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NATIONAAL LUCHT- EN RUIMTEVAARTLABORATORIUM
NATIONAL AEROSPACE LABORATORY NLR
THE NETHERLANDS

NLR MP 77028 U

IN-FLIGHT MEASUREMENT OF AERODYNAMIC LOADS
ON CAPTIVE STORES
DESCRIPTION OF THE MEASUREMENT EQUIPMENT
AND COMPARISON OF RESULTS WITH DATA
FROM OTHER SOURCES

BY

G.J. ALDERS

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DOCUMENT CONTROL SHEET

<p>(14)</p>	<p>ORIGINATOR'S REF. NLR-MF-77/28-U</p>	<p>SECURITY CLASS. Unclassified</p>															
	<p>ORIGINATOR National Aerospace Laboratory (NLR) Amsterdam, The Netherlands.</p>																
<p>TITLE (2) In-flight measurement of aerodynamic loads on captive stores. Description of the measurement equipment and comparison of results with data from other sources.</p>																	
<p>PRESENTED AT the fourth JTCG/MD Aircraft/Stores Compatibility Symposium, held in Fort Walton Beach, Florida, USA, 12-14 October 1977.</p>																	
<p>AUTHORS (10) G. J. Alders</p>	<p>6 Sep 77</p>	<p>DATE 6-IX-1977</p>	<p>PP ref 33 4</p>														
<p>DESCRIPTORS</p> <table border="0"> <tr> <td>Fighter aircraft</td> <td>Aerodynamic interference</td> </tr> <tr> <td>NF-5 aircraft</td> <td>Aerodynamic coefficients</td> </tr> <tr> <td>Aerodynamic characteristics</td> <td>Data acquisition</td> </tr> <tr> <td>External stores</td> <td>Measuring instruments</td> </tr> <tr> <td>Ejection</td> <td>Captive airloads</td> </tr> <tr> <td>Flight tests</td> <td>Store separation</td> </tr> <tr> <td>Captive tests</td> <td></td> </tr> </table> <p>(12) 3/4</p>				Fighter aircraft	Aerodynamic interference	NF-5 aircraft	Aerodynamic coefficients	Aerodynamic characteristics	Data acquisition	External stores	Measuring instruments	Ejection	Captive airloads	Flight tests	Store separation	Captive tests	
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33 pages

Division: Flight

Prepared: GJA/ *G*

Approved: LRL *LRL*

Completed : 6-IX-1977

Ordernumber: 31.403

Typ. : GC

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(Article UNCLASSIFIED)

by

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LIST OF SYMBOLS

a_y	acceleration along the lateral axis of the store
a_z	acceleration along the top axis of the store
C_{l_0}	$\frac{L_0}{qSd}$
C_{m_0}	$\frac{M_0}{qSl}$
C_{n_0}	$\frac{N_0}{qSl}$
C_{y_0}	$\frac{Y_0}{qS}$
C_{z_0}	$\frac{Z_0}{qS}$
d	store diameter
KAES	equivalent airspeed in kts
L_0	rolling moment on a captive store
l	store length
M_0	pitching moment on a captive store
M	Mach number
N_0	yawing moment on a captive store
n_z	aircraft normal load factor
p_s	static pressure
q	dynamic pressure
S	$\frac{\pi}{4} d^2$
S_1 thru S_5	balance strain gage output signals
Y_0	lateral force on a captive store
Z_0	normal force on a captive store

LIST OF SYMBOLS
(continued)

- α angle of attack of aircraft
- β angle of sideslip of aircraft
- δ_a aileron deflection angle

INTRODUCTION

In the last decade NLR has carried out airworthiness demonstration programs for new aircraft configurations for the Royal Netherlands Air Force (RNLAf). In this period the tools required for this work have been subject to constant improvement. A large part of the research underlying these improvements, including the work described in this paper, has been carried out under contract with the RNLAf.

Store separation prediction at NLR is carried out using the computer model shown in figure 1. The results obtained with this model differ from the store behaviour measured in flight. Trials have shown that the submodels labelled ejection system and wing response are adequate. The differences thus must be attributed to an incorrect representation of the aerodynamic forcing function. This may have two causes:

- incorrect aerodynamic input data, possibly due to differences between wind tunnel measurements or calculations and the full scale situation
- instationary aerodynamic effects that are not accounted for in the calculations.

Due to this uncertain basis of the predictions, critical store separation cases have to be cleared in a stepwise manner. A typical program set-up is shown in figure 2. At each stage of this program one or two stores per configuration have to be dropped in flight.

The aerodynamic load measuring store was developed to gain more insight in the limitations of the various sources of aerodynamic interference data and in the cause of the differences between predicted and measured store motion.

Furthermore it was expected that in-flight measurements could be used with future projects to reduce the number of stores required for safe separation demonstration and would improve the confidence that can be put in the final result.

A BLU-1/B-like store shape was selected for the flight test program, to evaluate the aerodynamic load measuring store. The tests were carried out with an NF-5 aircraft. This selection was made because for this aircraft-store combination measured and calculated information on interference aerodynamics as well as on store motion was available from various sources.

Flight tests started in August 1977. Five configurations, with the store in the normal captive position, have been tested to date. Tests with the store mounted .15 m below the pylon are planned.

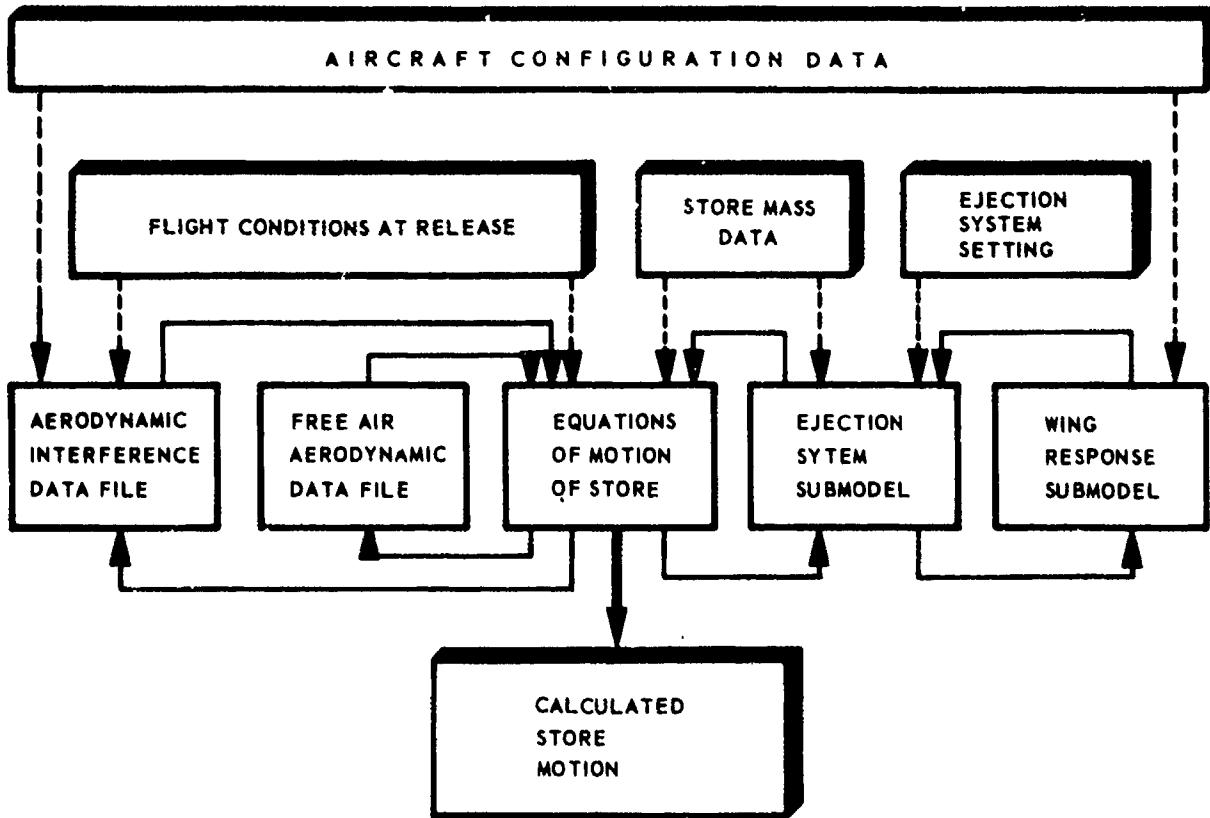


Figure 1 Store separation prediction model

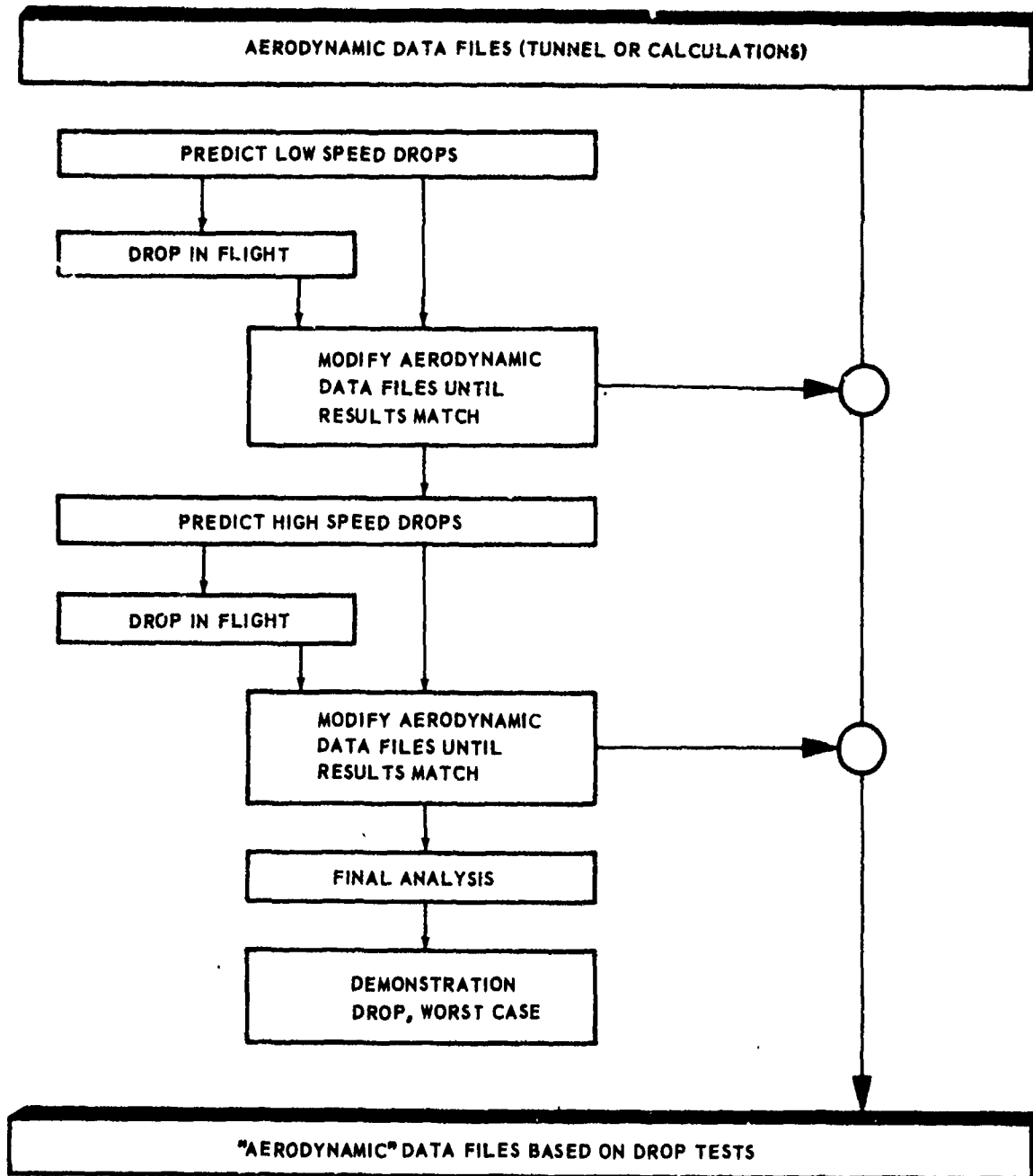


Figure 2 Evaluation procedure to determine the safe store separation envelope

THE FIVE COMPONENT AERODYNAMIC LOAD MEASURING STORE

The store is shown schematically in figure 3. It consists of four parts:

- a. A support beam, provided with bomb lugs and sway brace reaction areas. The beam serves as a mounting base for the load measuring balance and for the instrumentation. The bomb lugs can be replaced by two pillars of up to .15 m length. The pillars are mounted on a bracket that replaces a bomb rack. Thus air loads can be measured with the store .15 m below its normal captive position.
- b. A five component balance (Fig. 4) to measure normal and side force as well as the moments in pitch, yaw and roll. The measuring ranges are ± 4000 N and ± 2000 Nm. The balance is designed to withstand five times its measuring range. The design speed limit is 650 KEAS/Mach 2.0. The balance can be shifted in a forward/aft sense in the store, to obtain an optimum position of its moment centre. Measurement of the axial force has been omitted to improve the ruggedness of the construction. This could be done as axial forces need not be known accurately for store separation analysis.
The space around the balance is sealed off with a thermal insulation material. Heaters are provided to maintain a constant balance temperature.
- c. A shell, representing the store to be measured: in the present case a BLU-1/B type weapon (Fig. 5). The shell has to be kept as light as possible to minimize the effect of mass forces, to make optimum use of the measuring range of the balance. The more complicated parts (nose and tail) have been taken from a real store. The cylindrical center section has been specially built, and is provided with a bulkhead to mount the balance. Holes are made in the skin to allow lugs and sway braces to pass. The remaining openings are sealed by means of rubber bellows.
- d. Instrumentation (Fig. 6). For the first evaluation of the store use was made of an instrumented aircraft. The instrumentation in the store was limited to two accelerometers and the power supply and signal conditioning for the strain gages, but space is available for a small but complete data acquisition system. This offers the possibility to use the store on any 14 inch weapon station on any aircraft where 28 VDC and 115 VAC are available.

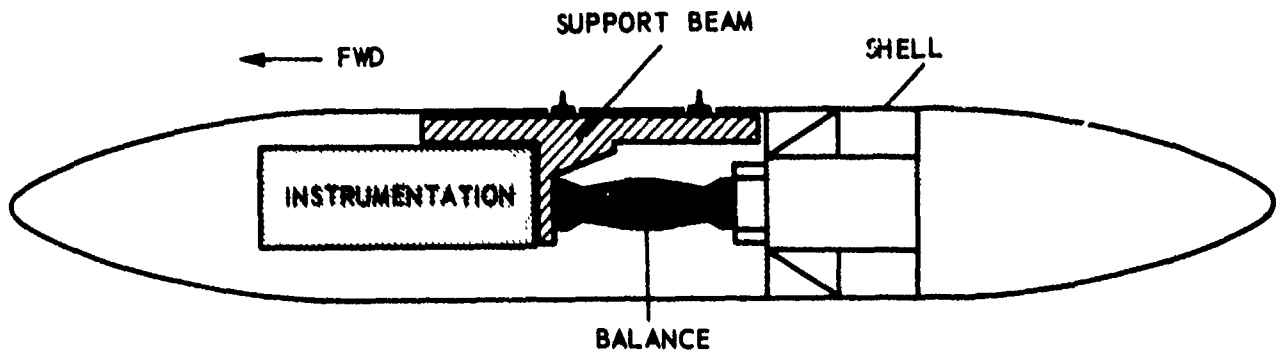


Figure 3 Five component aerodynamic load measuring store



Figure 4 Store balance



Figure 5 Store installed at the inboard pylon of the RNLAF NF-5A test aircraft

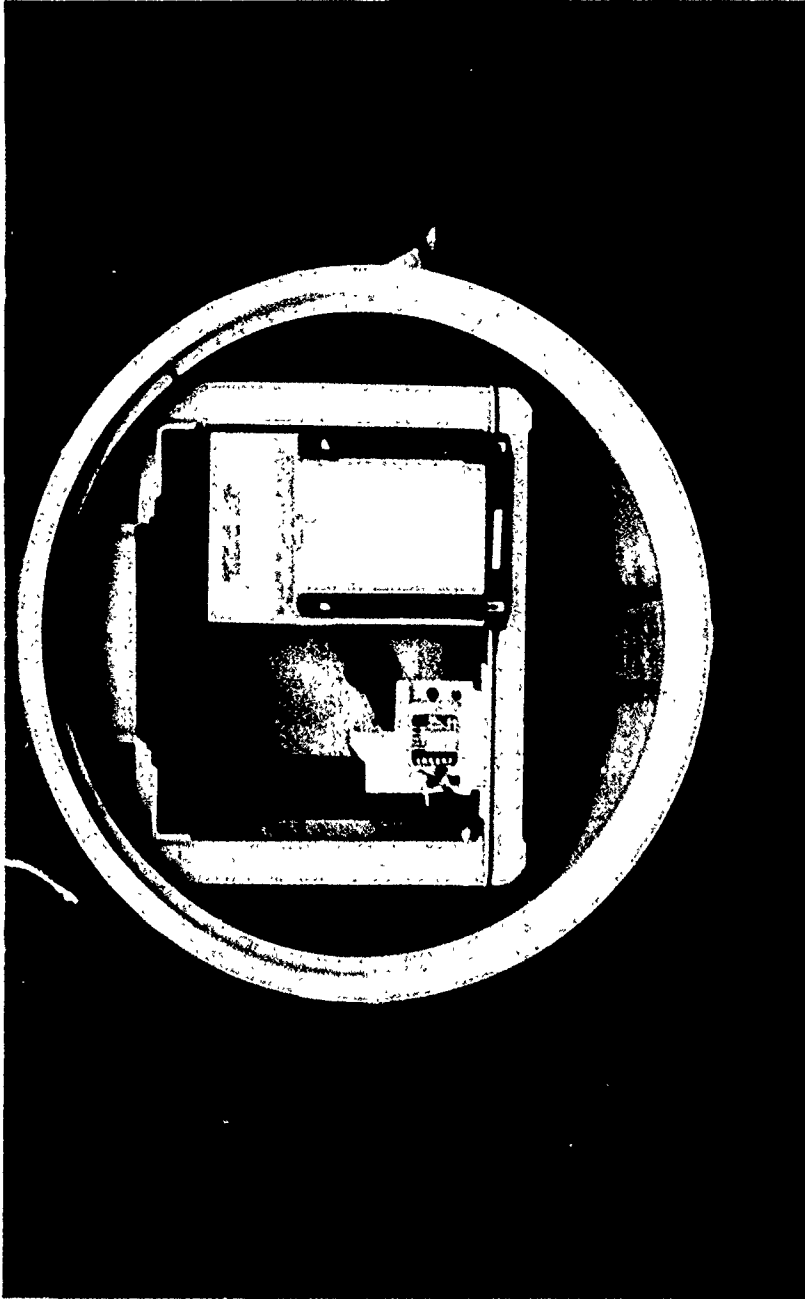


Figure 6 Instrumentation space in the store

The total store mass is 165 kg. The weighed part is 90 kg. When mounting the store from a wing pylon, store mass properties may be of importance. The present store has the mass properties of a LAU-3/A. By adding mass to the support beam other mass-inertia combinations can be made to satisfy peculiar flutter requirements.

The store was designed to make a change in shape as simple as possible. When other stores are to be measured only the shell needs modification. Balance, support beam and instrumentation remain unchanged. Stores with a diameter down to 14 inch can be accommodated.

DATA ACQUISITION AND PROCESSING

For the present trials the existing NF-5A K-3001 PCM-10 instrumentation system has been used for data acquisition. The most important parameters that have been recorded are shown in the schematic representation of data acquisition and processing in figure 7. Other parameters have been recorded during this first evaluation as a check on the validity of the information that has been obtained, but these are not essential to obtain the aerodynamic coefficients.

The PCM-10 system operates with 138 samples per second and records data with a resolution of one per mill. All signal conditioning used has a cut-off frequency of 5 Hz. The transfer functions of the strain gage and accelerometer channels were made identical, to minimize errors due to dynamic store behaviour.

Standard data selection, reduction and calibration routines are used to convert the raw data on the flight tape into computer compatible data files.

The processing consists of two parts. First force and moment coefficients are calculated, then a sorting and selection process is carried out to yield aerodynamic coefficients as a function of flight parameters. The loads acting on the balance are calculated using the strain gage outputs. The aerodynamic contributions are derived by subtracting the effect of store mass, as measured by the accelerometers. Using Mach number and static pressure the captive aerodynamic coefficients are calculated.

During flight tests it is difficult, if not impossible, to vary one flight parameter at a time. To arrive at an acceptable data presentation some sorting procedure has to be used. Sorting is done in an array consisting of specified intervals of Mach number and one other parameter (either α , β or δ_a). For the two remaining parameters intervals are set before the sorting process takes place. Only data within those intervals is admitted. The data loaded in the array consists of means and standard deviations of the five aerodynamic coefficients and the mean of the second array variable. Prints and plots are available as output. Print-out samples are provided in tables I and II.

When a self-contained instrumentation system is used in the store, a slightly different data acquisition scheme will be used. Static pressure and Mach number will be derived from a small pitot-static system, mounted in the store. Angle of attack and angle of side slip will be calculated from normal and lateral accelerations as measured in the store. For this purpose the pilot will have to record aircraft gross weight as a function of time and time will be recorded in the store as well. Difficulties will be encountered in measuring aileron deflection angle.

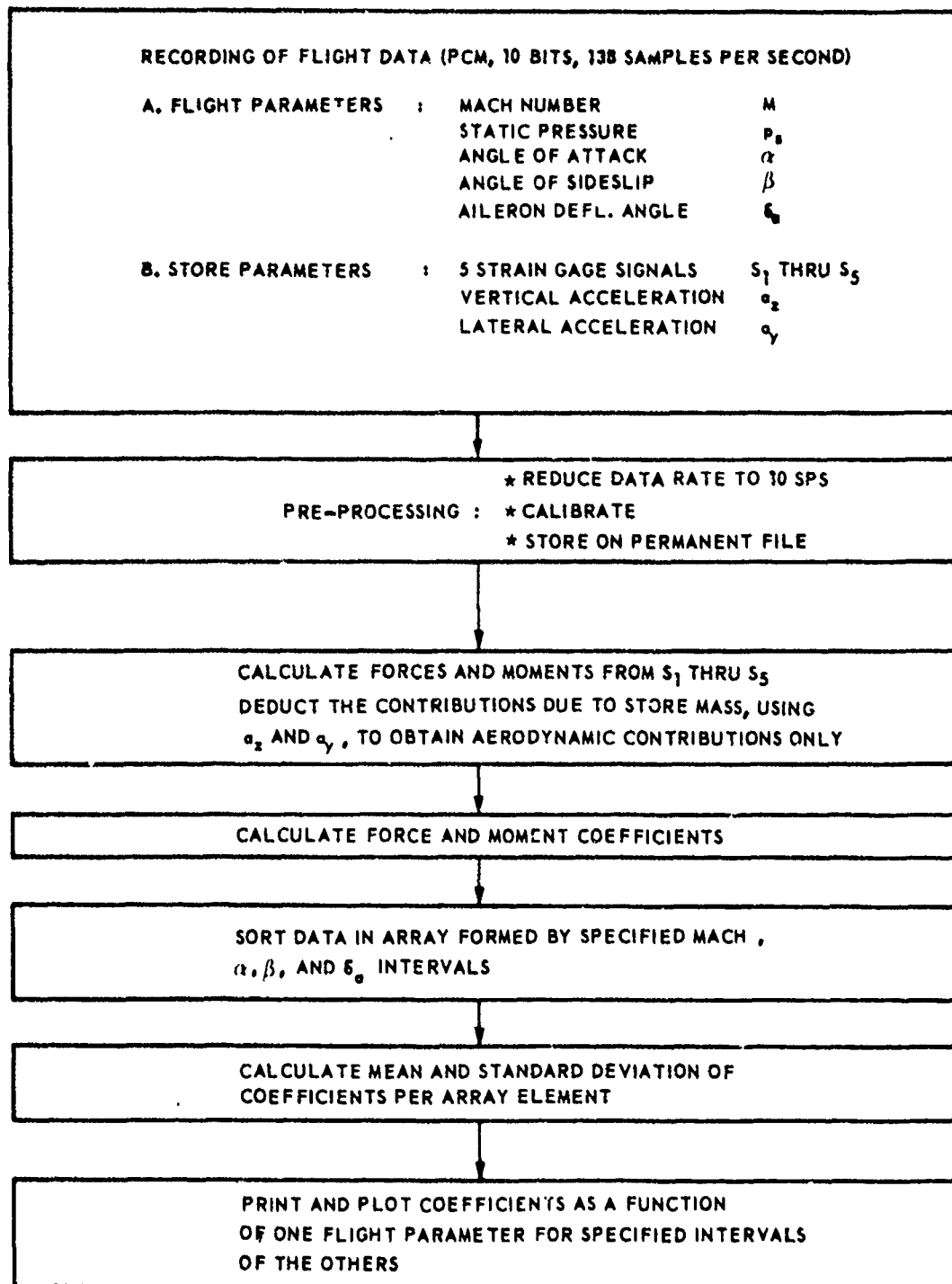


Figure 7 Data acquisition and processing scheme

AVERAGES AND STANDARD DEVIATIONS OVER EACH INTERVAL .750 - .850 $(-0.5^\circ < \beta < 0.5^\circ - \delta_0 < 1^\circ)$

α	C_{z_0}	C_{y_0}	C_{β}	C_{m_0}	C_{n_0}	NUMBER OF MEASUREMENTS
1	0.000	0.	0.	0.	0.	0.
2	0.000	0.	0.	0.	0.	0.
3	0.000	0.	0.	0.	0.	0.
4	0.000	0.	0.	0.	0.	0.
5	0.000	0.	0.	0.	0.	0.
6	.804	.674F-02	.558E-02	.202E-02	.677E-02	.120E-02
7	.654	.658F-02	.101E-02	.140E-02	.499E-02	.469E-02
8	.875	.541F-02	.608E-01	.805E-02	.110E-02	.844E-01
9	1.124	.269E-01	.576F-01	.130E-02	.755E-01	.399E-02
10	1.301	.548E-01	.691F-02	.140E-02	.702E-01	.174E-02
11	1.621	.497E-01	.621F-02	.146E-02	.385E-02	.105E-02
12	1.877	.631E-01	.497E-01	.124E-02	.385E-01	.235E-01
13	2.107	.853F-01	.473E-01	.124E-02	.346E-02	.243E-02
14	2.340	.962F-01	.438E-01	.138F-02	.375E-02	.353E-01
15	2.624	.113E+00	.401E-01	.111E-02	.354E-02	.283E-02
16	2.943	.130E+00	.367E-01	.117E-02	.325E-02	.417E-01
17	3.141	.149F+00	.300E-01	.100E-02	.306E-02	.472E-02
18	3.357	.158E+00	.220F-01	.150E-02	.289E-02	.463E-01
19	3.618	.174E+00	.154F-01	.144E-02	.311E-02	.240E-02
20	3.847	.194F+00	.115F-01	.115E-02	.290E-02	.240E-02
21	4.122	.208F+00	.120F-01	.150E-02	.290E-02	.314E-02
22	4.348	.223F+00	.122F-01	.153E-02	.294E-02	.322E-02
23	4.533	.238E+00	.142F-01	.117E-02	.347E-02	.294E-02
24	4.819	.253E+00	.172F-01	.141F-02	.375E-02	.341E-02
25	5.119	.274E+00	.212F-01	.174E-02	.391E-02	.382E-02
26	5.347	.287E+00	.180F-01	.142E-02	.400E-02	.449E-02
27	5.643	.302E+00	.192E-01	.134E-02	.435E-02	.415E-02
28	5.855	.322E+00	.167E-01	.167E-02	.455E-02	.446E-02
29	6.119	.325F+00	.194F-01	.180E-02	.466E-02	.466E-02
30	6.350	.345F+00	.164E-01	.225E-02	.455E-02	.466E-02
31	6.616	.372E+00	.221F-01	.237E-02	.444E-02	.412E-02
32	6.842	.372E+00	.221F-01	.252E-02	.460E-02	.276E-02
33	7.110	.389E+00	.303E-01	.291E-02	.460E-02	.615E-02
34	7.397	.412E+00	.303F-01	.351E-01	.472E-02	.615E-02
35	7.599	.422E+00	.281F-01	.422E-02	.494E-01	.380E-02
36	7.873	.444F+00	.244F-01	.432E-02	.494E-02	.436E-02
37	8.103	.439F+00	.207E-01	.234E-02	.487E-01	.246E-02
38	8.356	.457E+00	.140F-01	.240E-02	.483E-01	.486E-02
39	8.672	.468E+00	.202F-01	.251E-02	.472E-02	.182E-02
40	8.944	.493F+00	.252F-01	.254E-02	.458E-01	.280E-02
41	9.120	.472E+00	.101F-01	.164E-02	.479E-01	.317E-03
42	9.403	.560E+00	.931F-01	.128E-01	.463E-01	.294E-02
43	9.612	.513E+00	.186E-01	.153E-01	.513E-01	.206E-02
44	9.659	.524F+00	.185F-01	.153E-01	.483E-01	.314E-02
45	10.124	.535E+00	.158F-01	.192E-01	.519E-01	.313E-02
46	10.373	.543F+00	.317F-01	.180E-01	.484E-01	.363E-02
47	10.563	.559E+00	.376F-01	.179E-01	.540E-01	.340E-02
48	10.811	.583E+00	.319F-01	.220E-02	.629E-01	.457E-02
49	11.001	.605E+00	.923E-01	.160E-01	.583E-01	.101E+00
50	11.400	.625F+00	.401F-01	.167E-01	.714E-01	.372E-02

Table I Print-out sample with angle of attack as a variable

AVERAGES AND STANDARD DEVIATIONS OVER MACH INTERVAL 0.000 - .600 ($3^\circ < \alpha < 4^\circ$ - $4^\circ < \delta < 4^\circ$)

β	C_{z_0}	C_{y_0}	C_{l_0}	C_{m_0}	C_{n_0}	NUMBER OF MEASUREMENTS
1	-5.564	.954E-01	-.217E-01	.151E-01	.131E+00	1.
2	-5.195	.792E-01	-.197E-01	.137E-01	.130E+00	1.
3	0.000	0.	0.	0.	0.	0.
4	-4.210	.771E-01	.262E-01	.603E-02	.113E-01	5.
5	0.000	0.	-.127E-01	.570E-02	.100E+00	0.
6	-3.068	.525E-01	.540E-02	.149E-02	.971E-01	0.
7	-2.602	.264E+00	.433E-02	.313E-02	.760E-01	2.
8	-2.005	.227E+00	-.527E-02	.922E-04	.620E-01	2.
9	-1.718	.181E+00	.677E-01	.258E-01	.786E-02	1.
10	-1.105	.147E+00	.411E-01	.133E-01	.623E-01	2.
11	-.532	.921E-02	.272E-01	.289E-02	.124E-01	2.
12	-.320	.134E+00	.233E-01	.514E-02	.456E-02	2.
13	.115	.107E-01	.535E-02	.427E-02	.453E-02	3.
14	.775	.270E-01	.401E-02	.192E-02	.354E-02	19.
15	1.348	.237E-01	.184E-02	.212E-02	.604E-02	5.
16	1.721	.437E-01	.341E-02	.130E-02	.130E-01	1.
17	0.000	0.	-.873E-03	-.793E-02	.660E-02	2.
18	2.659	.162E-01	.374E-02	.152E-02	.740E-02	0.
19	3.234	.156E-04	.242E-02	.463E-02	.456E-02	4.
20	3.732	.164E-01	.254E-02	0.	.115E-01	3.
21	4.354	.130E-01	.653E-02	.192E-02	.580E-02	1.
22	4.727	.821E-02	.420E-02	.128E-01	.576E-01	3.
23	0.000	0.	0.	-.143E-01	-.733E-01	1.
24	0.000	0.	0.	0.	0.	0.

Table II Print-out sample with angle of side slip as a variable

FLIGHT TESTS

A summary of the configurations tested to date is provided in table III (M indicates the position of the measuring store). In configuration A the structural integrity of the store was demonstrated. On configurations B and C the largest body of measured and calculated aerodynamic and store motion data is available. Configuration C was selected to evaluate repeatability of the measurements, D to evaluate the effect of the presence or absence of an inboard store.

As a follow-on to this program measurements will be carried out with the store mounted 0.15 m below the pylon. In this way the variation of aerodynamic interference with vertical position relative to the pylon can be evaluated.

To obtain adequate coverage of the Mach number-angle of attack data array a slow symmetrical flight manoeuvre was prescribed. The pilot had to start this manoeuvre at Mach number intervals of approximate 0.025. A number of actual measurement runs is shown in figure 8. Normal load factor was limited to 3, as a precaution not to overload the balance. In the figure it is shown how a typical data sorting array element will be filled. See also table I for the number of measurement points per array element. Variation in aerodynamic coefficients as a function of angle of side slip or aileron deflection angle is measured by means of rudder pulses (β) and aileron oscillations (δ_a) during nominal straight and level flight.

FLIGHT TEST SUMMARY

(ONE FLIGHT PER CONFIGURATION)






NF - 5A CONFIGURATIONS	MACH RANGE																								
<p>A</p> 	0 → 1.0																								
<p>B</p> 	}																								
<p>C</p> 																									
<p>D</p> 																									
<p>E</p> 																									
0 → 0.85																									
<p>FLIGHT CONDITIONS :</p> <table border="0"> <tr> <td>0</td> <td>TO</td> <td>30,000</td> <td>FEET</td> </tr> <tr> <td>200</td> <td>TO</td> <td>600</td> <td>Kts</td> </tr> <tr> <td>0</td> <td>TO</td> <td>12</td> <td>DEGREES ANGLE OF ATTACK</td> </tr> <tr> <td>-5</td> <td>TO</td> <td>5</td> <td>DEGREES SIDESLIP ANGLE</td> </tr> <tr> <td>-20</td> <td>TO</td> <td>20</td> <td>DEGREES AILERON ANGLE</td> </tr> <tr> <td>-0.5</td> <td>TO</td> <td>3.0</td> <td>NORMAL LOAD FACTOR</td> </tr> </table>		0	TO	30,000	FEET	200	TO	600	Kts	0	TO	12	DEGREES ANGLE OF ATTACK	-5	TO	5	DEGREES SIDESLIP ANGLE	-20	TO	20	DEGREES AILERON ANGLE	-0.5	TO	3.0	NORMAL LOAD FACTOR
0	TO	30,000	FEET																						
200	TO	600	Kts																						
0	TO	12	DEGREES ANGLE OF ATTACK																						
-5	TO	5	DEGREES SIDESLIP ANGLE																						
-20	TO	20	DEGREES AILERON ANGLE																						
-0.5	TO	3.0	NORMAL LOAD FACTOR																						

Table III Flight test summary

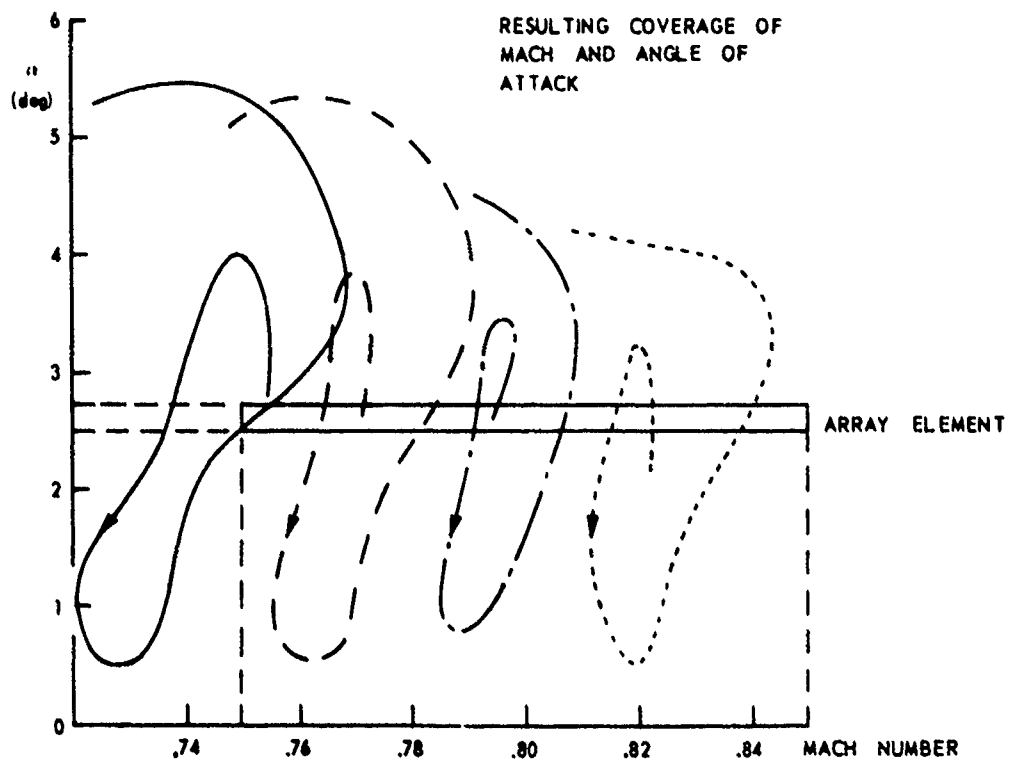
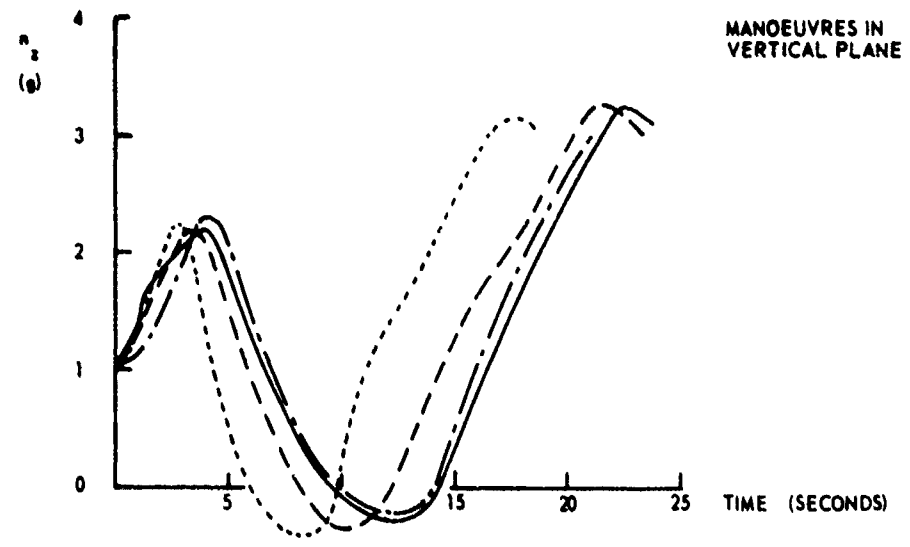


Figure 8 Typical data acquisition manoeuvres

RESULTS

PROPERTIES OF THE MEASURED DATA

From static and dynamic ground trials the accuracy of the aerodynamic load measuring store has been estimated. The accuracy of the mean value of the measurements in case a large number of measurements is taken and of the standard deviation in that case is shown in table IV.

Parameter	Accuracy of force/moment		Accuracy of coefficients at:					
			200 kts		300 kts		400 kts	
	mean	SD	mean	SD	mean	SD	mean	SD
Z, C _z	±45 N	±70 N	.045	.070	.015	.025	.011	.015
Y, C _y								
L, C _l	± 3 Nm	± 5 Nm	.003	.010	.002	.005	.001	.003
M, C _m	±20 Nm	±40 Nm	.005	.010	.002	.004	.001	.002
N, C _n								

Table IV Measurement accuracy data

The standard deviations of the flight test data that have been obtained under low to moderate turbulence conditions match the table IV values. Repeatability checks, where the data obtained in one configuration was processed in batches did confirm the accuracy estimate for the mean value.

In the configuration with the store at the outboard pylon two flights have been carried out, one with the store of the left hand station, and one with the store at the right hand station. Comparison of the results of both flights show a definite difference in captive yawing moment data. The difference appears as a pure shift of ~ 0.006 . As the free air moment coefficient derivative about the vertical store axis is .016 per degree, the difference can be caused by:

- a relative misalignment of left hand and right hand store of 0.4 degree or
- an average aircraft angle of side slip of 0.2 degree.

Either of these conditions may have existed without being noticed.

The measurement runs have been repeated at various altitudes (5,000; 10,000; 20,000; and 30,000 feet). Data has been processed per altitude to evaluate whether any Reynolds-effect was present. No significant differences were noted.

DATA SOURCE/ CONFIGURATION	SCALE	REYNOLDS NUMBER 1)	BOUNDARY LAYER TRANSITION STRIP	GAP BETWEEN STORE AND PYLON	METHOD, PARTICULARS
Wind tunnel Ref.1	1/7	$\sim 2 \cdot 10^6$	on store nose	partly blocked by balance support	Force/moment measurements full model
Wind tunnel Ref.2	1/4.5	$5 \cdot 10^5$ to $10 \cdot 10^6$.05 m from store nose	no gap	Integration of pressure measurements; pressure holes in 11 cross sections, 8 holes per cross-section. Half-wing model, no inboard pylon
Calculations Ref.3	-	-	-	with gap	Assuming potential flow, partly corrected for vis- cosity effects
Flight tests	1/1	$6 \cdot 10^6$ to $5 \cdot 10^7$	none	with gap	Separation trials. Coeffi- cients calculated according to Fig.2.
Flight tests	1/1	$8 \cdot 10^6$ to $5 \cdot 10^7$	none	with gap	Force/moment measurements

1) Based on wing mean aerodynamic chord.

Table V Leading particulars on the data sources for aerodynamic coefficients of captive stores.

COMPARISON WITH DATA FROM OTHER SOURCES

The configuration labelled B in table III has been used in the past to evaluate accuracy of store separation measurement techniques as well as to demonstrate the prediction possibilities of the model shown in figure 1. Thus a large and varied body of information is available. The part that is used is summarized in table V.

The data is compared with the results of the measuring store in figures 9 (pitching moment), 10 (yawing moment) and 11 (normal and lateral forces). Furthermore store motion during separation has been calculated for a flight condition at 450 KEAS, $M=0.7$, $\alpha=2.5$, using the $M=0.7$ wind tunnel data (Ref. 1) as well as the data measured in flight. Note that only the pitching moment coefficient differs in this particular case. The result, shown in figure 12 is indicative of the significance of the differences in the various data sets in figures 9 and 10.

Wind tunnel and calculated force coefficients agree reasonably with the values measured with the store. A notable exception is the C_{z0} value obtained from reference 2, possibly due to the absence of the gap. The moment coefficients from these sources agree less well. No effort will be made yet to identify the cause of these differences. Candidate causes are listed in table V.

Moment coefficients, calculated by modifying captive aerodynamic coefficient sets based on wind tunnel measurement according to the scheme of figure 2, agree very well with the data measured with the store. In this particular case the prediction model was operating using captive aerodynamic data as the basis for the calculation of interference aerodynamics. The variation of aerodynamic interference with vertical position was based on panel method calculations (Ref. 3).

Difference between measured and recalculated captive aerodynamic data may originate from errors due to the quasi-steady treatment of a non-steady process as is done in the model of figure 1, or from wrong modelling of the variation in interference with vertical position. As the moment coefficients agree well, it is likely that both the quasi-steady treatment and the calculated variation in interference are sufficiently accurate. This will be verified by carrying out measurements in flight with the store 0.15 m below its normal position at the pylon.

Inversely it indicates that, when using aerodynamic coefficients measured in-flight for prediction of store separation, the result will be very reliable, especially when the aerodynamic coefficients are measured at one (or more) positions below the pylon. This possibility will be of prime importance in case separations from multiple ejector racks are concerned.

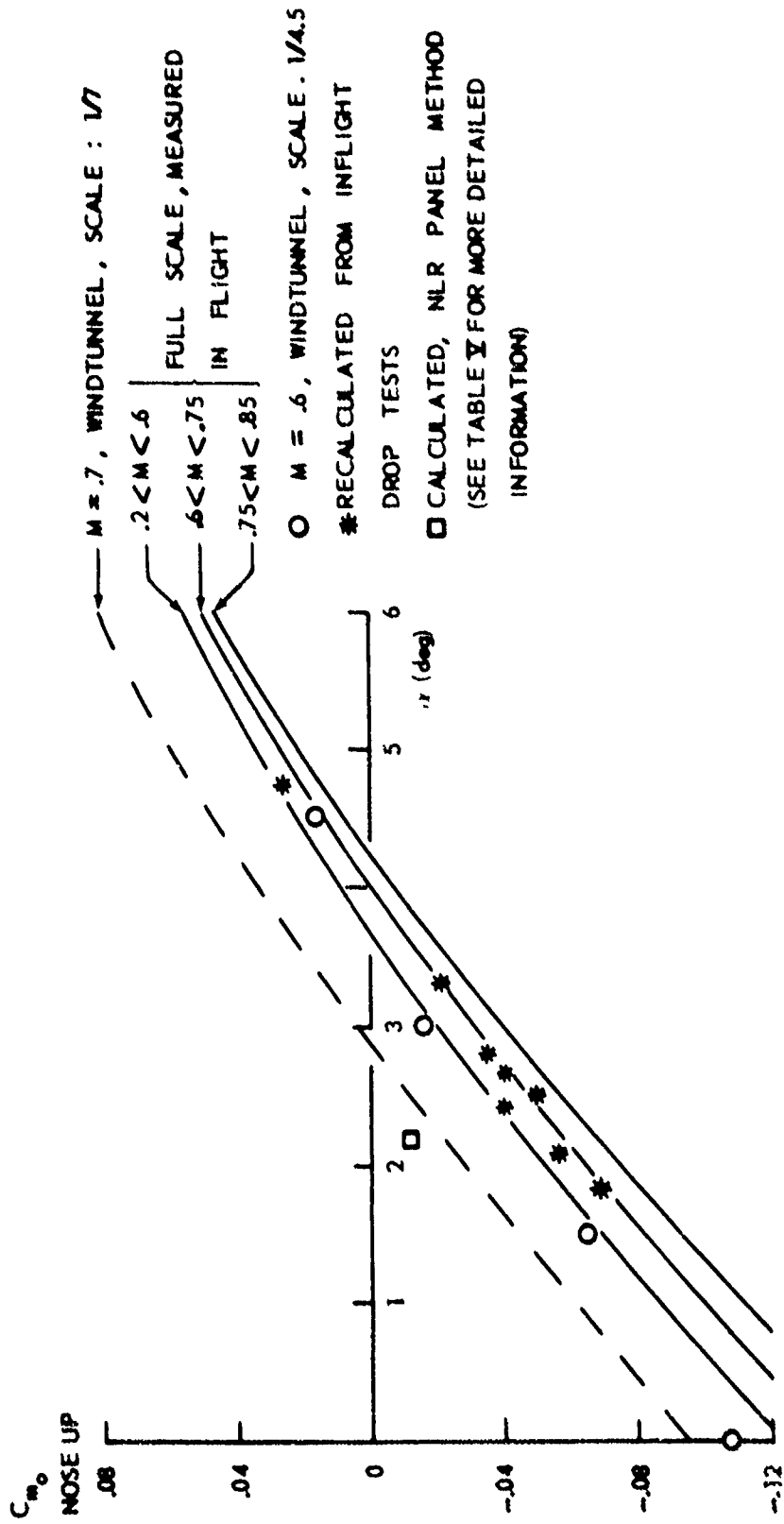


Figure 9 Captive pitching moment coefficient

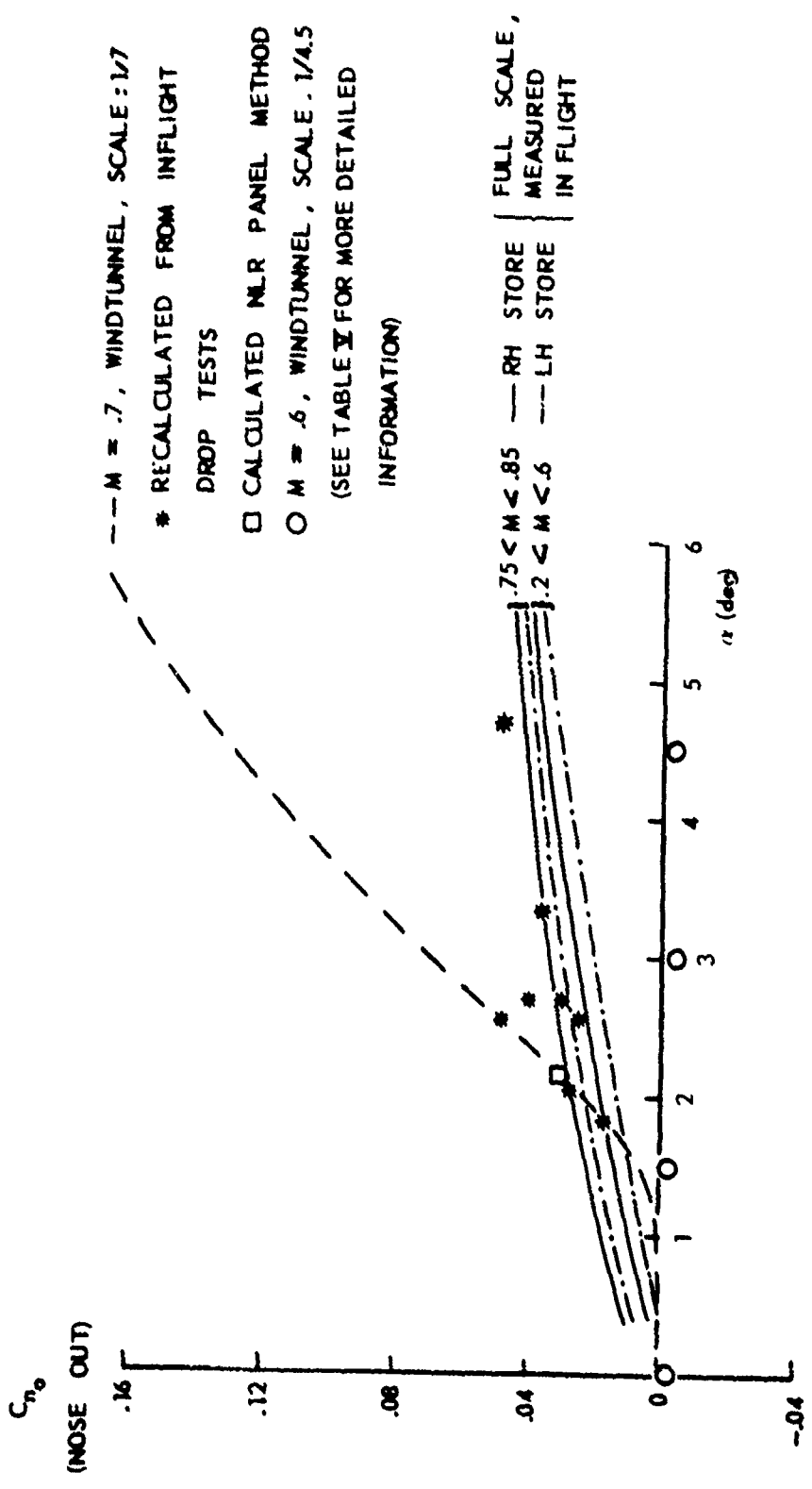


Figure 10 Captive yawing moment coefficient

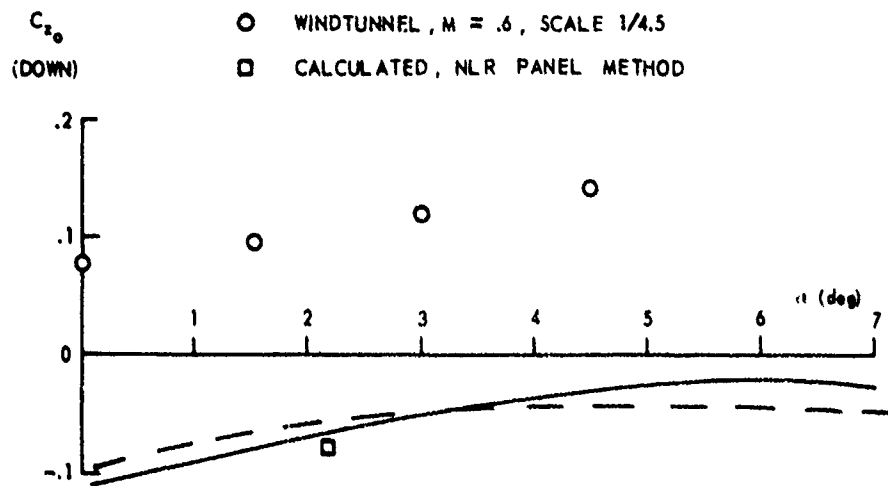
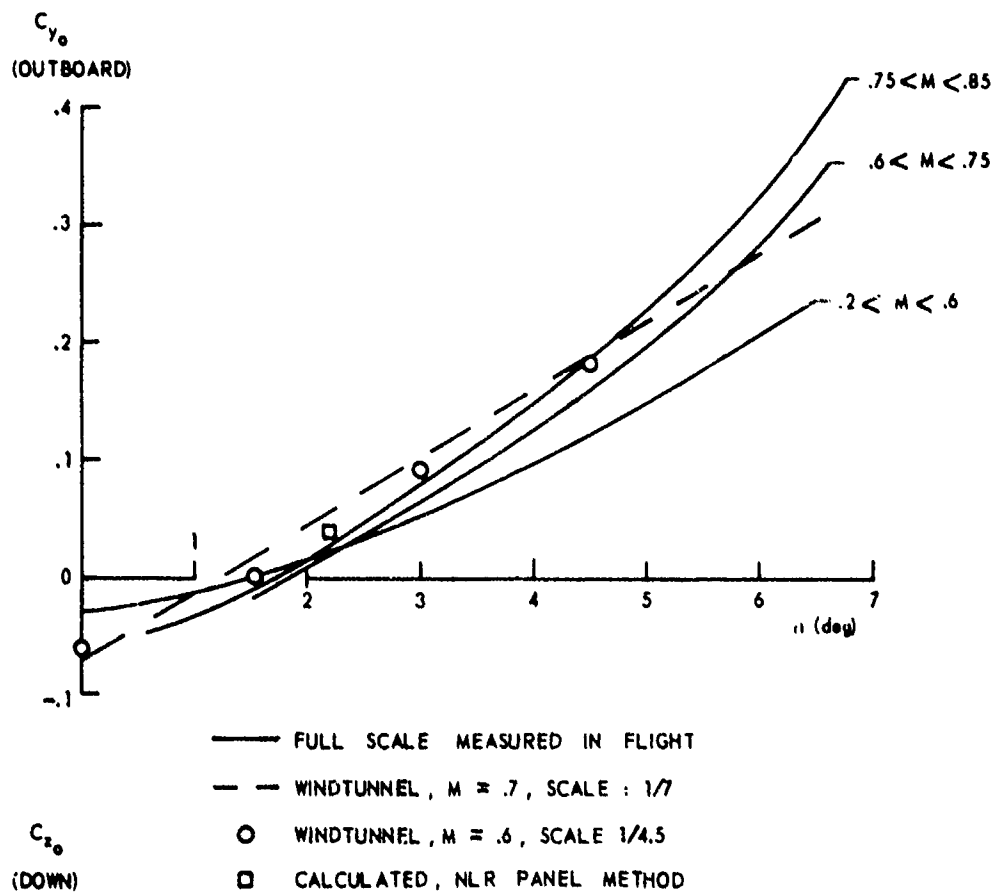


Figure 11 Captive force coefficients

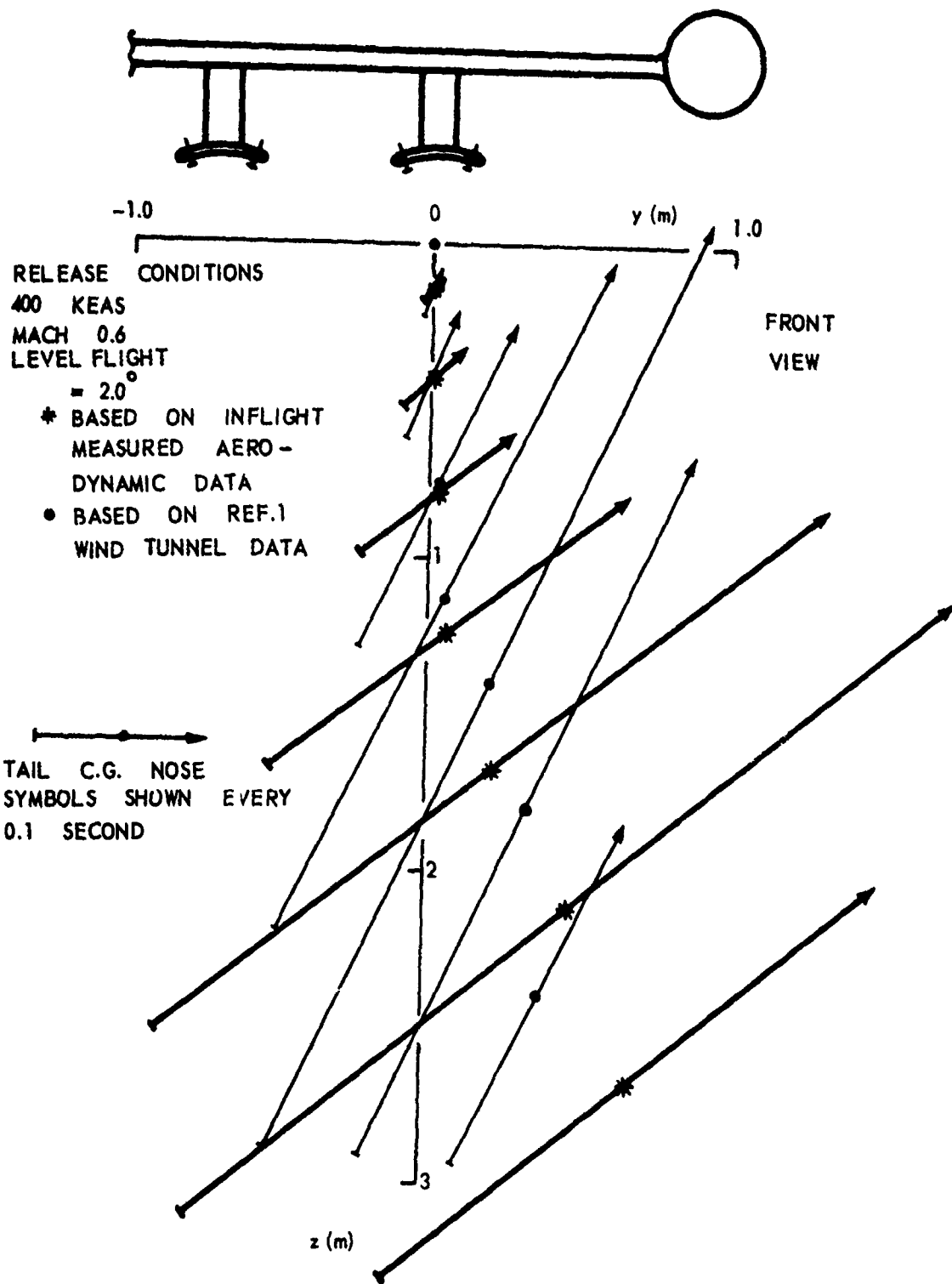


Figure 12 Differences in captive pitching moment coefficient, translated in differences in store motion

CONCLUDING REMARKS

The tests have demonstrated the feasibility of in-flight measurement of aerodynamic coefficients in an accurate manner.

Such measurements, when used in combination with a adequate store separation prediction program, will make store separation analysis more trustworthy. Subsequently the number of drops required to demonstrate safe separation may be reduced.

It is expected that the use of an aerodynamic load measuring store will pay off primarily in cases where separation might be critical. Light and large stores, unstable stores, and the transonic flight regime are examples of such cases.

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AUTOBIOGRAPHY

The author graduated from the Delft University of Technology in 1966 as an aeronautical "ingenieur", with a specialization in the field of flying qualities.

The years 1966 thru 1968 he spent with the Royal Netherlands Air Force, where he was a project officer in the Bureau for Operations Research and Evaluations.

From 1968 on he is employed by the National Aerospace Laboratory NLR in Amsterdam as a project manager and flight test engineer, mainly in the field of airworthiness demonstration and systems evaluation projects with military aircraft. His activities in the field of store separation analysis include the development of a store separation prediction programme, and of a method to determine actual store motion with on-board film cameras.