SMALL SCALE MODEL TESTS IN
SMALL WIND AND WATER TUNNELS AT HIGH
INCIDENCE AND PITCH RATES

VOLUME III - WATER TUNNEL (HFF)
DATA BASE

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John R. Mercer
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GENERAL DYNAMICS
Fort Worth Division

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FINAL REPORT

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The force testing of small-scale models in either a small wind tunnel or a water tunnel was investigated as an inexpensive and quick means to obtain meaningful dynamic force and moment data representative of rapidly maneuvering full-scale aircraft. Force tests of flat-plate semi-span models were conducted in the General Dynamics Aerodynamic Development Facility (ADF) which is a small 14x14 in$^2$ low speed wind tunnel. Oscillatory model motions up to 48° (peak to peak) amplitude were tested at frequencies of 1 to 3 Hz. Force tests of flat and three-dimensional full span models were conducted in the General Dynamics Hydroflow Facility (HFF) which is a horizontal flow water tunnel with a 24x24 in$^2$ test section. Pitch/pulse model motions were tested for conditions similar to those tested in the (continued)
19. ABSTRACT (contd.)

ADF. The test velocities were 100 fps in the ADF and 0.8 fps in the HFF which yielded nominal Reynolds numbers of $0.6 \times 10^6$ and $0.06 \times 10^6$ respectively (based on root chord). Frequencies of motion in the HFF were scaled with velocity to maintain constant non-dimensional frequencies and pitch rates. Thus, frequencies for the HFF tests were nominally 0.01 and 0.03 Hz. Specific objectives of this investigation were: (1) verify static and dynamic force and moment measurements from the small scale tests with results from reliable or multiple sources; (2) determine time history effect for various frequencies, amplitudes, starting angles and peak angles; (3) evaluate the effects of test medium; (4) determine Reynolds number effects; (5) demonstrate the importance of model three-dimensionality; and (6) evaluate the effects of planform geometry variations.

This Volume III presents the data base generated from tests in the HFF. The normal force and pitching moment data are in plotted and tabulated form for the straked wing, $55^\circ$ and $70^\circ$ delta wings and $70^\circ/30^\circ$ cranked wing full span models. In addition to the four basic models, results are also given for the three-dimensional E-7 configuration with fuselage and fin along with a flat plate version of this model. Steady results and unsteady results are included for the overall incidence range of $0^\circ$ to $90^\circ$. Geometric data for the models are also given.
FOREWORD

The small scale wind and water tunnel tests discussed in this report were sponsored by the Office of Naval Research under Contract Number N00014-85-C-0419 and performed by the Fort Worth Division of General Dynamics. The investigation spanned the period from 16 September 1985 through 15 September 1988. The program was monitored by Dr. Robert E. Whitehead, Dr. T. C. Tai and finally Dr. Spiro Lekoudis all of ONR.

The program manager and principle investigator was Dr. Atlee M. Cunningham, Jr. of the Computational Fluid Dynamics Group who was assisted by Todd Bushlow and Steve Schwoerke of the Aeroanalysis Group as well as Tim Wilson and John Mercer of the Aerospace Technology Labs.
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This volume presents the data base generated from tests in the General Dynamics Hydroflow Facility (HFF). This facility is a 24x24in² horizontal flow water tunnel with velocity capability of up to 1.0 fps. Both static and dynamic data as well as model geometry are included. The normal force and pitching moment results are in plotted and tabulated form for the straked wing, 55° and 70° delta wings and 70°/30° cranked wing full-span models. In addition to the four basic models, results are also given for the three-dimensional E-7 configuration with fuselage and fin along with a flat plate version of this model. The static range of test incidence is from 0° to about 90° whereas the dynamic range is nominally from 8° to 64°.

A discussion of the plot format used in this volume is given in Section 4.1 of Volume I of this report. Multiple conditions are shown on each plot to highlight the development of unsteady forces and moments with varying starting and peak angles for model motion at fixed frequencies. The plots all include static data for a reference. The dynamic data are represented as solid lines for positive pitch rate and dashed lines for negative pitch rate.

In Volume I, all discussions referred to nominal values of reduced frequency and non-dimensional pitch rate. The actual test velocities and frequencies are listed in Table 1 and are used in the plots and listings given in this data volume. Table 2 provides a directory for the page numbers of various plots which are keyed on the overall incidence range, which angle is held constant (i.e., starting or peak angle) and configuration. Table 3 provides a similar directory for listings but only refers to the incidence range and configuration.
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\[ k = \frac{2 \pi Cr}{2 VT} \]
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APPENDIX A

PLOTS AND LISTINGS OF THE HFF FORCE AND
MOMENT DATA FOR THE FULL-SPAN STRAKED WING MODEL
Straked Wing
0.060" Thick Aluminum

- All Leading Edges Rounded, All Side and Trailing Edges
  Left Square (Strake was Sharp L.E.)

Straked Wing, Steady
Straked Wing, Incidence = 8° to 56°
Straked Wing, Incidence = 16° to 64°
Straked Wing, Incidence = 24° to 56°
Straked Wing, Incidence = 32° to 64°
Straked Wing, Incidence = 8° to 40°
Straked Wing, Incidence = 16° to 48°
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HFF Water Tunnel
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Alpha Min. = 8 deg.
Alpha Max. = 24 deg.
Straked Wing

HFF Water Tunnel

Red. Freq. = 0.0268

Alpha Min. = 8 deg.

Velocity = 0.802 ft/s

Alpha Max. = 40 deg.

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HFF Water Tunnel

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**HFF Water Tunnel**

**Velocity** = 0.802 ft/s

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**Straked Wing**

**HFF Water Tunnel**

*Red. Freq. = 0.0268*

*Alpha Min. = 24 deg.*

*Velocity = 0.802 ft/s.*

*Alpha Max. = 40 deg.*

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**Velocity** = 0.802 ft/s.

**Red. Freq.** = 0.0268

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**Alpha Max.** = 56 deg.

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Velocity = 0.802 ft/s.
Alpha Max. = 56 deg.

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APPENDIX B

PLOTS AND LISTINGS OF THE HFF FORCE AND
MOMENT DATA FOR THE FULL-SPAN 55° DELTA WING MODEL
55° Delta

0.050" Thick Aluminum

- All Leading Edges Rounded, All Side and Trailing Edges Left Square

55° Delta, Steady
$k = 0.0276$

$\Delta$, Incidence = 8° to 56°
$k = 0.0276$

$\Delta$, Incidence = $16^\circ$ to $64^\circ$
$k = 0.0276$

$\alpha = 0.0828$

$55^\circ \Delta \text{, Incidence } = 24^\circ \text{ to } 56^\circ$
55° Delta, Incidence = 32° to 64°
$k = 0.0276$

$Z$

$0.5$

$0$

$1.5$

$0.5$

$0$

$ALPHA$

$0$

$10$

$20$

$30$

$40$

$50$

$60$

$70$

$0$

$10$

$20$

$30$

$40$

$50$

$60$

$70$

$0.1$

$0.05$

$0$

$-0.05$

$-0.1$

$55^\circ$ Delta, Incidence $= 8^\circ$ to $40^\circ$
$k = 0.0276$

$\Delta = 16^\circ$ to $48^\circ$

$55^\circ$ Delta, Incidence = $16^\circ$ to $48^\circ$
$k = 0.0276$

$\kappa = 0.0828$

55° Delta, Incidence = 8° to 56°
$k = 0.0276$

$z = 0.5$

$0 < z < 1$

$\alpha = 0.1$

$\Delta = 55^\circ$

Incidence = $16^\circ$ to $64^\circ$
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$\alpha = 0.0828$

$55^\circ$ Delta, Incidence = $8^\circ$ to $24^\circ$
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$\kappa = 0.0828$

55° Delta, Incidence = 8° to 40°
$k = 0.0276$

$\delta$

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$-0.05 -0.05$

$\alpha$

$0.1 0.1$

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HFF Water Tunnel Alpha Min. = 8 deg.
Velocity = 0.802 ft/s. Alpha Max. = 24 deg.

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### 55 Deg. Delta

**HFF Water Tunnel**

**Velocity = 0.802 ft/s.**

**Alpha Min. = 8 deg.**

**Alpha Max. = 40 deg.**

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### 55 Deg. Delta

**Red. Freq. = 0.0276**

**HFF Water Tunnel**

**Velocity = 0.802 ft/s.**

**Alpha Min. = 8 deg.**

**Alpha Max. = 56 deg.**

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Velocity = 0.802 ft/s. Alpha Max. = 56 deg.

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**Alpha Max. = 64 deg.**

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HFF Water Tunnel

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Velocity = 0.802 ft/s.

Alpha Max. = 64 deg.

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Red. Freq. = 0.0276

HFF Water Tunnel

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Velocity = 0.802 ft/s.  Alpha Max. = 64 deg.

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Alpha Max. = 64 deg.

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APPENDIX C

PLOTS AND LISTINGS OF THE HFF FORCE AND MOENT DATA FOR THE FULL-SPAN 70° DELTA WING MODEL
70° Delta
0.060" Thick
Aluminum

- All Leading Edges
  Rounded, All Side
  and Trailing Edges
  Left Square

70° Delta, Steady
$k = 0.0276$

$\alpha$ = $

\begin{align*}
\hline
\text{Incidence} & = 8^\circ \text{ to } 56^\circ
\end{align*}$
$25 \quad \quad \quad \quad \quad 2.5 \quad k = 0.0276$

$\frac{1}{1.5} \quad \quad \quad \quad \quad 2.5 \quad k = 0.0828$

$I \quad / \quad z$

$U \quad / \quad 0 \quad 0$

$0 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \quad 70$

$ALPHA \quad ALPHA$

$\theta \quad Delta, \quad Incidence = 16^\circ \quad to \quad 64^\circ$

$0 \quad 0.05 \quad 0 \quad 0.05 \quad 0 \quad 0.05 \quad 0 \quad 0.05$

$1 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \quad 70$

$ALPHA \quad ALPHA$

$70^\circ \quad Delta, \quad Incidence = 16^\circ \quad to \quad 64^\circ$
$k = 0.0276$

$k = 0.0828$

$70^\circ$ Delta, Incidence = $24^\circ$ to $56^\circ$
$k = 0.0276$

$\Delta = \frac{1}{2.5}$

$k = 0.0828$

$\Delta = \frac{1}{2.5}$

$70^\circ$ Delta, Incidence = $32^\circ$ to $64^\circ$
$k = 0.0276$

$70^\circ$ Delta, Incidence = $8^\circ$ to $24^\circ$
$k = 0.0276$

$\Delta = 0.0828$

$70^\circ$ Delta, Incidence $= 16^\circ$ to $48^\circ$
\[ k = 0.0276 \]

\[ k = 0.0828 \]

70° Delta, Incidence = 8° to 56°
70° Delta, Incidence = 16° to 64°
$k = 0.0276$

$\kappa = 0.0828$

$\Delta$, Incidence = 8° to 40°
$k = 0.0276$

$\Delta$, Incidence = $8^\circ$ to $40^\circ$
$k = 0.0276$

$2$

$\begin{array}{c}
\text{ALPHA}
\end{array}$

$k = 0.0828$

$2$

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$70^\circ$ Delta, Incidence = $8^\circ$ to $56^\circ$
### 70 Deg. Delta Static Data

**HFF Water Tunnel**  
**Velocity** = 0.802 ft/s.  
**Alpha Min.** = 0 deg.  
**Alpha Max.** = 90 deg.

### Red. Freq. = 0.0000

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### Delta Red. Freq. = 0.0828

#### HFF Water Tunnel

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**Alpha Max.** = 24 deg.  
**Velocity** = 0.802 ft/s.

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**70 Deg. Delta**

**HFF Water Tunnel**

**Velocity** = 0.802 ft/s.

**Red. Freq.** = 0.0276

**Alpha Min.** = 16 deg.

**Alpha Max.** = 48 deg.

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### 70 Deg. Delta

**HFF Water Tunnel**

**Velocity** = 0.802 ft/s.

**Red. Freq.** = 0.0828

**Alpha Min.** = 16 deg.

**Alpha Max.** = 48 deg.

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Velocity = 0.802 ft/s. Alpha Max. = 64 deg.

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70 Deg. Delta Red. Freq. = 0.0828

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Velocity = 0.802 ft/s. Alpha Max. = 64 deg.
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APPENDIX D

PLOTS AND LISTINGS OF THE HFF FORCE AND
MOMENT DATA FOR THE FULL-SPAN 70°/30° CRANKED WING MODEL
Cranked Wing
0.050" Thick Aluminum

- All Leading Edges Rounded, All Side and Trailing Edges Left Square

70°/30° Cranked Wing, Steady
$k = 0.0276$

$z$

$0.1$

$\delta$

$70^\circ/30^\circ$ Cranked Wing, Incidence = $8^\circ$ to $56^\circ$
$k = 0.0276$

$\delta$

$\zeta$

$\zeta$

$\alpha$

$\alpha$

$70^\circ / 30^\circ$ Cranked Wing, Incidence = $16^\circ$ to $64^\circ$
$k = 0.0276$

$2.5$

$0.0276$

$k = 0.0828$

$2.5$

$0.5$

$0.05$

$0.1$

$0.5$

$1$

$1.5$

$2$

$2.5$

$20, 30, 40, 50, 60, 70$

$0, 10, 20, 30, 40, 50, 60, 70$

$70^\circ/30^\circ$ Cranked Wing, Incidence = $24^\circ$ to $56^\circ$
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$2$

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$1$

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$0$

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$50$

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$70$

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$-0.1$

$0$

$10$

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$30$

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$70$

$70^\circ/30^\circ$ Cranked Wing, Incidence = $32^\circ$ to $64^\circ$
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$70^\circ/30^\circ$ Cranked Wing, Incidence = $8^\circ$ to $40^\circ$
$2.5 k = 0.0276$

$2.5 k = 0.0828$

$70^\circ/30^\circ$ Cranked Wing, Incidence = $16^\circ$ to $48^\circ$
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$\kappa = 0.0828$

$70^\circ/30^\circ$ Cranked Wing, Incidence = $8^\circ$ to $56^\circ$
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70°/30° Cranked Wing, Incidence = 16° to 64°
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$70^\circ/30^\circ$ Cranked Wing, Incidence = $8^\circ$ to $40^\circ$
$70^\circ/30^\circ$ Cranked Wing, Incidence = $8^\circ$ to $56^\circ$
Cranked Wing Static Data

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HFF Water Tunnel Alpha Min. = 8 deg.  
Velocity = 0.802 ft/s. Alpha Max. = 24 deg.

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Cranked Wing

HFF Water Tunnel

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Alpha Max. = 24 deg.

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Cranked Wing

HFF Water Tunnel

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HFF Water Tunnel
Velocity = 0.802 ft/s.
Cranked Wing
HFF Water Tunnel

Velocity = 0.802 ft/s.

Red. Freq. = 0.0828

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HFF Water Tunnel

Velocity = 0.802 ft/s.

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Cranked Wing
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Alpha Max. = 48 deg.

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Cranked Wing

HFF Water Tunnel

Red. Freq. = 0.0828

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Velocity = 0.802 ft/s.

Alpha Max. = 48 deg.

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Cranked Wing

Red. Freq. = 0.0276

HFF Water Tunnel

Alpha Min. = 32 deg.

Velocity = 0.802 ft/s. Alpha Max. = 64 deg.

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HFF Water Tunnel
Velocity = 0.802 ft/s

Red. Freq. = 0.0828
Alpha Min. = 32 deg.
Alpha Max. = 64 deg.

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Red. Freq. = 0.0276  
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### Cranked Wing

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- **Red. Freq.:** 0.0276
- **Alpha Min.:** 48 deg.
- **Alpha Max.:** 64 deg.
- **Velocity:** 0.802 ft/s

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Cranked Wing
HFF Water Tunnel
Velocity = 0.802 ft/s.

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APPENDIX E

PLOTS AND LISTINGS OF THE HFF FORCE AND
MOMENT DATA FOR THE FULL-SPAN E-7 MODELS
E-7, 3-D, Incidence = 8° to 56°
$k = 0.0335$

$\alpha = 0.0885$

E-7, 3-D, Incidence = $8^\circ$ to $56^\circ$
0.050" Thick Aluminum

Rounded

60°

PA

3.54"

1.31"

-10°

2.76"

E-7, Flat, Steady
$k = 0.0335$

$k = 0.0885$

E-7, Flat, Incidence = $8^\circ$ to $56^\circ$
E-7, Flat, Incidence = 8° to 56°
### E7 3-D Model Static Data

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**HFF Water Tunnel**  
**Velocity** = 0.802 ft/s  
**Alpha Min.** = 0 deg.  
**Alpha Max.** = 90 deg.

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### E7 3-D Model

**Red. Freq. = 0.0335**

**HFF Water Tunnel**

**Velocity = 0.802 ft/s.**

**Alpha Min. = 8 deg.**

**Alpha Max. = 56 deg.**

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### E7 3-D Model

**HFF Water Tunnel**

- Velocity: 0.802 ft/s.
- Red. Freq.: 0.0885
- Alpha Min.: 8 deg.
- Alpha Max.: 56 deg.

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**E7 Flat Model Static Data**

**Red. Freq. = 0.0000**

**HFF Water Tunnel**

**Alpha Min. = 0 deg.**

**Velocity = 0.802 ft/s.**

**Alpha Max. = 90 deg.**

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### E7 Flat Model

**Velocity** = 0.802 ft/s.  
**Red. Freq.** = 0.0335  
**HFF Water Tunnel**  
**Alpha Min.** = 8 deg.  
**Alpha Max.** = 56 deg.

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