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WIND LOADS ON A MIRAGE III O AIRCRAFT
MOUNTED ABOVE A GROUND PLANE

by

P. A. HERMSEN

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Wind Loads on Mirage III O Aircraft Mounted Above a Ground Plane

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SUMMARY

Measurements were made in ARL Salisbury's Low Speed Tunnel on a 1/72 scale model of a Mirage III O aircraft to determine steady wind loads when mounted above a ground plane. The six component data cover 360° in azimuth, and roll and pitch angles of $-20^{o}, 0^{o}, +20^{o}$.

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Notation

ψ Azimuth Angle

θ Pitch Angle

ϕ Roll Angle

C_F Force Coefficient

C_m Moment Coefficient

L   Wing Span

q   Dynamic Pressure

ρ Air Density

S   Surface Area of Wing

v   Wind Velocity

C_X = Axial Force Coefficient

     = Axial Force$/\frac{1}{2}\rho \cdot v^2 \cdot S$

C_Y = Side Force Coefficient

     = Side Force$/\frac{1}{2}\rho \cdot v^2 \cdot S$

C_Z = Normal Force Coefficient

     = Normal Force$/\frac{1}{2}\rho \cdot v^2 \cdot S$

C_1 = Rolling Moment Coefficient

     = Rolling Moment$/\frac{1}{2}\rho \cdot v^2 \cdot S \cdot L$

C_m = Pitching Moment Coefficient

     = Pitching Moment$/\frac{1}{2}\rho \cdot v^2 \cdot S \cdot L$

C_n = Yawing Moment Coefficient

     = Yawing Moment$/\frac{1}{2}\rho \cdot v^2 \cdot S \cdot L$

1. Introduction

Opto-electronics Division, SRL, has requested aerodynamic data to estimate wind loads upon a Mirage III O aircraft mounted on variable hydraulic supports above a ground plane. The data are required for 0° to 360° azimuth and roll and pitch angles of -20°, 0°, 20°. The required data differ greatly from the extensive aerodynamic data available for the aircraft under flight conditions, so a test programme using ARL Salisbury's low speed tunnel was initiated. In spite of the limitations of this approach (that is using a small scale model in a wind tunnel not equipped to model the atmospheric boundary layer) it was felt that the results obtained would provide useful guidance on the steady state loads to be expected.

The hydraulic supports were not represented in the model configuration as the aim of this study was to assist in their design.

2. Technique

The ARL-Salisbury low speed tunnel is equipped with a four component (Y & Z forces, and m & n moments) strain gauge balance. To measure the six force and moment components of the Mirage two series of tests were performed.

In the first test, the balance was mounted in the floor of the tunnel, and the model was supported a scale distance of 4.1 metres (as required by the client) above the tunnel floor, see Figure 1. This enabled measurement of the horizontal forces on the aircraft.

Secondly the balance was relocated to the side wall of the tunnel (but in the same orientation), and again the model was supported a scale distance of 4.1 metres from the tunnel side wall, see Figure 1. This allowed the lift force and yawing moment to be measured, and duplicated the drag force and rolling moment.

The force and moment coefficients for the clean balance sting were subtracted from the measured force and moment coefficients.

Data were collected for the following configurations:

Run #	Pitch (θ)	Roll (ϕ)	Azimuth (ψ)
1	0°	0°	$0^c \le \psi \le 180^o$, each 45°
2	-20°	0°	$0^o \le \psi \le 180^o$, each 45°
3	0°	0°	$0^o \le \psi \le 180^o$, each 45°
4	0°	$+20^o$	$-180^o \le \psi \le 180^o$, each 45°
5	$+20^o$	$+20^o$	$-180^o \le \psi \le 180^o$, each 45°
6	-20°	-20°	$-180^o \le \psi \le 180^o$, each 45°

Table 1: Configurations for test runs.

The rotations were performed as azimuth, then pitch, and then roll, as per the standard convention.

The tunnel speed was approximately 18 m·s^{-1}. The working section of the tunnel measures 300 mm wide by 380 mm high.

The Reynolds number for the tests was 9.4×10^4, based on the mean aerodynamic chord.

2.1 Definitions

The two balance positions resulted in two different balance co-ordinate systems being used to measure the data.

These two co-ordinate systems were combined to give the force and moment data in terms of the aircraft co-ordinate system, Figure 2.

Aircraft Orientation: The aircraft was mounted with its base on the balance sting at a scale distance of 4.1 metres above the ground plane The attitude of the model was changed so that the reference point always remained a scale distance of 4.1 metres above the ground plane. The zero pitch datum is defined as a nose up angle of 1° between the wing root chord and the ground plane. The azimuth datum is defined as the direction of the oncoming wind.

Coefficients of Force and Moment: The force and moment data are non-dimensionalised by the following relations:

$$C_F = \frac{F}{q \cdot S}$$

$$C_m = \frac{m}{q \cdot S \cdot L}$$

where: q is the dynamic pressure calculated as

$$q = \tfrac{1}{2}\rho \cdot v^2$$

L is the wing span
S is the wing area (see below)
and F and m represent the Forces and Moments respectively.

As shown in Figure 3, the wing area, S, has been defined as the basic triangle described by the wing span and wing root chord, without consideration of the more complex shape of the Mirage's delta wing. As the aim of this study was to assist in the mechanical design of the supports, and not the aerodynamic performance of the aircraft, it was decided that a simple definition of the reference dimensions would be more useful.

The model has the dimensions;
Wing Span   = 0.115 metres,
Wing Root Chord   = 0.109 metres.
Hence;

$$S_{\{model\}} = 0.00627 \text{ metres}^2,$$

$$L_{\{model\}} = 0.115 \text{ metres}.$$

For the full scale aircraft;

$$S_{\{mirage\}} = 34.0025 \text{ metres}^2,$$

$$L_{\{mirage\}} = 8.222 \text{ metres}.$$

Aircraft Centre of Reference: Figure 4 shows the attachment point of the model support which was the point used to define the moment centre of the model. The point lies 0.062 metres aft of the vertex of the delta wing (level with the air intakes), and midway between the top and bottom of the fuselage, i.e. 0.01 metres from the top.

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3. Results

The six component data for the coefficients C_X, C_Y, C_Z, C_l, C_m, and C_n are presented in Figures 5.1 to 5.6. Tables 3.1 to 3.6 list the aerodynamic data.

Using the two configurations of the four component balance, as mentioned previously, gave two measurements of drag force and roll moment for each run. A comparison of the two data sets show an average error of 3.9% of the maximum observed force between the two orientations. The maximum force of 1.24 Newtons represented 79% of the full scale deflection of the balance.

Additionally, a comparison was made with the results of Pollock and Forsyth (1970) for the two cases where the aircraft orientations coincided. Table 2 presents the C_X and C_Z values at 0° azimuth, and pitch angles of 0° and 20°. Values of C_Y have not been included for comparison because at 0° azimuth they are negligible. The results of Pollock and Forsyth (1970) have been corrected to compensate for the different wing areas used to non-dimensionalise the force coefficients.

	Present Study (1991)		Pollock and Forsyth (1970)	
	$\theta=0^\circ$	$\theta=20^\circ$	$\theta=0^\circ$	$\theta=20^\circ$
C_X	-0.084	0.037	-0.014	0.017
C_Z	-0.056	-1.010	0.037	-0.870

Table 2: Comparison of force data between present study and Pollock and Forsyth (1970).

The model in the present study exhibits positive lift and much higher drag at $\theta=0^\circ$ than Pollock and Forsyth (1970) (herein referred to as PF 1970). The value of C_X at $\theta=20^\circ$ for this study is also much larger. The increased lift is most likely due to the model datum in this study (i.e. $\theta=0^\circ$) being set at 1° nose up from the horizontal plane. PF 1970 gives a slight downforce (i.e. positive C_Z) at $\theta=0^\circ$, becoming zero at approximately $\theta=1^\circ$, and decreasing nearly linearly to $C_Z=-1.0$ at $\theta=22^\circ$.

The force and moment coefficients of the clean balance sting were subtracted from the measured model force and moment coefficients. It is not expected that the interaction between the model and the sting would be very large so the increased magnitude of the C_X data in the present study is attributed to interaction with the ground plane.

Both the pitching moment and the yawing moment data show the aircraft to be statically unstable for the chosen centre of reference. This was verified later when the model was placed in the tunnel, supported on a ball joint, and allowed to rotate under the aerodynamic forces.

In the graphs of Figures 5.1 to 5.6 the data points are linked by lines only to enable easier identification of the different runs. The data points are too sparse to allow reliable interpolation.

This work has only considered the loads on the model under steady conditions. Before the loads expected to be experienced in the turbulent atmospheric boundary layer can be estimated, consideration must be given to the unsteady wind gusts and upwind terrain features (buildings, trees, topography, et cetera). The speed and direction of a wind gust will vary both spatially and in time and the resulting forces and moments may be several times larger than the steady loads, and cannot be neglected when considering the design of the support structure. Consultation of ESDU Structural Engineering/Wind Engineering-M Volumes will assist in calculating sufficient safety factors to apply to the steady loads data.

3

4. References

Pollock, N., and Forsyth, G.F.
Wind Tunnel measurements of the Characteristics of a Mirage III O Model at Angles of Attack up to 90°.
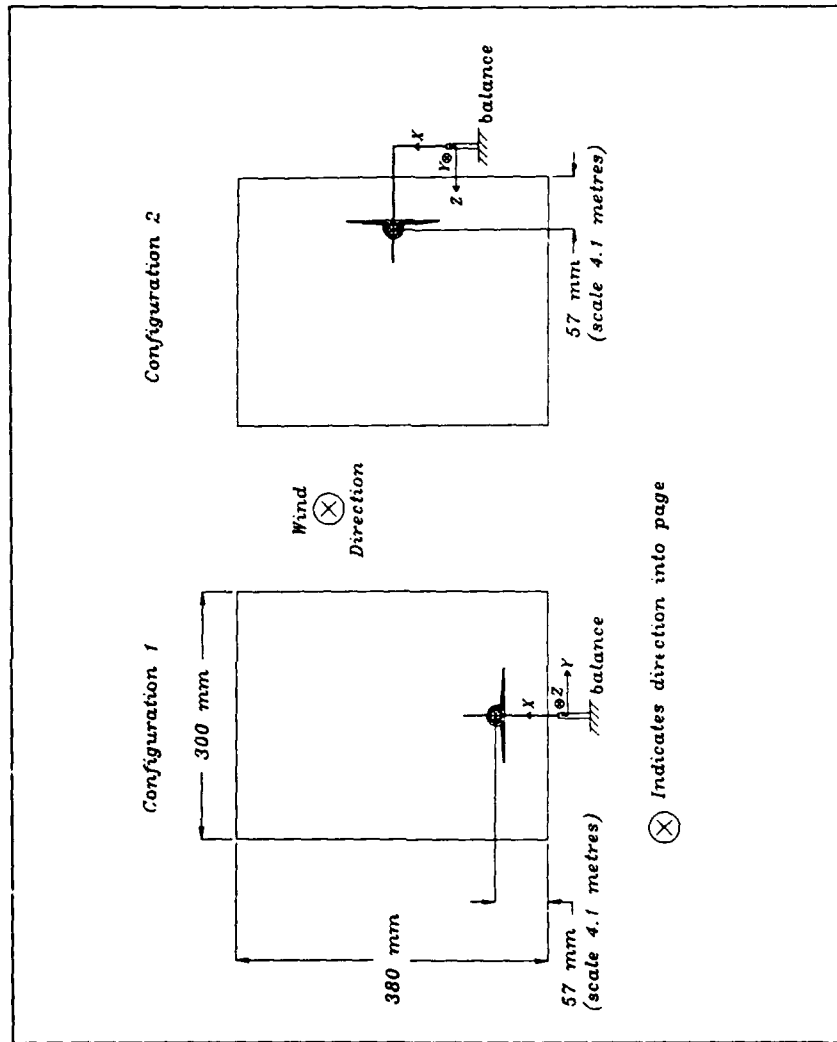ARL Aerodynamics Note 323.
August 1970

Figure 1: Model and Balance Orientations.
Configuration 1 (left): Model in Tunnel Floor.
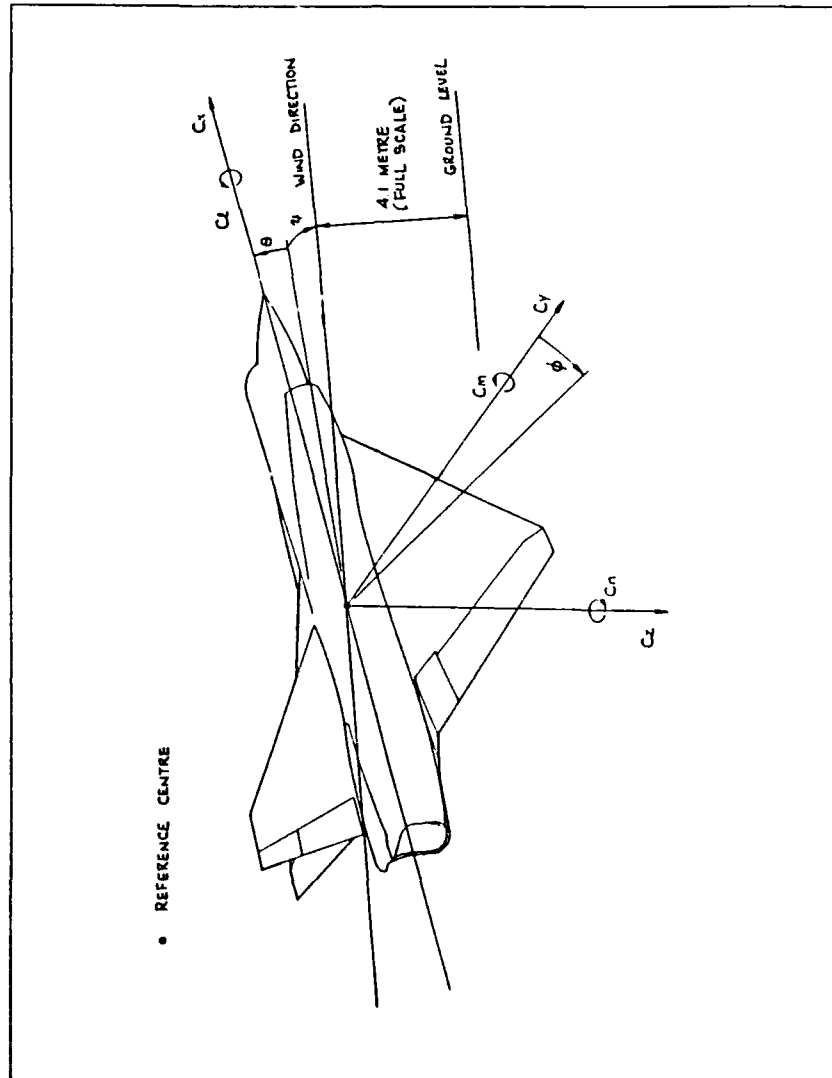Configuration 2 (right): Model in Tunnel Side Wall.
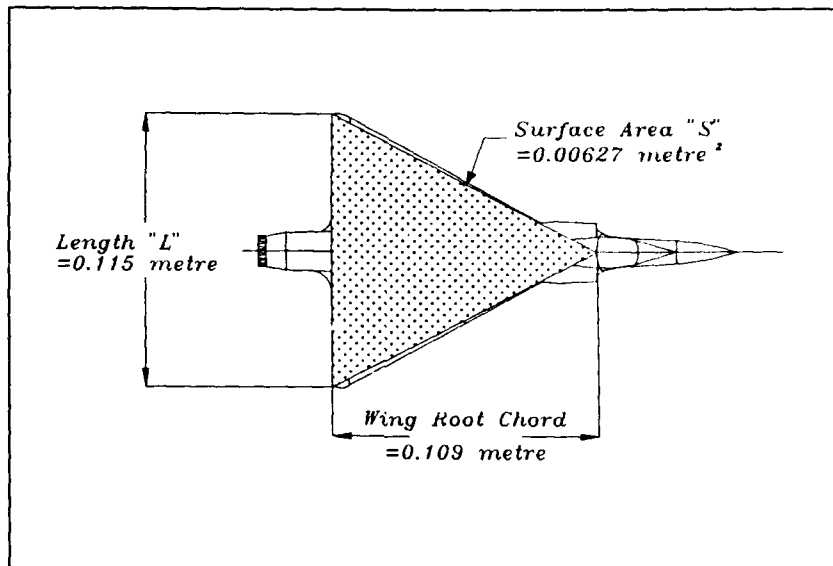
Figure 2: Aircraft Force and Moment Axes System.

Figure 3: Dimensions used to non-dimensionalise Forces and Moments
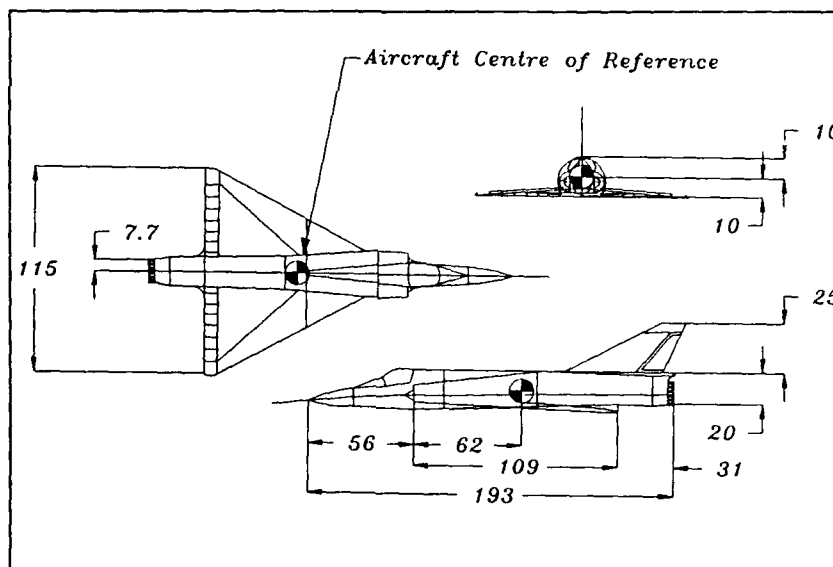
Figure 4: Model dimensions (in millimetre).

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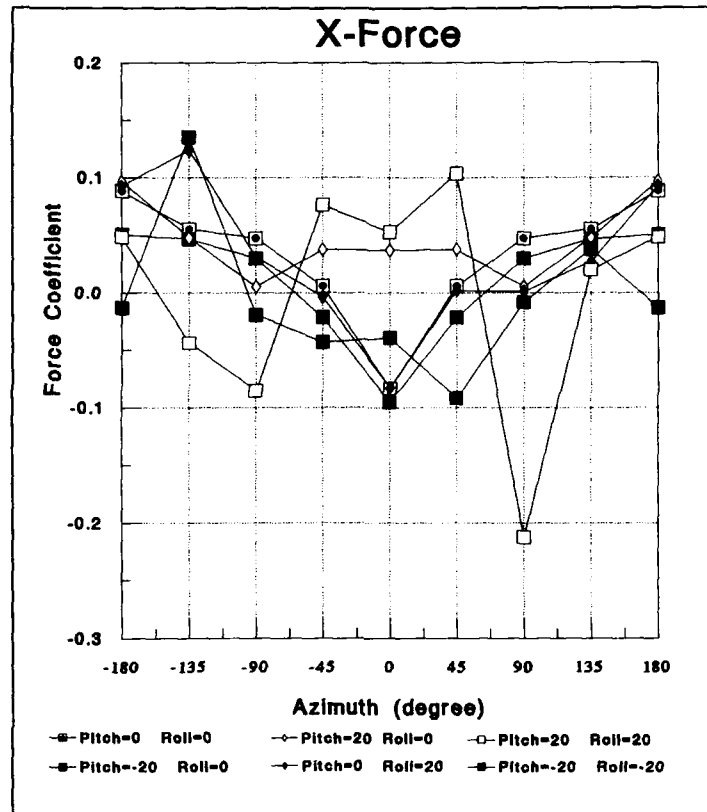
Figure 5.1: X Force Coefficient.

Pitch	0°	-20°	20°	0°	20°	-20°
Roll	0°	0°	0°	20°	20°	-20°
Azimuth						
-180°	0.088	0.050	0.097	0.093	0.048	-0.013
-135°	0.055	0.047	0.048	0.124	-0.043	0.135
-90°	0.047	0.030	0.005	0.031	-0.086	-0.019
-45°	0.006	-0.021	0.037	-0.004	0.076	-0.043
0°	-0.084	-0.096	0.037	-0.083	0.053	-0.039
45°	0.006	-0.021	0.037	0.002	0.104	-0.092
90°	0.047	0.030	0.005	0.001	-0.213	-0.008
135°	0.055	0.047	0.048	0.027	0.020	0.038
180°	0.088	0.050	0.097	0.093	0.048	-0.013

Table 3.1: X Force Coefficient

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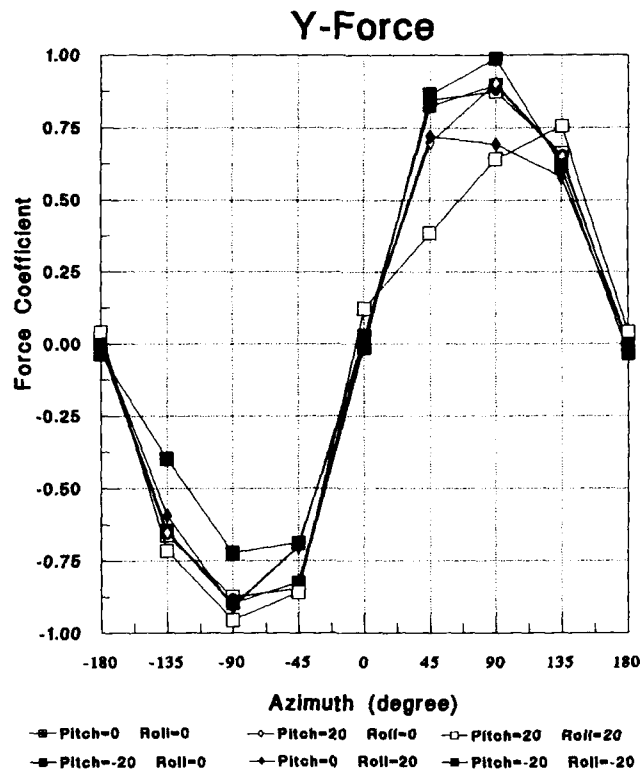
Y-Force

Figure 5.2: Y Force Coefficient

Pitch	0°	-20°	20°	0°	20°	-20°
Roll	**0°**	**0°**	**0°**	**20°**	**20°**	**-20°**
Azimuth						
-180°	-0.008	0.005	-0.004	0.002	0.042	-0.035
-135°	-0.662	-0.646	-0.652	-0.593	-0.716	-0.398
-90°	-0.874	-0.895	-0.902	-0.910	-0.955	-0.723
-45°	-0.846	-0.825	-0.700	-0.702	-0.860	-0.689
0°	-0.002	0.028	0.028	0.030	0.122	-0.013
45°	0.846	0.825	0.700	0.721	0.385	0.864
90°	0.874	0.895	0.902	0.693	0.641	0.988
135°	0.662	0.646	0.652	0.580	0.755	0.617
180°	-0.008	0.005	-0.004	0.002	0.042	-0.035

Table 3.2: Y Force Coefficient.
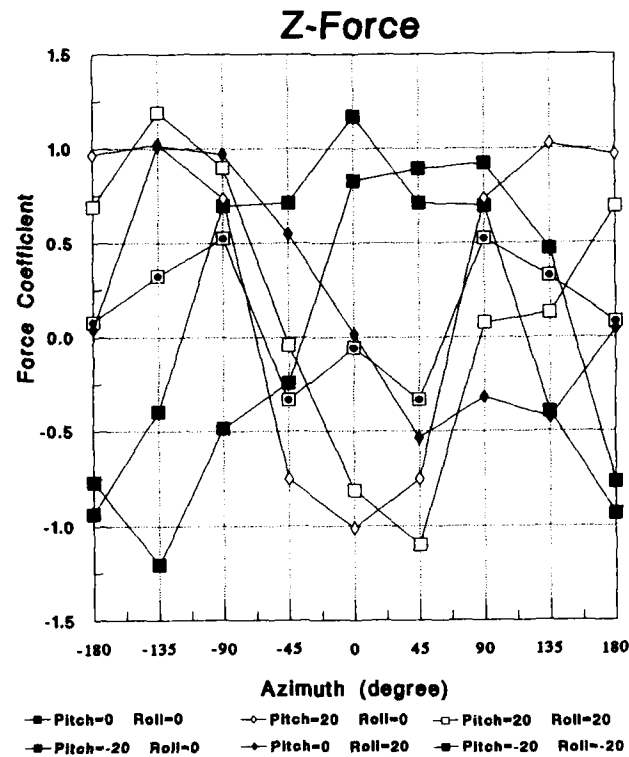
Figure 5.3: Z Force Coefficient.

Pitch	0°	-20°	20°	0°	20°	-20°
Roll	0°	0°	0°	20°	20°	-20°
Azimuth						
-180°	0.080	-0.935	0.966	0.042	0.692	-0.767
-135°	0.322	-0.395	1.023	1.015	1.194	-1.205
-90°	0.523	0.696	0.735	0.971	0.898	-0.485
-45°	-0.334	0.712	-0.751	0.548	-0.042	-0.244
0°	-0.056	1.172	-1.010	0.016	-0.810	0.827
45°	-0.334	0.712	-0.751	-0.536	-1.101	0.895
90°	0.523	0.696	0.735	-0.319	0.076	0.923
135°	0.322	-0.395	1.023	-0.428	0.127	0.467
180°	0.080	-0.935	0.966	0.042	0.692	-0.767

Table 3.3: Z Force Coefficient.

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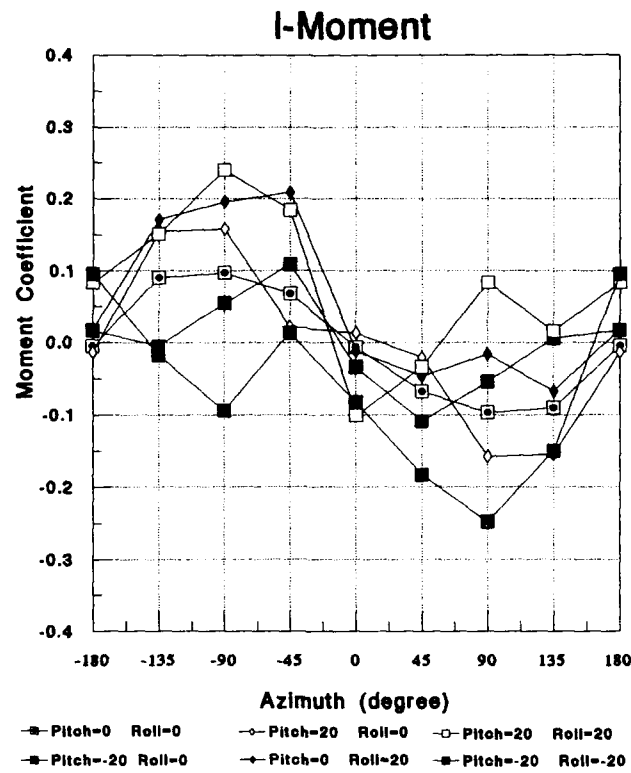
I-Moment

Figure 5.4: 1 Moment Coefficient.

Pitch Roll Azimuth	0° 0°	-20° 0°	20° 0°	0° 20°	20° 20°	-20° -20°
-180°	-0.005	0.016	-0.014	0.018	0.083	0.096
-135°	0.090	-0.005	0.155	0.171	0.151	-0.018
-90°	0.097	0.054	0.158	0.196	0.239	-0.094
-45°	0.067	0.109	0.021	0.209	0.184	0.013
0°	-0.007	-0.034	0.012	-0.012	-0.101	-0.083
45°	-0.067	-0.109	-0.021	-0.047	-0.034	-0.184
90°	-0.097	-0.054	-0.158	-0.016	0.083	-0.248
135°	-0.090	0.005	-0.155	-0.067	0.015	-0.150
180°	-0.005	0.016	-0.014	0.018	0.083	0.096

Table 3.4: 1 Moment Coefficient.
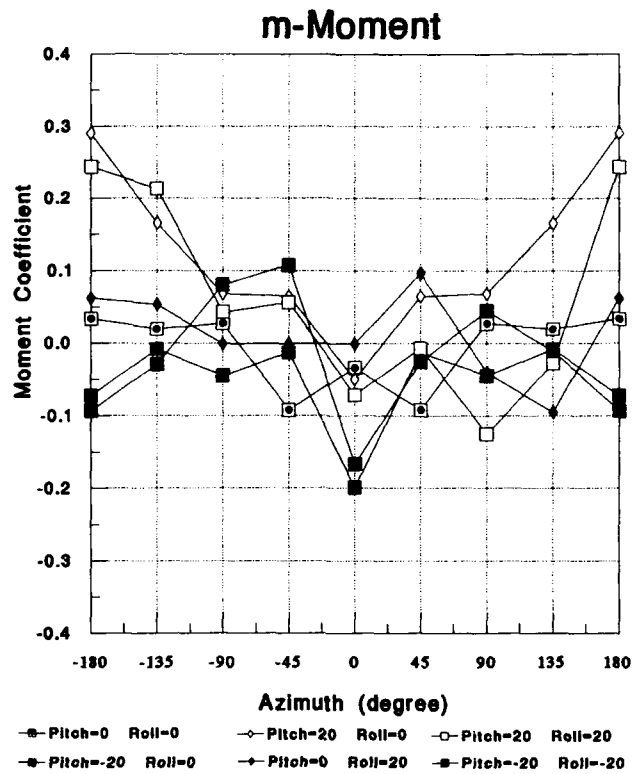
m-Moment

Figure 5.5: m Moment Coefficient.

Pitch	0°	-20°	20°	0°	20°	-20°
Roll	0°	0°	0°	20°	20°	-20°
Azimuth						
-180°	0.034	-0.072	0.291	0.062	0.244	-0.093
-135°	0.019	-0.009	0.165	0.053	0.213	-0.029
-90°	0.027	-0.045	0.068	-0.001	0.043	0.081
-45°	-0.092	-0.013	0.064	-0.001	0.056	0.107
0°	-0.034	-0.199	-0.050	-0.001	-0.071	-0.166
45°	-0.092	-0.013	0.064	0.096	-0.007	-0.026
90°	0.027	-0.045	0.068	-0.040	-0.125	0.045
135°	0.019	-0.009	0.165	-0.095	-0.028	-0.011
180°	0.034	-0.072	0.291	0.062	0.244	-0.093

Table 3.5: m Moment Coefficient.

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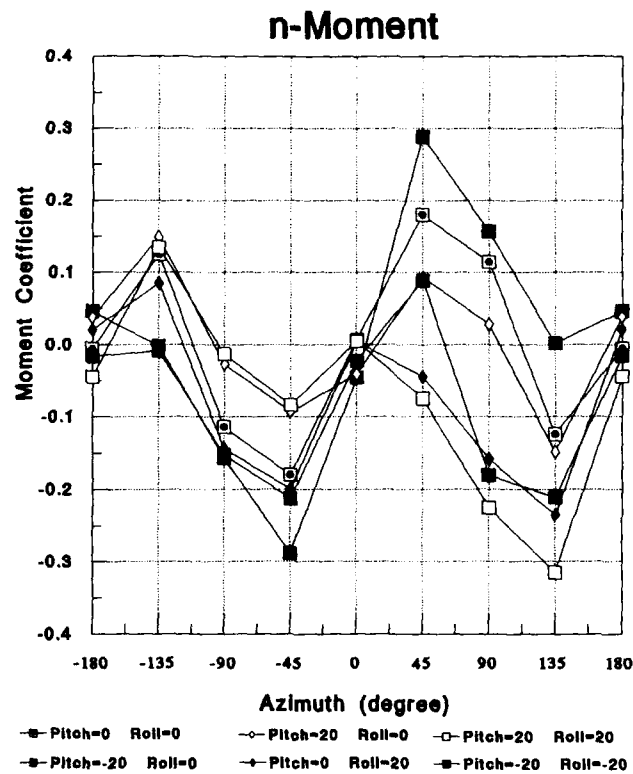
n-Moment

Figure 5.6: n Moment Coefficient.

Pitch	0°	-20°	20°	0°	20°	-20°
Roll	0°	0°	0°	20°	20°	-20°
Azimuth						
-180°	-0.006	0.046	0.038	0.021	-0.045	-0.016
-135°	0.124	-0.002	0.149	0.085	0.134	-0.009
-90°	-0.114	-0.157	-0.028	-0.144	-0.013	-0.152
-45°	-0.180	-0.289	-0.093	-0.200	-0.084	-0.213
0°	0.006	-0.046	-0.041	0.004	0.005	-0.023
45°	0.180	0.289	0.093	-0.045	-0.075	0.088
90°	0.114	0.157	0.028	-0.158	-0.226	-0.181
135°	-0.124	0.002	-0.149	-0.236	-0.315	-0.211
180°	-0.006	0.046	0.038	0.021	-0.045	-0.016

Table 3.6: n Moment Coefficient.

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16. ABSTRACT

Measurements were made in ARL Salisbury's Low Speed Tunnel on a 1/72 scale model of a Mirage III O aircraft to determine steady wind loads when mounted above a ground plane. The six component data cover 360° in azimuth, and roll and pitch angles of -20°, 0°, + 20°.

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