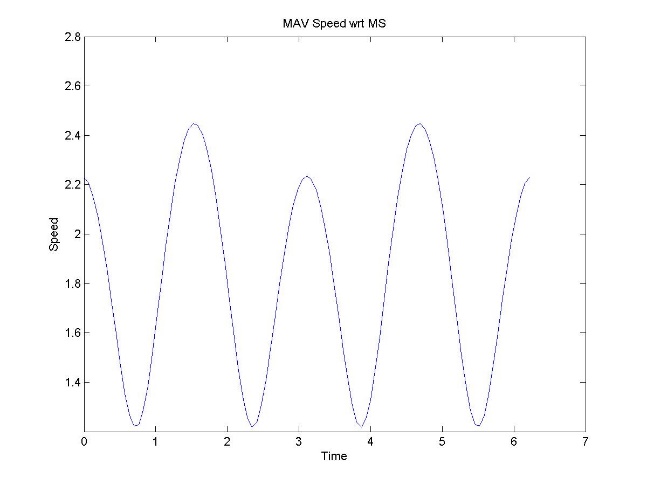
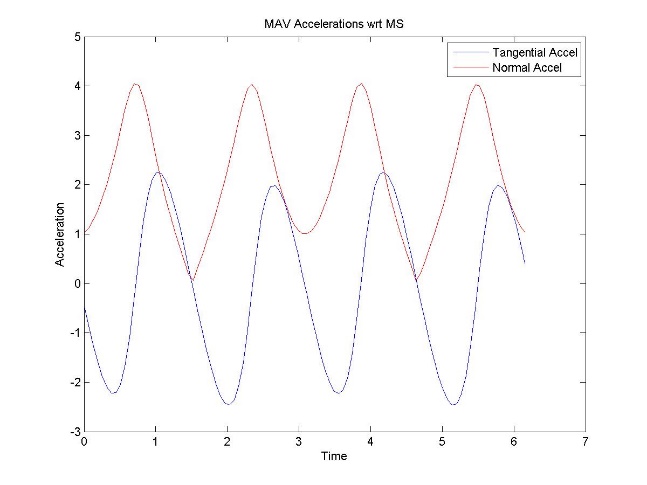
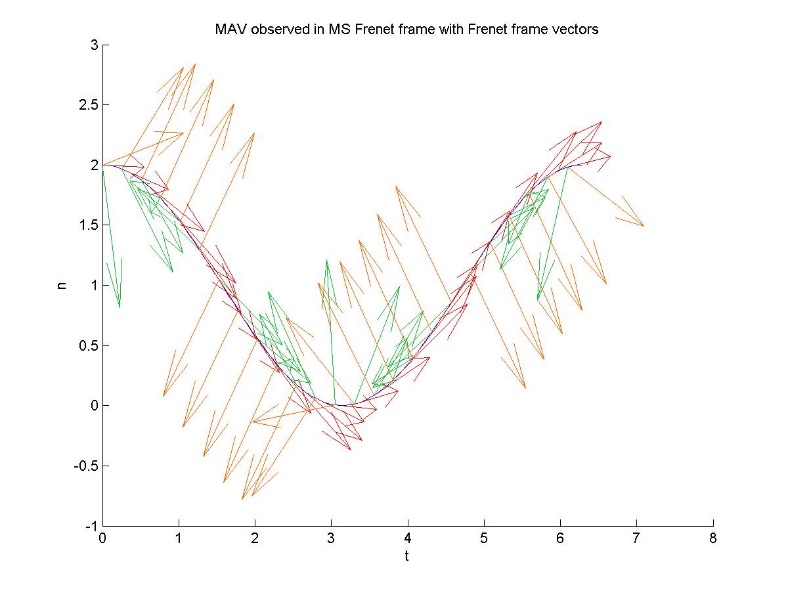
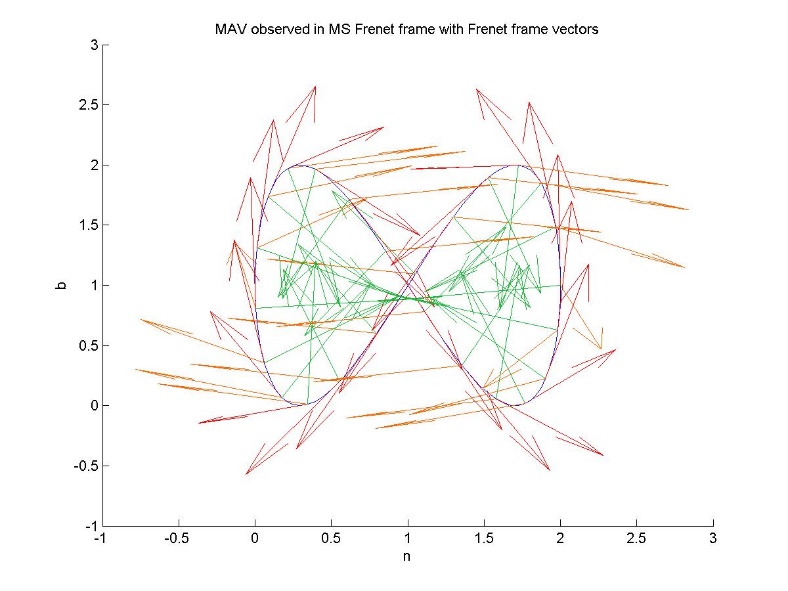
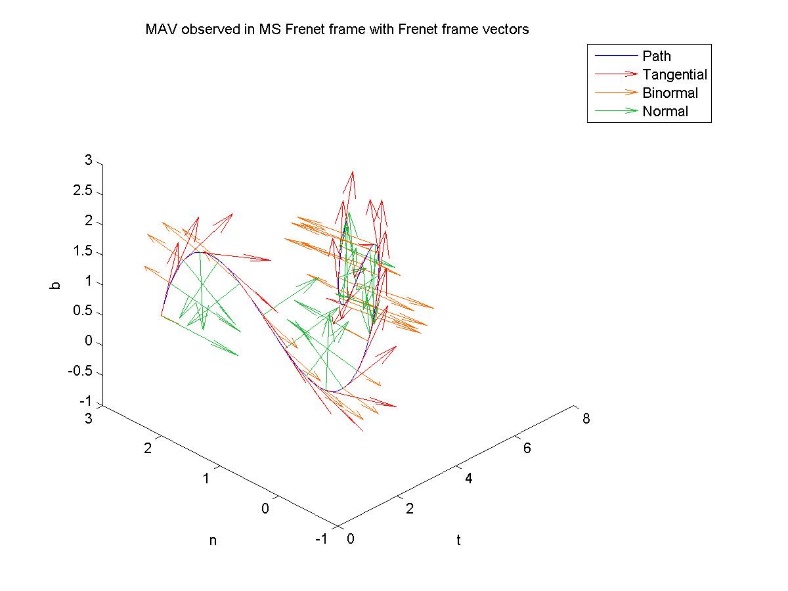


Figure : MAV position and Frenet vectors wrt MS Frenet frame, obtained from discrete data



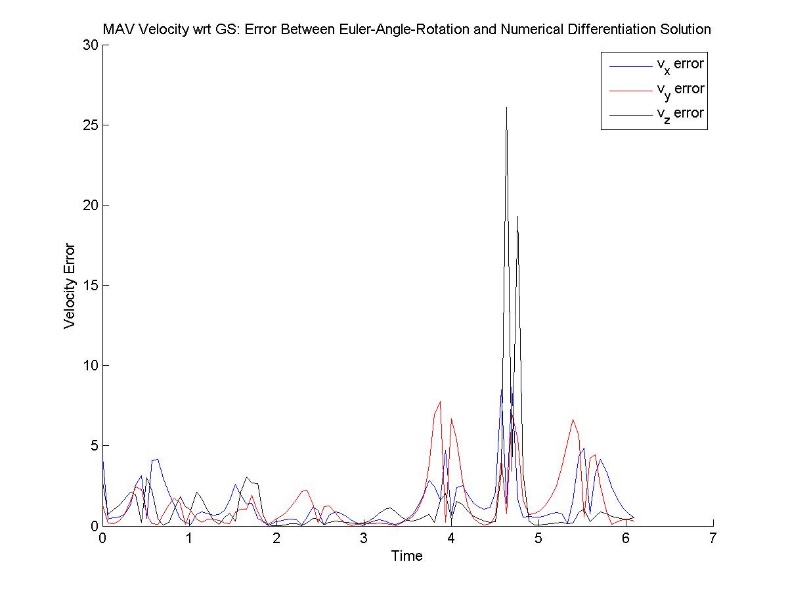
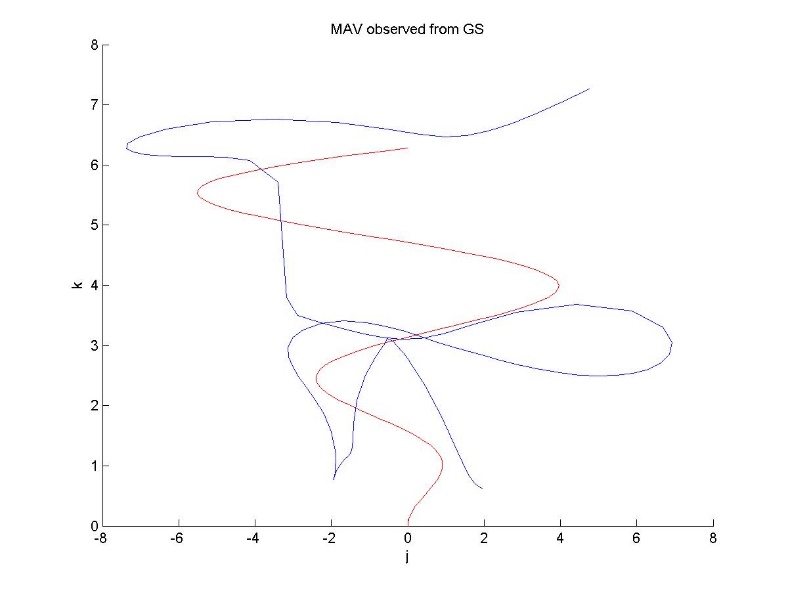
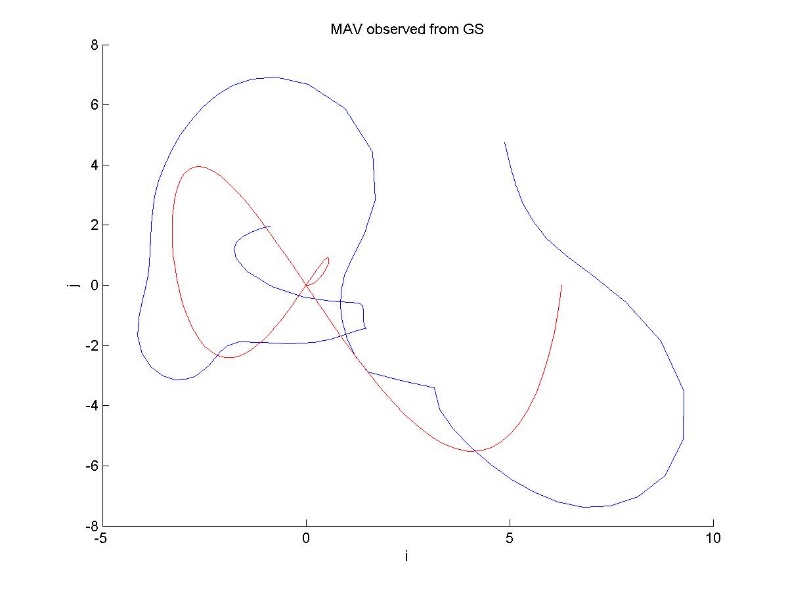
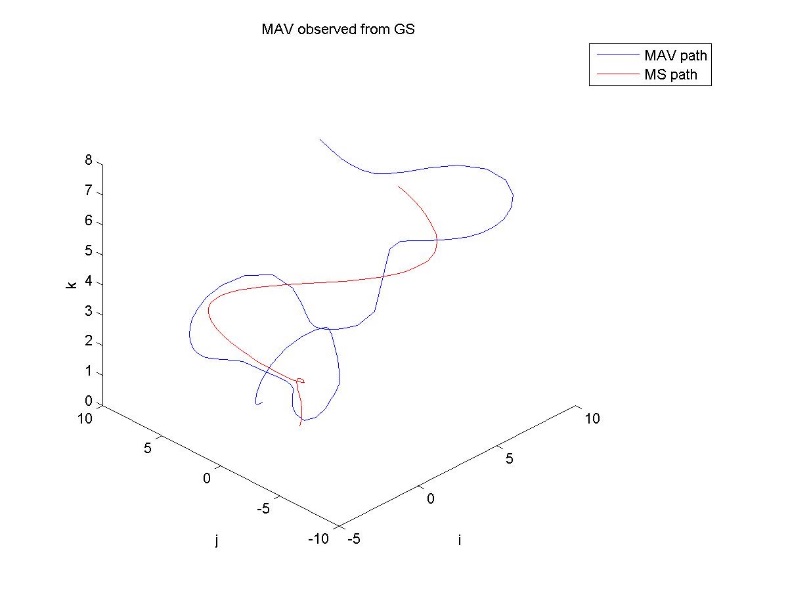


Figure : Error in velocity between Euler-angle frame rotation and numerical differentiation, obtained from discrete data

Figure : MAV position wrt GS, obtained from discrete data



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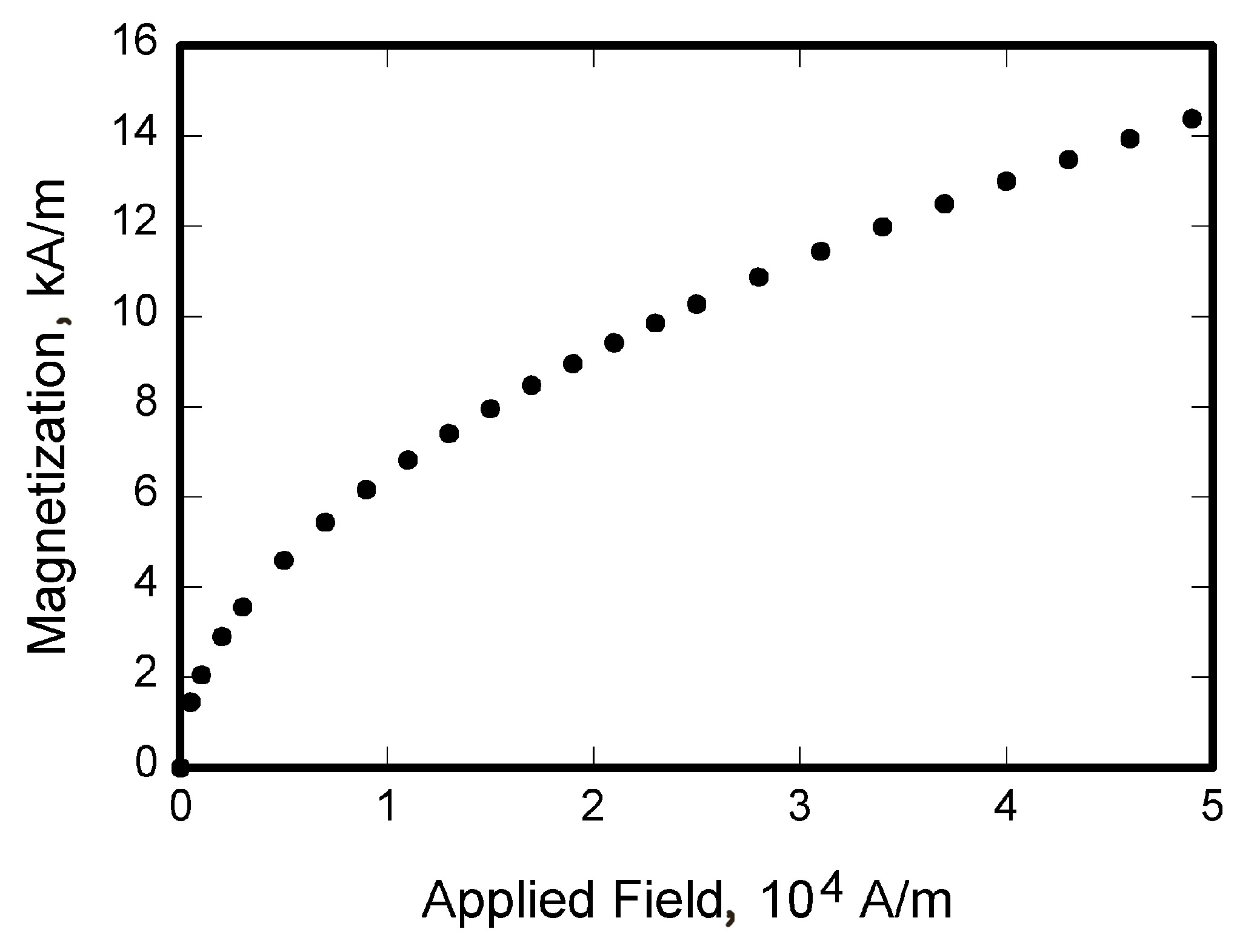


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Figure axis labels are often a source of confusion. Use words rather than symbols. As in the example to the right, write the quantity “Magnetization” rather than just “M.” Do not enclose units in parenthesis, but rather separate them from the preceding text by commas. Do not label axes only with units. As in Fig. 1, for example, write “Magnetization, A/m” or “Magnetization, Am−1,” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature, K,” not “Temperature/K.”

Multipliers can be especially confusing. Write “Magnetization, kA/m” or “Magnetization, 103 A/m.” Do not write “Magnetization (A/m) x 1000” because the reader would not then know whether the top axis label in Fig. 1 meant 16000 A/m or 0.016 A/m. Figure labels must be legible, approximately 8-12 point type.

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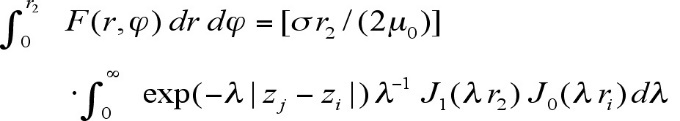
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 (1)

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*Periodicals*

1Vatistas, G. H., Lin, S., and Kwok, C. K., “Reverse Flow Radius in Vortex Chambers,” *AIAA Journal*, Vol. 24, No. 11, 1986, pp. 1872, 1873.

2Dornheim, M. A., “Planetary Flight Surge Faces Budget Realities,” *Aviation Week and Space Technology*, Vol. 145, No. 24, 9 Dec. 1996, pp. 44-46.

3Terster, W., “NASA Considers Switch to Delta 2,” *Space News*, Vol. 8, No. 2, 13-19 Jan. 1997, pp., 1, 18.

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*Books*

4Peyret, R., and Taylor, T. D., *Computational Methods in Fluid Flow*, 2nd ed., Springer-Verlag, New York, 1983, Chaps. 7, 14.

5Oates, G. C. (ed.), *Aerothermodynamics of Gas Turbine and Rocket Propulsion*, AIAA Education Series, AIAA, New York, 1984, pp. 19, 136.

6Volpe, R., “Techniques for Collision Prevention, Impact Stability, and Force Control by Space Manipulators,” *Teleoperation and Robotics in Space*, edited by S. B. Skaar and C. F. Ruoff, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1994, pp. 175-212.

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*Proceedings*

7Thompson, C. M., “Spacecraft Thermal Control, Design, and Operation,” *AIAA Guidance, Navigation, and Control Conference*, CP849, Vol. 1, AIAA, Washington, DC, 1989, pp. 103-115

8Chi, Y., (ed.), *Fluid Mechanics Proceedings*, SP-255, NASA, 1993.

9Morris, J. D. “Convective Heat Transfer in Radially Rotating Ducts,” *Proceedings of the Annual Heat Transfer Conference*, edited by B. Corbell, Vol. 1, Inst. Of Mechanical Engineering, New York, 1992, pp. 227-234.

At a minimum, proceedings must have the same information as other book references: paper (chapter) and volume title, name and location of publisher, editor (if applicable), and pages or chapters cited. Do not include paper numbers in proceedings references, and delete the conference location so that it is not confused with the publisher’s location (which is mandatory, except for government agencies). Frequently, CP or SP numbers (Conference Proceedings or Symposium Proceedings numbers) are also given. These elements are not necessary, but when provided, their places should be as shown in the preceding examples.

*Reports, Theses, and Individual Papers*

10Chapman, G. T., and Tobak, M., “Nonlinear Problems in Flight Dynamics,” NASA TM-85940, 1984.

11Steger, J. L., Jr., Nietubicz, C. J., and Heavey, J. E., “A General Curvilinear Grid Generation Program for Projectile Configurations,” U.S. Army Ballistic Research Lab., Rept. ARBRL-MR03142, Aberdeen Proving Ground, MD, Oct. 1981.

12Tseng, K., “Nonlinear Green’s Function Method for Transonic Potential Flow,” Ph.D. Dissertation, Aeronautics and Astronautics Dept., Boston Univ., Cambridge, MA, 1983.

Government agency reports do not require locations. For reports such as NASA TM-85940, neither insert nor delete dashes; leave them as provided by the author. Place of publication *should* be given, although it is not mandatory, for military and company reports. Always include a city and state for universities. Papers need only the name of the sponsor; neither the sponsor’s location nor the conference name and location are required. *Do not confuse proceedings references with conference papers*.

*Electronic Publications*

CD-ROM publications and regularly issued, dated electronic journals are permitted as references. Archived data sets also may be referenced as long as the material is openly accessible and the repository is committed to archiving the data indefinitely. References to electronic data available only from personal Web sites or commercial, academic, or government ones where there is no commitment to archiving the data are not permitted (see Private Communications and Web sites).

13Richard, J. C., and Fralick, G. C., “Use of Drag Probe in Supersonic Flow,” *AIAA Meeting Papers on Disc* [CD-ROM], Vol. 1, No. 2, AIAA, Reston, VA, 1996.

14Atkins, C. P., and Scantelbury, J. D., “The Activity Coefficient of Sodium Chloride in a Simulated Pore Solution Environment,” *Journal of Corrosion Science and Engineering* [online journal], Vol. 1, No. 1, Paper 2, URL: <http://www.cp/umist.ac.uk/JCSE/vol1/vol1.html> [cited 13 April 1998].

15Vickers, A., “10-110 mm/hr Hypodermic Gravity Design A,” *Rainfall Simulation Database* [online database], URL: <http://www.geog.le.ac.uk/bgrg/lab.htm> [cited 15 March 1998].

Always include the citation date for online references. Break Web site addresses after punctuation, and do not hyphenate at line breaks.

*Computer Software*

16TAPP, Thermochemical and Physical Properties, Software Package, Ver. 1.0, E. S. Microware, Hamilton, OH, 1992.

Include a version number and the company name and location of software packages.

*Patents*

Patents appear infrequently. Be sure to include the patent number and date.

17Scherrer, R., Overholster, D., and Watson, K., Lockheed Corp., Burbank, CA, U.S. Patent Application for a “Vehicle,” Docket No. P-01-1532, filed 11 Feb. 1979.

*Private Communications and Web Sites*

References to private communications and personal Web site addresses are generally not permitted. Private communications can be defined as privately held unpublished letters or notes or conversations between an author and one or more individuals. They *may* be cited as references in some case studies, but only with permission of the AIAA staff. Depending on the circumstances, private communications and Web site addresses may be incorporated into the main text of a manuscript or may appear in footnotes.

*Unpublished Papers and Books*

Unpublished works can be used as references as long as they are being considered for publication or can be located by the reader (such as papers that are part of an archival collection). If a journal paper or a book is being considered for publication choose the format that reflects the status of the work (depending upon whether it has been accepted for publication):

18Doe, J., “Title of Paper,” Conference Name, Publisher’s name and location (submitted for publication)

19Doe, J., “Title of Paper,” *Name of Journal* (to be published).

20Doe, J., “Title of Chapter,” *Name of Book*, edited by… Publisher’s name and location (to be published).

21Doe, J., “Title of Work,” Name of Archive, Univ. (or organization) Name, City, State, Year (unpublished).

Unpublished works in an archive *must* include the name of the archive and the name and location of the university or other organization where the archive is held. Also include any cataloging information that may be provided. Always query for an update if a work is about to be published.

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