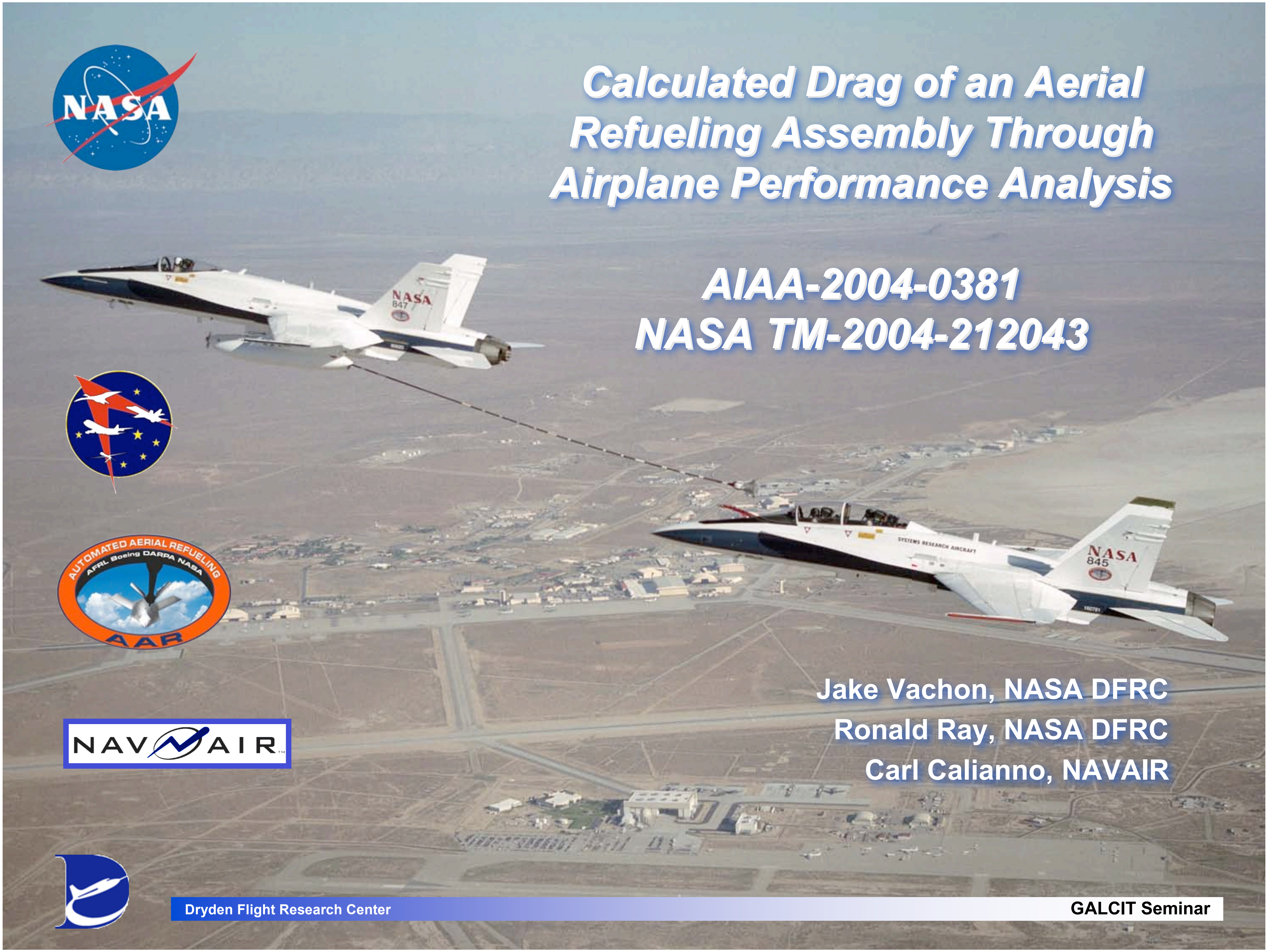


Calculated Drag of an Aerial Refueling Assembly Through Airplane Performance Analysis

AIAA-2004-0381
NASA TM-2004-212043

Jake Vachon, NASA DFRC
Ronald Ray, NASA DFRC
Carl Calianno, NAVAIR

Presentation Overview

•Overview
•Objectives
•Evolution
•Airplanes
•ARS
•Engine
•FTT
•Sample Data
•Drag Results
  •Paradrogue
  •Relief
  •Wind Tunnel
  •Drag Polars
  •Constant CD
•Conclusions

- 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

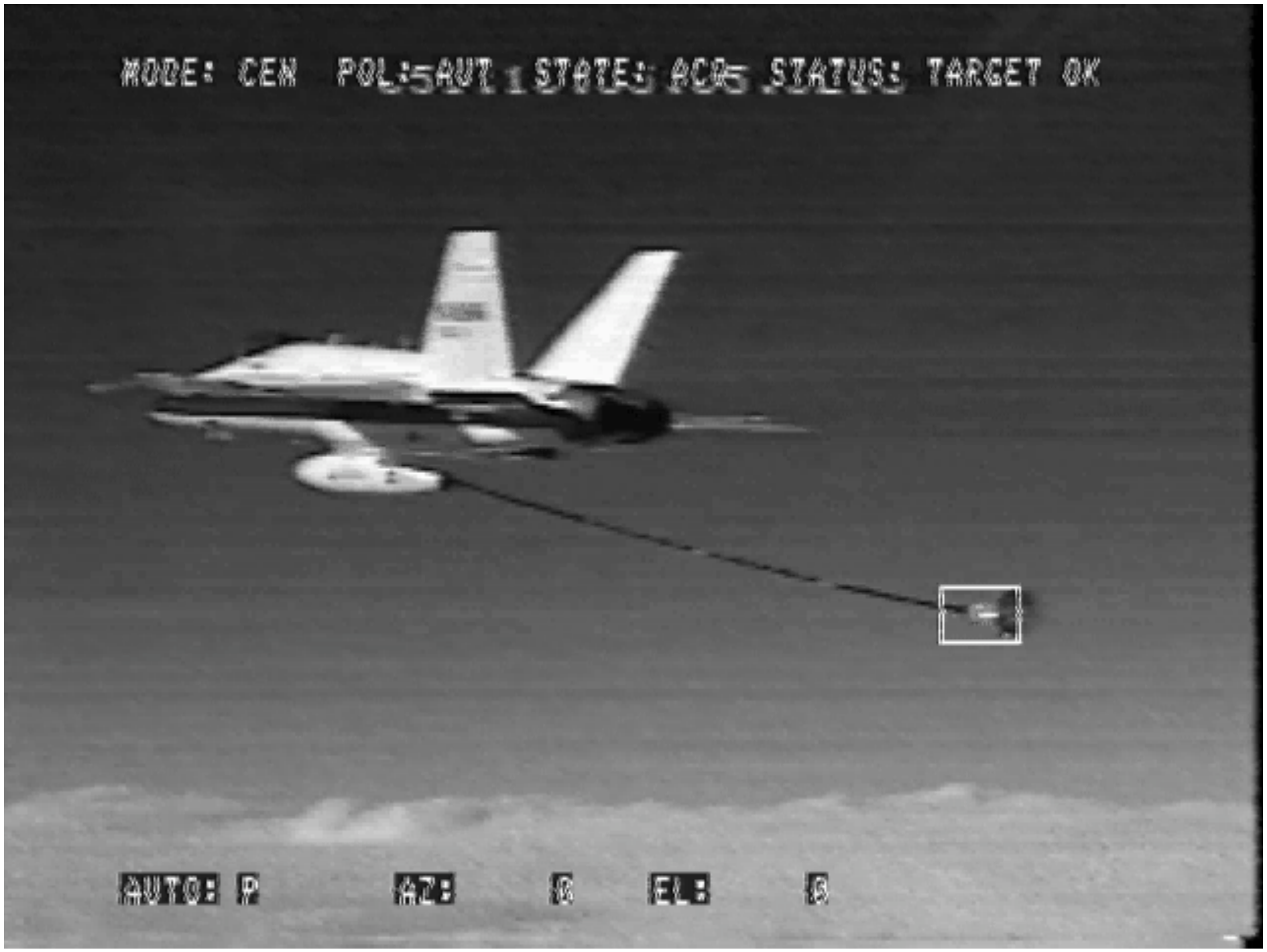
- **Automated Aerial Refueling (AAR)**

- **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

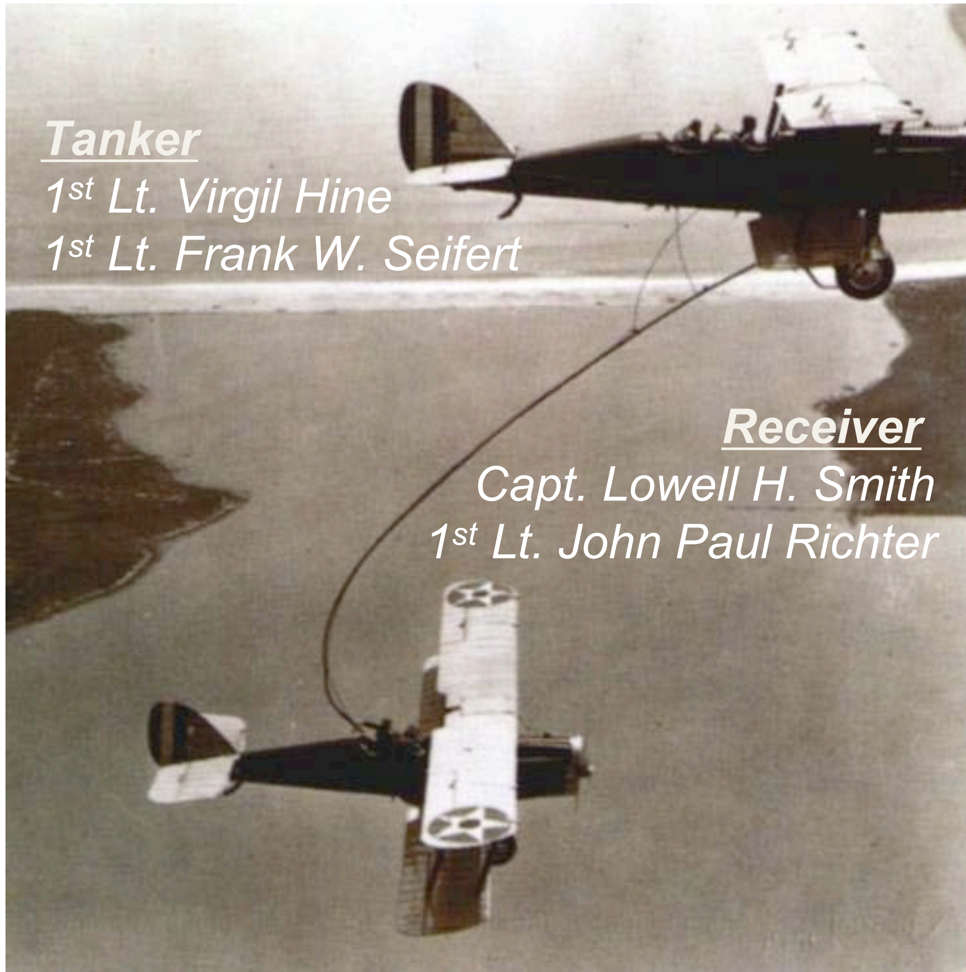
Evolution of Aerial Refueling

1921: Wingwalking Transfer Method

Wesley May

Evolution of Aerial Refueling

1923: Hanging Hose Transfer Method



Evolution of Aerial Refueling

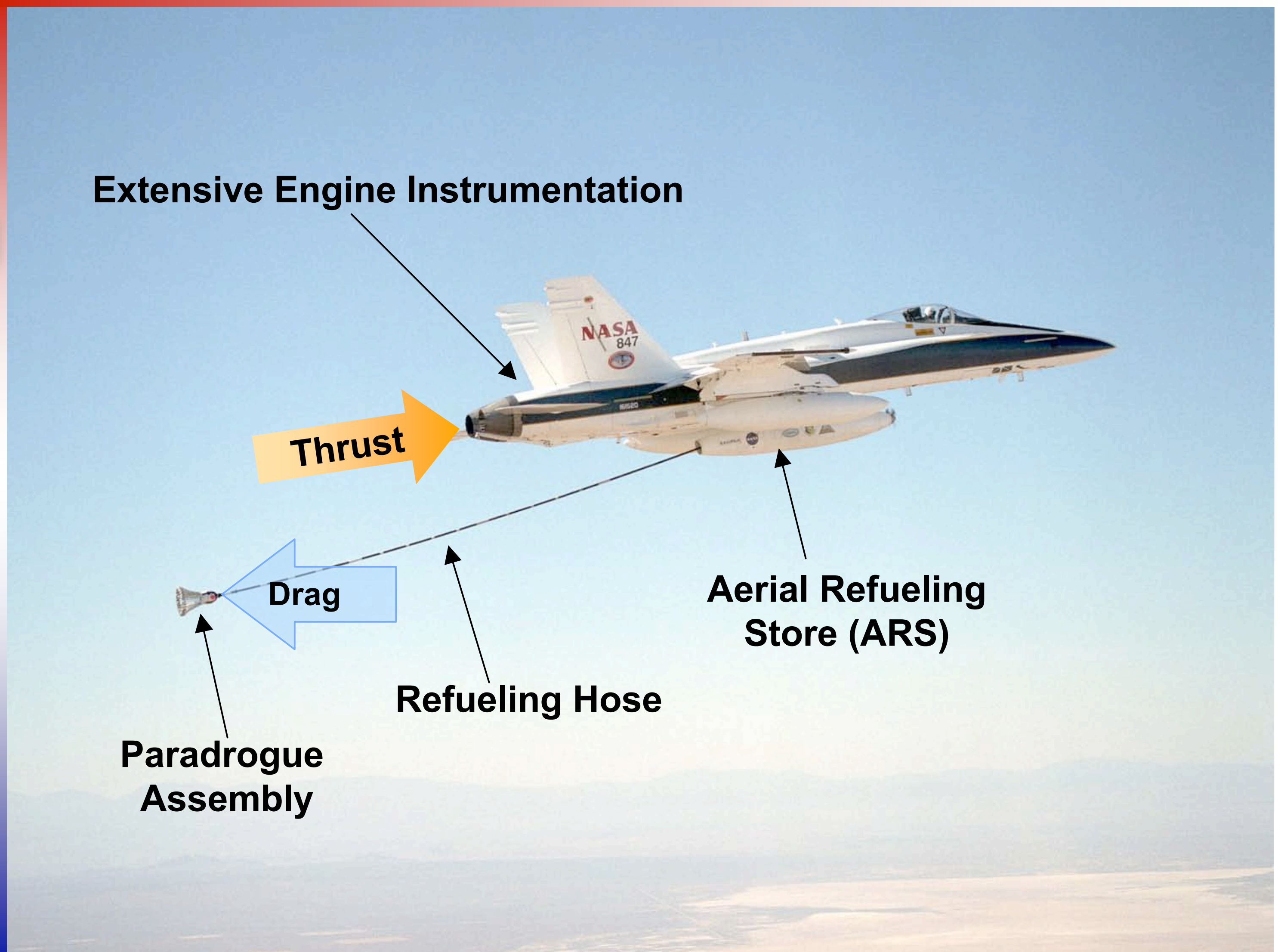
Evolution of Aerial Refueling

2003: Precision Engagements

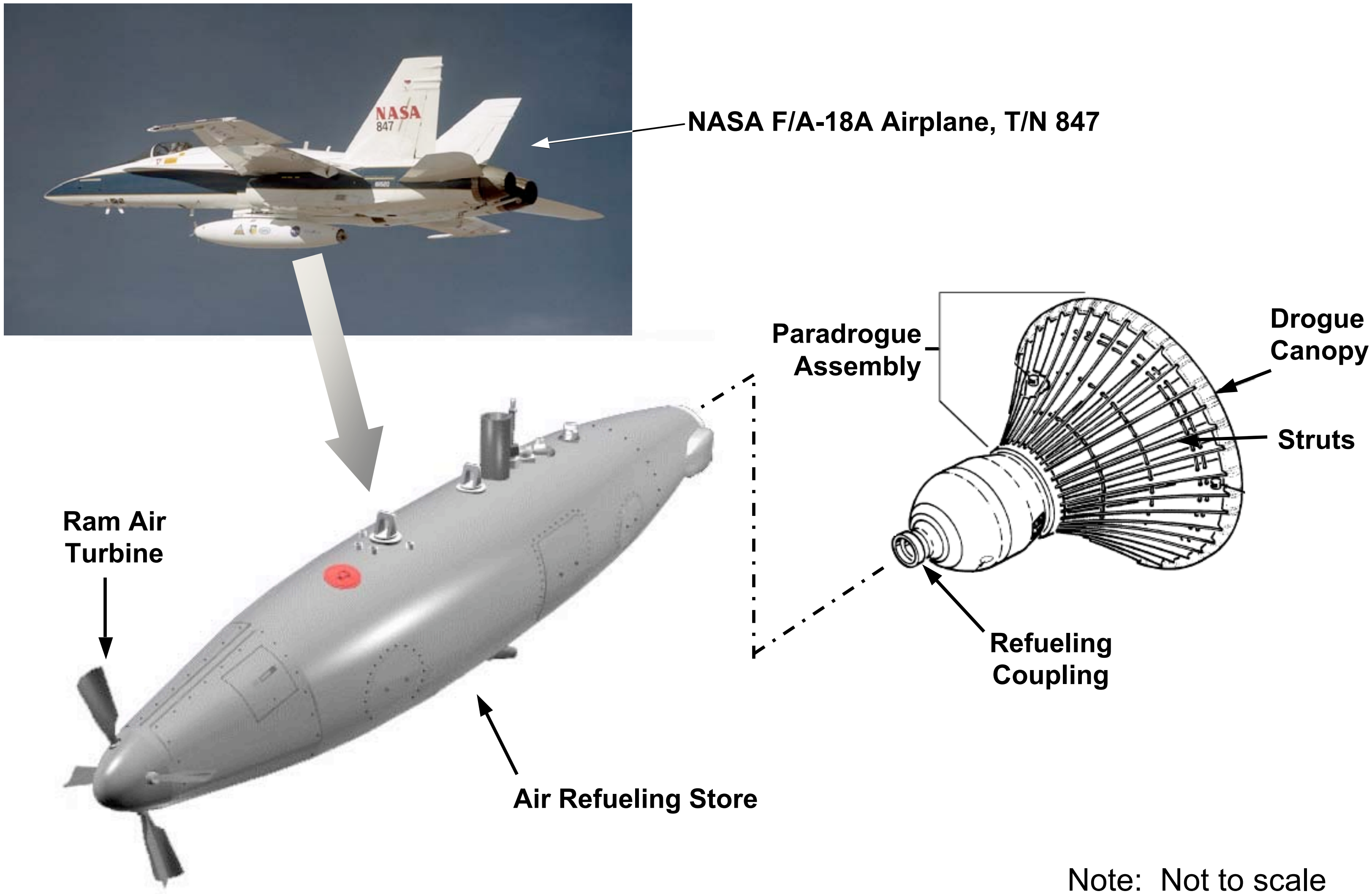
AAR Project Aircraft

- 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

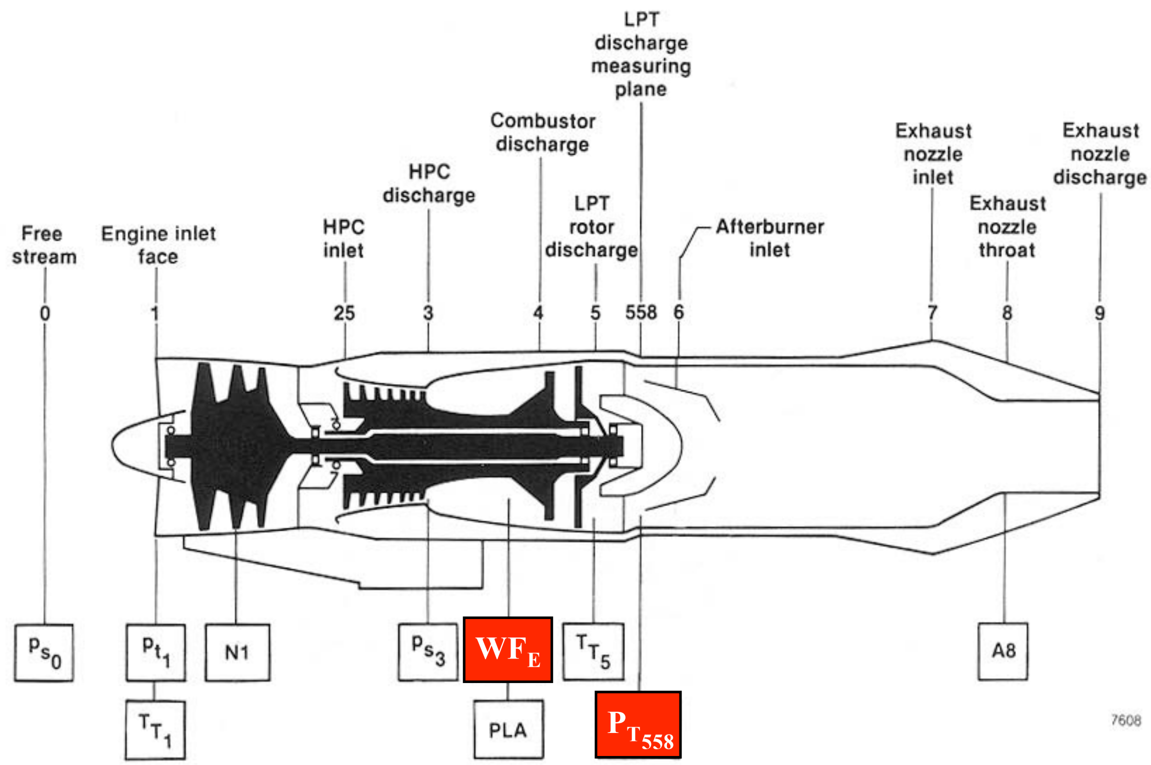


Aerial Refueling Store



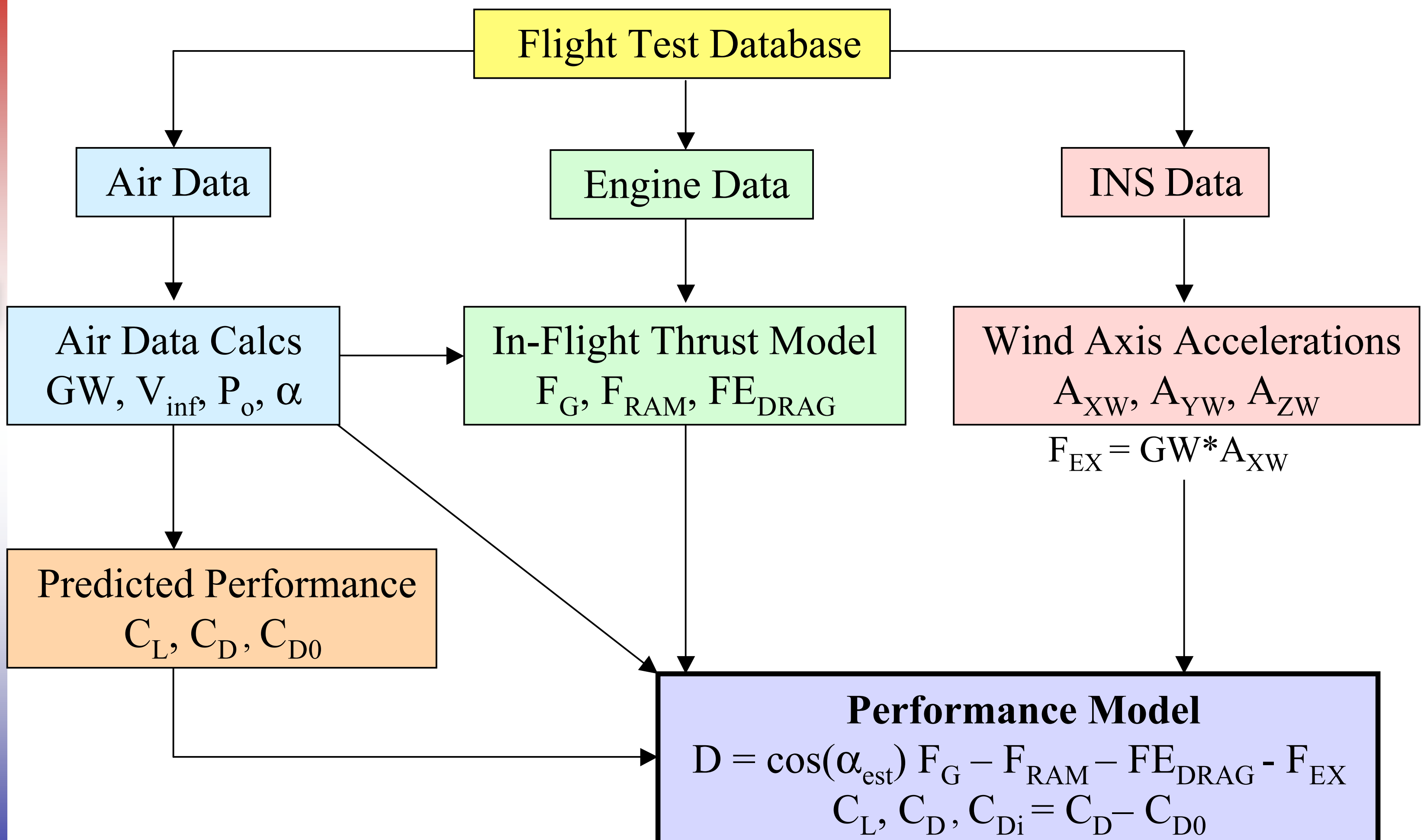
Note: Not to scale

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

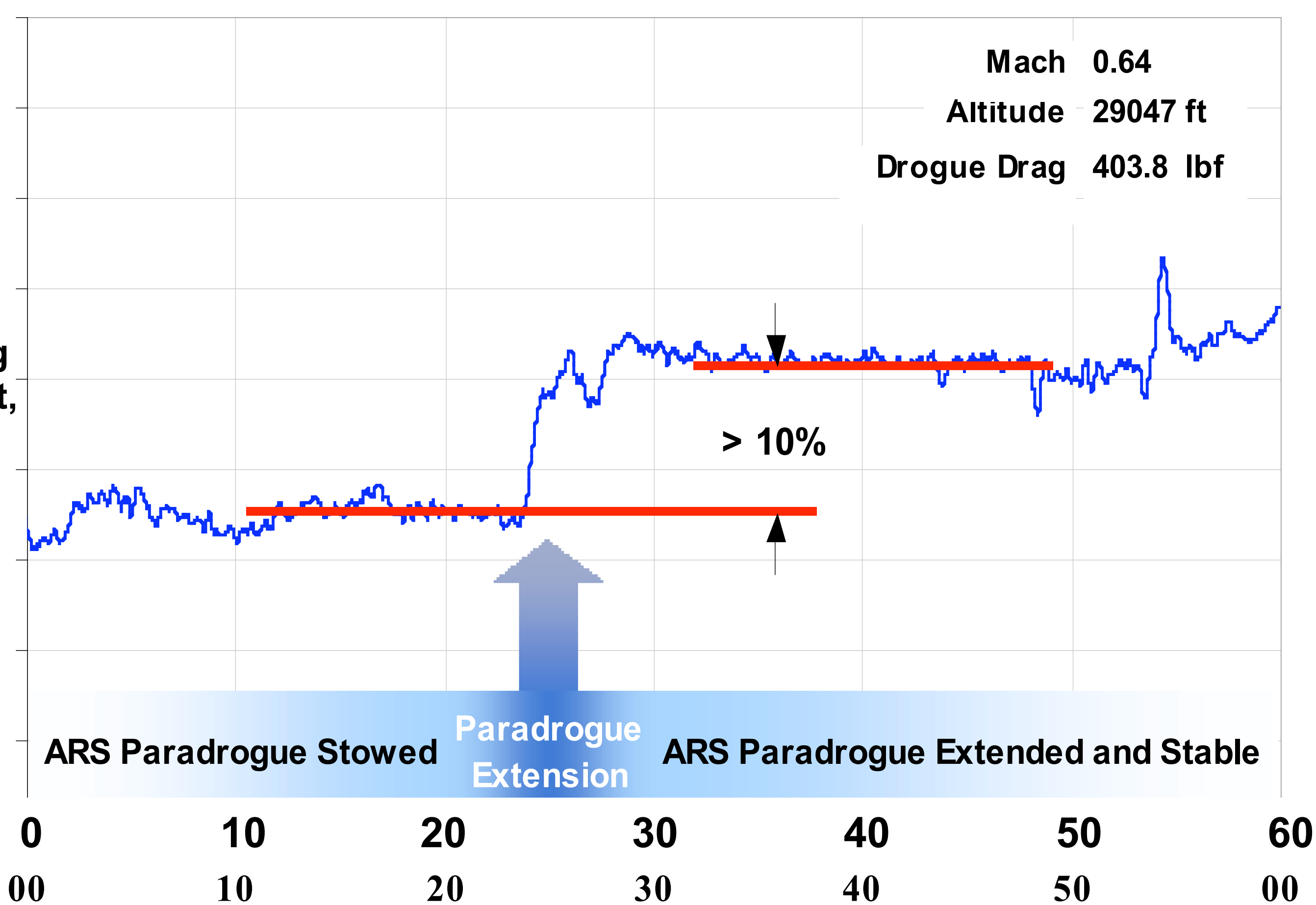


Flight Test Technique

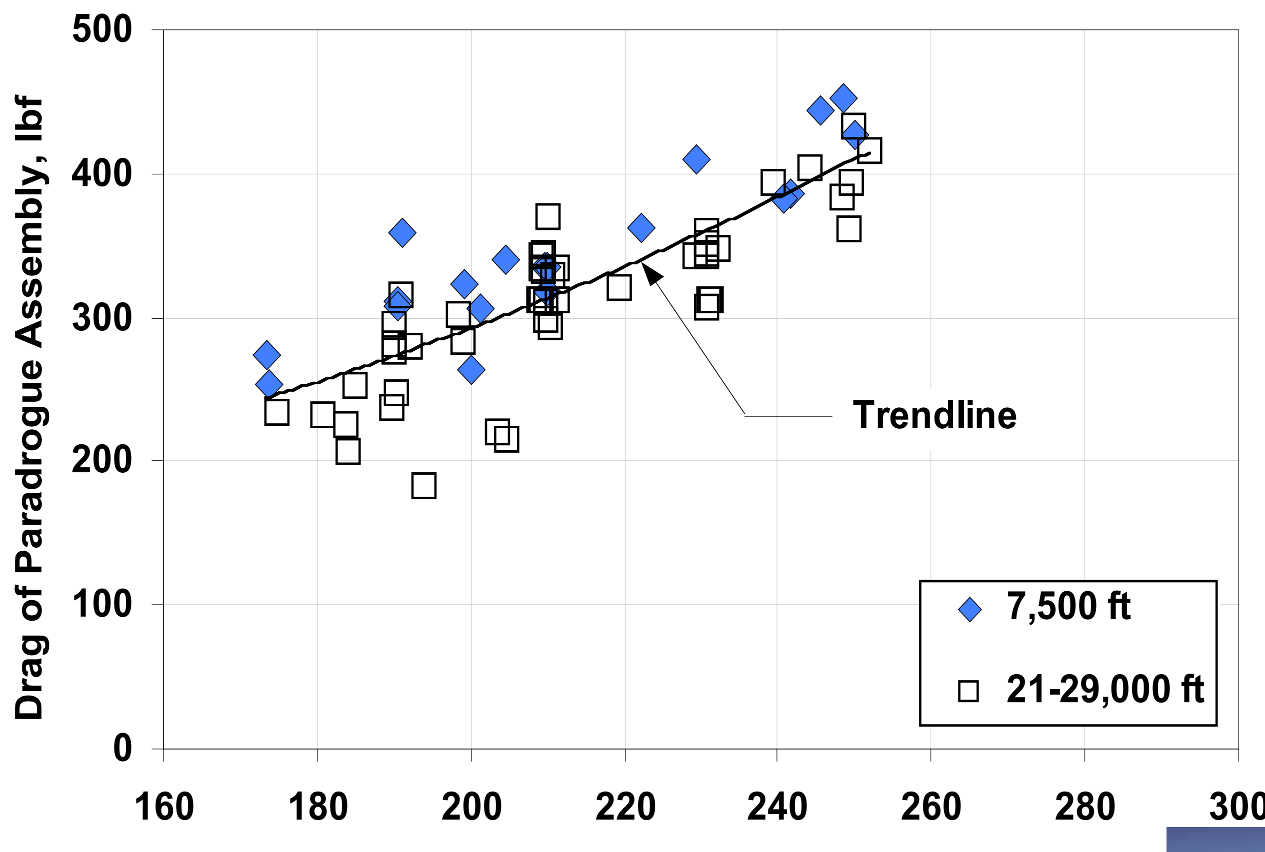
- **Test Point Description**
  - All-subsonic test points
  - Stabilized paradrogue deployments and retractions
- **Data Uncertainty**
  - Drag calculation ~ 3 to 5%
  - Trim angle of attack < 1%
    - Airplane weight
    - Drogue deployment
- **Data Quality**
  - Bias error is virtually eliminated by 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

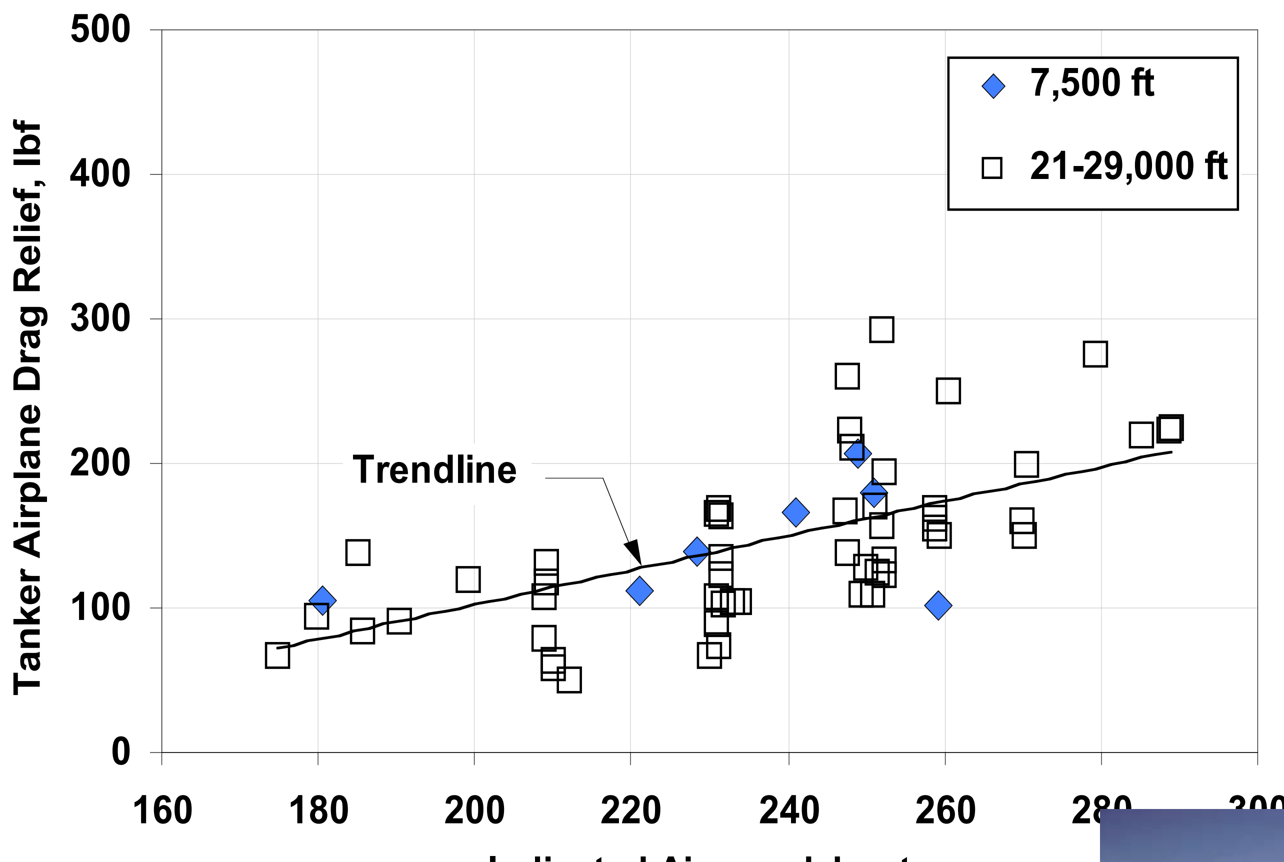


Paradrogue Drag Summary



- 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

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  - •Constant CD
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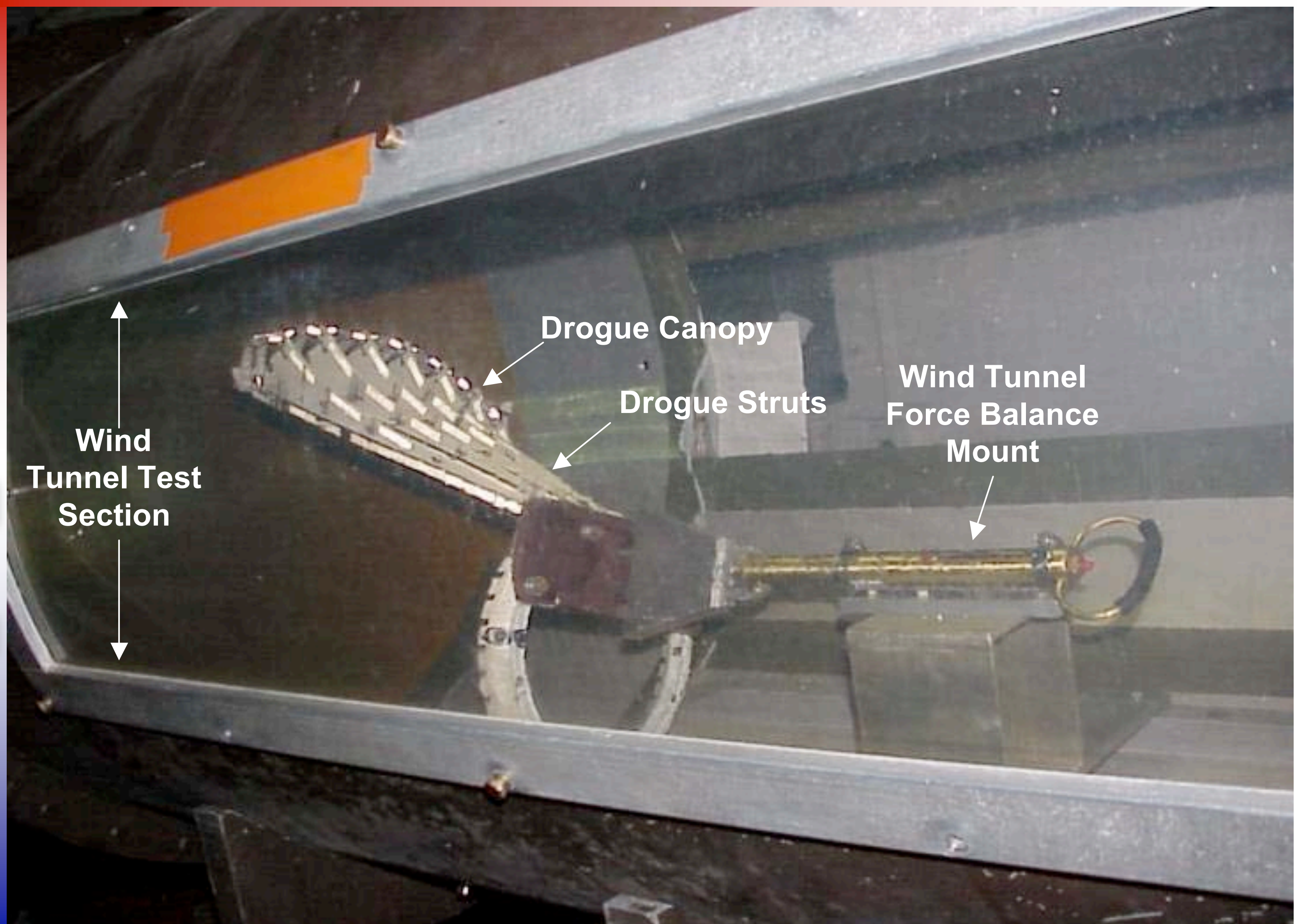
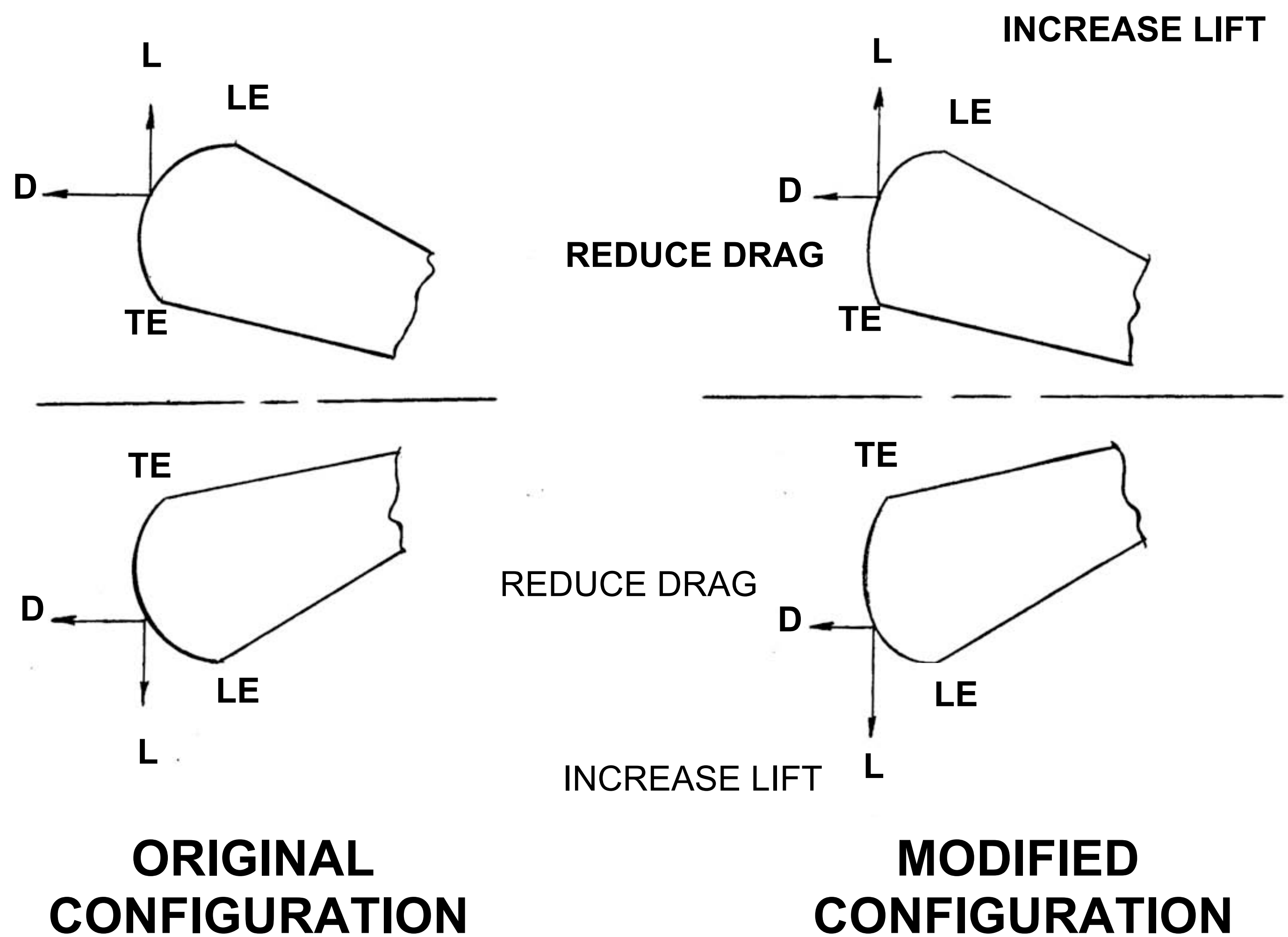
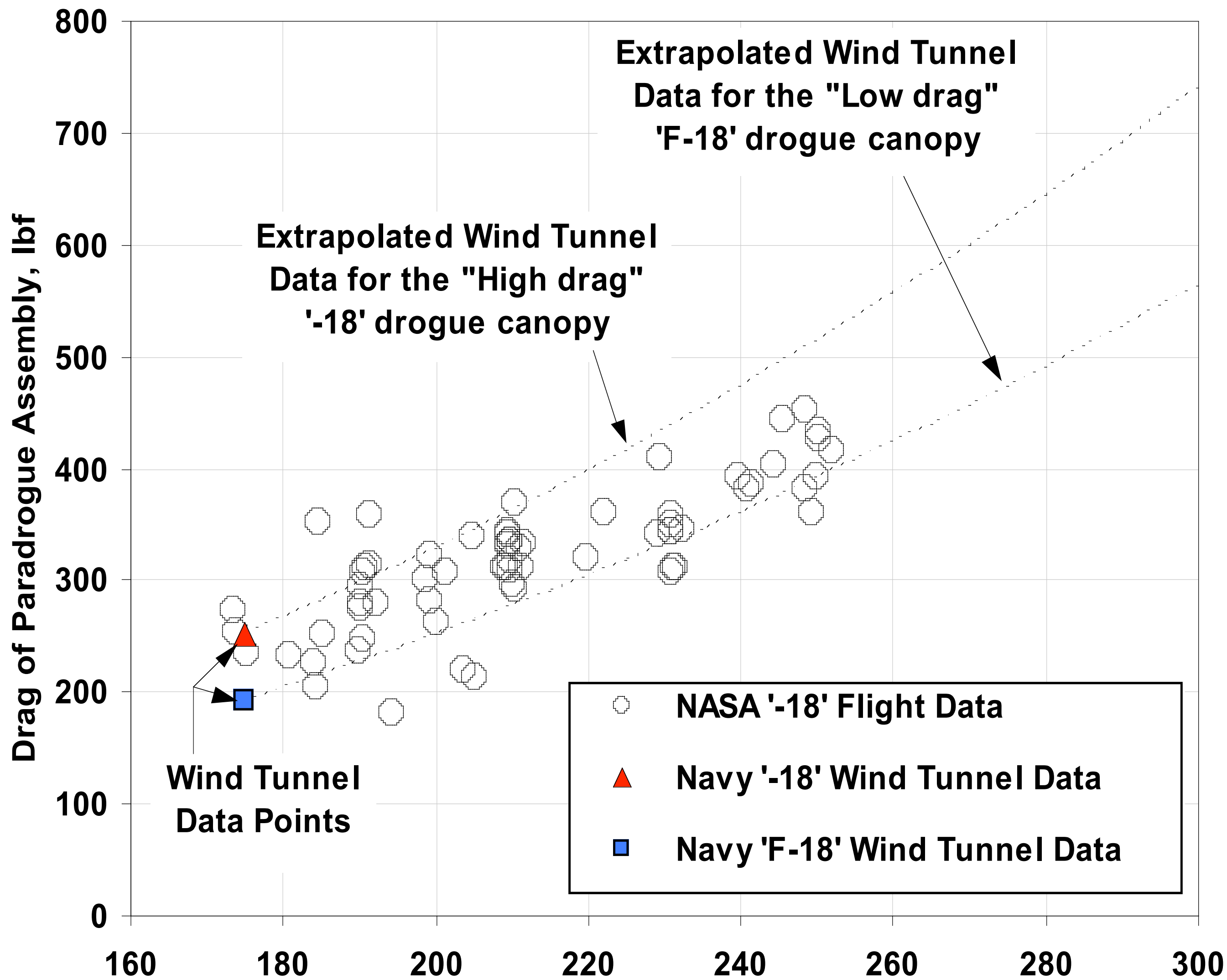


Canopy Aerodynamics

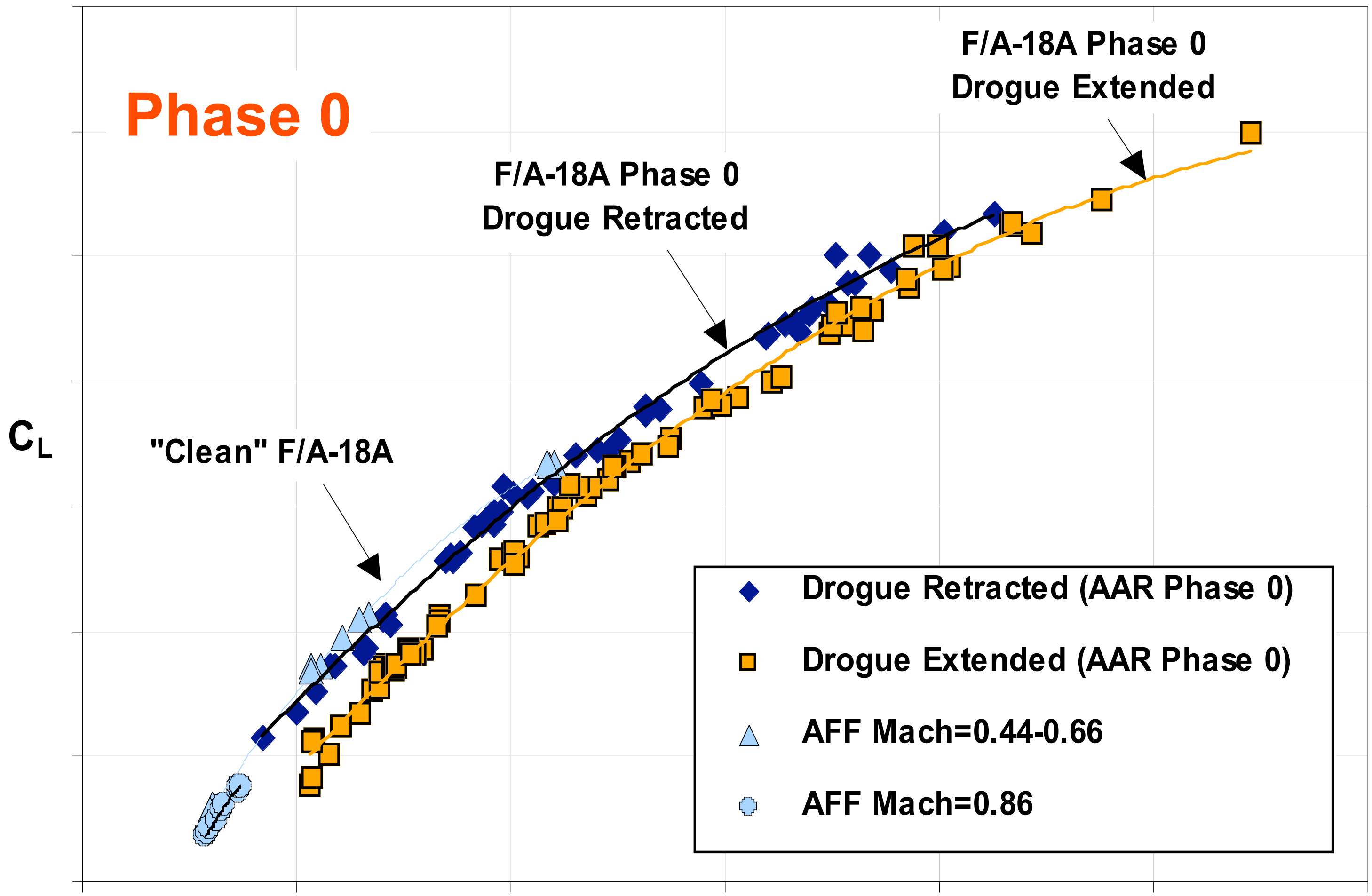
- The canopy is an inflatable airfoil which generates lift and drag



Flight vs. Wind Tunnel

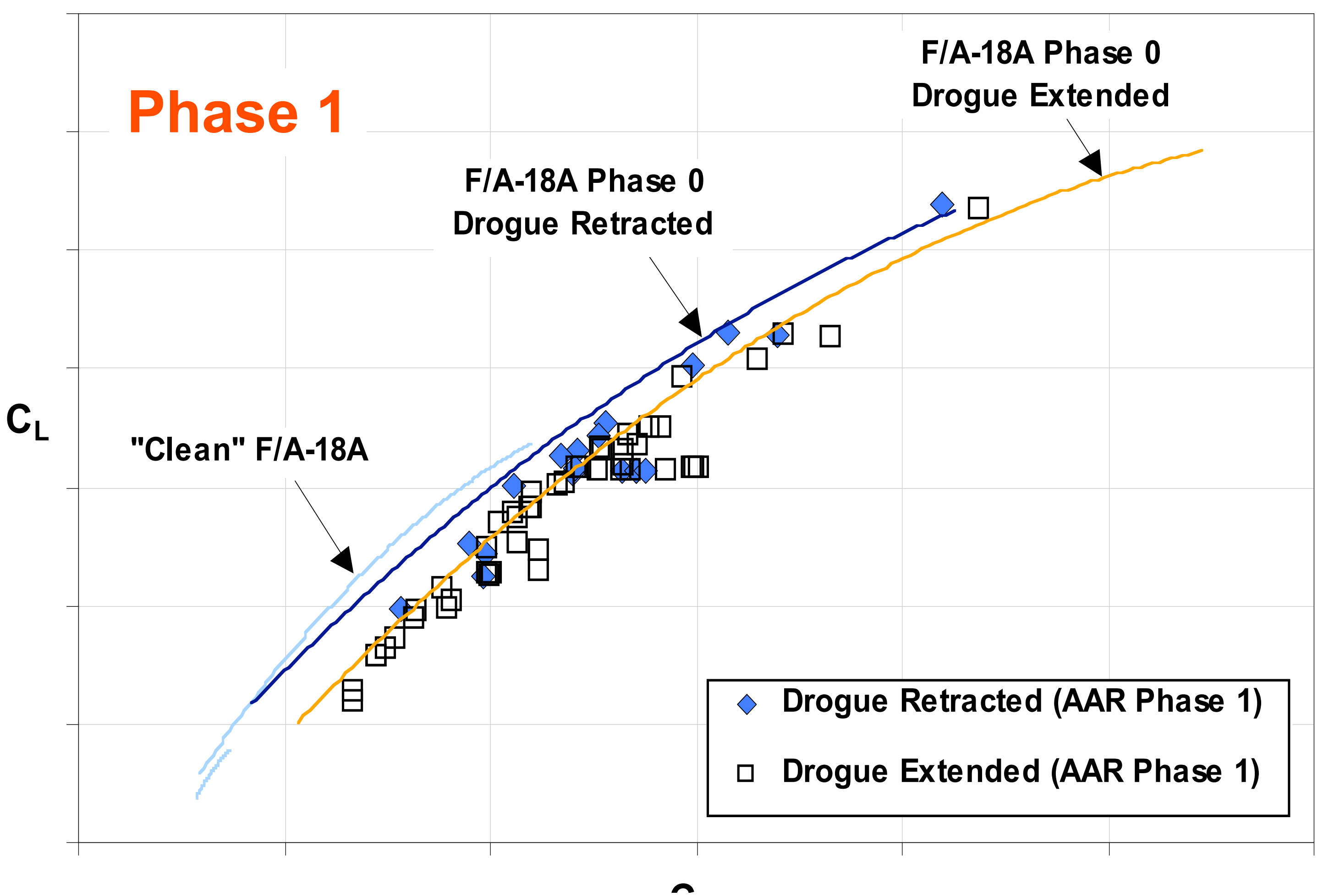


Drag Polars



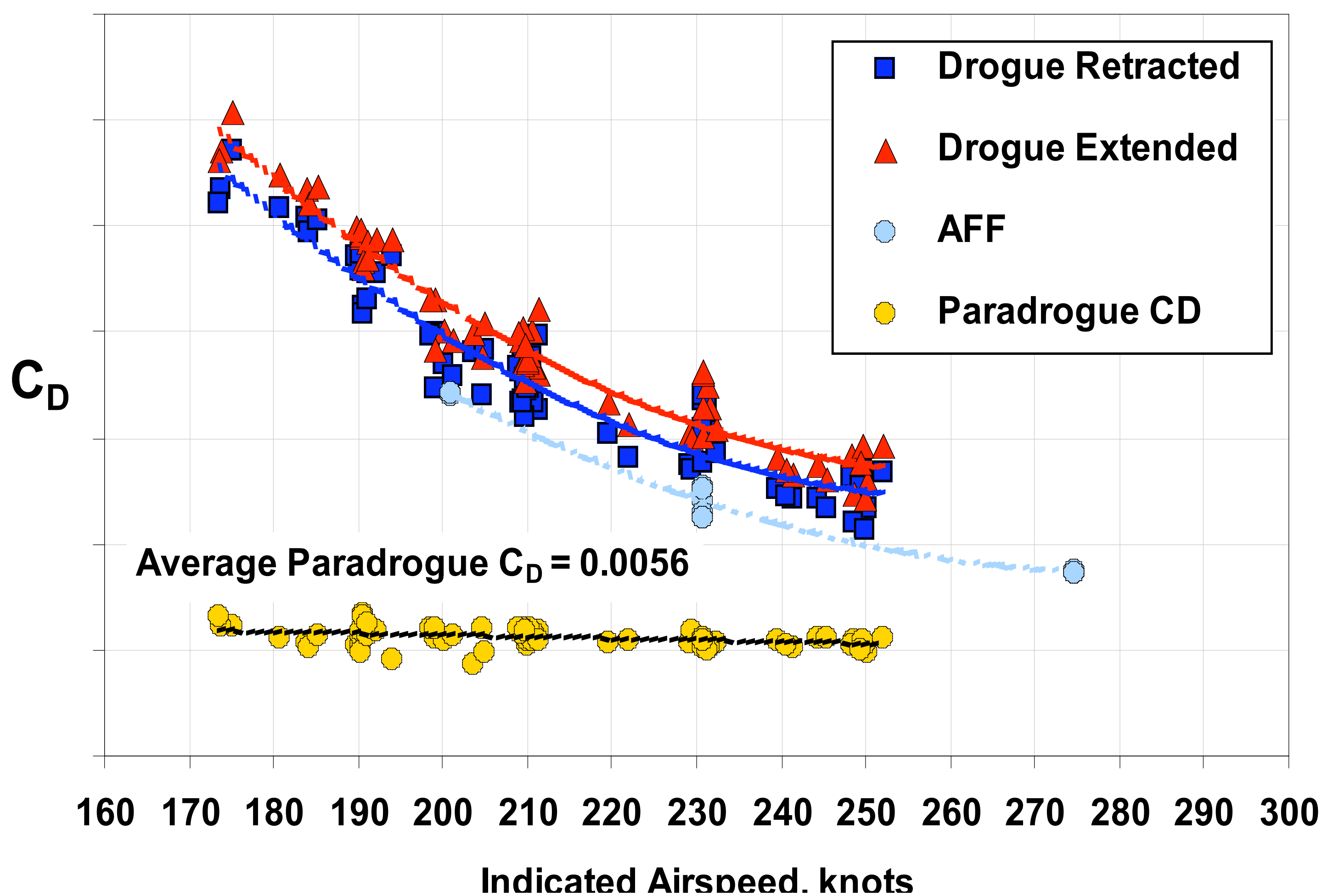
Phase 0
C_L
"Clean" F/A-18A
F/A-18A Phase 0 Drogue Retracted
F/A-18A Phase 0 Drogue Extended
Drogue Retracted (AAR Phase 0)
Drogue Extended (AAR Phase 0)
AFF Mach=0.44-0.66
AFF Mach=0.86

Drag Polars



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