

Swift Navigation Test Track Data

April 2017

Introduction

This document is intended as a guide to the data that was generated and recorded by Swift Navigation during the Self Racing Cars autonomous vehicle event that took place at Thunderhill Raceway in Willows, California on April 1, 2017. In the open spirit of the event, Swift has recorded and posted its data publicly.

Equipment Setup

Swift Navigation installed and configured a differential GPS base station powered by a Piksi Multi™ RTK GPS receiver in the center of the west track at Thunderhill Raceway. A GNSS corrections service was used to determine the location of the differential station. Correction data from this base station was communicated to the test vehicle over 915 MHz radio link.

Surveyed Latitude	Surveyed Longitude	Surveyed Altitude (ellipsoidal)
39.5371254637	-122.337089374	95.076

Table 1 - Base Station Location

Note: the absolute position reported by an RTK system is limited in accuracy (but not precision) by the determined location of the base station.

The test vehicle utilized 3 [Piksi Multi](#) RTK GPS receivers receiving correction data from the base station described above, a corrections service, and the P336 CORS station respectively. Redundant communication efforts (radio and cellular) were utilized to avoid any uncertainty in cellular coverage at the raceway. Redundant sources of correction data (local base station, CORS, corrections service) were utilized to avoid any uncertainty in correction data availability.

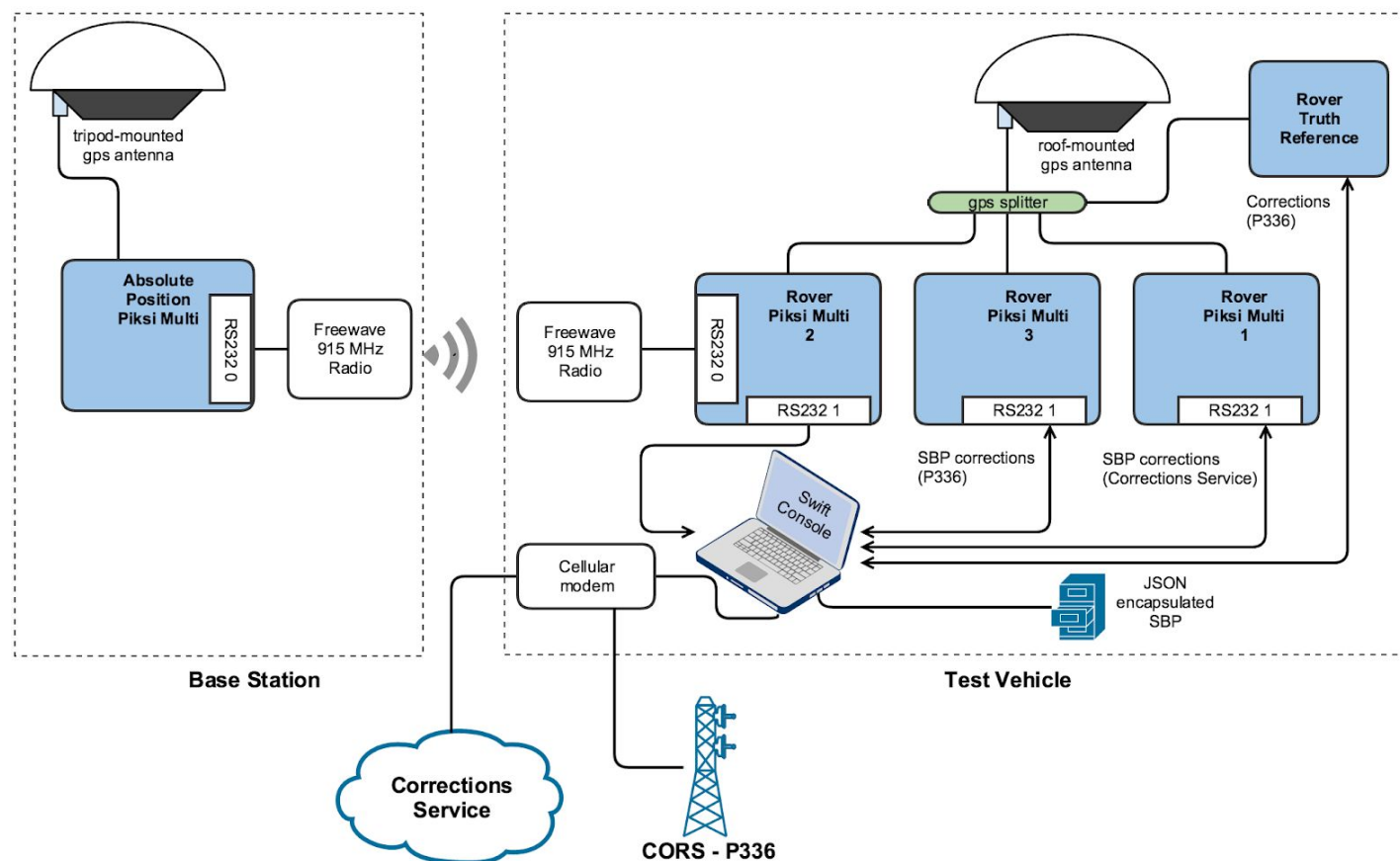
Additionally, the test vehicle was equipped with a Novatel FlexPak 6 and IMU-IGM-S1 to serve as a source of ground truth for performance evaluations. During laps, the FlexPak 6 produced RTK position solutions in real-time, using correction data from the P336 CORS station - but *not* using the IMU. Additionally, the raw GNSS observables and IMU data were captured, and later used to produce a high-accuracy reference trajectory as ground truth in post processing.

All receivers on the test vehicle were connected to the same GNSS antenna. The Piksi Multi receivers were running v1.0.0-branch-100, a pre-release build of the Piksi Multi 1.1 firmware which is scheduled to be released in May 2017.

GNSS Receiver	Corrections Source
Novatel FlexPak 6 with IMU-IGM-S1	Continuously Operating Reference Station
Piksi Multi 1	Corrections Service
Piksi Multi 2	Local Piksi Multi Base Station
Piksi Multi 3	Continuously Operating Reference Station

Table 2 - GNSS Receivers and Corrections Sources

The diagram below sketches the setup on the race day. Please contact Swift Navigation for any detailed questions about implementation.



Test Methodology

Multiple sessions were run over the course of the event. With this report, we present a subset of the data that includes an inside line, outside line, and centerline of the racetrack. The presented position tracks are intended to show the precision achievable from real time kinematic positioning techniques. Note that these positioning tracks are derived from GPS measurements only; there is no inertial sensing or dead reckoning included in the solution.



Figure 1 - Inside Line (green) and Outside Line (Blue)

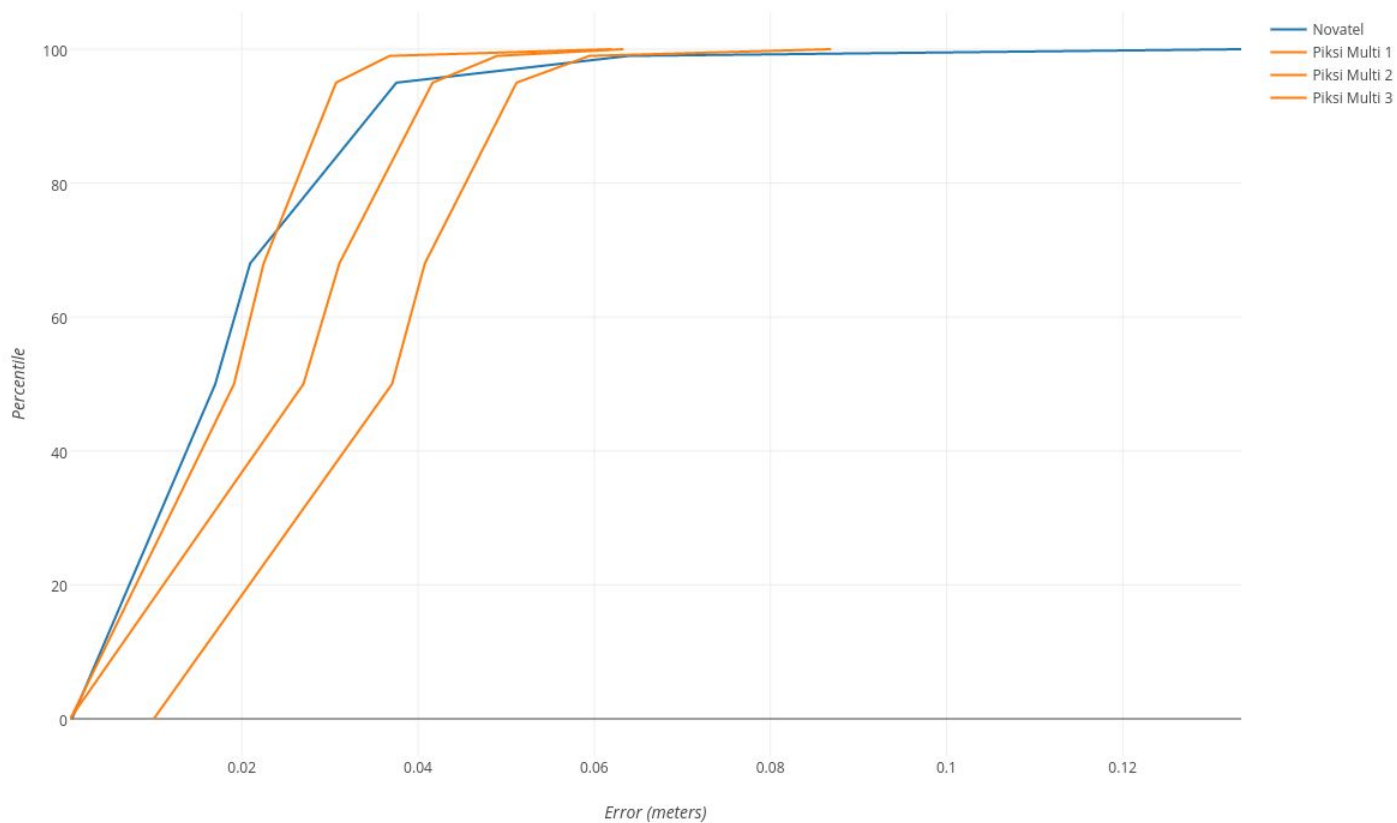
Performance Analysis

Using the raw data gathered from the Novatel FlexPak receiver and IMU, a reference trajectory was calculated with Novatel Waypoint. P336 was used as the reference station and the inertial data was tightly coupled in the solution. This reference trajectory was then used to calculate the horizontal error for each receiver. The results are presented in the tables and graphs on the following pages.

Centerline

GNSS Receiver	50%	68%	95%	99%	Std. Dev.
Novatel FlexPak 6	0.017	0.021	0.038	0.064	0.012
Piksi Multi 1	0.019	0.022	0.031	0.037	0.007
Piksi Multi 2	0.027	0.031	0.042	0.049	0.009
Piksi Multi 3	0.037	0.041	0.051	0.059	0.009

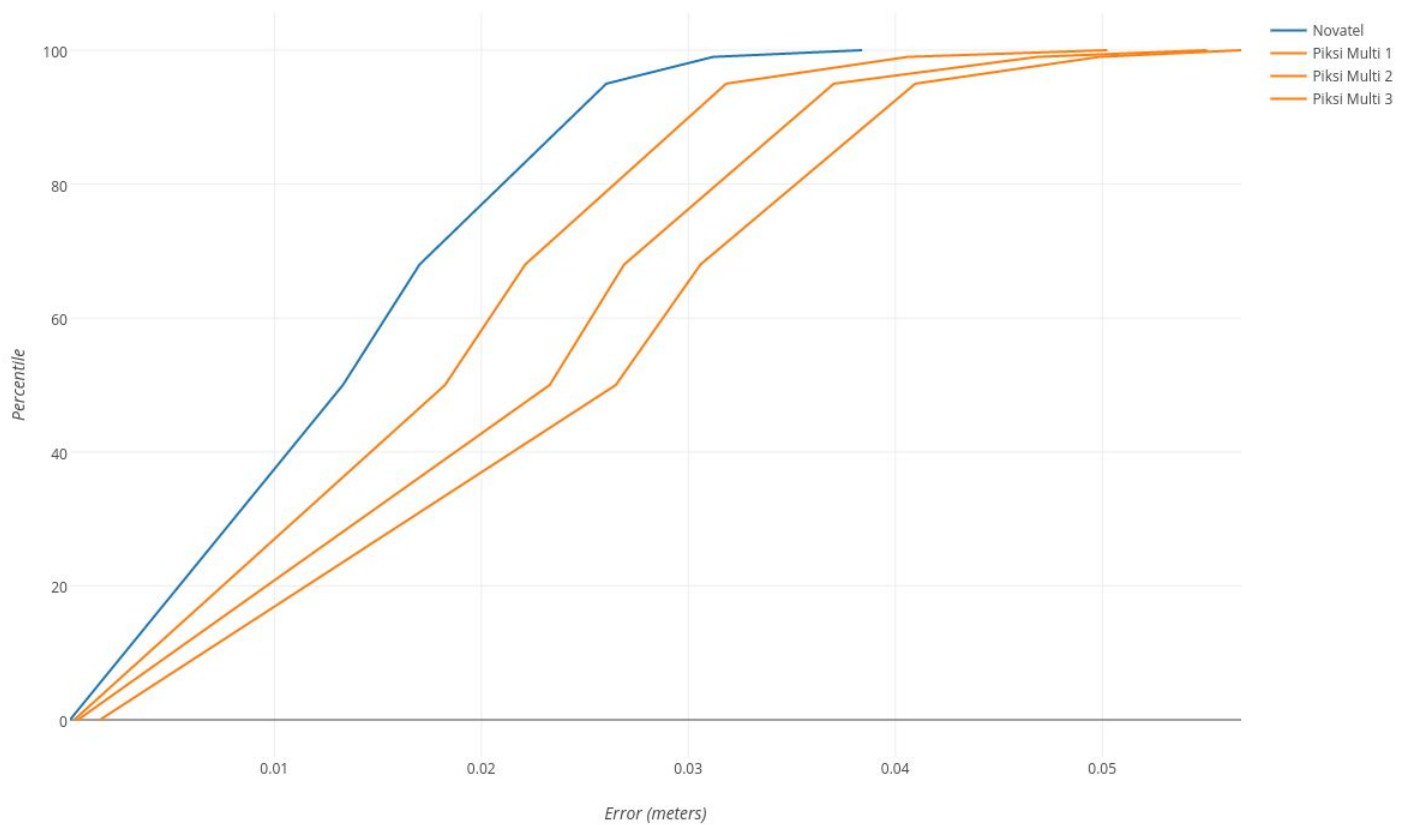
Cumulative Distribution Function (Horizontal Error) - Centerline



Inside Track

GNSS Receiver	50%	68%	95%	99%	Std. Dev.
Novatel FlexPak 6	0.013	0.017	0.026	0.031	0.007
Piksi Multi 1	0.023	0.027	0.037	0.047	0.008
Piksi Multi 2	0.018	0.022	0.032	0.041	0.008
Piksi Multi 3	0.026	0.031	0.041	0.050	0.008

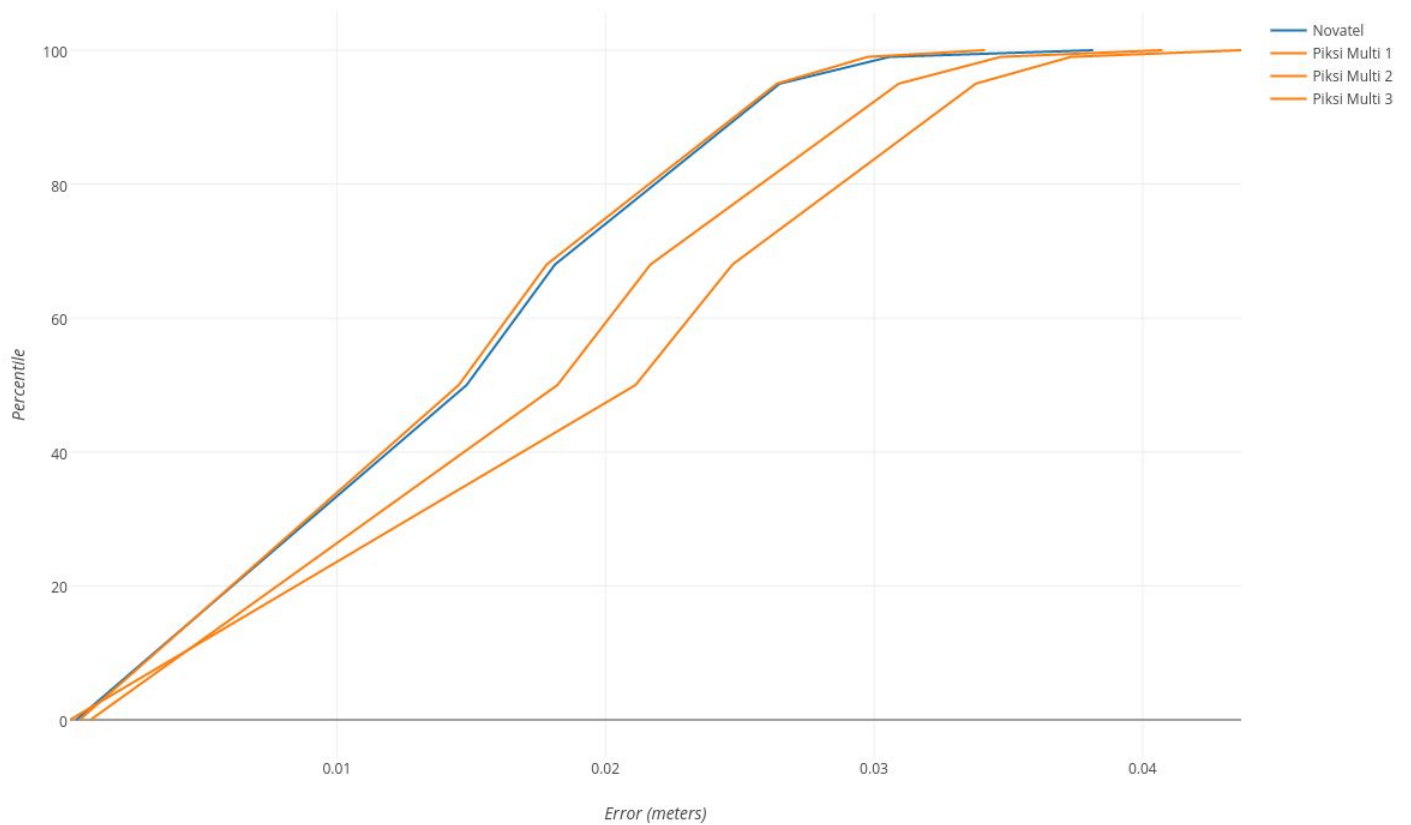
Cumulative Distribution Function (Horizontal Error) - Inside Track



Outside Track

GNSS Receiver	50%	68%	95%	99%	Std. Dev.
Novatel FlexPak 6	0.015	0.018	0.026	0.031	0.007
Piksi Multi 1	0.018	0.022	0.031	0.035	0.008
Piksi Multi 2	0.015	0.018	0.026	0.030	0.007
Piksi Multi 3	0.021	0.025	0.034	0.037	0.008

Cumulative Distribution Function (Horizontal Error) - Outside Track



Reference Data

On the following pages, data for each receiver is presented in the Swift Binary Protocol expanded to a JSON representation, a Google Earth KML, and a CSV of position information. The Google Earth KML was produced with the altitude clamped to the ground and is intended to be opened with the google earth desktop software. The root of the data directory is available here that includes this report and all files:

<https://drive.google.com/open?id=0B5X2nBadaPD1RUhsUzIJYW1PT2M>

Piksi Multi 1

Inside Track - PM1			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122215- inner-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1Nk5Mcm9LMnpNcGM	
KML position track	swift-gnss-20170401-122215- inner-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1Sm90RWZUTlhGeFE	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122215- inner-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1ZkwxUmpjTkZIWUk	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Outside Track - PM1			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122215- outer-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1Tk1jc096QjVZalU	
KML position track	swift-gnss-20170401-122215- outer-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1MTF0U1pPSjVZcms	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122215- outer-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1djlQazEwdS1sLTg	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Centerline - PM1			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-141738- trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1My1CSDF5Wk1mTFE	
KML position track	swift-gnss-20170401-141738- trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1MThrTEJMXzFfczg	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-141738- trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1M2F1REVDNDdIV00	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Piksi Multi 2

Inside Track - PM2			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122223-inner-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1aIJZd3lxdDJuczg	
KML position track	swift-gnss-20170401-122223-inner-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1b0I2NzNjQ1BXY1U	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122223-inner-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1eFBEWWI0ZGJ0MUJ	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Outside Track - PM2			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122223-outer-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1ZFg5LU1RSHZHVKU	
KML position track	swift-gnss-20170401-122223-outer-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1N1EzMW0yQlpmUHM	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122223-outer-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1VHgtb00ybWhMc2s	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Centerline - PM2			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-141743-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1LXRtQWFMREQwVjA	
KML position track	swift-gnss-20170401-141743-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1TFlodnVJdGxqYXc	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-141743-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1cGM0Mkc0c2tJdlk	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Piksi Multi 3

Inside Track - PM3			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122226-inner-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1aW11OUw0VHczMlk	
KML position track	swift-gnss-20170401-122226-inner-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1QIZPNk1WTXJjTEE	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122226-inner-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1cmZRdWpMOV04SW8	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Outside Track - PM3			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-122226-outer-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1VWV5ZnpYZjhuMWc	
KML position track	swift-gnss-20170401-122226-outer-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1ak1jcmJ4WW91bWs	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-122226-outer-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1YkowMHIwZ0FicVE	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Centerline - PM3			
Data Type	Name	Link	Notes
JSON encapsulated SBP	swift-gnss-20170401-141748-trimmed.sbp.json	https://drive.google.com/open?id=0B5X2nBadaPD1SFhFN3l5MEVYT1k	
KML position track	swift-gnss-20170401-141748-trimmed.kml	https://drive.google.com/open?id=0B5X2nBadaPD1dzNjTmtFQTJmeTg	KML file should be opened in Google Earth.
CSV position	swift-gnss-20170401-141748-trimmed.csv	https://drive.google.com/open?id=0B5X2nBadaPD1bTZGMWl5dEJSS1E	Flags field indicates fix type: 0 - Single Point 1 - RTK Float 2 - RTK Fixed

Reference Trajectory

Inside Track			
Data Type	Name	Link	Notes
Novatel Waypoint Text File	2017-04-01-drive3-mapping-pp.txt	https://drive.google.com/open?id=0B5X2nBadaPD1WFVVMENCUEFVhMXM	Start TOW: 589523 End TOW: 589797

Outside Track			
Data Type	Name	Link	Notes
Novatel Waypoint Text File	2017-04-01-drive3-mapping-pp.txt	https://drive.google.com/open?id=0B5X2nBadaPD1WFVVMENCUEFVhMXM	Start TOW: 588569 End TOW: 588907

Centerline			
Data Type	Name	Link	Notes
Novatel Waypoint Text File	2017-04-01-drive4-pp.txt	https://drive.google.com/open?id=0B5X2nBadaPD1bWh5bDdtSHRlaW8	Start TOW: 595821 End TOW: 595623