P/AERODYNAMICS OF ARMAMENT/5

CF-105 ARMAMENT INSTALLATION

REVIEW OF EXPERIMENTAL AND ANALYTICAL PROGRAM

J. Stalony-Dobrzanski

June 1955

INDEX

INDEX TO FIGURES

1. INTRODUCTION

The proposed armament of the C-105 consists of internally stowed missiles. Under design consideration are the following installations:

(i) 8 Falcon missiles stowed in fuselage in two rows of 4 abreast.

(ii) 3 or 4 Sparrows stowed in fuselage, in one row.

To be able to proceed with the design of these installations considerable amount of aerodynamic data is necessary to evaluate the problems of mechanical operation and of aerodynamic separation from the aircraft under varying flight conditions.

This report presents the planning of both experimental and analytical efforts which were conceived to provide the required data. It also reports on the state of completion of various phases of the program up to date.

2. SURVEY OF EXPERIMENTAL TECHNIQUES

Existing experimental techniques indicated several ways of tackling the problem.

2.1 Detailed wind tunnel testing.

2.2 Testing and development using high speed sled technique.

2.3 Testing and development in actual flight testing.

3. CHOICE OF EXPERIMENTAL TECHNIQUE

Survey of existing aerodynamic data shows lack of adequate general data to calculate the problems of a particular installation involving, as it does, strong interference effects.

Number of parameters requiring investigation is large and therefore, the number of tests will be large. This eliminates the supersonic sled and flight test as techniques for gathering basic design data as the time and expenditure would be prohibitive. They can be very useful, however, as final check-out of the overall performance at the stage when only minor modifications can be expected. They also provide sole means of proving the dynamic operation of the full scale mechanism under actual aerodynamic loading. For obtaining basic and extensive data the only suitable technique appeared to be wind tunnel testing. Consequently, a large wind tunnel program was proposed.in October 1954. Design, manufacture of the models and the actual testing was completed in April 1955.

4. CHOICE OF WIND TUNNEL TECHNIQUE

The solution of the problem of interference data can be approached in two ways:

4.1 Attempt to map the flow around the aeroplane in areas of interest to trajectory calculation. Obtain the aerodynamic characteristics of the missile in the unobstructed flow. Combine the two sources of data analytically to arrive at the forces acting on the missile in any particular location. This is by no means easy and possibly subject to a considerable error. It should be remembered here that this method introduces of necessity interference of measuring instruments themselves.

4.2 Place the missile actually in the proper locations with respect to the aeroplane and measure the forces including all interference effects directly on the missile. It should be fairly obvious that the second method is much superior if possible of accomplishment within the very real limitations of physical space available.

4.3 Detailed investigation shown that it was possible to construct an .04 scale model of the C-105 in which the forces and moments on the missiles would be measured on balances contained entirely inside the missile. Cornell Aeronautical Laboratories Inc., were given a contract for designing and manufacturing of the models and wind-tunnel testing of these in the 3' x 4' variable density transonic wind tunnel.

5. WIND TUNNEL PROGRAM

The program was divided into four parts:

5.1 Check on the validity of tests using .04 scale model. This size model, which was dictated by minimum space requirements for internal balances of the missiles, is somewhat critical when used in a 3' x 4' tunnel. To establish the absence of any undesirable interference effects between the model and the tunnel tests were scheduled of longitudinal and directional stability throughout the entire available ranges of:

5.1.1 Mach Number (.5 to 1.23)

5.1.2 Angle of incidence (-4° to $+12^{\circ}$).

5.1.3 Angle of sideslip ($\pm 12^{\circ}$).

5.2 Determination of aerodynamic forces acting on the missile installation during the lowering of the missiles and launching.

Missiles were always tested in rows of all four abreast but in various combinations of front row only, aft row only, both rows together and the positions during lowering. As can be seen the number of combinations is large and it was deemed impractical to go any further and add combinations due to incomplete rows. Measurements were made in various stages of lowering with doors open and closed as follows:

5.2.1 Door open.

5.2.1.1 Missiles fully up.

5.2.1.2 Missiles half way down.

5.2.1.3 Missiles fully down.

5.2.2 Door closed.

5.2.2.1 Missiles fully down.

5.2.3 Particular measurements taken were:

5.2.3.1 Normal force and pitching moment, side force and yawing moment including as metric missile, launcher and lowering links.

5.2.3.2 Pressures inside the armament bays on the roof, sides, forward and aft bulkhead: total (14) pressure orifices.

5.2.3.3 Hinge moments on all the doors.

5.2.4 Mach number range was limited to .95 and 1.23, one representing the high subsonic condition the other the highest supersonic condition available in the test facility. Increasing the number of Mach numbers (transonics) would result in prohibitive time and cost penalty.

5.2.5 Full incidence range was tested (α = - 4° to + 12°).

5.3 Determination of aerodynamic forces acting on the missiles for trajectory purposes.

5.3.1 Missiles were located in case of Falcons in 5 and in case of Sparrows in 4 positions along the fuselage until clearing the nose. Location was on the approximate theoretically calculated trajectories. At each position measurements were taken on 4 missiles abreast (3 in case of Sparrows) to include full interference effects between the aircraft and the missiles and between the missiles themselves. Again it was considered impractical to increase the number of combinations due to incomplete rows (See 5.2).

5.3.2 In each position measurements were taken with missiles in the normal position (pointing in the direction of the theoretical trajectory) and ∓ 1.5° in pitch and yaw from that position for Falcons and ∓ 1° for Sparrows. The reason for this is discussed below in section 7.5 Analysis of results.

5.3.3 Measurements taken on all the missiles were normal force and pitching moment, side force and yawing moment including as metric the missile only.

5.3.4 Balances were completely contained inside the missiles supported by stings terminating well aft on the fuselage. Thus, the interference due to instrumentation was nil in the supersonic case and at minimum in the subsonic case.

5.3.5 Mach numbers tested: .95 and 1.23 (see 5.2.4).

5.3.6 Incidence range tested $\alpha = -4^{\circ}$ to $+ 12^{\circ}$.

5.4 Determination of the effect of missiles on the aircraft.

5.4.1 Missiles wer located in various stages of lowering and combinations of rows and doors open or closed as in 5.2.1 and 5.2.2.

5.4.2 Measurements taken were:

5.4.2.1 From the six component balance contained inside the aircraft supported on a sting: lift, drag, side force, pitching, yawing and rolling moments.

5.4.2.2 Base pressure.

5.4.3 Missiles were attached to aircraft by properly represented linkage and launchers. No forces on missiles were measured in this test.

5.4.4 Mach numbers tested: .95 and 1.23 (see 5.2.4).

5.4.5 Incidence range tested $\alpha = -4^{\circ}$ to $+12^{\circ}$.

5.5 For detail wind tunnel schedule, see Appendix 1.

5.6 For location of the Falcon models with respect to the aircraft, see Figures 1 and 2.

6. RESULTS OF WIND TUNNEL TESTS

6.1 Inspite of the great complexity, large number of channels of information and extremely small sizes of balances inside the missiles, the tests were very successful. All measurements set forth under 5 were obtained with exception of one Falcon missile which was inoperative through part of test 5.3.

6.2 The data were corrected for interaction, aeroelastic distortions of the model and static tare.

6.3. Basic data are presented as functions of a/c incidence. Typical results are shown on Figures 3,4,5, 6 for outboard, rear row Falcon (No. 7).

7. ANALYSIS OF WIND TUNNEL RESULTS

Analysis of results will fall logically into four parts corresponding to the sub-division of wind tunnel program (see Section 5).

7.1 It was found that the .04 model was free from any adverse effects of interference between the tunnel walls and the model. This was established by comparing stability data of the .04 model and previously obtained .03 model data. These two models had the same configuration: 10% leading edge extension and 5% notches. There were small local changes in the shape of the fuselage and the intakes. These changes, as expected, resulted in slightly different C_{M_o} and α_o.

However, the shapes of the curves representing longitudinal stability, as can be seen from Figure 7, were unaffected.

7.2 Analysis of the forces acting on the missiles during lowering and launching will be completed in two phases:

7.2.1 Static analysis will determine the distortion of the lowering mechanism during lowering of the missile and launching, neglecting the dynamics of the mechanism. This will give an approximate answer to the problem to get the "feel" of the situation. The main advantage of tackling the problem in this way, in stages of increasing complexity, is that (i) answers to static problems can be obtained relatively much faster and educated estimates can be formed which are immediately useful to the Design Office, (ii) Solving a problem with all the possible complications included right from the start takes of course much longer, and also, which is worse, usually results in errors creeping in due to lack of physical interpretation for intermediate steps of an involved calculation. This is particularly so, if performed in a semi-automatic manner which will be the case.

This part of the program is well advanced and a typical example is shown on Figures 8 and 9, where linkage distortion and angular position of the missile is given as function of missile travel on the launcher for different stiffnesses of the links (Schemes 1 and 2).

7.2.2 Dynamic analysis including all the effects neglected in 7.2.1 above, results in a system of non-linear differential equations. It is proceeding at present by evaluating a typical case by hand calculations and simultaneous preparation of the problem for handling by computing machines. Pilot hand calculation is rather lengthy, but absolutely essential as a check for machine results. It is expected that the results of the dynamic calculation will confirm the conclusions arrived at on the basis of static calculations described above.

The final product of these calculations will be criteria for linkage stiffness and the length of the launcher.

7. ANALYSIS OF WIND TUNNEL RESULTS Cont'd.

7.3 Analysis of the trajectories of the missiles from the aircraft safety point of view is being handled similarly to 7.2 as on the previous page.

7.3.1 Static analysis in this case leads to determination of the initial angle of launch which will result in a stable missile in both longitudinal and directional plane. It also determines the equilibrium angle to which the missile will tend as it travels along the fuselage. The contention here is that a stable missile, particularly with respect to gusts, with known equilibrium conditions will be much safer to an unstable one. Typical results of this type of analysis are shown on Figures 10 and 11. From Figure 11 it can be seen that to be well in a stable region, the initial missile launching angle in pitch should be about -3^{o} with respect to fuselage datum.

7.3.2 Dynamic analysis will result in fully calculated trajectories in the horizontal and vertical planes. It may possibly happen that in some cases with an initially unstable missile, a clean separation could be achieved. However, such a calculation is very involved and will necessarily take a long time. It is hardly justifiable to delay design decisions to await these results.

Therefore, it seems that the better course of action is to start with a stable missile established by the static analysis and then only confirm this decision by a subsequent full dynamic treatment. It is thought most unlikely that the dynamic calculations of an initially stable configuration will indicate necessity of design modifications.

7.4 The effect of the missiles on the aircraft during lowering and when fully down were determined as far as steady state change of pitch is concerned and are presented on Figures 12 and 13. As can be seen from this graph, these effects in terms of change in the normal load factor are quite small and above 20,000 feet can be considered negligible. It should be remembered that these changes will be further alleviated by the operation of the pitch damper.

In view of the smallness of these effects, their transient dynamic analysis is not contemplated at the present time. However, when the time comes for a full simulation of fire control runs on the analogue computer, they will of course, be included. In the meantime, it is concluded that a special compensating input into the elevator in anticipation of missile lowering (compare CF 100) will not be required.

7.5 The actual design of the armament installation has changed somewhat from the time of initiation of the wind tunnel program (October 1954). To get any tests at all completed in a reasonable time, it was necessary to disregard any changes once the model manufacture started. However, as indicated in 5.3.2 measurements were taken with some deviations from standard positions and it is believed that enough data was obtained to allow reliable interpolation and extrapolation.

8. STATE OF THE PROGRAM UP TO DATE (JUNE 1955)

8.1 Wind tunnel test - completed by April 1955.

8.2 Reduction of data and plotting of basic data, i.e. all the variable versus aircraft incidence - completed 80%.

8.3 Static analysis of the lowering mechanism and aeroelastic distortion during launching - 40% completed.

8.4 Static analysis of the trajectories - 30% completed.

8.5 Dynamic analysis of aeroelastic distortion of linkage during lowering and launching - 10% completed.

8.6 Dynamic analysis of the trajectories - 10% completed.

8.7 Analysis of the jettisoning problems - 20% completed.

9. PROPOSED FURTHER EXPERIMENTAL PROGRAM

9.1 Jettison tests to be conducted at N.A.E. Low Speed Tunnel. Design of missile models to be used with the .07 scale CF 105 model is proceeding at Avro. Target date for design completion 31st July 1955. Models to be manufactured by Avro by 1st October 1955. Tentative test date 15th October 1955.

9.2 High speed sled tests are in the initial proposal stage. They would be conducted at Inyokern U.S. Navy establishment. These tests to be of any value will have to be conducted with a full scale model of the actual installation and to have representative front portion of the fuselage (ahead of the missile bay) and the intakes.

It is expected to obtain the following data as result of these tests:

9.2.1 Operation and stability of the lowering mechanism during lowering and launching under forces simulating full dynamic pressures expected in flight.

9.2.2 Evaluation of the interference of the missiles with the intakes which could possibly lead to engine blow-out in some conditions.

10. SUMMARY

The reasoning which led to wind tunnel tests of armament installation is reviewed. It is concluded that the only practical technique for obtaining basic design data are extensive wind tunnel tests. The program according to which these tests were completed is presented. Tests results and method of analysis are discussed. It is proposed that, in view of the urgency with which design information is needed, such information be based upon static type of analysis. Full dynamic analysis is progressing concurrently and it is thought that its results, when available, will confirm this decision. The present state of the completion of the program is presented. Finally the proposed further experimental program is discussed.

APPENDIX I

CF-105 TRANSONIC WIND TUNNEL TESTS

DETAIL SCHEDULE OF ARMAMENT TESTS

		RUNS
1.	**Check on the Wind Tunnel Model Interference**	
	M = .5, .8, .9, .95, .98, 1.00, 1.05, 1.10, 1.15, 1.23	
	1.1 Longitudinal Stability $\alpha_{var} = -4^{\circ} +12^{\circ}$	10
	1.2 Directional Stability $\alpha = + 2^{\circ}$ $\psi = \pm 12^{\circ}$	10
	TOTAL	20
2.	**Forces on Missiles, Doors and Pressures inside the Armament Bay**	
	M = .95, 1.2 $\alpha_{var} = -4^{\circ} + 12^{\circ}$	
	2.1.0 **Missiles fully retracted - door open**	
	2.1.1 Missiles in both bays - forward missiles instrumented	2
	2.1.2 Missiles in both bays - aft missiles instrumented	2
	2.1.3 Missiles in forward bay only	2
	2.1.4 Missiles in aft bay only	2
	2.2.0 **Missiles half way down - door open**	
	2.2.1 Forward Missiles - Missiles in aft bay retracted	2
	2.2.2 Forward Missiles - no missiles in aft bay	2
	2.2.3 Aft Missiles - Missiles in forward bay retracted	2
	2.2.4 Aft Missiles - No Missiles in forward bay	2
	2.3.0 **Missiles fully down - door open**	
	2.3.1 Forward Missiles - Missiles in aft bay retracted	2
	2.3.2 Forward Missiles - No missiles in aft bay	2
	2.3.3 Aft Missiles - Missiles in forward bay retracted	2
	2.3.4 Aft Missiles - No missiles in forward bay	2
	2.4.0 **Missiles fully down - door closed**	
	2.4.1 Forward Missiles	2
		26

		RUNS
		26
2.4.2	Aft missiles	2
		28
2.5.0	Sparrows (repeat above program)	8
		36

3. **Forces on the Missiles for Trajectory Purposes**

3.1.0 Falcons will be tested in 5 locations along the fuselage. At each location, attitude of the missile will be changed so as to obtain 3 points in pitch and 3 points in yaw about the mean attitude. That means 5 runs per each location per Mach Number.

$M = .95, 1.2 \quad \alpha_{var} = -4 \quad +12$

		RUNS
3.1.1	Location "A" - aft bay	10
3.1.2	Location "B" - Forward bay	10
3.1.3	Location "C"	10
3.1.4	Location "D"	10
3.1.5	Location "E"	10
3.2.0	Sparrows will be tested in 4 locations along the fuselage.	
3.2.1	Location "B" - bay	10
3.2.2	Location "C"	10
3.2.3	Location "D"	10
3.2.4	Location "E"	10
		90

4. **Effect of Missiles on A/C**

$M = .95, 1.2 \quad \alpha_{var} \quad -4 \quad +12$

Stability

4.1.0 **Missiles fully retracted - door open**

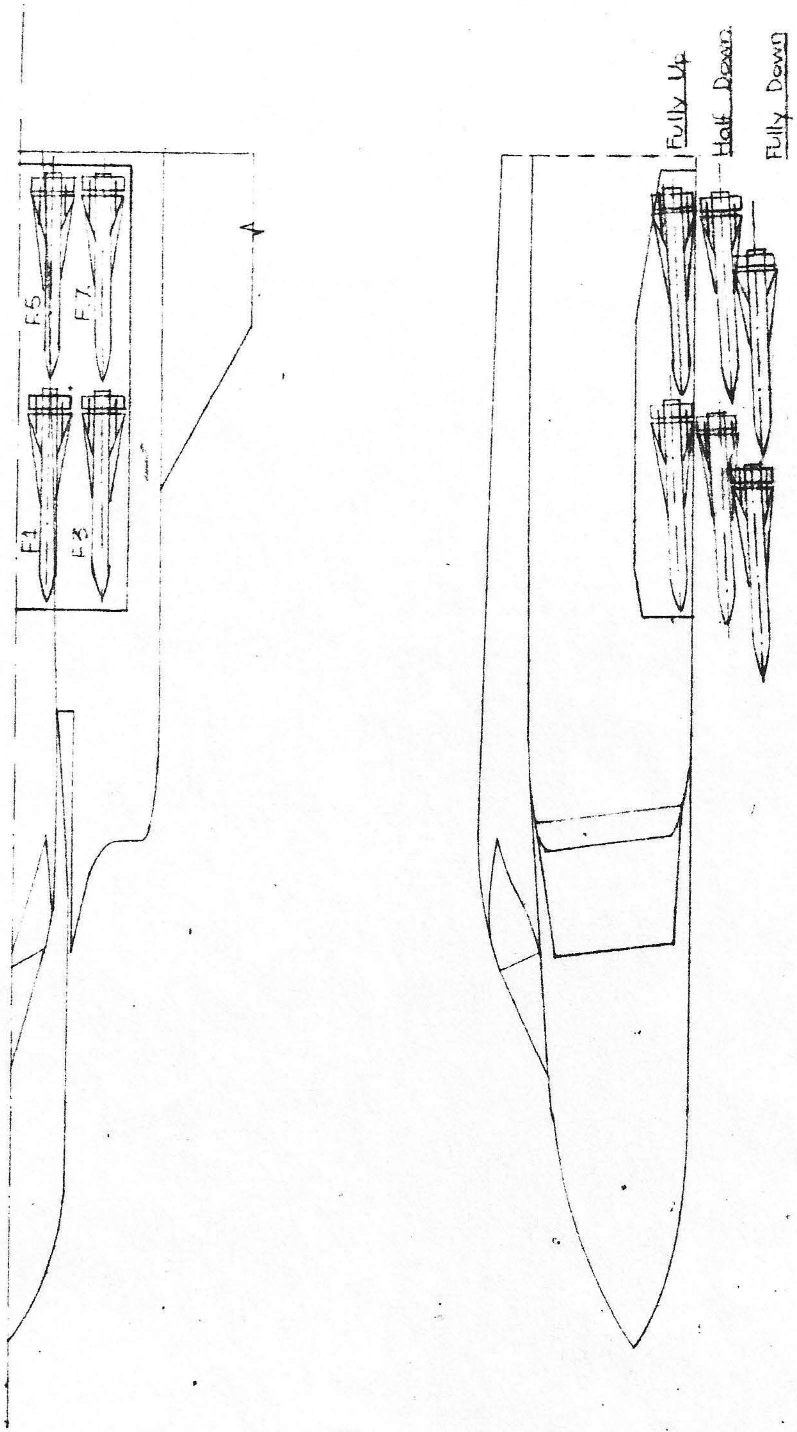
		RUNS
4.1.1	Missiles in both bays	2
4.1.2	Missiles in forward bay	2
4.1.3	Missiles in Aft bay	2
		6

		RUNS
		6
4.2.0	Missiles half way down - door open	
4.2.1	Forward Missiles - Missiles in aft bay retracted	2
4.2.2	Forward Missiles - no missiles in aft bay	2
4.2.3	Aft Missiles - Missiles in forward bay retracted	2
4.2.4	Aft Missiles - No missiles in forward bay	2
4.3.0	Missiles fully down - door open	
4.3.1	Forward Missiles - Missiles in aft bay retracted	2
4.3.2	Forward Missiles - No missiles in aft bay	2
4.3.3	Aft Missiles - Missiles in forward bay retracted	2
4.3.4	Aft Missiles - No missiles in forward bay	2
4.4.0	Missiles fully down - door closed	
4.4.1	Forward missiles	2
4.4.2	Aft Missiles	2
		26
4.5.0	Sparrows (repeat above program)	8
		34

AVRO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT:		REPORT NO	
C-105	Falcon & Linkage Tests.	SHEET NO.	
		PREPARED BY	DATE
		GWH	
		CHECKED BY	DATE



FALCON POSITIONS FOR INVESTIGATION OF LOWERING & LAUNCHING (P/WT/E.C. TESTS)

UNLIMITED
CONFIDENTIAL

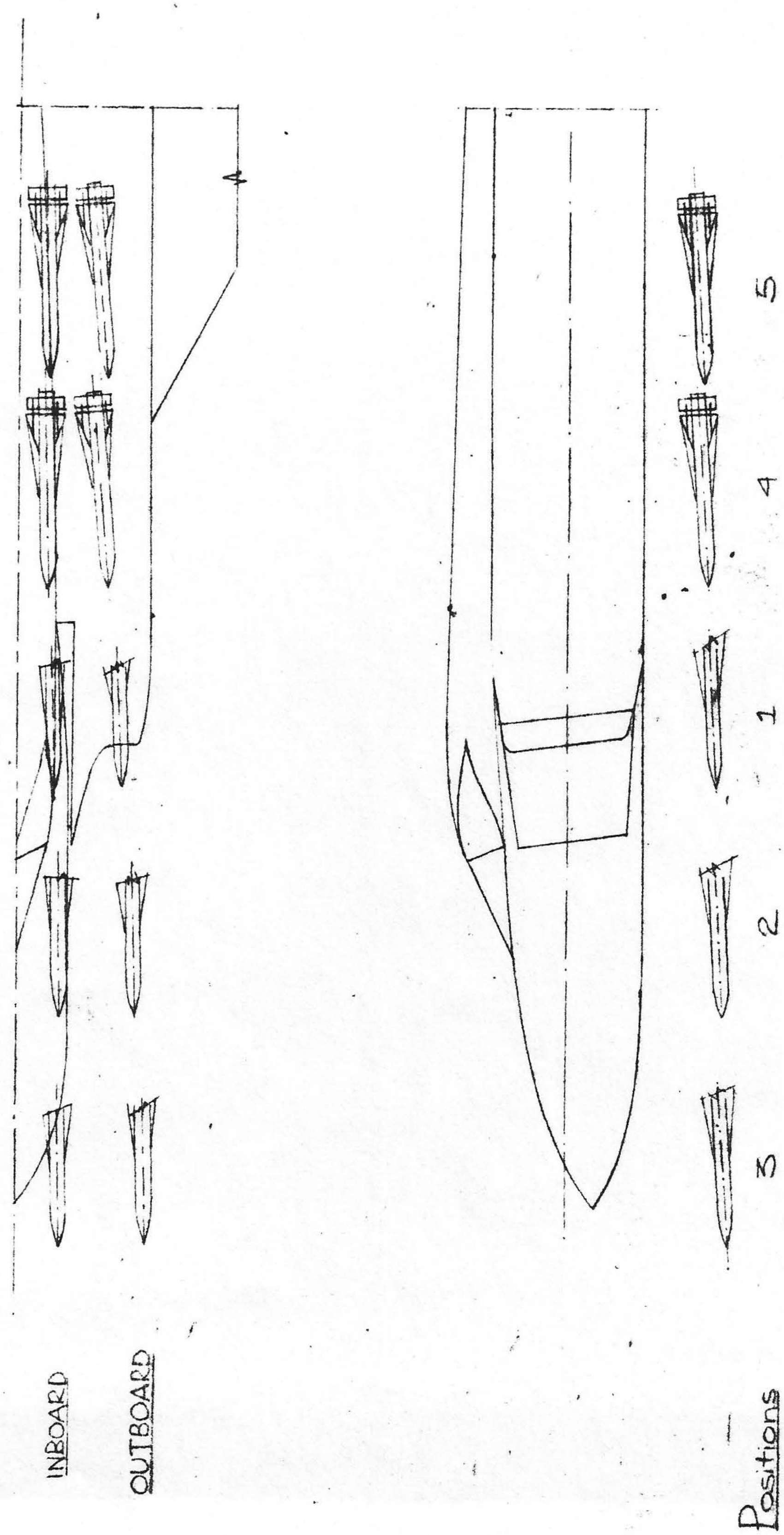
Fig. 1

ORM 1119A

AVRO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT: C-105	Falcon traj. for W/T testing	REPORT NO.	
		SHEET NO.	
		PREPARED BY: GWH	DATE
		CHECKED BY	DATE

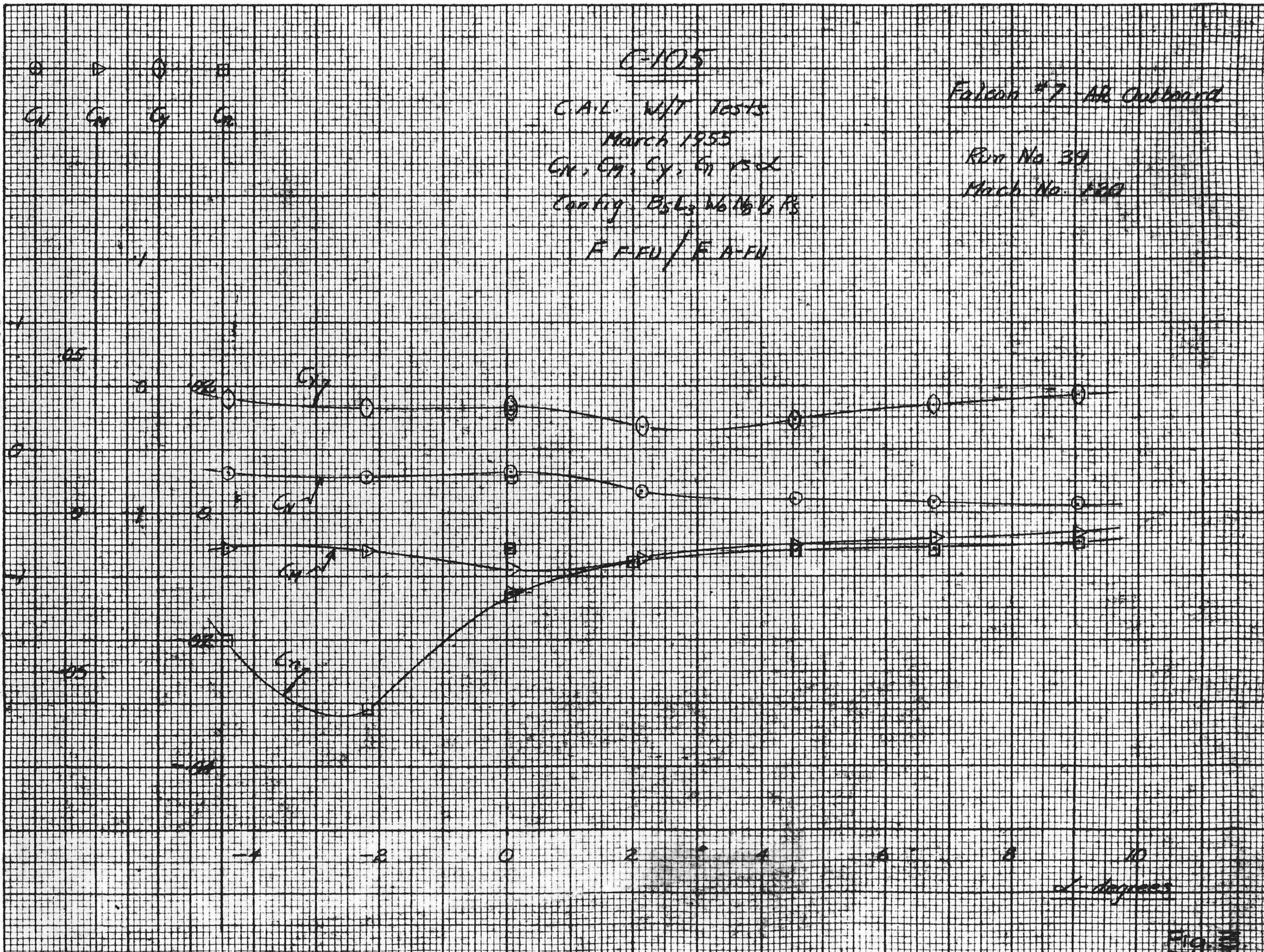


FALCON POSITIONS FOR TRAJECTORIES INVESTIGATIONS (P/WT/68)

Fig. 2

CONFIDENTIAL

FORM 1319A


C-105
C.A.L. W/T Tests
March 1955
C_N, C_m, C_Y, C_n vs α
Falcon #7 - AR Outboard
Run No. 39
Mach No.
C_N C_m C_Y C_n
C_m
C_N
C_Y
C_n
-4 -2 0 2 4 6 8 10
α - degrees

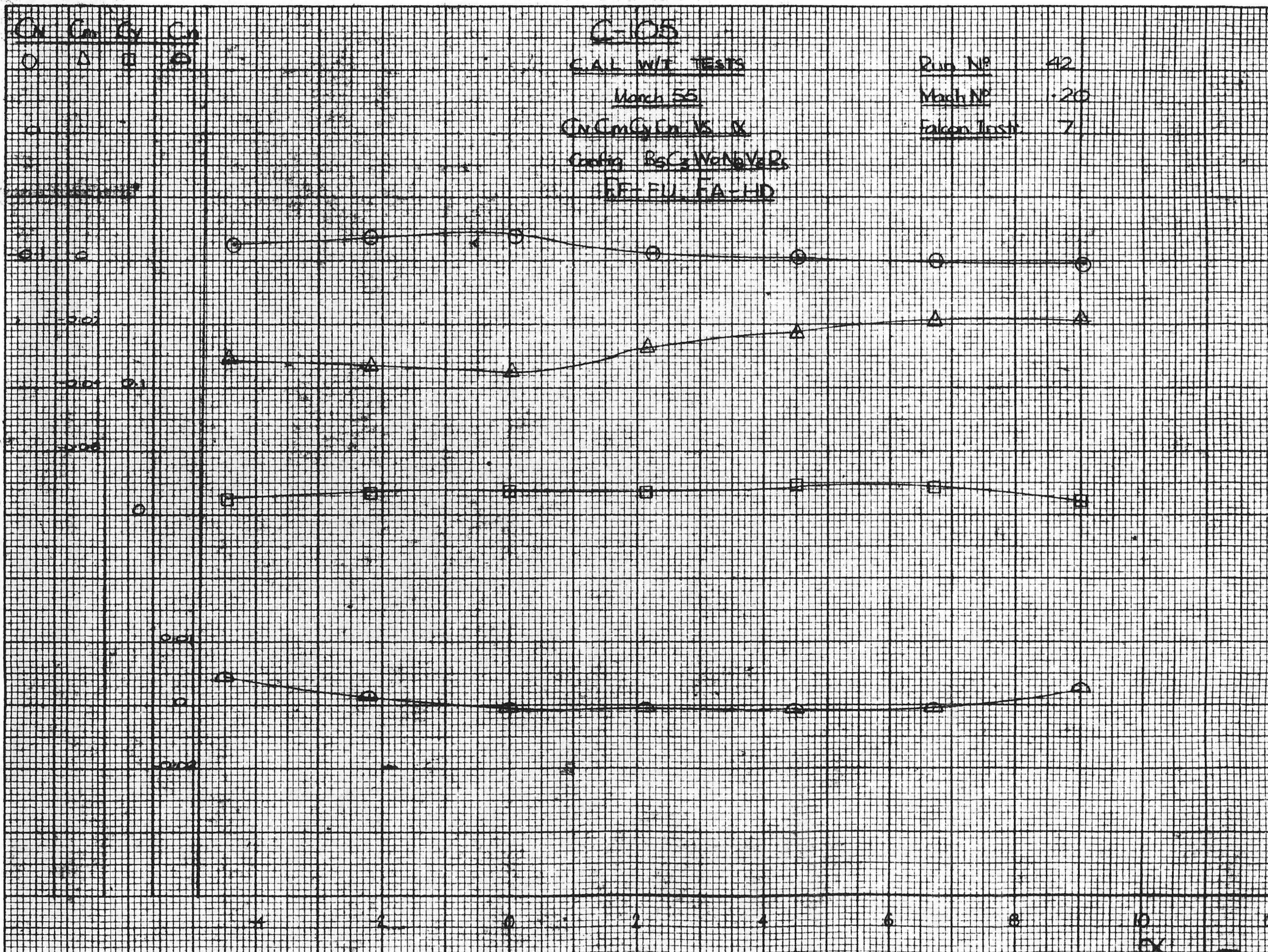


Fig. 4

GWH

2.11.2

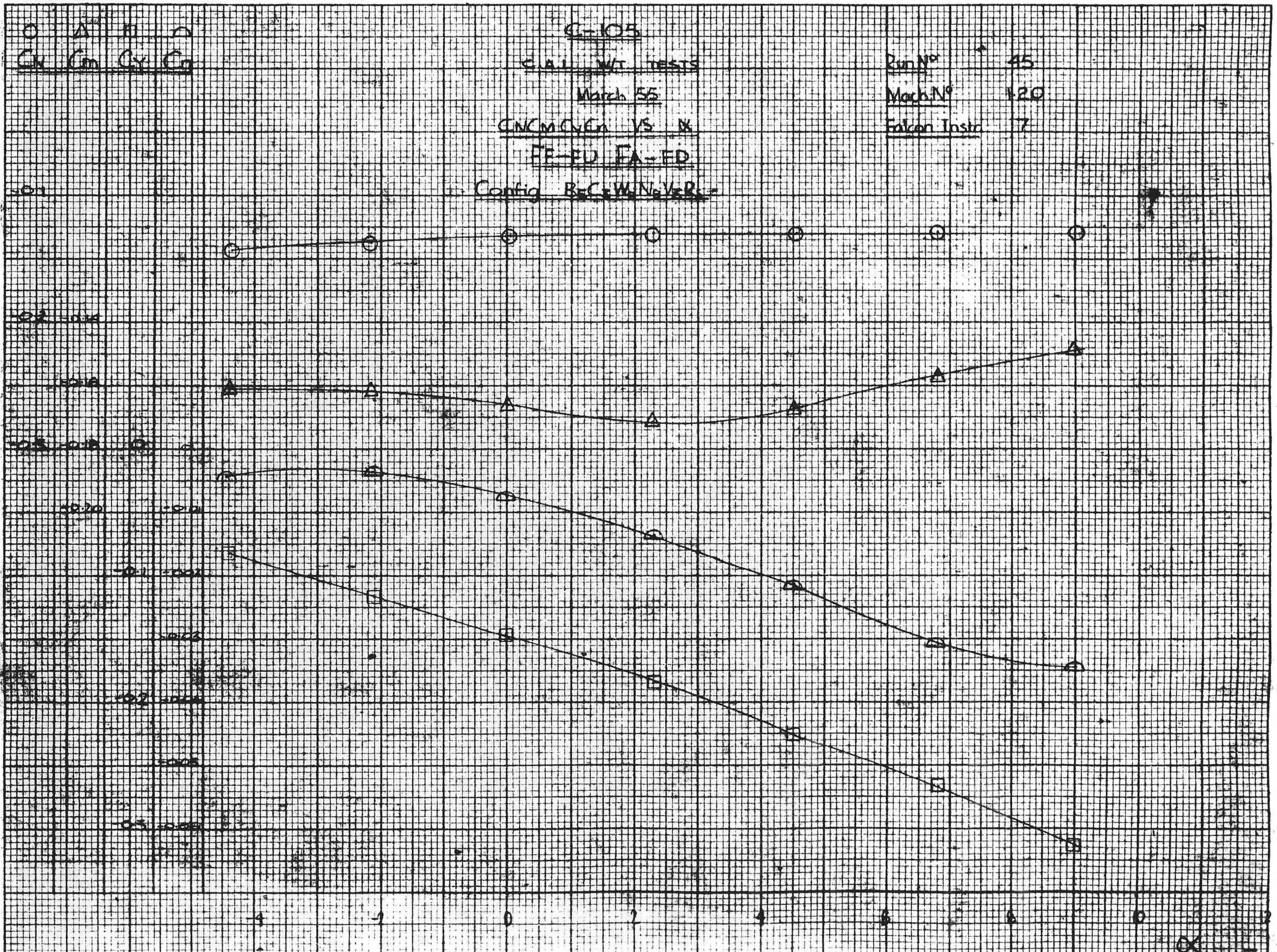


Fig. 5

P/WT/60
GWH
2.15.2

K+E 10 X 10 TO THE ½ INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

P/WT/60
GWTH.

2.18.2

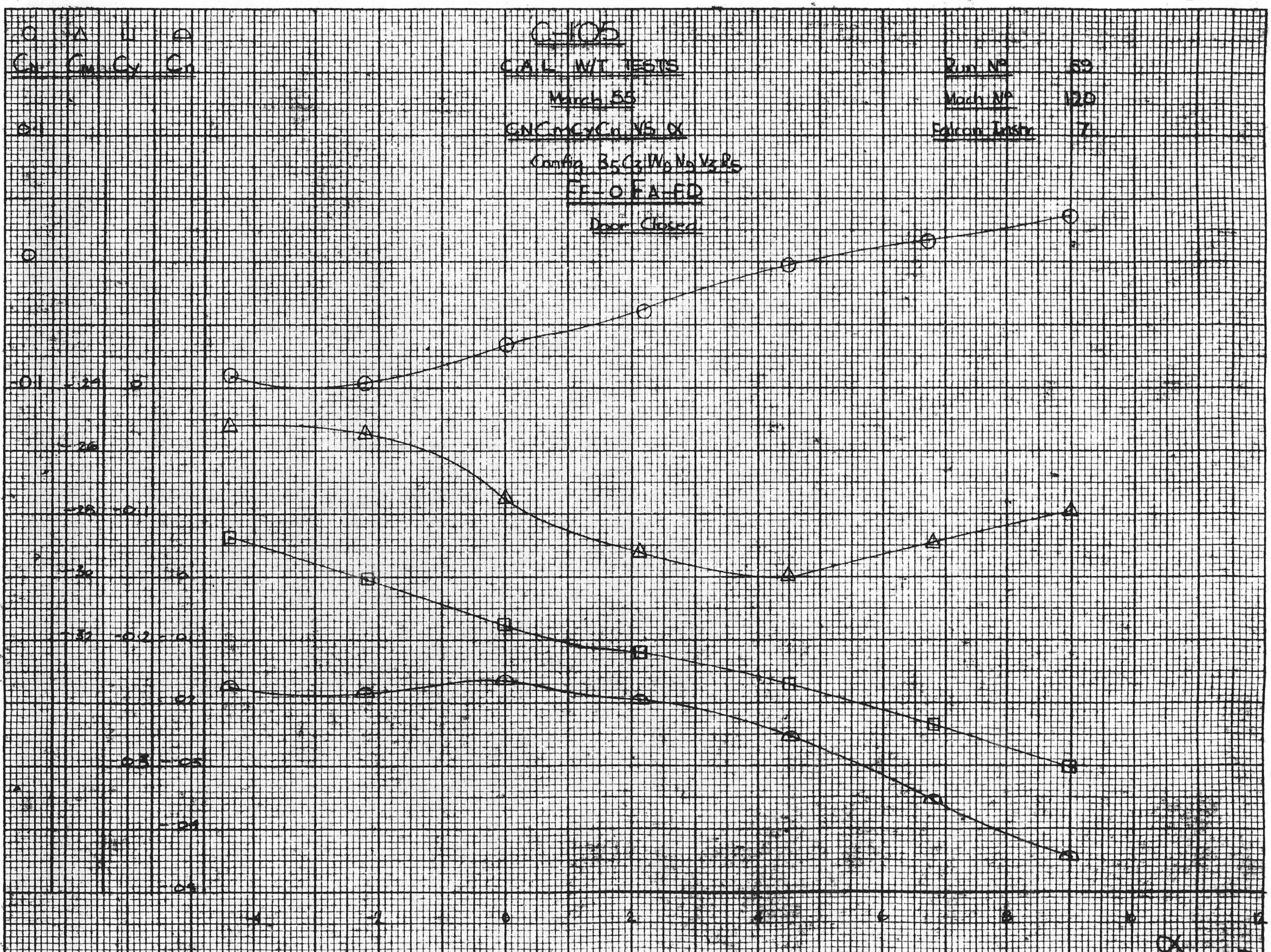


Fig. 6

CON[redacted]IAL

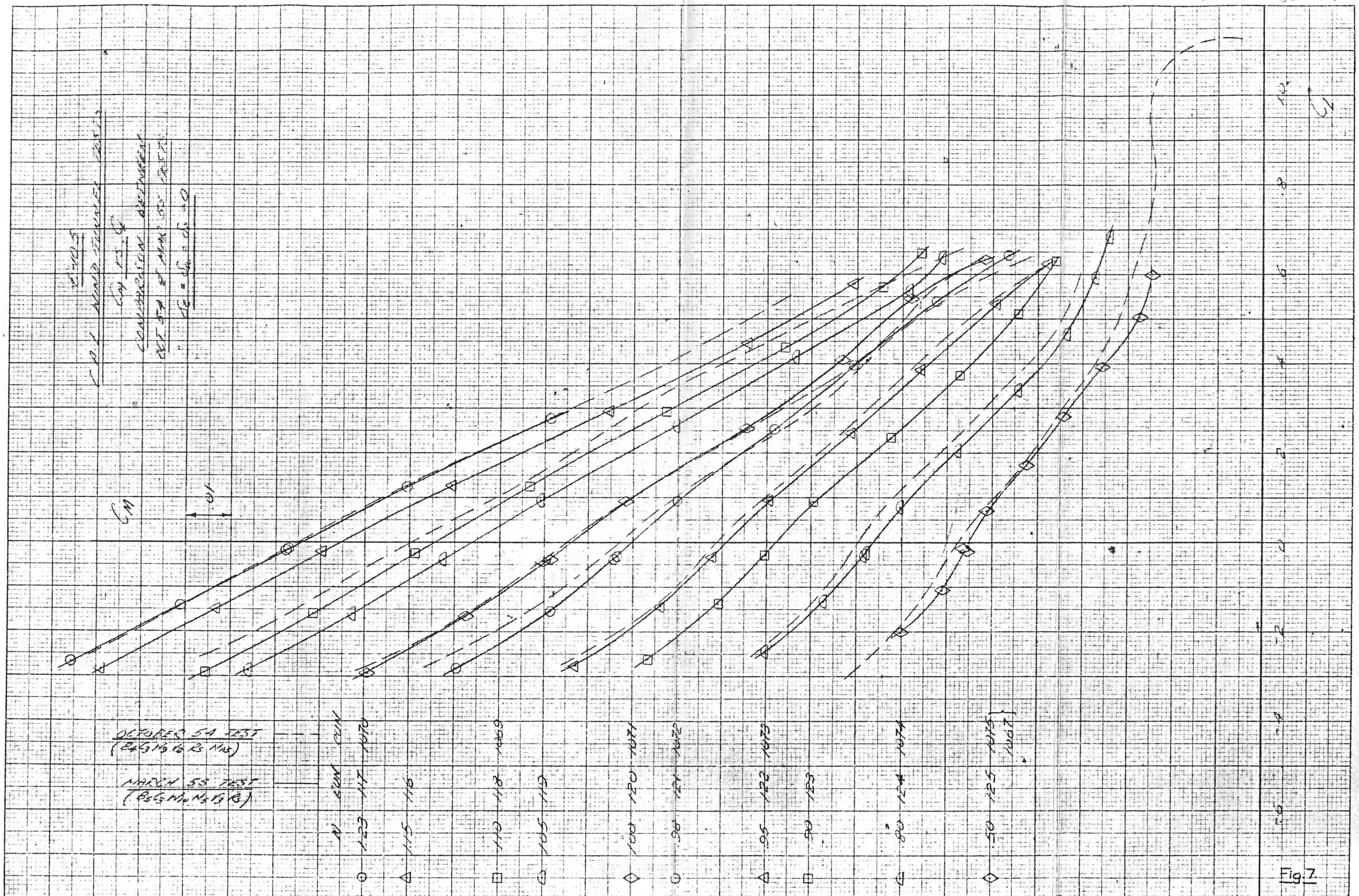


Fig. 7

CONFIDENTIAL
UNLIMITED

10 X 10 TO THE CM. 359-14
KEUFFEL & ESSER CO. MADE IN U.S.A.

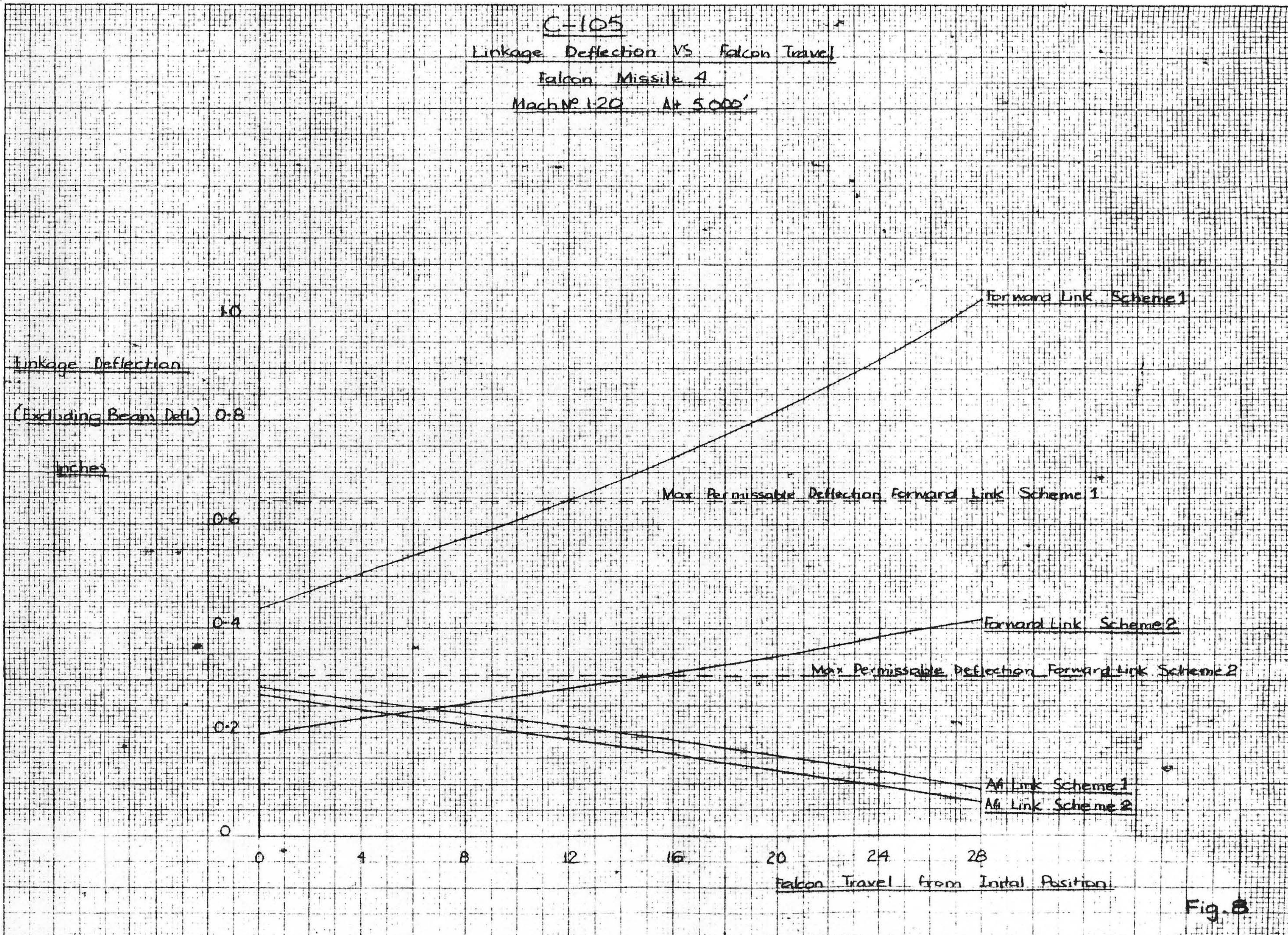


Fig. 8

CONFIDENTIAL

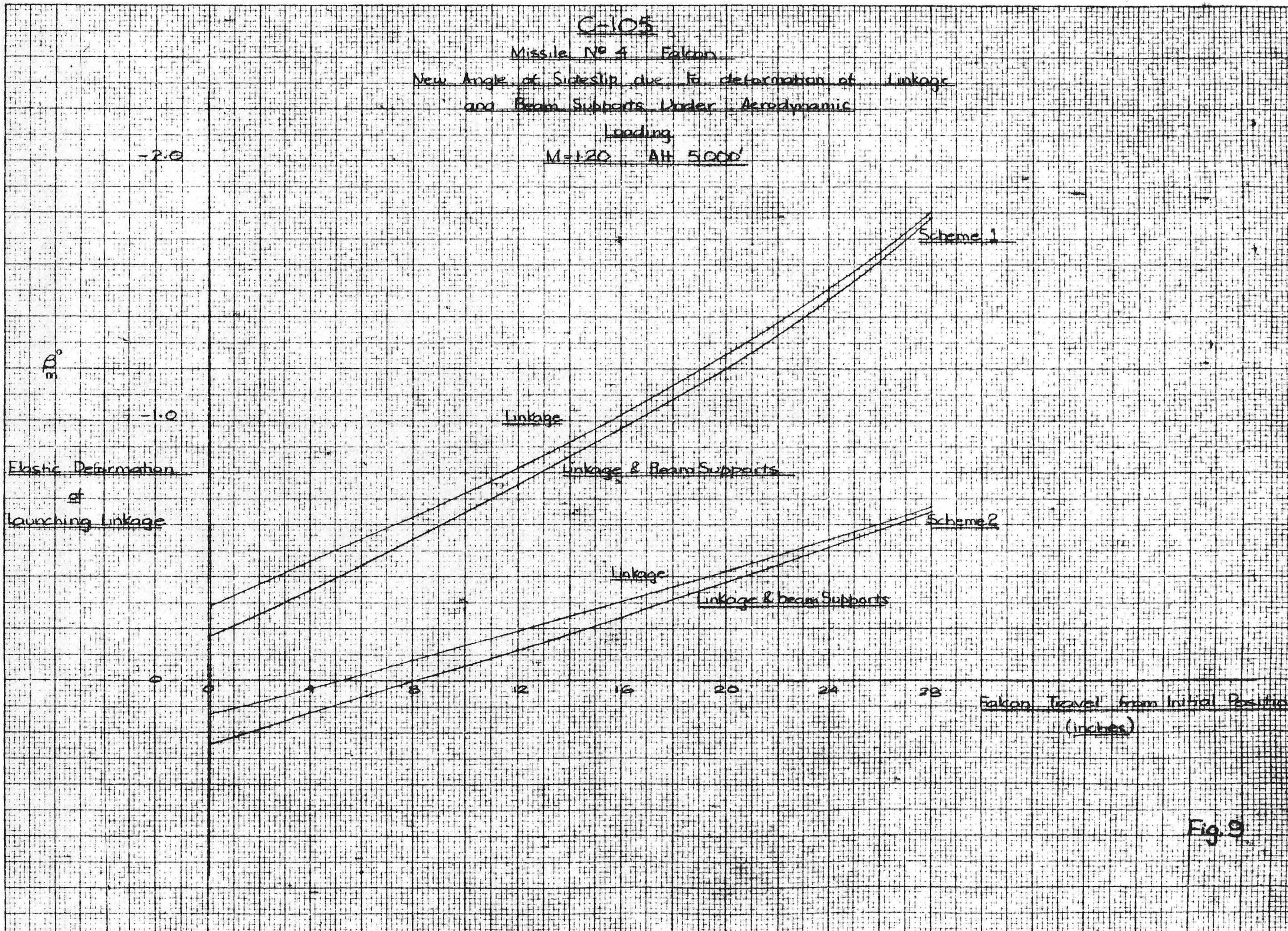
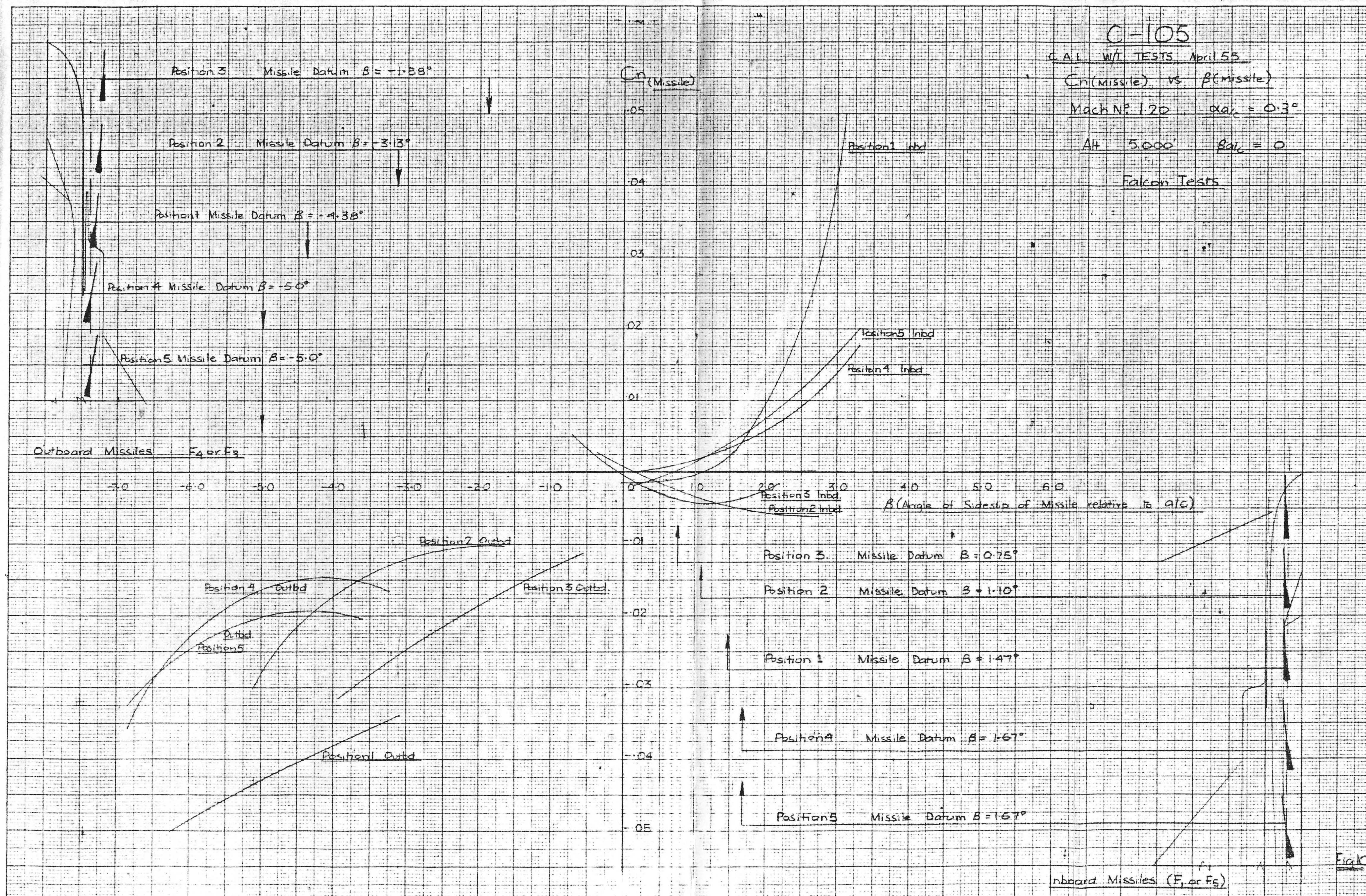

C-105
Missile No 4 Falcon
New Angle of Sideslip due to deformation of Linkage
and Beam Supports Under Aerodynamic
Loading
M=1.20 Alt 5000'
-2.0
-1.0
0
β_m°
Elastic Deformation
of
Launching Linkage
Linkage
Linkage & Beam Supports
Scheme 1
Linkage
Linkage & beam Supports
Scheme 2
0
4
8
12
16
20
24
28
Falcon Travel from Initial Position
(inches)

Fig. 9



CONFIDENTIAL UNLIMITED

C-105

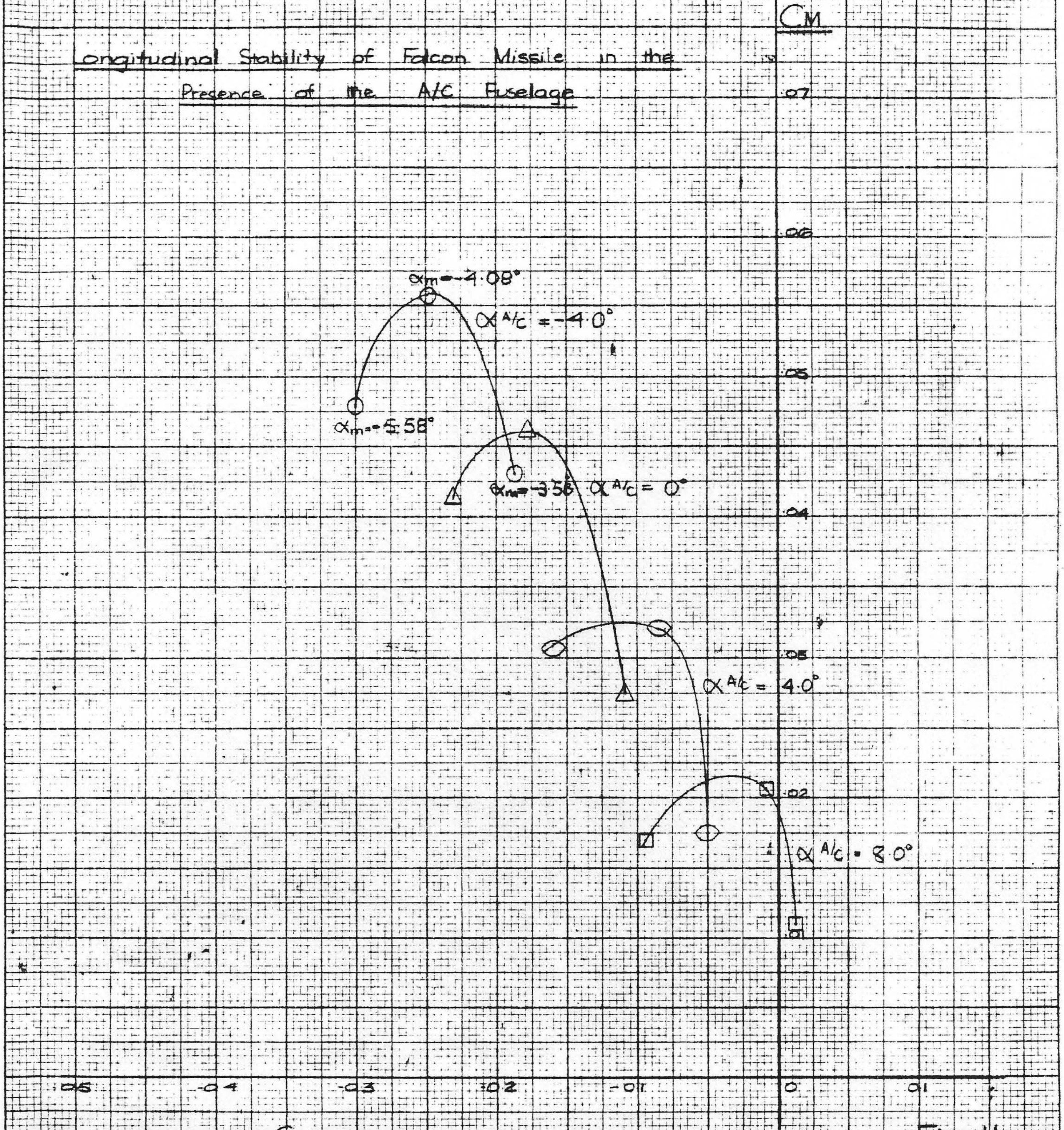
C.A.L. W/T TESTS

P/WT/70 Series

Falcon 2

Mach N° 1.20

Longitudinal Stability of Falcon Missile in the Presence of the A/C Fuselage



C_N

Fig. 11

359-14 KEUFFEL & ESSER CO.
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U.S.A.

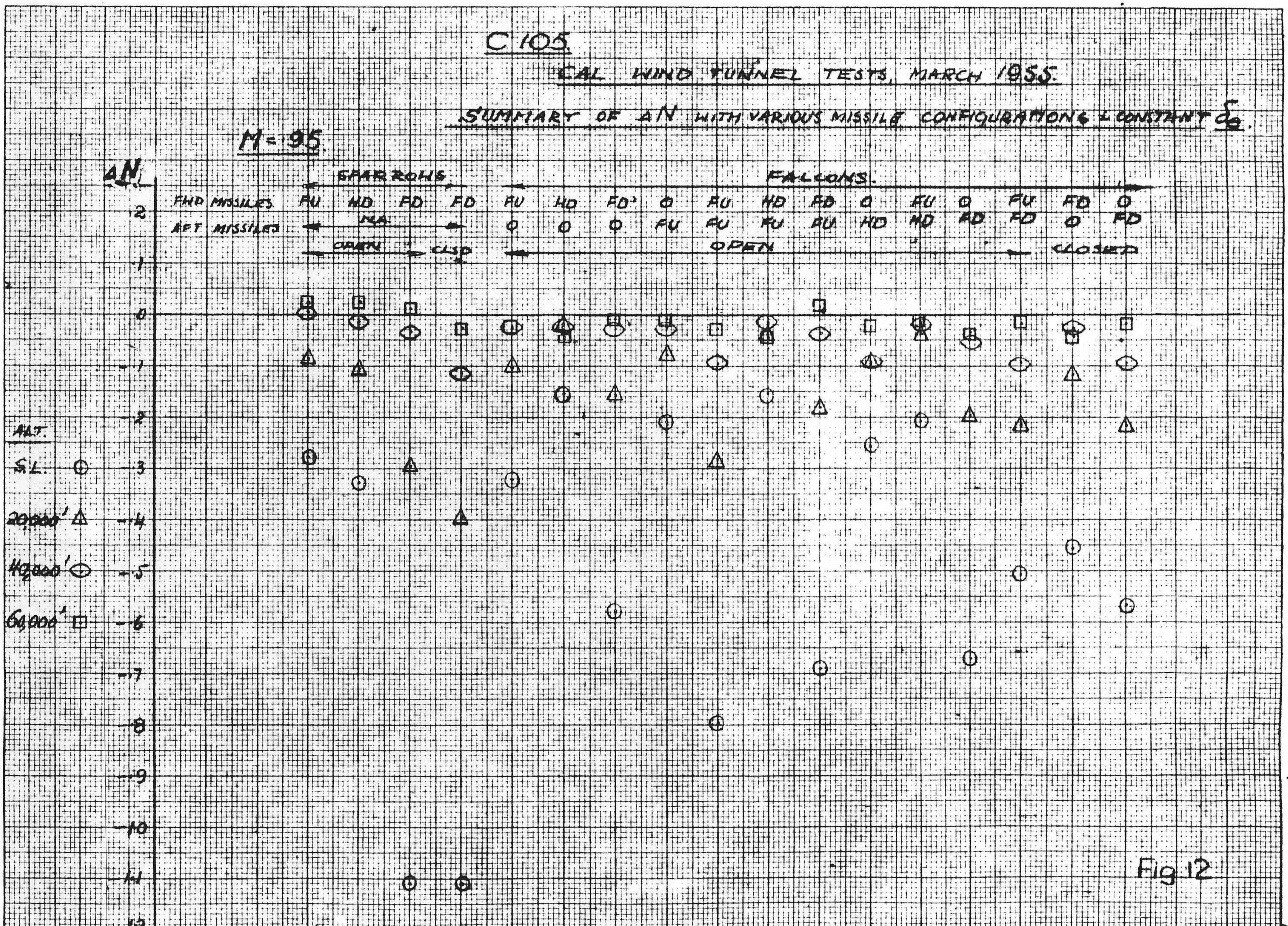


Fig 12

CONFIDENTIAL

2.11. P/CONTROL/74
March 1955 J. Papis

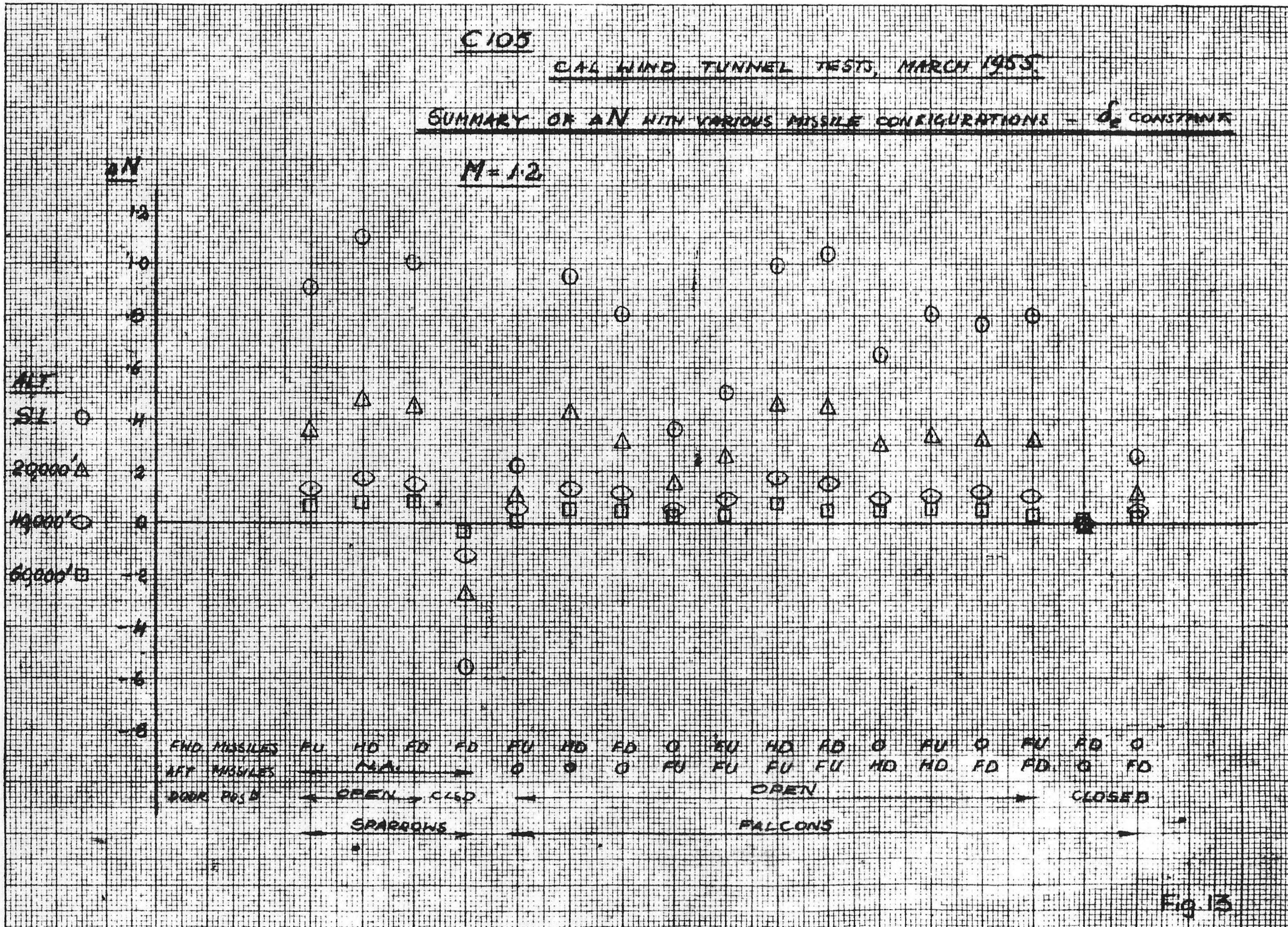


Fig. 13

March 1955 J. Papis