A Machine Learning Approach to Pitot Static Error Detection & Airspeed Prediction

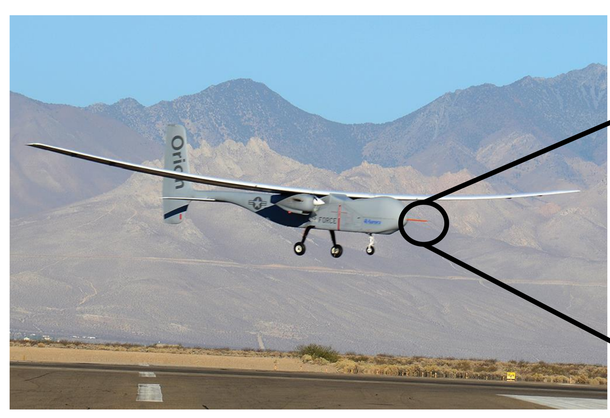
Renee Swischuk[1], Douglas Allaire[2]

[1]Texas A&M University, Department of Mathematics

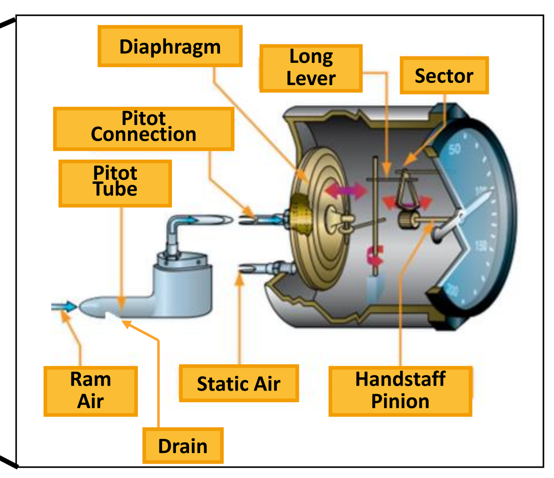
[2]Texas A&M University, Department of Mechanical Engineering

Motivation

Unmanned Aerial Vehicles only have one pitot static system used for guidance so system failure can result in critical missions being aborted. If autonomous error detection software is developed, these missions may be able to continue on.



Orion UAV, Aurora Flight Sciences



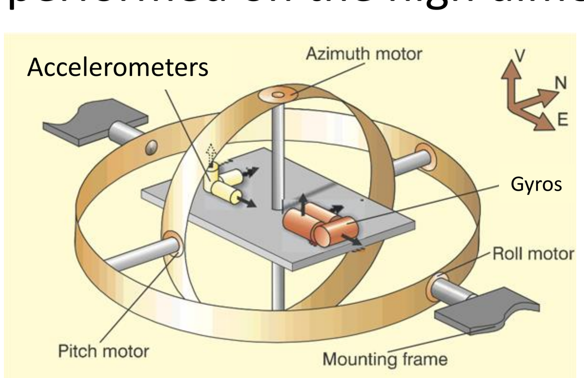
Pitot Static System Diagram[1]

Objective

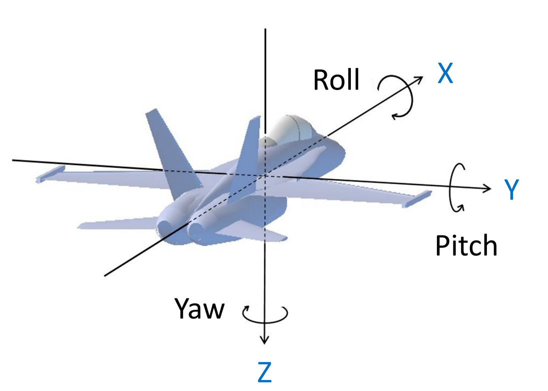
Our goal is to create a system capable of detecting pitot static blocks within 30 seconds of failure. Failures result in inaccurate airspeed readings so in addition, we attempt to predict a corrected airspeed which lies within 10 knots of the true airspeed.

Approach

Using highly reliable Inertial Navigation System (INS) data, we can detect pitot static errors and trigger a classification model for identifying the state of the system. In the event of a failure, a corrected airspeed is predicted using k-nearest neighbors in an offline/online paradigm. Initial feature selection and reduction is performed on the high dimensional flight data.



Inertial Navigation System [1]



Body Coordinate System[2]

Error Detection

- Two running estimates of airspeed from pitot tube and accelerometer data:

$$V_{pitot}(t) = \sqrt{\frac{2(P_t(t)-P_s(t))}{\rho_{air}(t)}} \qquad V_{INS}(t) = \int_{t-1}^{t} a_x \, dt$$

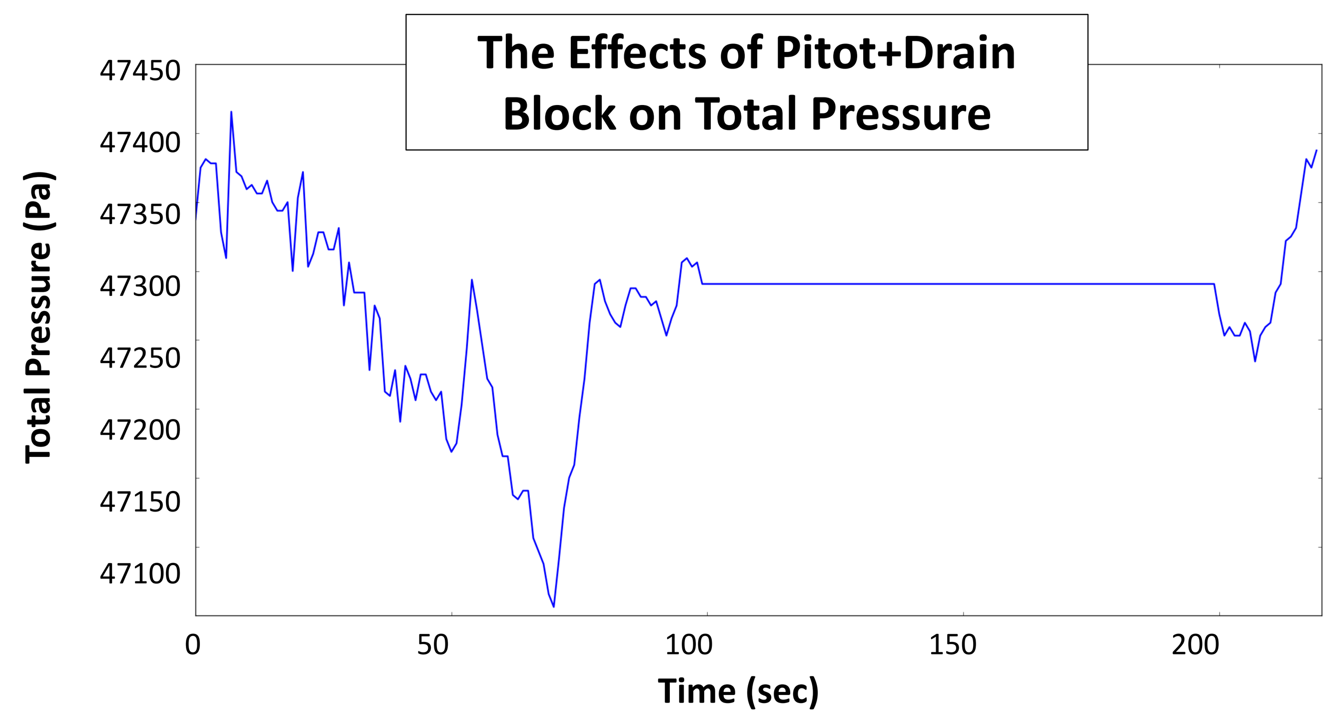
- Anytime $|V_{pitot} - V_{INS}| > V_{thresh}$, classify the state of the system.

System states:

1. Pitot tube block – Airspeed indicator drops to 0
2. Pitot drain block – Total pressure constant
3. Static port block – Static pressure constant

Classifying the State of the System

- Erroneous pressure streams are manually simulated for 100 seconds.

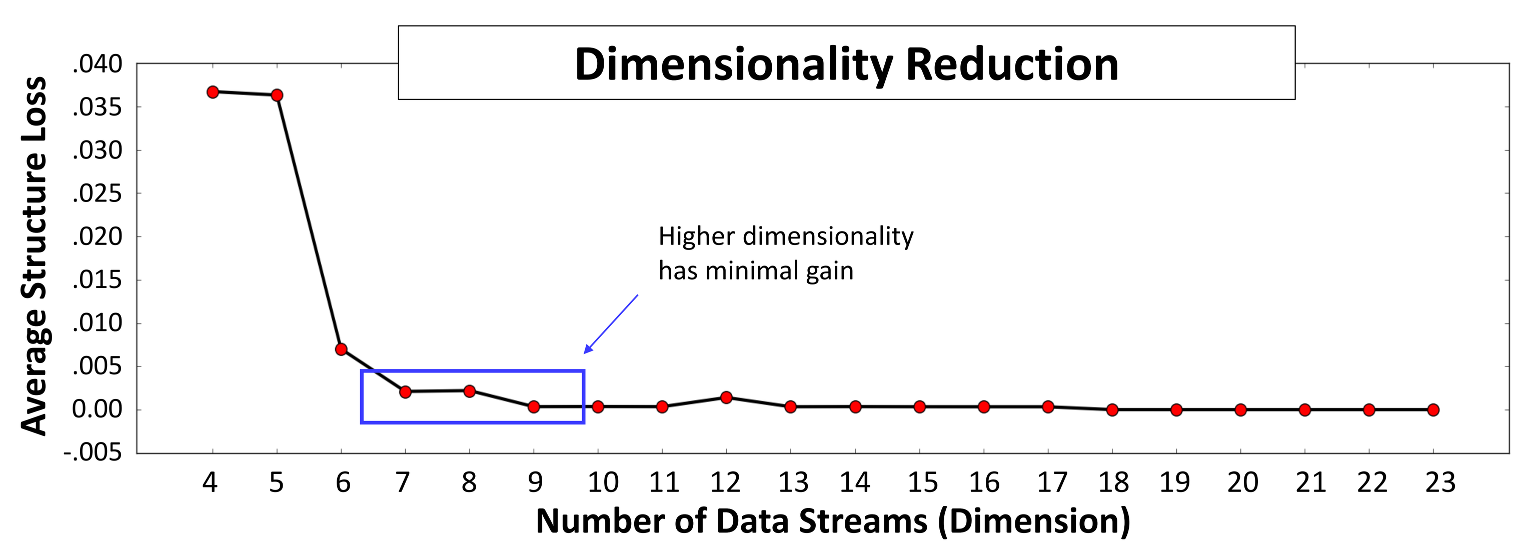


- Autocorrelation for each pressure stream is stored in the error library.
- Autocorrelation is calculated online every 10 seconds.
- Online case is classified into the error library to detect constant signals.
- System state is determined using minimum Euclidean distance.

Offline Airspeed Library

- Hundreds of redundant data streams are recorded in flight.
- Sammons Mapping Function[3] was minimized to find lower dimensional data sets which preserve the structure and distances of the original high dimensional data:

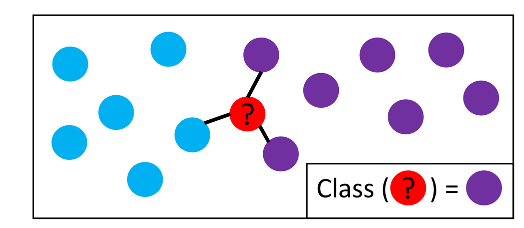
$$E = \frac{\sum_{i<j}^{n} \frac{[d_{ij}^{*} - d_{ij}]^2}{d_{ij}^{*}}}{\sum_{i<j}^{n} d_{ij}^{*}}$$



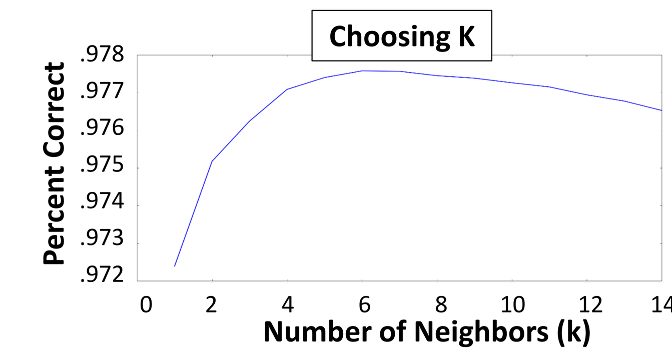
- In the reduced dimension, the following most informative features for predicting airspeed were chosen using simulated annealing optimization:
  - Fuel Flow
  - Engine Core Speed
  - Engine Fan Speed
  - Pitch
  - Angle of Attack
  - Thrust Target
  - Thrust Command

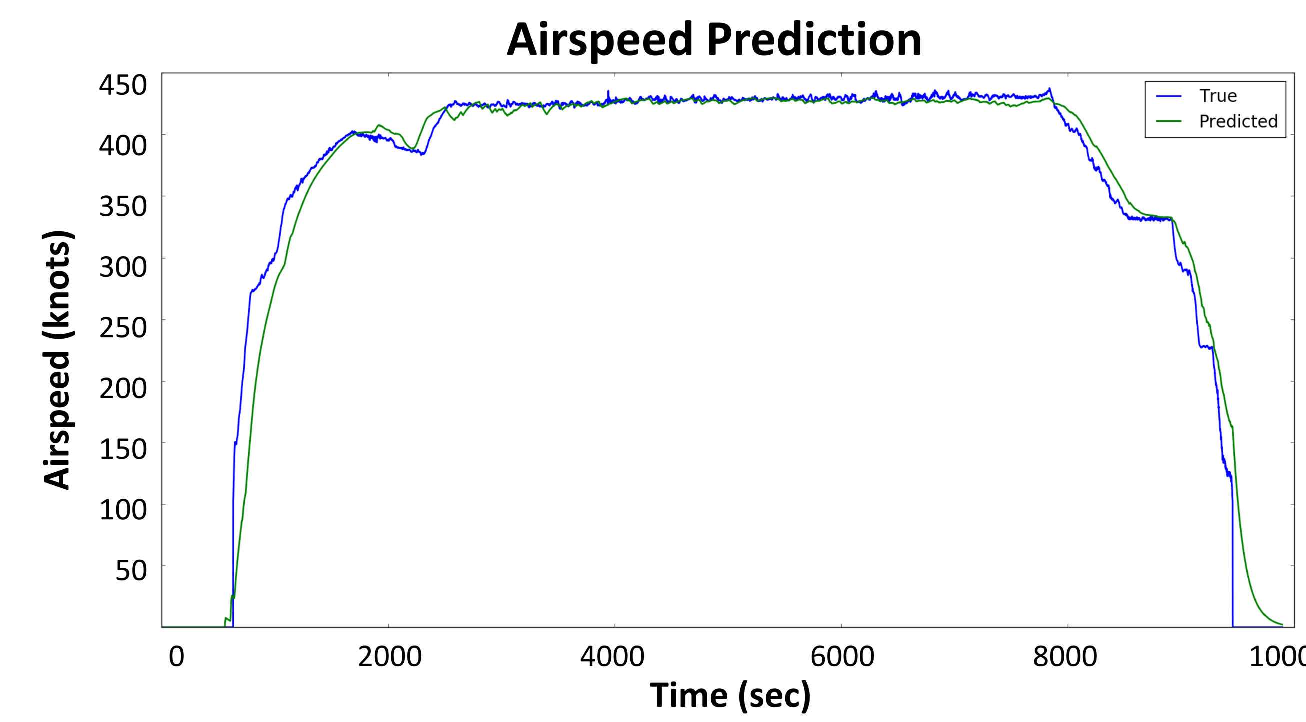
Airspeed Prediction

- Airspeed predicted using K-nearest neighbors regression.



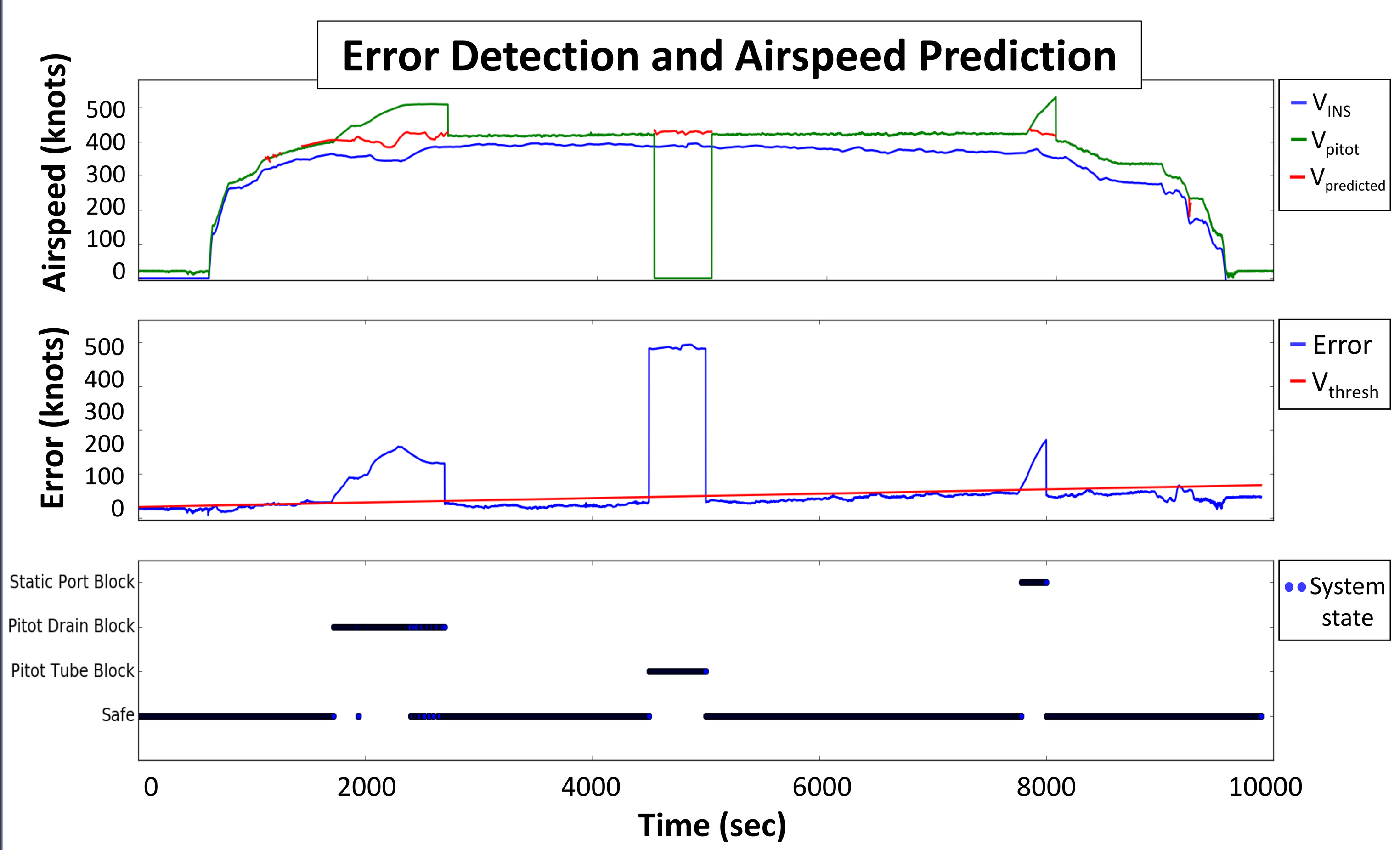
Example of K-Nearest Neighbor Classification K=3





Results

- This system is able to detect error within 20 seconds.
- Airspeed prediction is within 30 knots of the true airspeed during cruise.



- This system will allow pilots to safely navigate an aircraft in the event of a pitot static error and provide UAV's the ability to continue flight.

References

[1] U.S. Dept. of Transportation, Federal Aviation Administration , *Pilot's handbook of aeronautical knowledge*, 2008.

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[3]LLC, CH ROBOTICS. "Understanding Euler Angles." *November 26th, 2012*

[4]Camastra, Francesco. "Data dimensionality estimation methods: a survey." *Pattern recognition* 36.12 (2003): 2945-2954.

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