Objective Measures of Pilot Performance during Approach to Land & Landing Phases of Flight

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Introduction

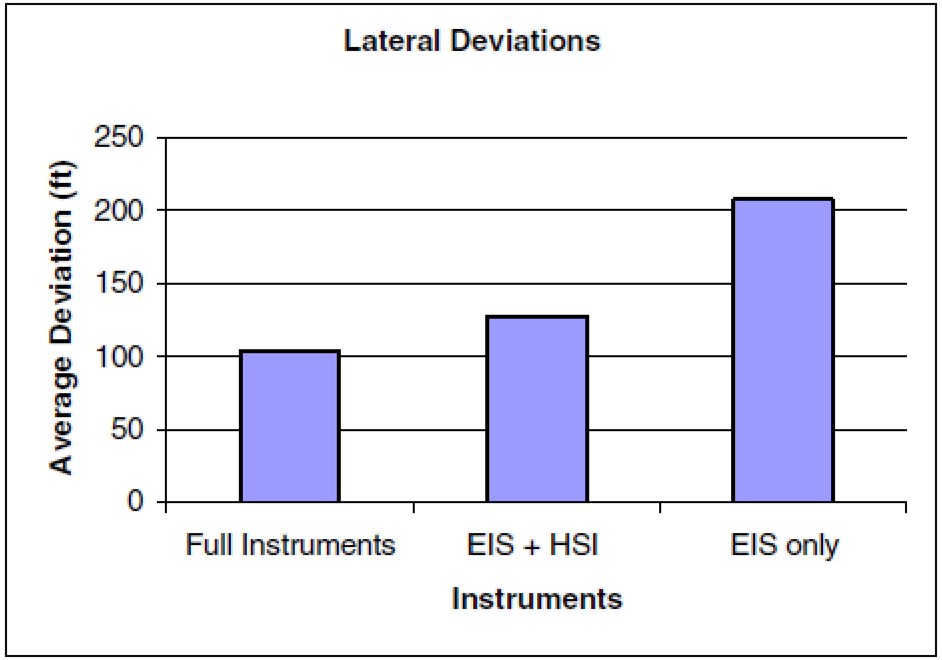
- Lack of objective measures
- Costly and inaccessible data
- Computer-based Avionics
- Connected Aircraft
- Big Data Analytics

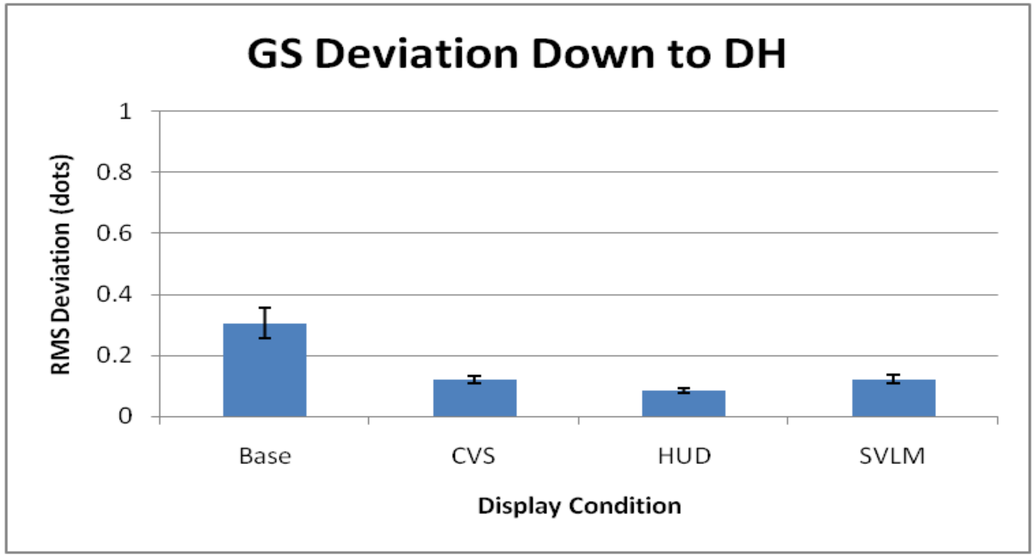
Objectives

- Detect significant events
- Objectively measure pilot performance
- Predict pilot performance

Background

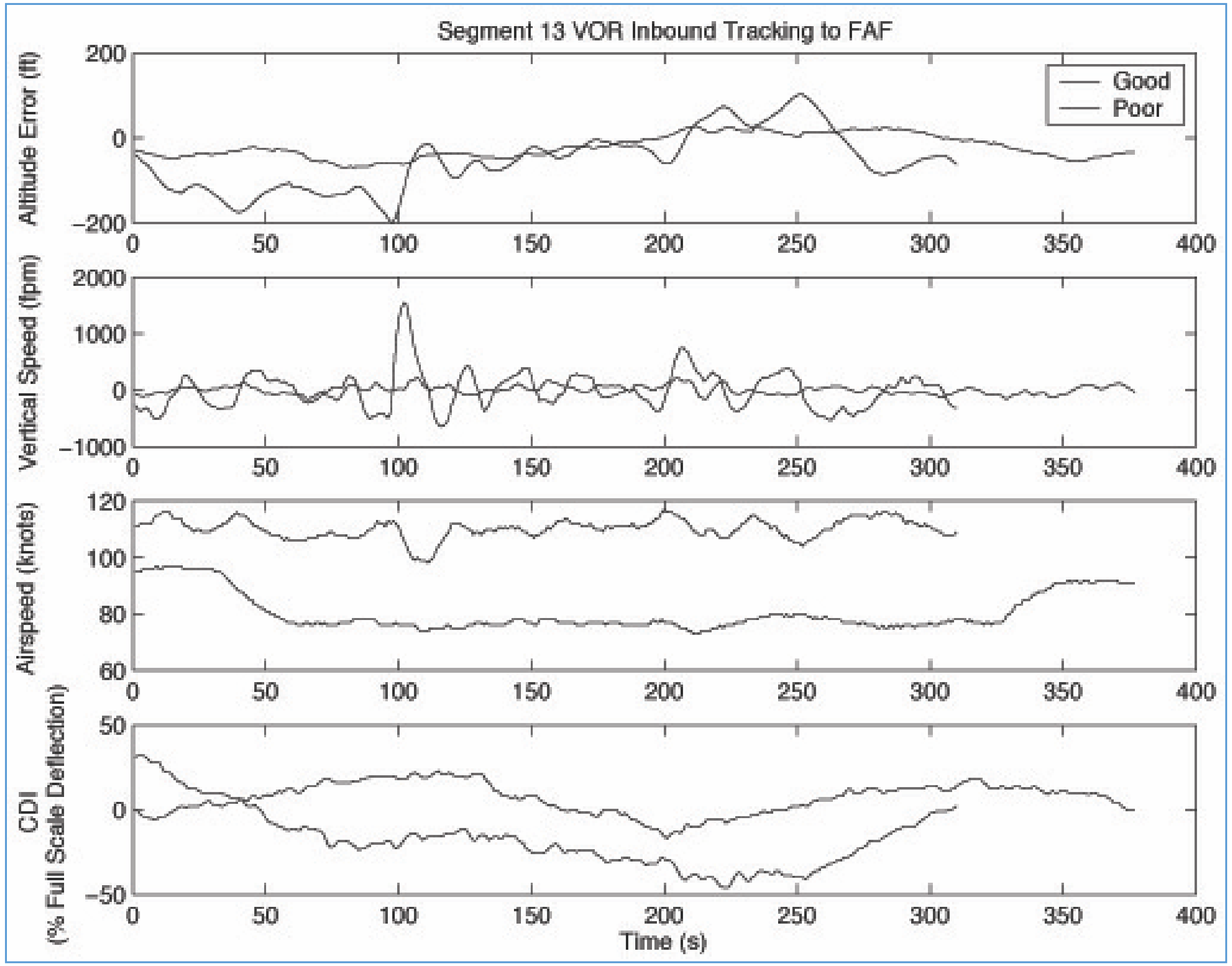
- 45 years of research
- Relatively few measures
- Summary measures
  - Mean, SD, RMSE, Tolerance Deviations, etc
- Static view of pilot performance





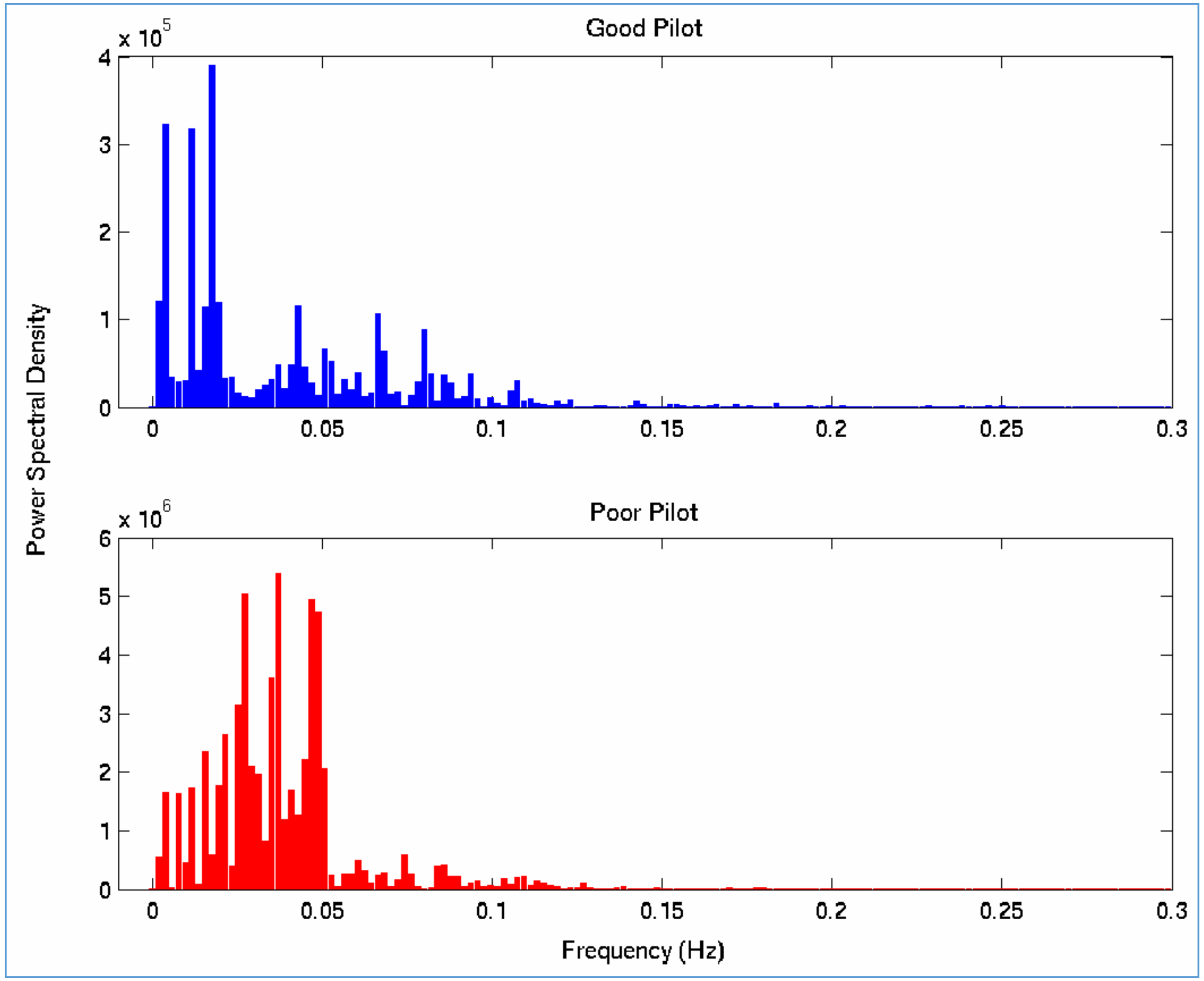
Time Series Data

- Capture the dynamic nature of pilot performance
- More granular analysis
- Uncover patterns of behavior



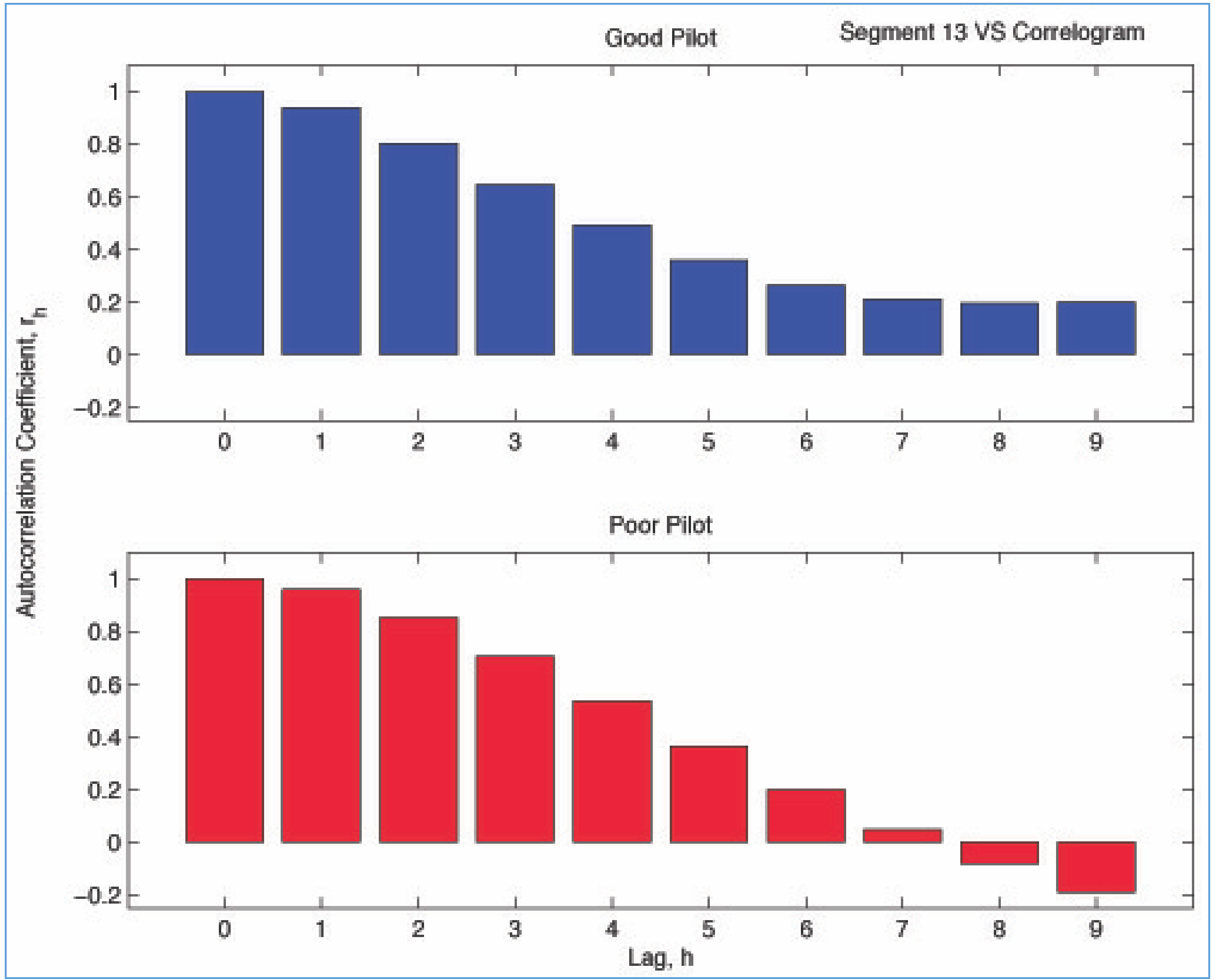
Time Series Based Objective Measures of Pilot Performance
(Johnson, Rantanen & Talleur, 2004)

- Expert pilots make frequent, small, smooth control inputs.
- Novice pilots make fewer but larger, jerky inputs



Time Series Based Objective Measures of Pilot Performance
(Johnson, Rantanen & Talleur, 2004)

- Expert pilots are more aware of the state of the airplane and better able to predict its future state.
- Autocorrelations of more skillful pilots will decay slower than less skillful pilots



Method

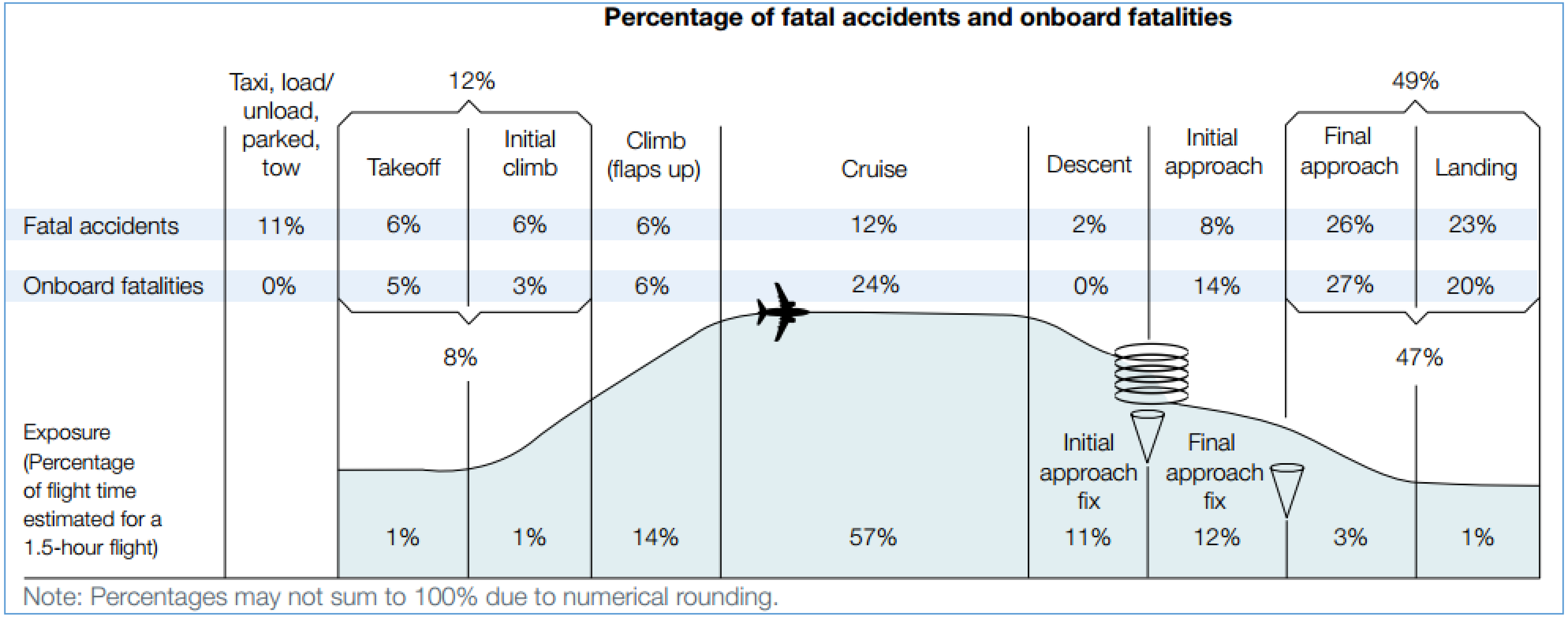
- Apply measures created by Johnson et al.
  - Slope of the autocorrelation coefficient
  - Time for autocorrelation coefficient to decay to zero
- Evaluate a new measure of pilot performance
  - Time after the autocorrelation coefficient reaches zero*
- Improvements
  - Stabilize the variance of the time series data making it stationary

Data Set

- 89 flight data recordings
- Approach and landings at San Francisco Airport, Runway 19L
- Airplane position (altitude, longitude, latitude)
- Airplane attitude (pitch, roll, yaw)
- Performance Data (airspeed, vertical speed, vertical acceleration, pitch rate, roll rate, yaw rate, etc.)
- Airplane state (landing gear configuration, flight control position, weight on wheels, sensor data, etc.)

Approach to Land and Landing Phases of Flight

- Two most critical phases of flight
- Physical and cognitive workload test the limits of the crew

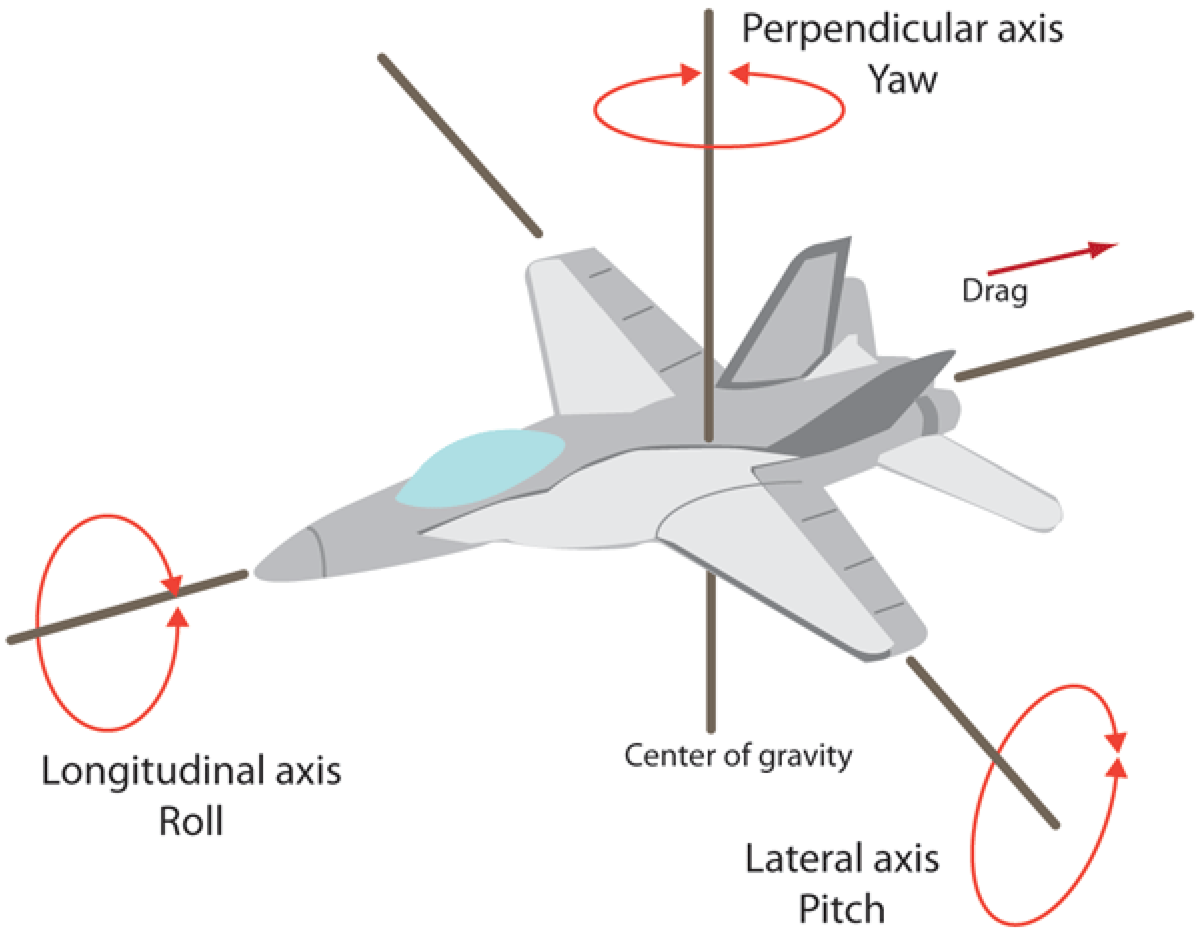


Calculating Pilot Performance

- Approach Stability
- Landing Precision
- Landing Quality

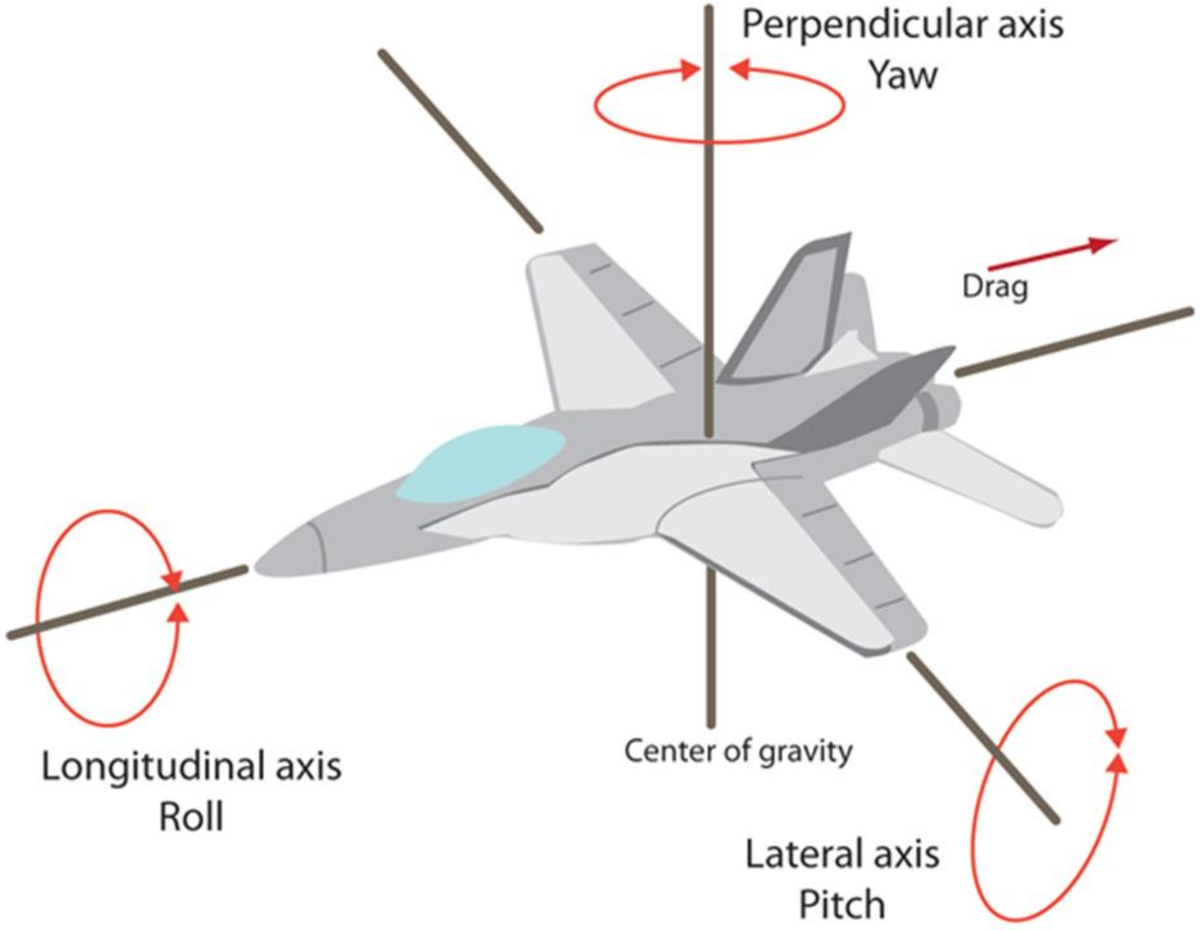
Approach Stability

- Aircraft is on the correct flight path;
- Only small changes in heading and pitch;
- Aircraft speed is not more than 20 knots above designated approach speed and not less than the designated approach speed;
- Descent rate no greater than 1000 ft./min;
- Power setting is appropriate for the aircraft configuration,
- Approach precision is appropriate for the associated instrument landing system.



Stabilized Approach Calculator

	Min	Max
Pitch	-5 deg	3 deg
Heading	-10 deg	10 deg
Roll	-5 deg	5 deg
Descent Rate		-1000 ft./min
Airspeed	126 kts	146 kts.



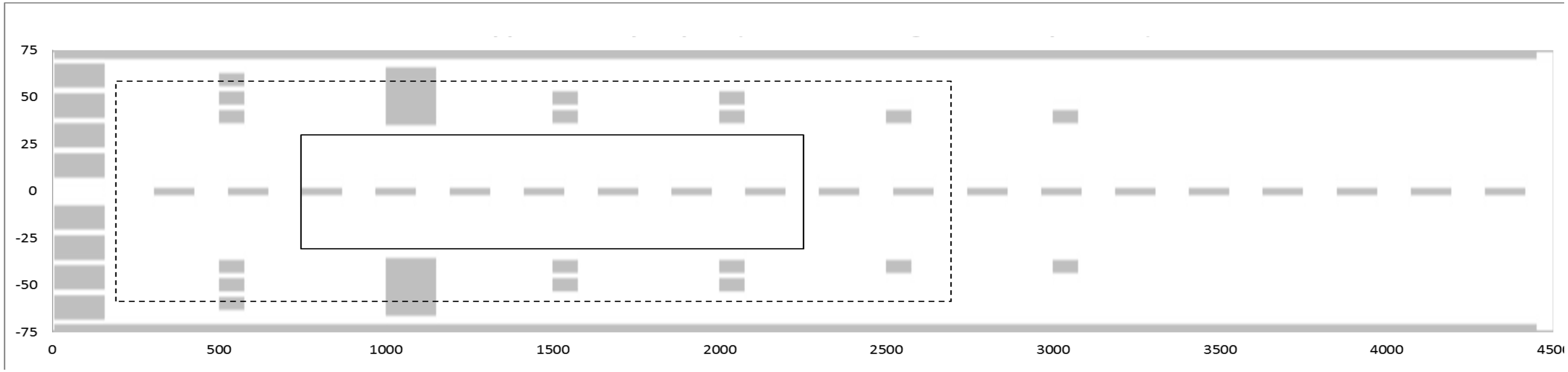
Stabilized Approaches

	Stable	Unstable
All Approaches	57	33
Heading	90	0
Pitch	79	11
Roll	**67**	**23**
Airspeed	86	4
Sink Rate	86	4

	1 axis	2 axis	3 axis
Unstable Axes	26	5	2

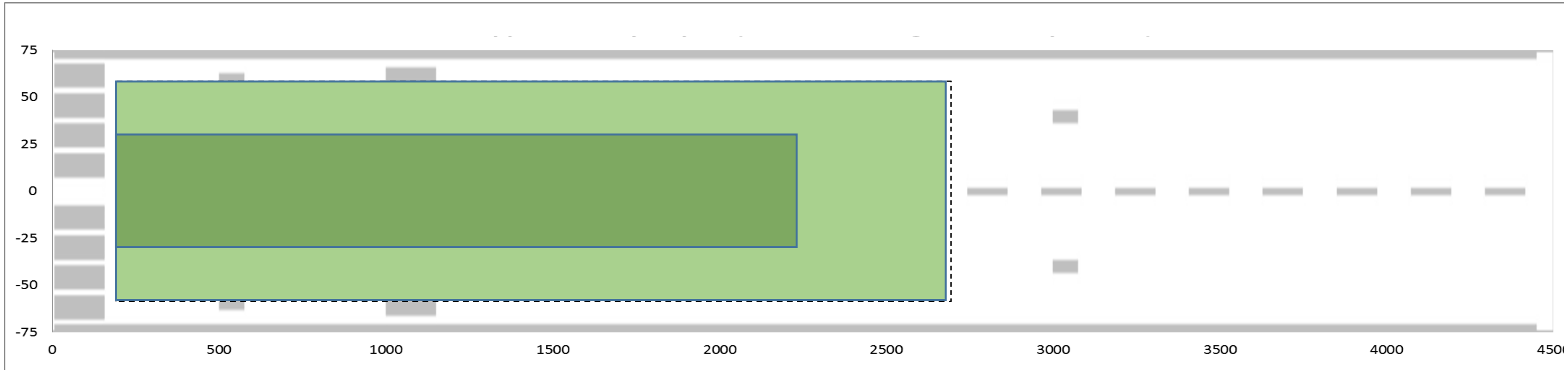
Landing Precision

- Distance from runway threshold
- Distance from runway centerline



Landing Precision Calculator

- Distance from threshold
  - Optimum (≥700 & ≤ 2200ft)
  - Ideal (≥ 200 & ≤ 2700 ft)
  - Out of bounds (<200ft)
- Distance from centerline
  - Optimum (+/- 25 ft)
  - Ideal (+/- 50 ft)
  - Out of bounds (>50ft)



Landing Precision

	Optimal	Good	Out of Bounds
Precision	61	20	8

Landing Quality Calculator

- Touch Down Quality
  - Vertical Acceleration
    - >1.7 = Hard
    - 1.5-1.7 = Rough
    - 1.3-1.5 = Good
    - 1-1.3 = Excellent
- Bounced Landing
  - WOW oscillation
- Uncoordinated Landing
  - Left WOW ≠ Right WOW

Landing Quality

TD Quality	Excellent	Good	Hard	rough
Landings	32	29	13	15

Bounced Landings	Normal	Bounced
Landings	81	8

Coordinated Landings	Coordinated	Uncoordinated	1sec	2sec	3sec	4sec
Landings	49	40	32	5	2	1

Statistical Analysis

Research Question: Can approach stability predict landing precision?

Dependent Variable	Statistical Analysis
Distance to Threshold	Multiple Linear Regression
Distance to Center Line	Multiple Linear Regression
Precision	Ordinal Logistic Regression

Results: Linear Regression

Distance to Threshold	Press	P-Value	R^2	RSE
Lag to Zero	95.52	2.03E-05	0.388	410.1
Reg Coeff	103.47	4.17E-05	0.3708	415.8
Lag to Zero + Reg Coeff	97.92	2.48E-06	0.5206	363
Lag to Zero + Reg Coeff + Diff Var	106.53	4.50E-07	0.642	313

Distance to Centerline	Press	P-Value	R^2	RSE
Lag to Zero	87.25	0.01	0.192	10.85
Reg Coeff	90.13	.404	0.014	11.97
Lag to Zero + Reg Coeff	88.03	.009	0.271	10.3

Results: Ordinal Logistic Regression

Distance to Threshold	AIC	Hit Rate
Lag to Zero	129.75	0.781
Reg Coeff	136.72	0.747
Diff Var	139.07	0.758
Reg Coeff + Diff Var	144.53	0.805

Lag To Zero: Ordinal Logistic Regression

```
 link  threshold nobs logLik AIC    niter max.grad cond.H
 logit flexible  87   -50.88 129.75 6(0)  2.58e-13 6.7e+05

Coefficients:
                              Estimate Std. Error z value Pr(>|z|)
`featureCat$Stable_approach`1  1.15452    0.60979   1.893   0.0583 .
LagToZero_inertialVerticalSpd -0.17647    0.07811  -2.259   0.0239 *
LagToZero_verticalAccel       -0.41177    0.16178  -2.545   0.0109 *
LagToZero_bodyPitchRate       -0.54660    0.24423  -2.238   0.0252 *
LagToZero_bodyRollRate         2.08220    1.91423   1.088   0.2767
LagToZero_bodyYawRate         -0.31409    0.24758  -1.269   0.2046
LagToZero_pitchAngle          -0.09640    0.08097  -1.191   0.2338
LagToZero_rollAngle           -0.03072    0.14707  -0.209   0.8345
LagToZero_calibratedAirspeed  -0.02746    0.06679  -0.411   0.6810
LagToZero_gsDev                0.04040    0.07278   0.555   0.5788
LagToZero_locDev              -0.08753    0.04504  -1.943   0.0520 .
LagToZero_lRadAlt              0.05432    0.07488   0.725   0.4682
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Coefficients

```
                      0|1                        1|2
              -7.47760729                -5.06313436
featureCat$Stable_approach`1 LagToZero_inertialVerticalSpd
               1.15451767                -0.17646595
   LagToZero_verticalAccel      LagToZero_bodyPitchRate
              -0.41177358                -0.54660116
    LagToZero_bodyRollRate        LagToZero_bodyYawRate
               2.08220203                -0.31408974
     LagToZero_pitchAngle           LagToZero_rollAngle
              -0.09640499                -0.03072361
LagToZero_calibratedAirspeed             LagToZero_gsDev
              -0.02745822                 0.04039837
          LagToZero_locDev             LagToZero_lRadAlt
              -0.08753308                 0.05432252
```

Symmetric Confidence Intervals

```
                                      2.5 %        97.5 %
0|1                            -13.70380423 -1.2514103552
1|2                            -11.04460980  0.9183410854
`featureCat$Stable_approach`1   -0.04065116  2.3496865067
LagToZero_inertialVerticalSpd   -0.32956306 -0.0233688326
LagToZero_verticalAccel         -0.72885718 -0.0946899762
LagToZero_bodyPitchRate         -1.02527403 -0.0679282876
LagToZero_bodyRollRate          -1.66961498  5.8340190322
LagToZero_bodyYawRate           -0.79934066  0.1711611771
LagToZero_pitchAngle            -0.25510211  0.0622921376
LagToZero_rollAngle             -0.31897253  0.2575253050
LagToZero_calibratedAirspeed    -0.15836769  0.1034512440
LagToZero_gsDev                 -0.10224939  0.1830461349
LagToZero_locDev                -0.17581907  0.0007529106
LagToZero_lRadAlt               -0.09244171  0.2010867564
```

Asymmetric Confidence Intervals

	2.5 %	97.5 %
0|1	1.118184e-06	0.2861010
1|2	1.597302e-05	2.5051311
`featureCat$Stable_approach`1	9.601640e-01	10.4822831
LagToZero_inertialVerticalSpd	7.192379e-01	0.9769021
LagToZero_verticalAccel	4.824600e-01	0.9096549
LagToZero_bodyPitchRate	3.586982e-01	0.9343275
LagToZero_bodyRollRate	1.883196e-01	341.7293441
LagToZero_bodyYawRate	4.496253e-01	1.1866820
LagToZero_pitchAngle	7.748374e-01	1.0642732
LagToZero_rollAngle	7.268955e-01	1.2937245
LagToZero_calibratedAirspeed	8.535359e-01	1.1089917
LagToZero_gsDev	9.028044e-01	1.2008698
LagToZero_locDev	8.387697e-01	1.0007532
LagToZero_lRadAlt	9.117024e-01	1.2227308

Summary

- Time series data collected by flight data recordings provides very detailed insight into pilot performance.
- Insights from the data can be used to objectively measure and categorize pilot performance.
- Continuous measures of landing precision did not detect a strong relationship between approach stability and landing precision; however,
- Categorical measures show promise but more data is needed.