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

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

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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

Overview

Objectives

Evolution

Airplanes

ARS

Engine

FTT

Sample Data

Drag Results

Paradogue

Relief

Wind Tunnel

Drag Polars

Constant CD

Conclusions
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
1923: Hanging Hose Transfer Method

Tanker
1st Lt. Virgil Hine
1st Lt. Frank W. Seifert

Receiver
Capt. Lowell H. Smith
1st Lt. John Paul Richter
Evolution of Aerial Refueling

2003

Surrogate UAV

Surrogate Tanker
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

Extensive Engine Instrumentation

Thrust

Aerial Refueling Store (ARS)

Drag

Refueling Hose

Paradroge Assembly

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Engine Thrust Instrumentation

- F404 Engines – Instrumented for Thrust Determination
  - Flight-test, volumetric fuel-flow meter installed ($WF_E$)
  - Turbine exit plane pressure rakes ($P_{T558}$)
- Manufacturer’s In-Flight Thrust Model used to calculate thrust
Lift and Drag Analysis

- **Overview**
- **Objectives**
- **Evolution**
- **Airplanes**
- **ARS**
- **Engine**
  - **FTT**
  - **Sample Data**
  - **Drag Results**
    - Paradrohge
    - Relief
    - Wind Tunnel
    - Drag Polars
    - Constant CD
- **Conclusions**

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**Flight Test Database**

**Air Data**

- **Air Data Calcs**
  - $GW$, $V_{inf}$, $P_o$, $\alpha$

**Engine Data**

- **In-Flight Thrust Model**
  - $F_G$, $F_{RAM}$, $F_{DRAG}$

**INS Data**

- **Wind Axis Accelerations**
  - $A_XW$, $A_YW$, $A_ZW$

$F_{EX} = GW*A_XW$

**Performance Model**

$$D = \cos(\alpha_{est}) F_G - F_{RAM} - F_{DRAG} - F_{EX}$$

$$C_L, C_D, C_{Di} = C_D - C_{D0}$$

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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

Drag Results
- Paradrogue
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Conclusions
Sample Real-Time Data

F/A-18A Airplane Total Drag Coefficient, $C_D$

- Mach 0.64
- Altitude 29047 ft
- Drogue Drag 403.8 lbf

- > 10%

ARS Paradrogue Stowed
- Paradrogue Extension
- ARS Paradrogue Extended and Stable

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Paradrogupe 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

- Wind Tunnel Test Section
- Drogue Canopy
- Drogue Struts
- Wind Tunnel Force Balance Mount
Canopy Aerodynamics

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

- ORIGINAL CONFIGURATION
  - INCREASE LIFT
  - REDUCE DRAG

- MODIFIED CONFIGURATION
  - INCREASE LIFT
  - REDUCE DRAG

The canopy is an inflatable airfoil which generates lift and drag.
**Flight vs. Wind Tunnel**

- Extrapolated Wind Tunnel Data for the "Low drag" 'F-18' drogue canopy
- Extrapolated Wind Tunnel Data for the "High drag" '-18' drogue canopy

**Drag Results**

- Paradrogue
- Relief
- Wind Tunnel
- Drag Polars
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- Conclusions

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Drag Polars

Phase 0

- Drogue Retracted (AAR Phase 0)
- Drogue Extended (AAR Phase 0)
- AFF Mach=0.44-0.66
- AFF Mach=0.86
Drag Polars

Phase 1

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

Drogue Retracted (AAR Phase 1)

Drogue Extended (AAR Phase 1)
Constant Drag Coefficient?

Average Paradrogue $C_D = 0.0056$

Note: Average Paradrogue $C_D A = 2.24 \text{ ft}^2$
Conclusions

- First known measurement and publication of in-flight drag of an aerial refueling system
- Paradroguve 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” paradroguve $C_D = 0.0056$
  - Based upon F/A-18 wing area
- All results compare favorably with clean F/A-18 data from the AFF project