Calculated Drag of an Aerial Refueling Assembly Through Airplane Performance Analysis

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Presentation Overview

- National Objectives
- Dryden Project Objectives
- Airplane Description
  - Tanker airplane, in-depth
- Flight Test Technique
- Sample Results
- Paradrogue Drag
- Drag Relief
- Comparison to Wind Tunnel Predictions
- Drag Polars
- Constant Drag Coefficient?
- Concluding Remarks

National AAR Program Interest

- **Automated Aerial Refueling (AAR)**
- **Unmanned Aerial Vehicles**
  - Extends range
  - Shortens response for time critical targets
  - Maintains in-theater presence using fewer assets

National AAR Program Interest

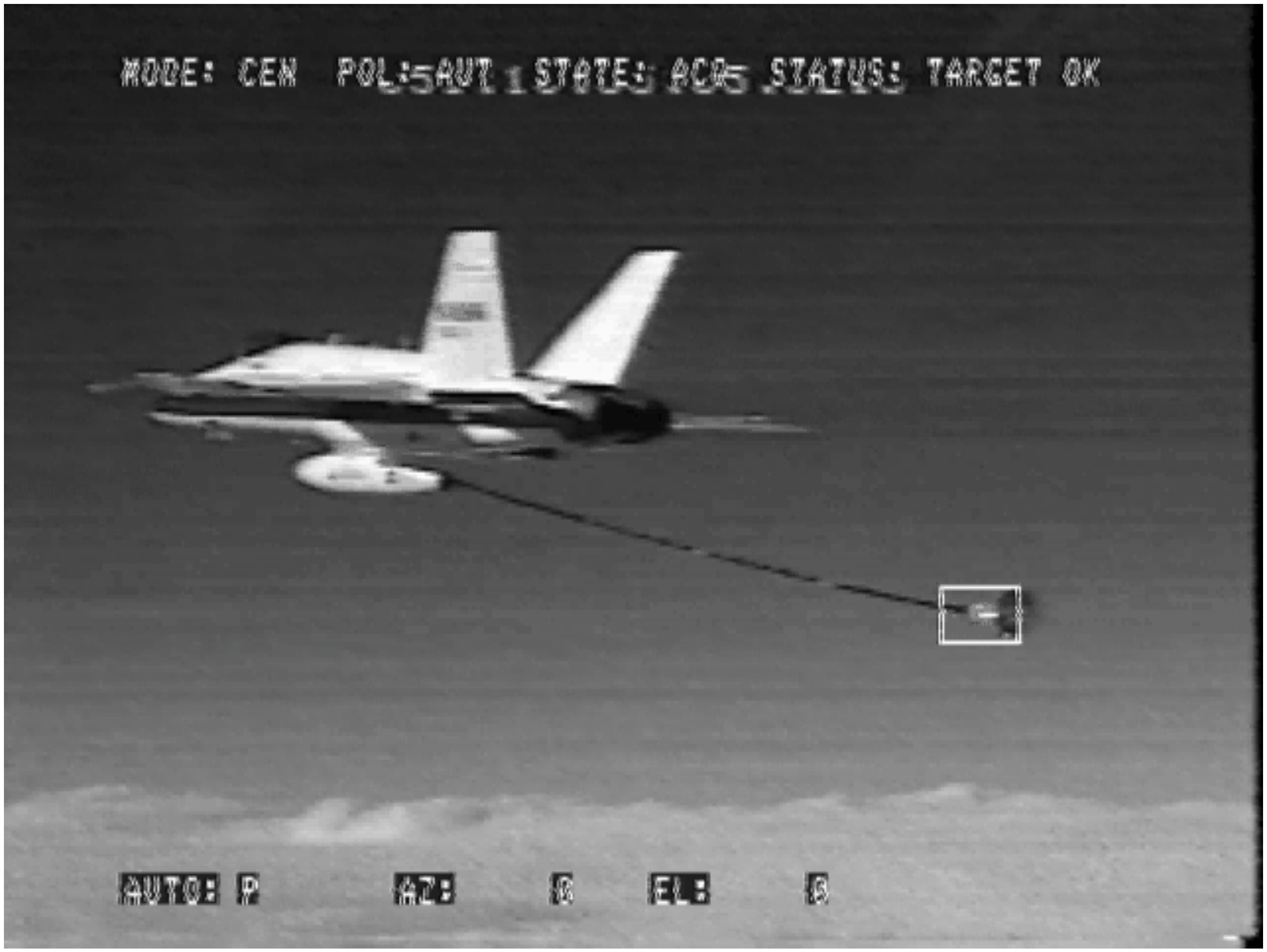
- **Automated Aerial Refueling (AAR)**

- **Manned Aircraft**
  - Facilitates adverse weather operations
  - Improves fueling efficiency
  - Enables multi-point simultaneous refueling

Dryden AAR Project Objectives

- **Quantify Assumptions**
  - Drogue is assumed stable in the proximity of a stable receiver aircraft
  - The drogue movement is repeatable and predictable
- **Assess the Approach**
  - Can adequate flight test data be captured through optical instrumentation?
  - Can individual model effects be superimposed to predict final drogue position?
  - Are the flight test techniques sufficient to collect the desired data?
  - Are the independent model parameters that affect drogue position observable through flight test?
  - Sufficient signal to noise ratio, measurement error, parameter coupling, etc.
- **Reduce risk for UCAV AAR program through early flight test**
  - Deliver flight validated drogue model to the AAR community for future automatic control system development
  - Correlate the drogue model to generic forebody influences
  - Develop organic UAV instrumented tanker capability
  - Develop expertise in electro-optic sensor technologies
  - Applicability of the model to alternate refueling scenarios

Dryden Optical Tracking



Dryden AAR Approach

- **Phase 0**
  - Envelope expansion
    - ARS on F/A-18A
    - ARS operational envelope
    - Flight test envelope
    - 1st refueling from a "K" F/A-18A
  - Drogue position vs. airspeed
  - Pilot proficiency

- **Phase 1**
  - Isolate drogue influences
    - Flight conditions
    - Hose effects
    - Tanker effects
    - Receiver forebody effects
    - Turbulence
  - Two additional external tanks

- **Opportunity for piggy-back experiment**
  - Existing instrumentation available onboard from the AFF project
  - Drag estimation for paradrogue and hose assembly

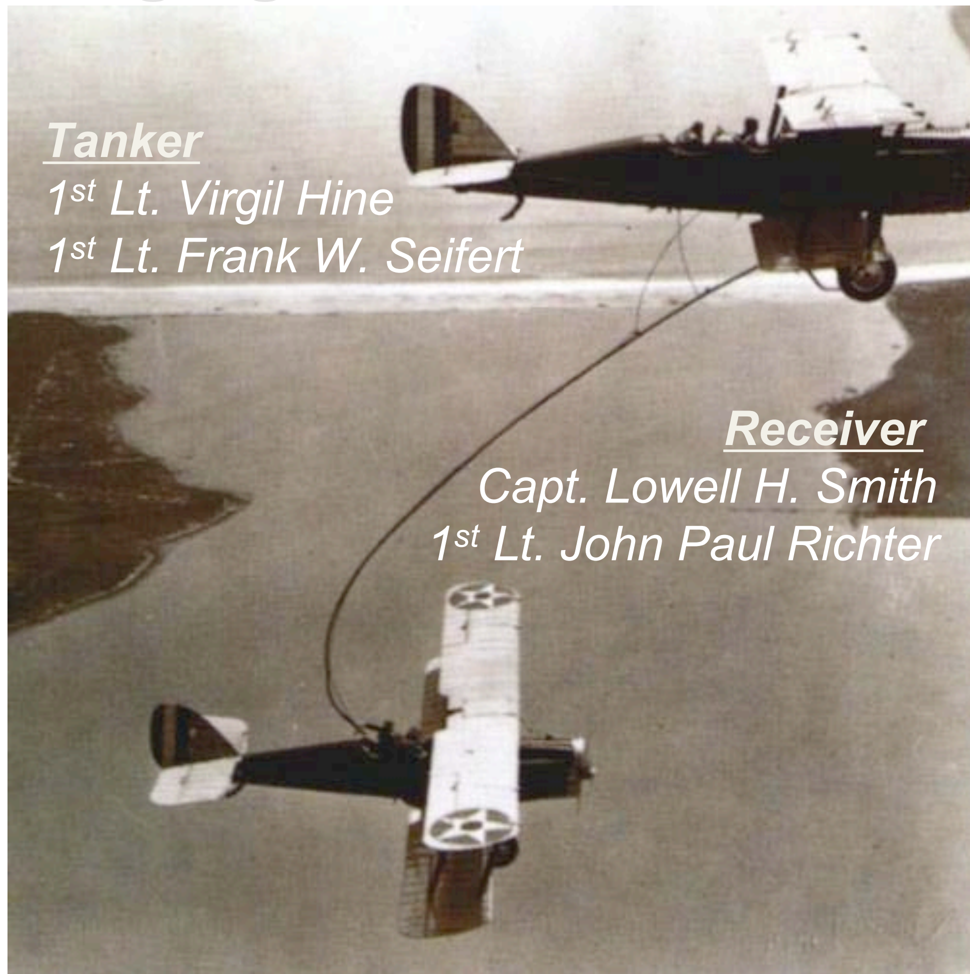
Evolution of Aerial Refueling

1921: Wingwalking Transfer Method

Wesley May

Evolution of Aerial Refueling

1923: Hanging Hose Transfer Method



Evolution of Aerial Refueling

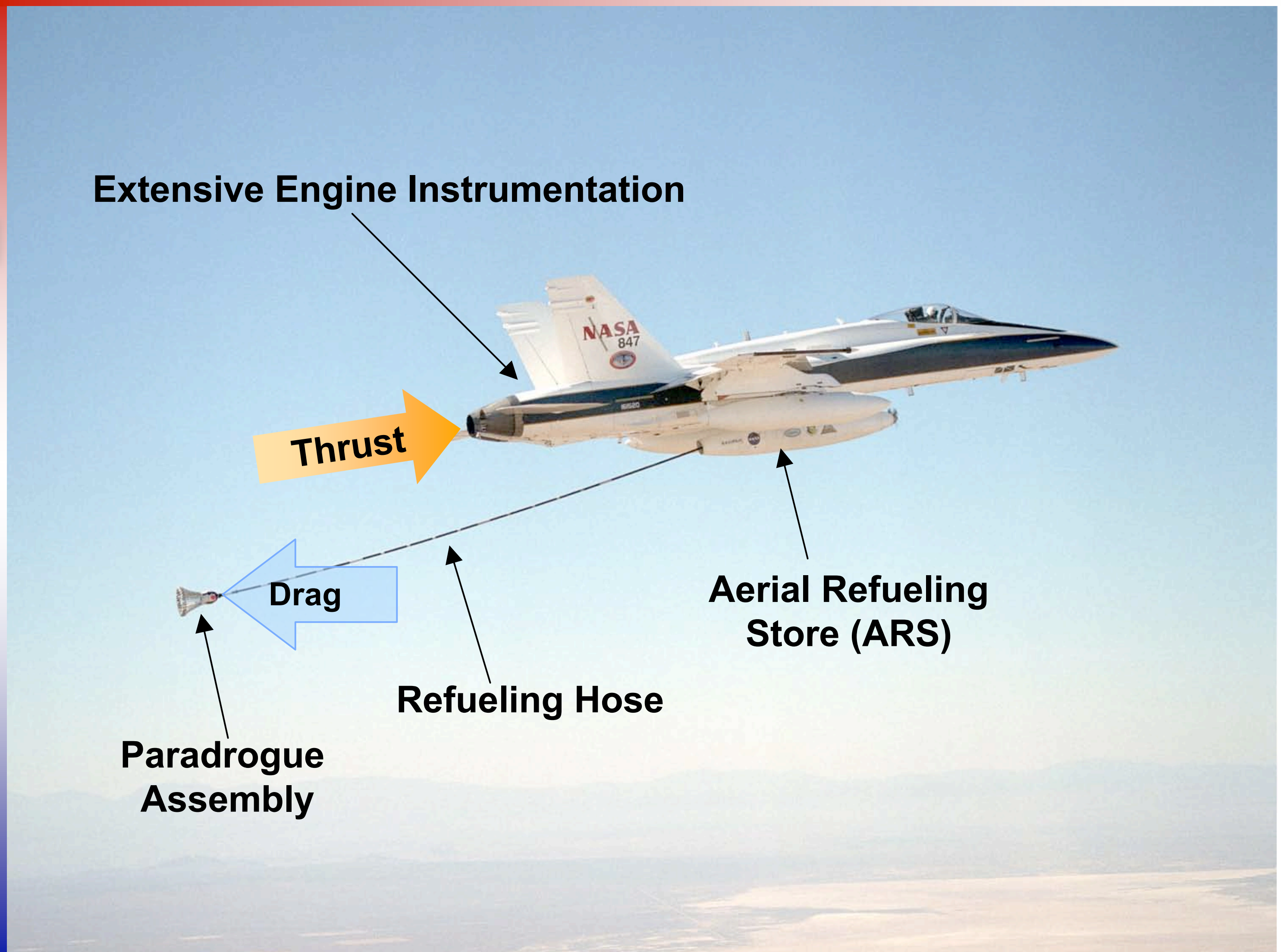
Evolution of Aerial Refueling

2003: Precision Engagements

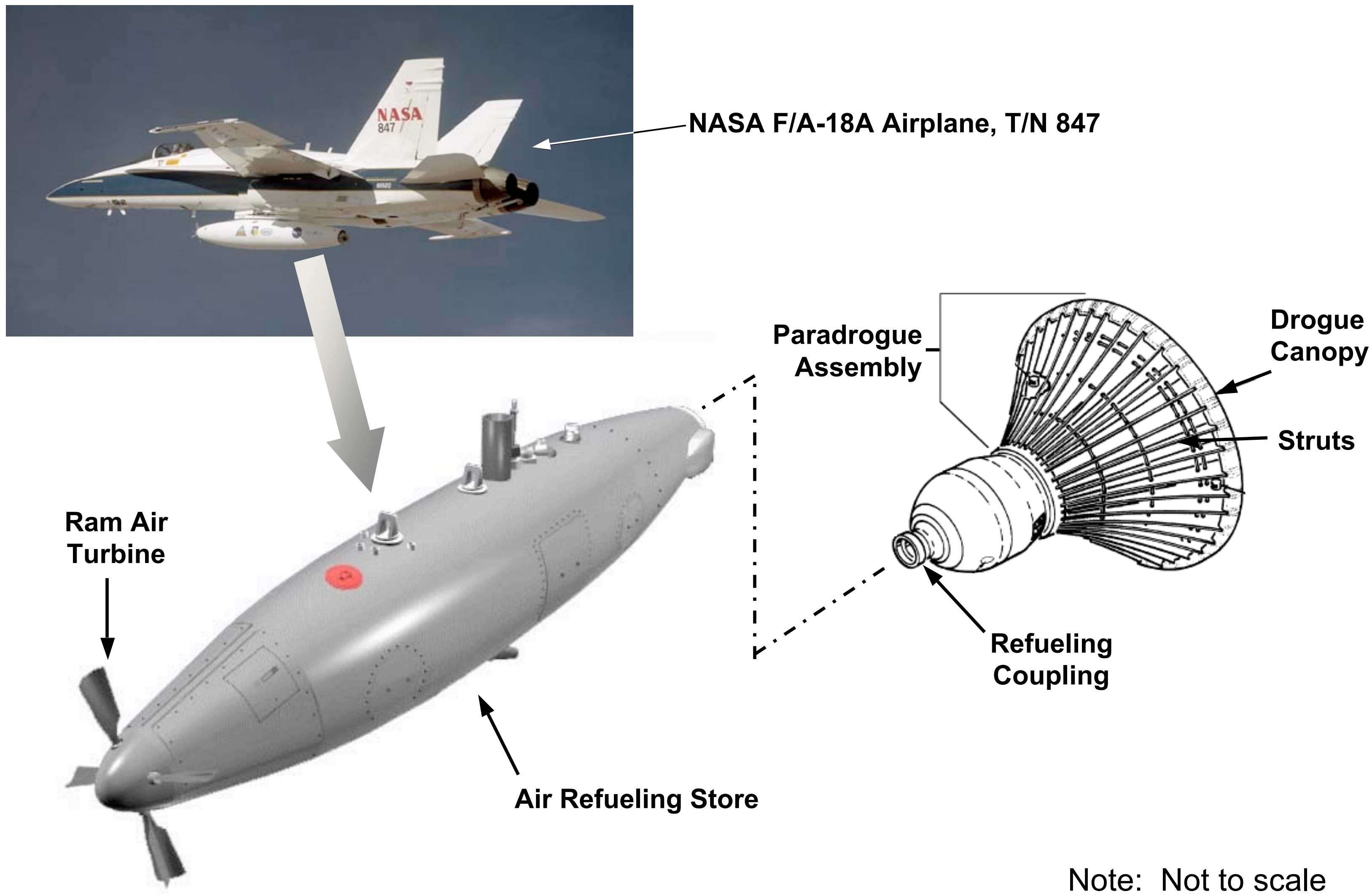
AAR Project Aircraft

- NASA 845
  - Two-seater
  - Systems Research Testbed
  - Two forward-facing cameras
- NASA 847
  - Single-seater
  - Tanker configuration w/ ARS
  - Thrust Instrumentation
  - Two aft-facing cameras
- Dual instrumentation
  - GPS receivers
  - Wireless modems
  - Multiple telemetry streams
- Additional NASA F/A-18s
  - Phase 0 chase support

Tanker Description

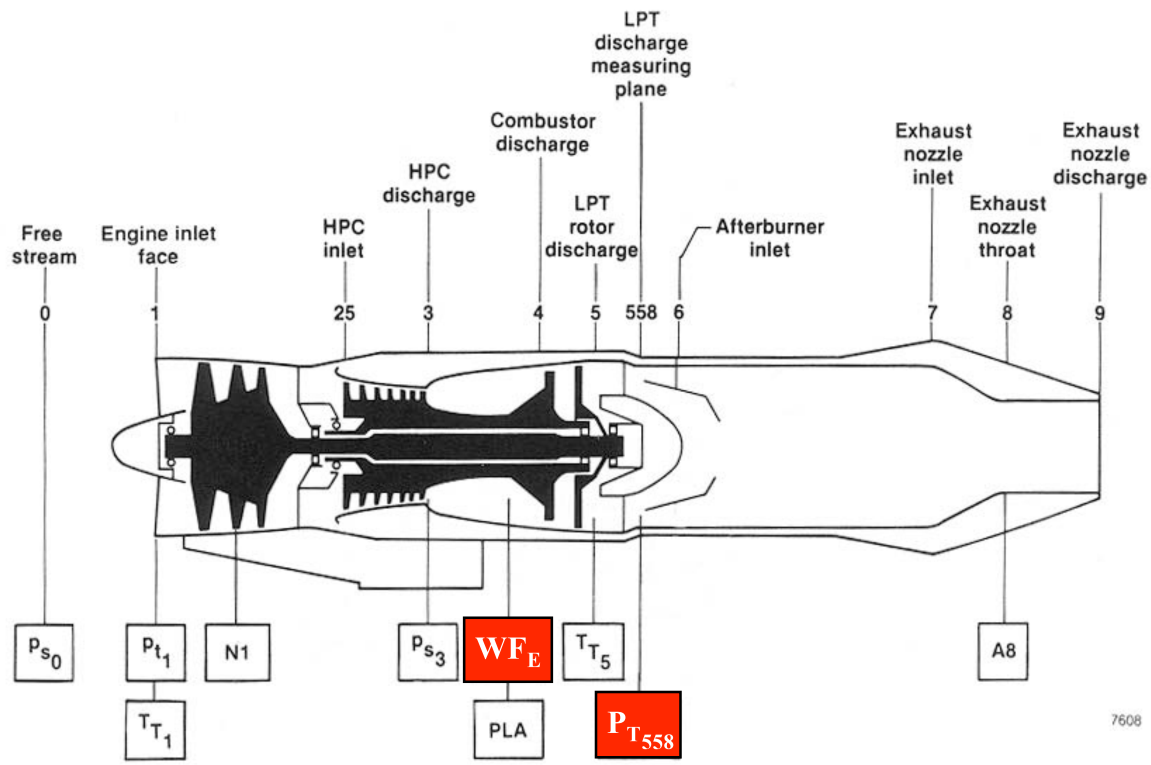


Aerial Refueling Store



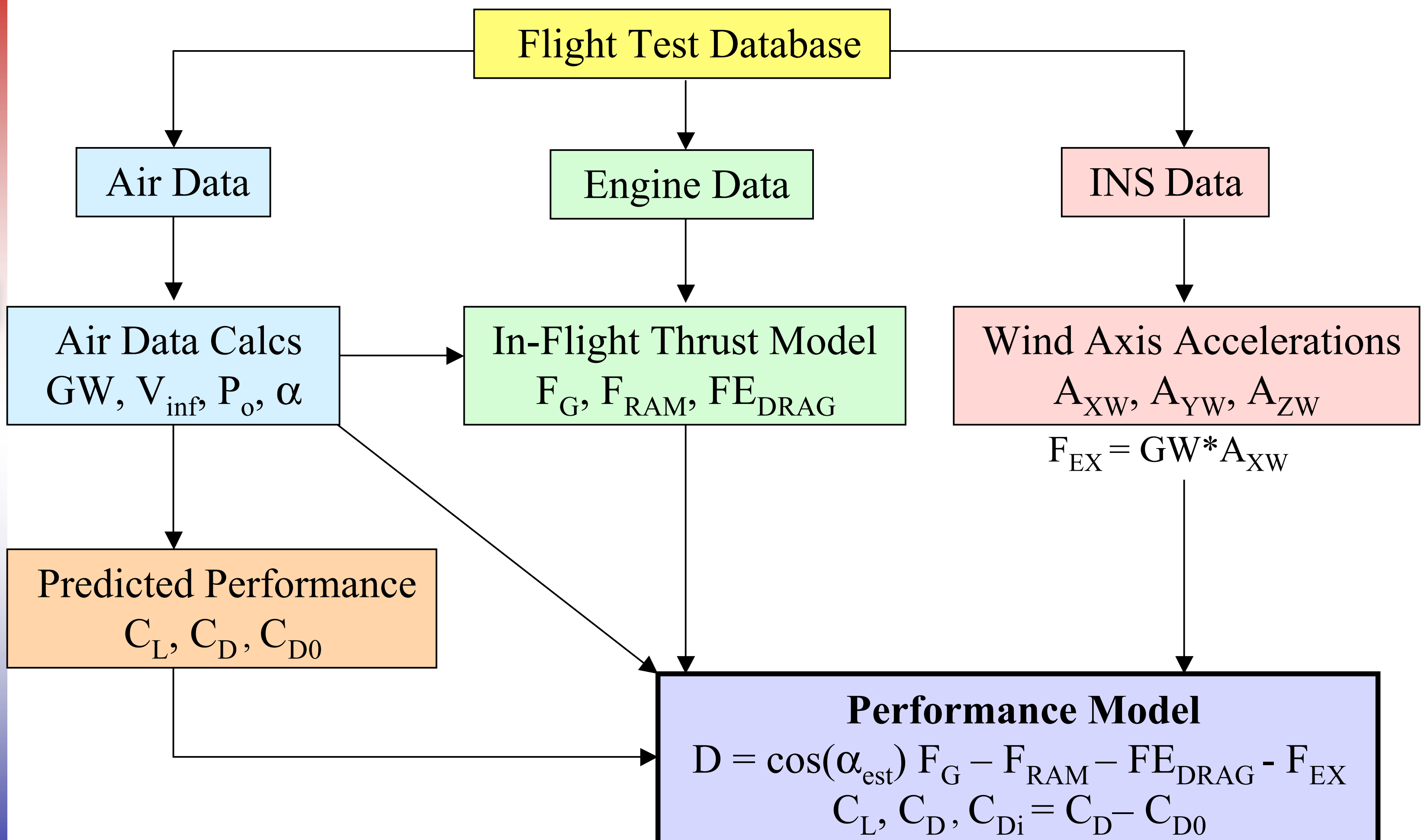
Note: Not to scale

Engine Thrust Instrumentation



- F404 Engines – Instrumented for Thrust Determination
  - Flight-test, volumetric fuel-flow meter installed (WF_E)
  - Turbine exit plane pressure rakes ($P_{T_{558}}$)
- Manufacturer's In-Flight Thrust Model used to calculate thrust

Lift and Drag Analysis

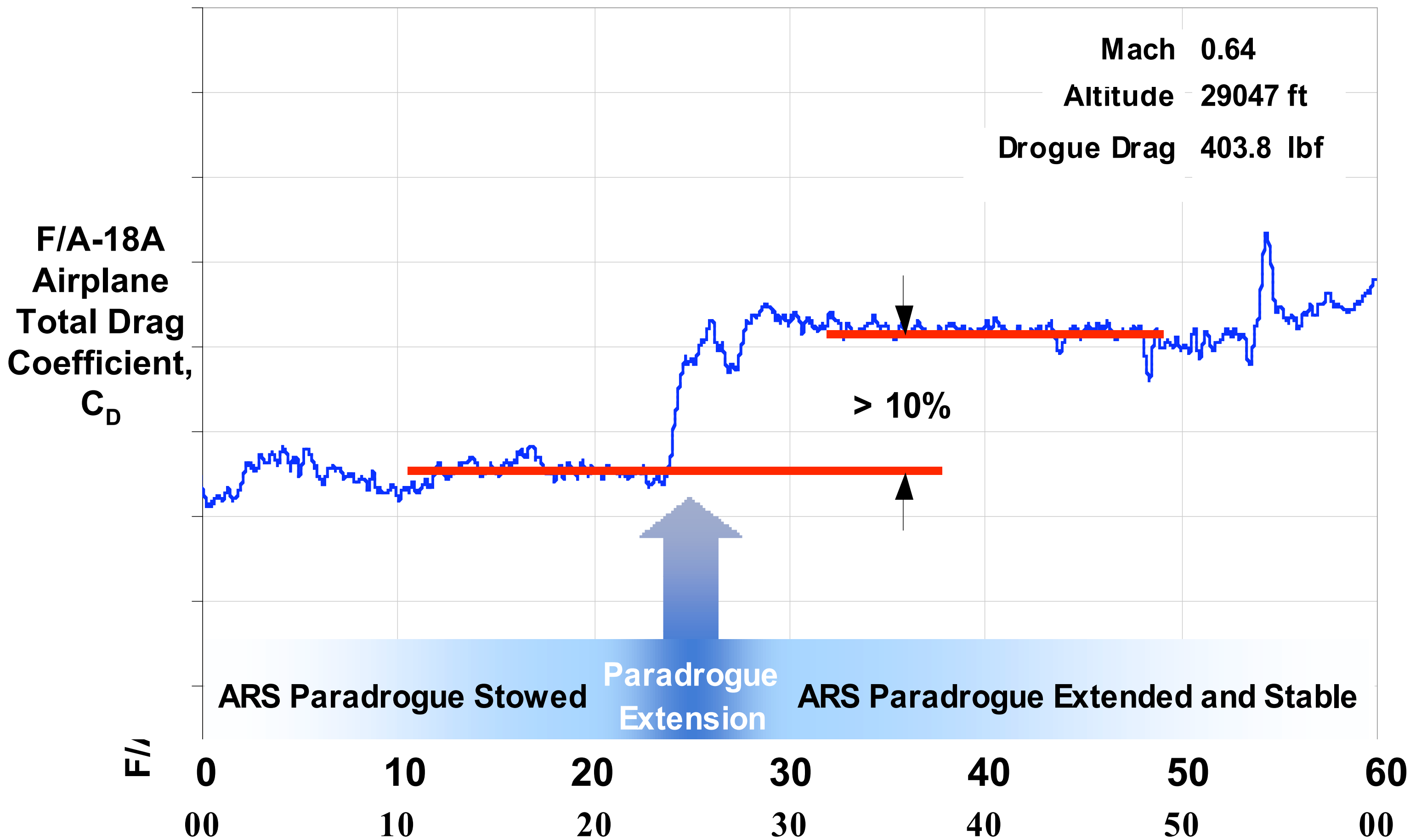


Flight Test Technique

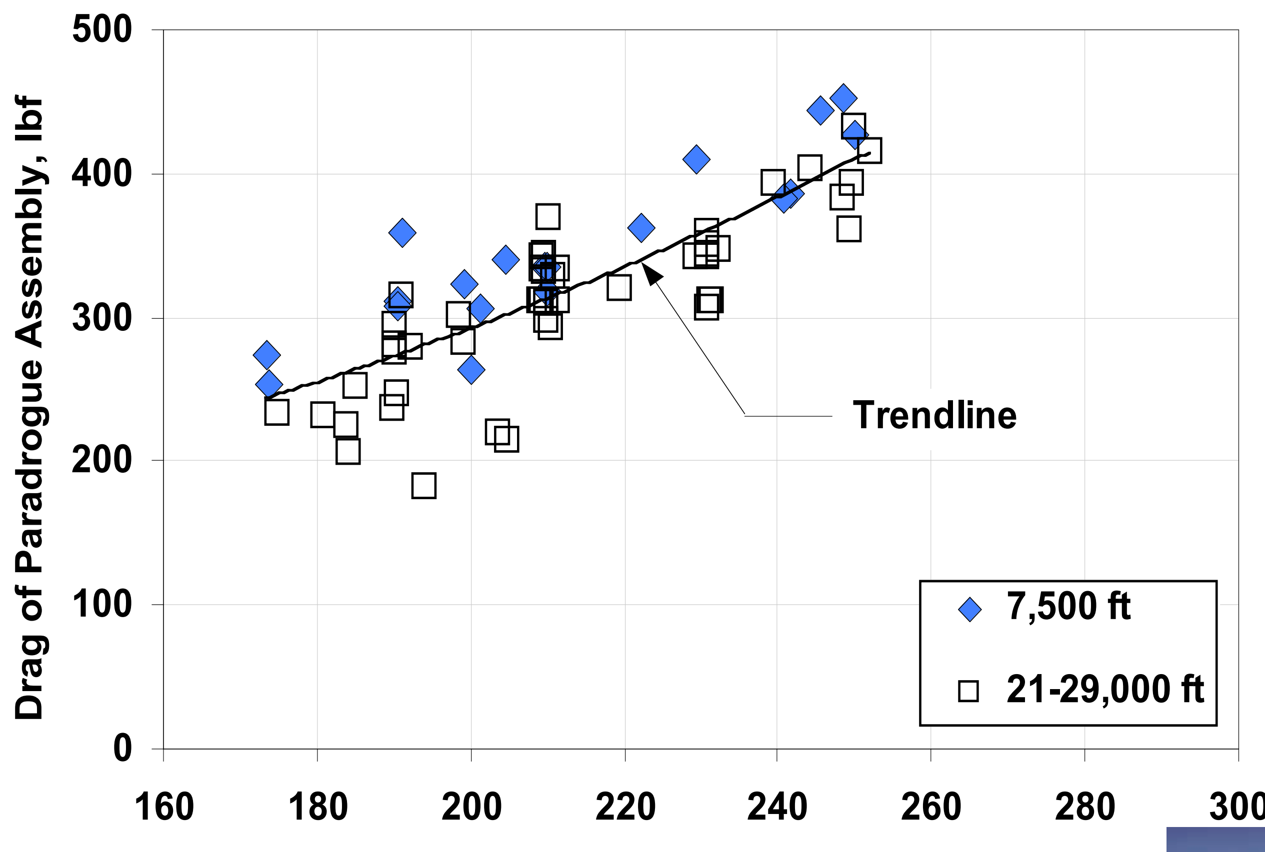
- **Test Point Description**
  - All-subsonic test points
  - Stabilized paradrogue deployments and retractions
- **Data Uncertainty**
  - Drag calculation ~ 3 to 5%
  - Trim angle of attack < 1%
    - Airplane weight
    - Drogue deployment
- **Data Quality**
  - Bias error is virtually eliminated by acquiring test data at back-to-back points during each flight, eliminating the effects of
    - Weight changes
    - Atmospheric effects
    - Calculation bias errors
  - Auto-throttle control
  - Variations in extended hose length < 2 feet
    - Extensions and retractions
    - Receiver engagements
  - Control room displays for evaluating data and maneuver quality

Sample Drag Change

Sample Real-Time Data

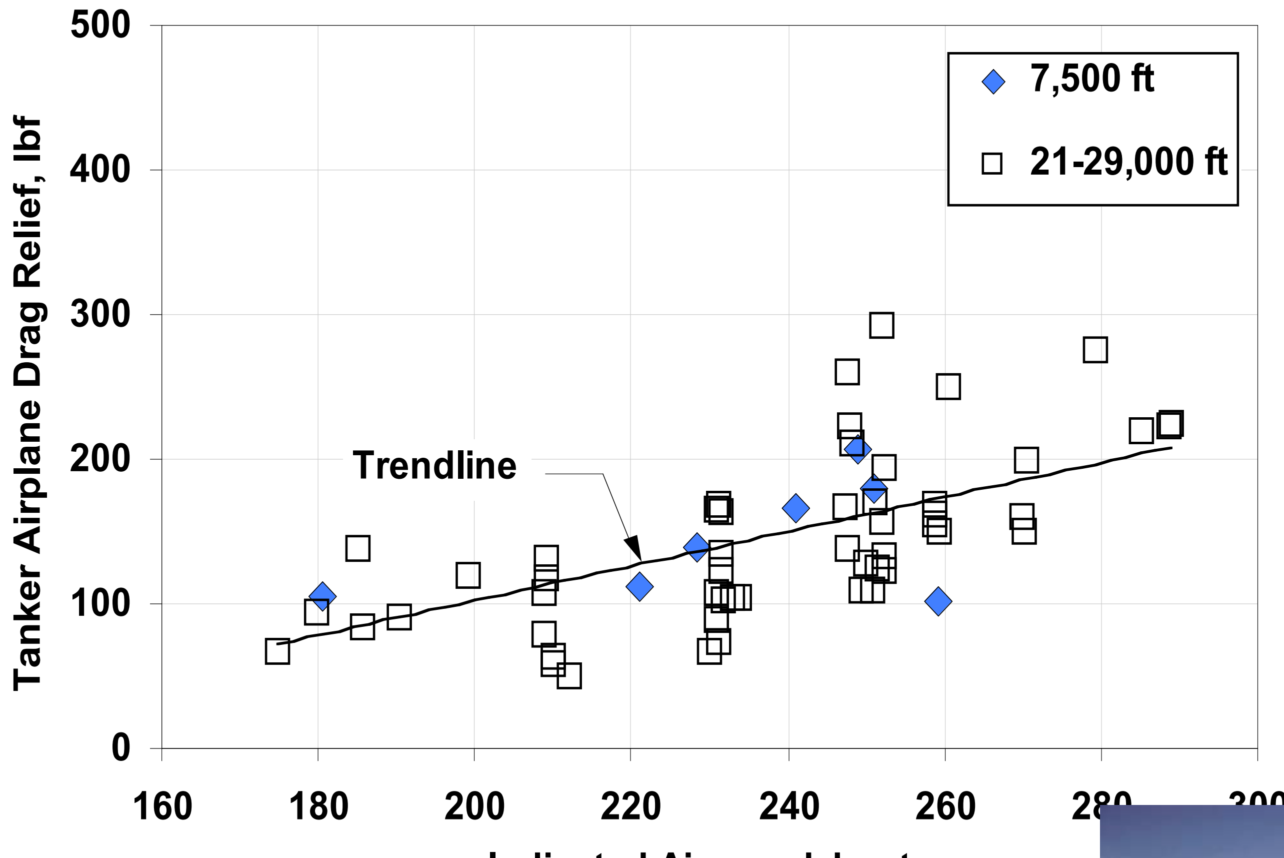


Paradrogue Drag Summary



- Parabolic trend evident
- Results appear to be independent of altitude

Receiver Engagements



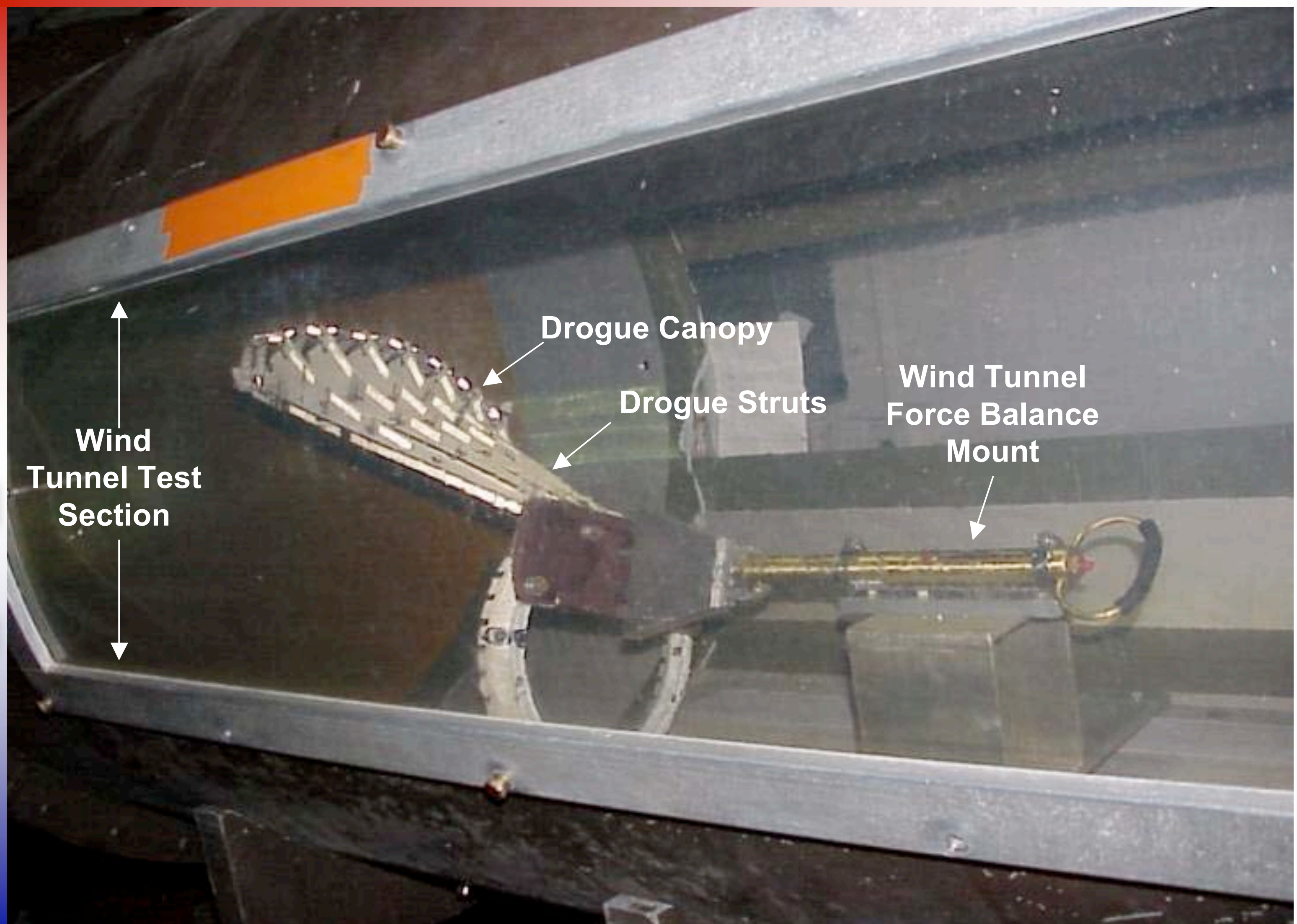
- Magnitude of drag relief is significant
- Data Scatter

Wind Tunnel Tests

- **Purpose**
  - Baseline aerodynamic performance of the Navy '-18' canopy for comparison purposes
  - Test various canopy designs for next-generation ARS canopy
    - Material type
    - Size, shape, cross-sectional area
  - Test various paradrogue mechanical designs
    - Struts
    - Linkages
    - Thread types
      - Used for attaching canopy to struts and maintaining shape while inflated

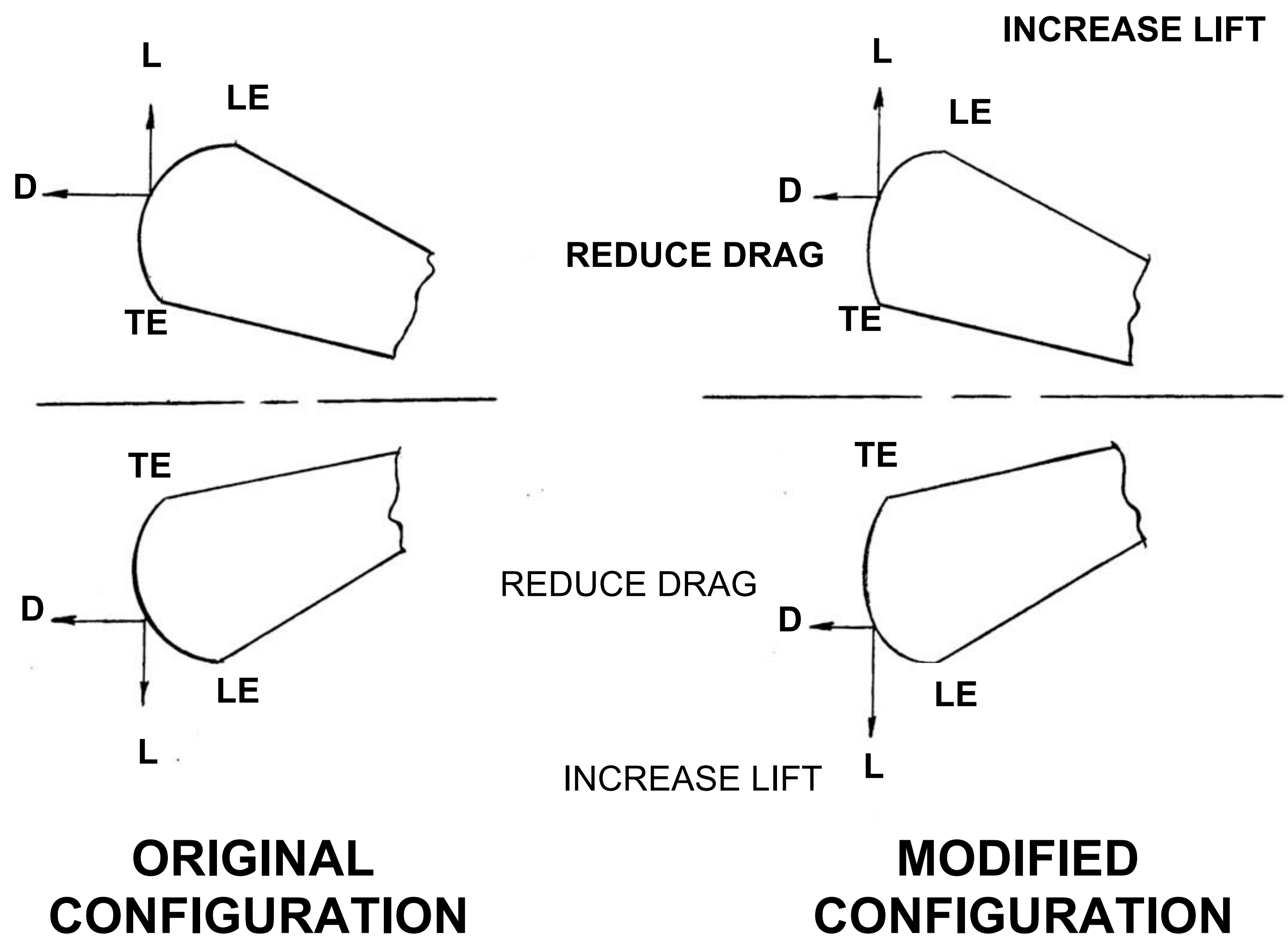
- **Tunnel Characteristics**
  - 3 Foot diameter test section
  - Maximum Airspeed = 200 kts
  - Blockage = Approximately 10%

Wind Tunnel Setup

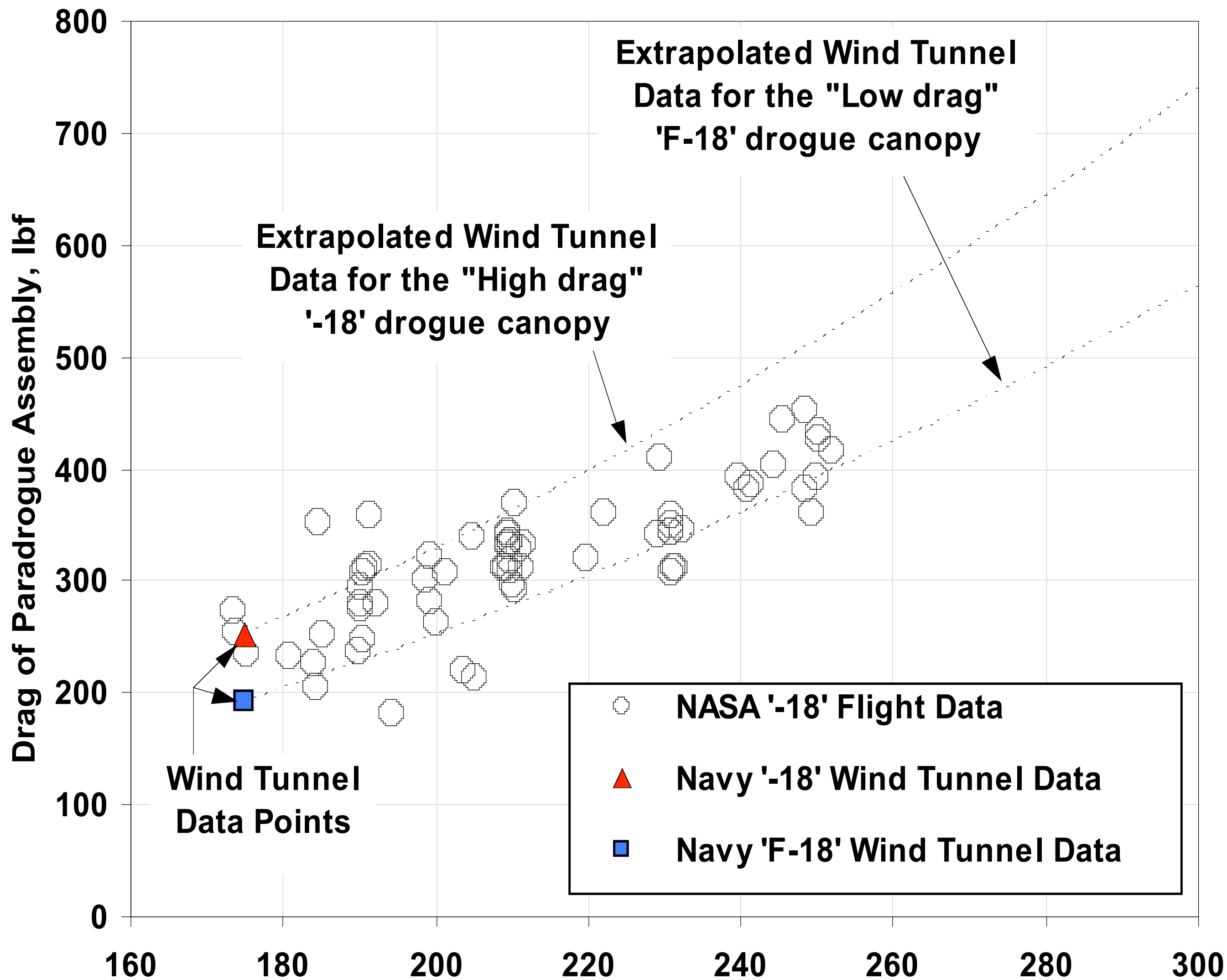


Canopy Aerodynamics

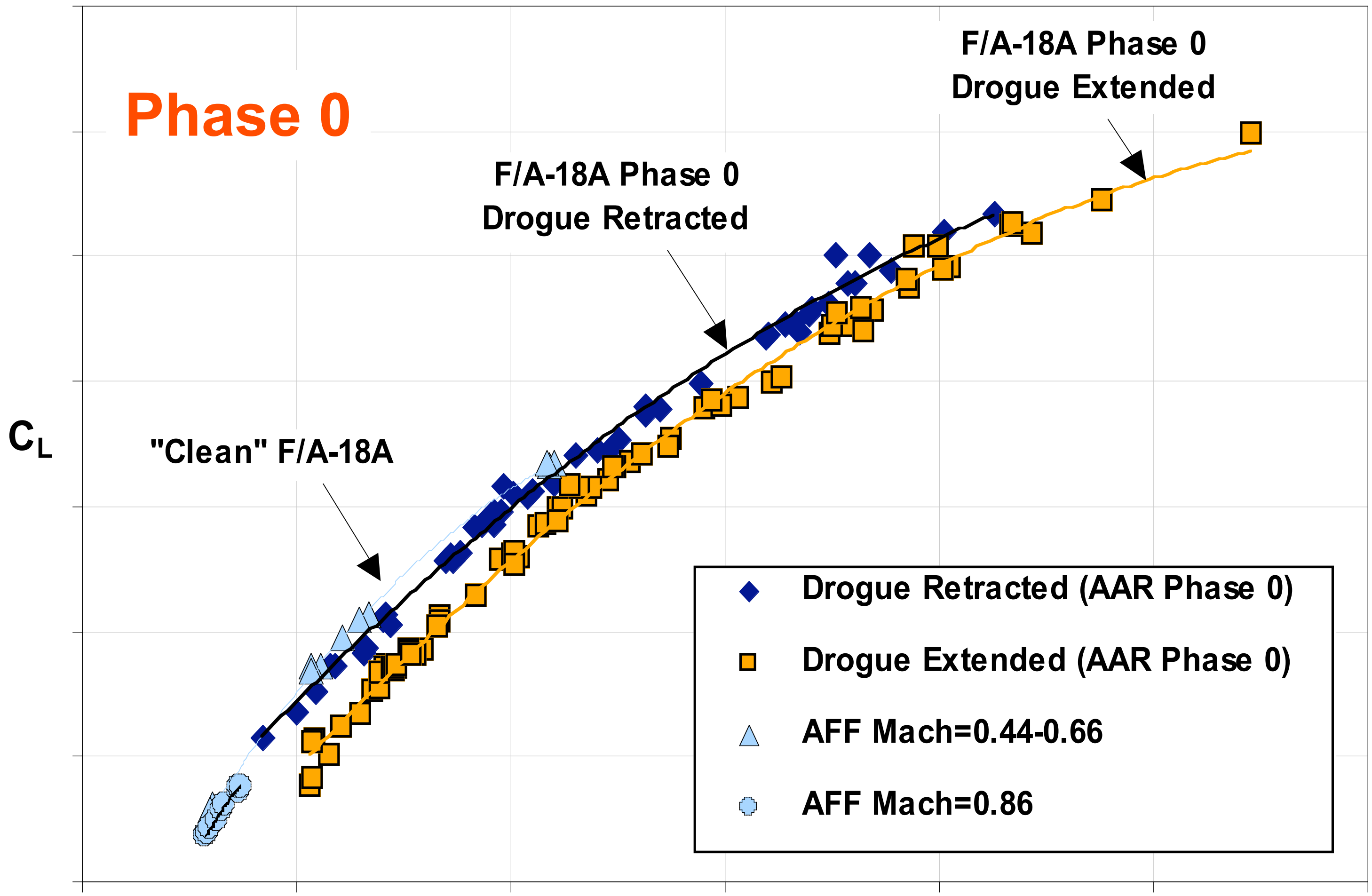
•The canopy is an inflatable airfoil which generates lift and drag



Flight vs. Wind Tunnel

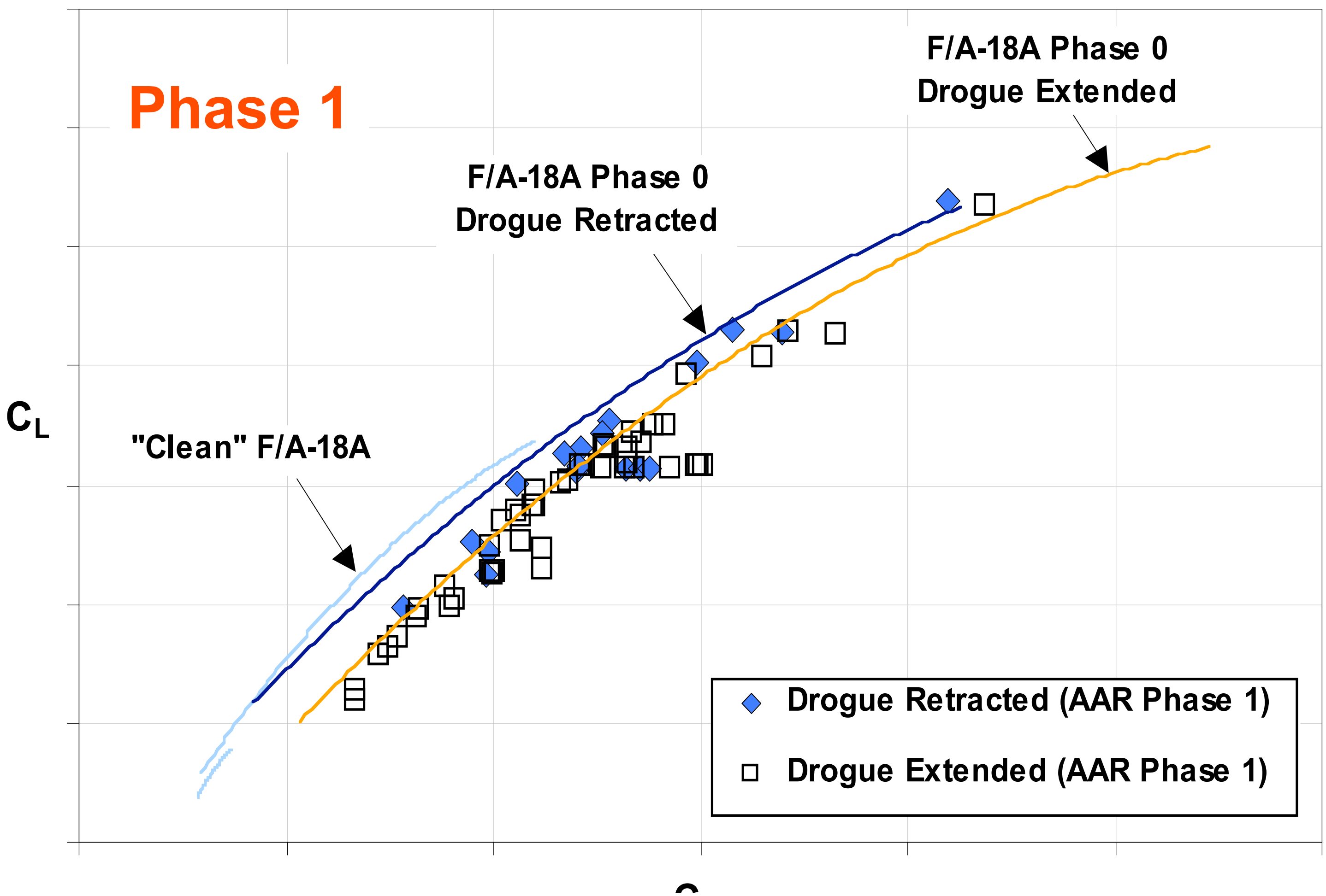


Drag Polars



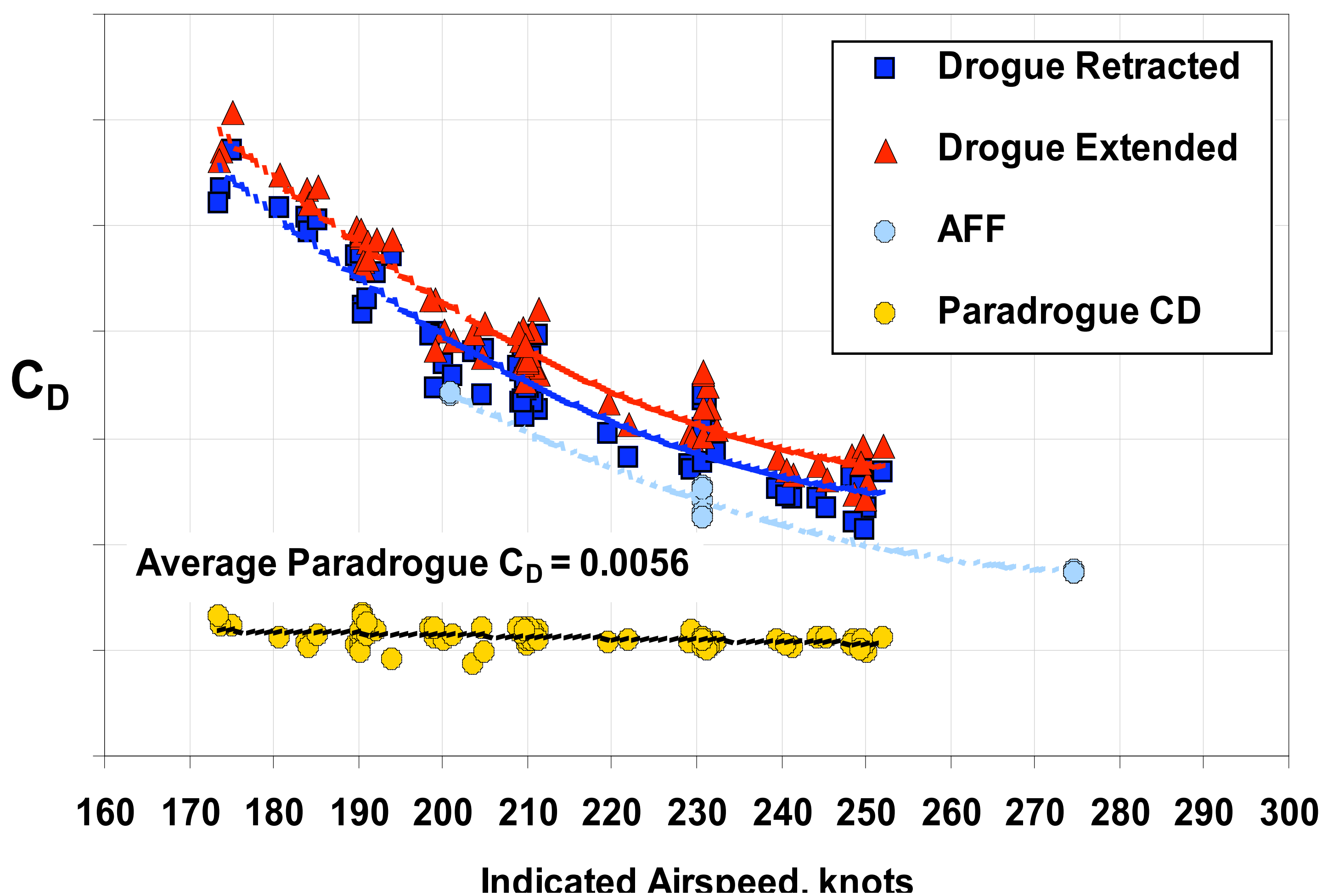
Phase 0
C_L
"Clean" F/A-18A
F/A-18A Phase 0
Drogue Retracted
F/A-18A Phase 0
Drogue Extended
Drogue Retracted (AAR Phase 0)
Drogue Extended (AAR Phase 0)
AFF Mach=0.44-0.66
AFF Mach=0.86

Drag Polars



Phase 1
C_L
"Clean" F/A-18A
F/A-18A Phase 0
Drogue Retracted
F/A-18A Phase 0
Drogue Extended
Drogue Retracted (AAR Phase 1)
Drogue Extended (AAR Phase 1)

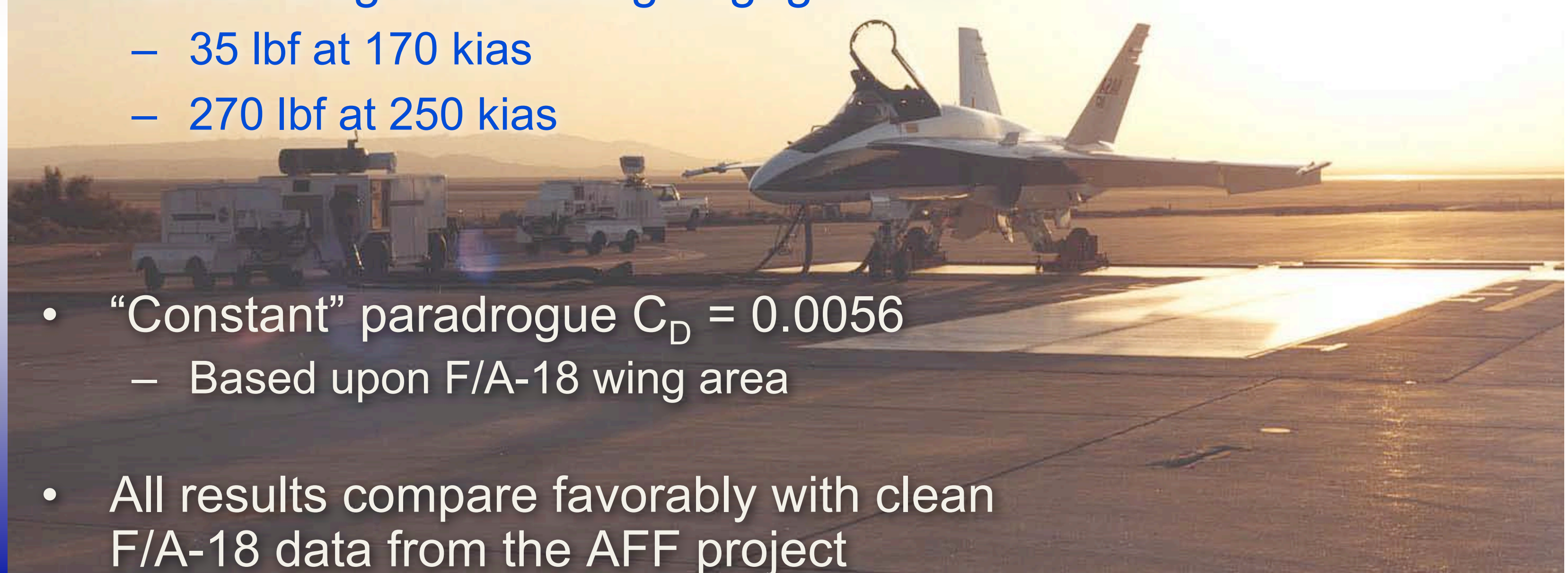
Constant Drag Coefficient?



Note: Average Paradrogue $C_DA = 2.24\ ft^2$

Conclusions

- First known measurement and publication of in-flight drag of an aerial refueling system
- Paradrogue drag
  - 200 lbf at 170 kias
  - 450 lbf at 250 kias
  - Good correlation with wind tunnel results
- Tanker drag relief during engagements
  - 35 lbf at 170 kias
  - 270 lbf at 250 kias



- "Constant" paradrogue $C_D = 0.0056$
  - Based upon F/A-18 wing area
- All results compare favorably with clean F/A-18 data from the AFF project