Calculated Drag of an Aerial Refueling Assembly Through Airplane Performance Analysis

AIAA-2004-0381

NASA TM-2004-212043

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Presentation Overview

• National Objectives
• Dryden Project Objectives
• Airplane Description
  – Tanker airplane, in-depth
• Flight Test Technique
• Sample Results
• Paradrope 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

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

Aerial Refueling Store (ARS)

Refueling Hose

Paradrogue Assembly

Thrust

Drag
Aerial Refueling Store

NASA F/A-18A Airplane, T/N 847

Paradrogue Assembly

Drogue Canopy

Struts

Refueling Coupling

Air Refueling Store

Ram Air Turbine

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 ($P_{T558}$)
- Manufacturer’s in-flight thrust model used to calculate thrust
Lift and Drag Analysis

Flight Test Database

Air Data

Engine Data

INS Data

Air Data Calcs

GW, V\text{\scriptsize{\textit{inf}}}, P_0, \alpha

In-Flight Thrust Model

F_G, F_{\text{RAM}}, F_{\text{DRAG}}

Wind Axis Accelerations

A_{\text{WX}}, A_{\text{Wy}}, A_{\text{Wz}}

F_{\text{EX}} = GW*A_{\text{WX}}

Predicted Performance

C_L, C_D, C_{D0}

Performance Model

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

C_L, C_D, C_{Di} = C_D - C_{D0}
Flight Test Technique

• Test Point Description
  – All-subsonic test points
  – Stabilized paradrogue deployments and retraction

• 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 Real-Time Data

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

ARS Paradroge Stowed  Paradroge Extension  ARS Paradroge Extended and Stable

Mach 0.64  Drogue Drag 403.8 lbf
Altitude 29047 ft

$C_D > 10\%$

Time, sec

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

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**

**MODIFIED CONFIGURATION**

- Increase lift
- Reduce 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 of Paradrope Assembly, lbf

Wind Tunnel Data Points

- NASA '-18' Flight Data
- Navy '-18' Wind Tunnel Data
- Navy 'F-18' Wind Tunnel Data

Indicated Airspeed, knots

160 180 200 220 240 260 280 300
0 100 200 300 400 500 600 700 800
Drag Polars

Phase 0

F/A-18A Phase 0
Drogue Retracted

F/A-18A Phase 0
Drogue Extended

"Clean" F/A-18A

Drogu Retracted (AAR Phase 0)
Drogu 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 Retracted (AAR Phase 1)

Drogue Extended (AAR Phase 1)

**Constant Drag Coefficient?**

![Graph showing drag results with different configurations](chart.png)

- **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
- Paradroguer 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" paradroguer \( C_D = 0.0056 \)
  - Based upon F/A-18 wing area
- All results compare favorably with clean F/A-18 data from the AFF project