TRC No. 1009

HONG KONG MASS TRANSIT TUNNEL VENTILATION

Model Tests on a Generalised Inlet Draught Relief Shaft Air Curtain

T. Ward

J.I. Simper, B.Sc.

August, 1973

bhra fluid engineering

Cranfield
Bedford
England

Tel. Cranfield 422
Telex 825059

HONG KONG MASS TRANSIT TUNNEL VENTILATION

Model Tests on a Generalised Inlet Draught Relief Shaft Air Curtain

Introduction

Previous tests on a generalised model of an outlet draught relief shaft (Ref. 1) were concerned with developing a scheme to minimise the proportion of train induced flow passing into an air conditioned station area from the running tunnel. Besides minimising this leakage flow the proposed scheme also helped in inducing a tunnel ventilating flow through the draught relief shafts through a jet pump action.

This report is concerned with tests on a generalised inlet draught relief shaft. The tests are similar to those with the outlet, i.e. concerned with minimising the leakage flow and maximising the jet pump action, and are reported in a chronological order. The initial designs tested are based on the suggestions contained in Ref. 1 with the later, successful, configurations based on work contained in Ref. 2.

Inlet Model Arrangement and Instrumentation

The general model arrangement is shown in Figs. 1 a and 1 b. Differences between this and the outlet model include the provision of an inlet nozzle to measure the inlet shaft flow, screens to adjust the inlet shaft head losses and reversing the tunnel flow fan, plenum chamber, diffuser and flow metering nozzle. For the first set of tests a new plenum chamber for the inlet air curtain was constructed at the junction of the tunnel inlet shaft and tunnel entrance. In later configurations the existing outlet model plenum chamber was used.

The tests used similar instrumentation to that used in the outlet tests. A smoke generator was used for flow visualisation and a thermistor anemometer used to indicate flow velocities in the tunnel entrance. Betz micromanometers were used to measure pressure differences.

Test Procedure

1. Inlet Draught Relief Shaft Losses

The majority of tests were with a nominal inlet shaft total head loss coefficient, K_{it} of 1.5* This was set by inserting screens of woven brass wire mesh and honeycomb in the 12 inch square inlet shaft. The measured mean total head loss coefficient was 1.6, ranging from 1.59 at $Q_t/Q_{t\ max}$ = 100% to 1.65 at 60%, the changes being due to Reynolds number effects. Loss coefficients were calculated using the tunnel to atmosphere static pressure difference (Δht) measured 5 tunnel hydraulic diameters (= 5 x 281 mm) downstream of the outlet tangent of the inlet draught relief shaft junction, and were based on the tunnel velocity head. Various combinations of screens were used to change this loss coefficient.

---

* This was considered by the client to be the maximum that would occur in the full scale system, rather than the value of 1.84 mentioned in the feasibility study (Ref. 2).

2. Air Curtain Jet Velocity and Train Induced Flow

As in the outlet tests, the jet nozzle was 33.3 mm wide (0.5 m full size) and the jet velocity(V_j)set at 18.5 m/s using a pitot static probe in the nozzle. The velocity was adjusted by a throttle in the air curtain fan inlet.

Train induced flow, Q_t, was measured using the tunnel flow measuring nozzle and adjusted by varying the speed of the axial flow fan. The maximum train induced flow was $Q_{t\ max} = 0.8\ m^3/sec$ ($180\ m^3/s$ full size).

Results

The results for the majority of tests are subjective, being based on the smoke visualisation results. For the most promising arrangements, quantitative measurements of the train induced flow (Q_t), the inlet draught relief shaft flow (Q_i) and the tunnel static head (Δh_t) were made.

The leakage flow was calculated from:

$$Q_l = Q_t - (Q_i + Q_j)$$

where $Q_j = V_j \times A_j$ (where $A_j = 33.3 \times 281.5\ mm^2$)

Test results are shown based on a percentage of the maximum train induced flow, i.e. $Q_l/Q_{t\ max} \times 100\%$

$= Q_l/0.8 \times 100\%$

i. Preliminary Tests

With the air curtain jet located at the junction of the inlet shaft and tunnel entrance, and arranged initially at right angles to the tunnel axis there was a large leakage from the station at high train induced flows. Minor changes in position did not make any significant improvement. The best arrangement with the air curtain in this location is shown in Fig. 1 c (configuration 1). The leakage characteristic is shown in Fig. 7 compared with the results for the final configuration (config. 4 b). With the nozzle located further up the inlet shaft (280 mm from the outside wall and angled to the centre of the bend) a large jet pump action was obtained, but, at high train induced flows, there was a large leakage from the station.

It was considered that configuration 1 was not as promising as had been considered in Ref. 1, so an alternative approach to the problem was suggested. The air curtain was moved to the inside wall of the exit and projected across the tunnel into a suitably shaped cavity. This cavity was designed to deflect the jet so as to remove the jet mass flow and project it down the running tunnel, thereby inducing further flow through the inlet shaft.

ii. Configuration 2

With the air curtain jet moved to the tunnel wall opposite the inlet shaft (shown in Figs. 2 a and 2 b) the measured leakage characteristic is as shown in Fig. 8, again compared with configuration 4 b. At low train induced flow there was a large scale circulation on the station side of the air curtain associated with buffeting in the tunnel entrance and little nett flow into the station. For train induced flows > 70% $Q_{t\ max}$ there was a strong vortex on the tunnel side of the air curtain. The inclusion of a fence (a 35 mm high projection) placed 300 mm from the upstream edge of the cavity helped in reducing the buffeting at the station/tunnel entrance by fixing the circulatory flow to an area bounded by the air curtain and projection. This also resulted in a contra-rotating circulation nearer the station. However, generally this arrangement was not satisfactory due to a weak curtain strength as indicated by the large leakage at high train induced flows.

iii. Configuration 3

In order to strengthen the curtain the jet nozzle was moved away from and inclined towards the station as shown in Fig. 3 (configuration 3). The leakage characteristic (Fig. 9) shows that at low train induced flow there was significant flow towards the station. Also considerable buffeting in the station area was noted for train induced flows < 60% $Q_{t\ max}$. The buffeting was caused by sudden changes in jet discharge angle as the main jet and cavity deflected jet interacted. Addition of the fence of configuration 2 did not significantly reduce the buffeting. At high train induced flow there was much reduced leakage indicating sufficient jet strength.

iv. Configuration 4

A compromise between configurations 2 and 3 is shown in Figs.4 a and 4 b (configuration 4 b). The design was chosen to reduce the flow into the station at low train induced flows whilst maintaining a reasonable curtain stiffness to inhibit leakage at high train induced flows. The cavity was deepened to reduce the buffeting due to the jet flows interacting.

The leakage characteristic of this configuration is shown in Fig. 10 (X symbols). As the train induced flow increases from 0 to 20% $Q_{t\ max}$ the quantity of the jet deflected by the upstream edge of the cavity (towards the station) reduces. Between 20 and 30% $Q_{t\ max}$ the station side of the jet entrains flow from the station into the cavity. This tendency reduces above about 30% $Q_{t\ max}$ due to a change in incidence of the jet, on the cavity wall, causing the vortex to decrease in strength because of "back spillage". Further deflection (occurring between about 50 and 70% $Q_{t\ max}$) causes more "back spillage" resulting in a vortex that rotates in the opposite direction to that in lower flow case. Above 80% $Q_{t\ max}$ the jet again entrains air from the station area but this only reaches a leakage flow of 10% $Q_{t\ max}$ at 100% maximum train induced flow.*

Between 45 and 55% $Q_{t\ max}$ there is some localised buffeting due to an oscillating jet. However, this was very small compared to that with the earlier cavity shapes. Compared to configuration 4 a (configuration 4 b minus fence) buffeting in the station was much lower. Addition of a second fence (opposite the first) did not improve the stability of the circulatory flow.

Reduction of the cavity size to that shown in Fig. 5 (configuration 5) indicated leakage resistance was similar to that of configuration 4 b but buffeting in the station area was worse.

After this attempt to reduce the cavity size configuration 4 b was rebuilt

---

* This corresponds to a measured tunnel entrance centreline velocity of about 1.0 m/sec and compares with a calculated mean velocity of 0.94 m/sec.

and tests repeated. The leakage between 20 - 50% $Q_{t\ max}$ had increased slightly and this was traced to the beginning of the cavity being some 5 - 10 mm further away from the station (resulting in more of the jet being deflected towards the station at medium train induced flow rates). It was decided to retain this basic geometry (configuration 4 b) and obtain the jet pumping characteristic, the effect of inlet total head loss and effect of air curtain jet velocity.

v. Effect of Air Curtain Jet Velocity

Tests were conducted with an inlet shaft head loss coefficient of 1.6 and a constant jet nozzle width of 33.3 mm. The effect of air curtain jet velocity is shown on Fig. 12. Above 70% $Q_{t\ max}$ the effects are as expected, the higher the velocity the stiffer the curtain and therefore the lower the leakage. Below 70% $Q_{t\ max}$ the results are less well ordered. The effect of a higher jet velocity greater than 18.5 m/sec is to delay changes in the detailed flow pattern described earlier and vice-versa at lower jet velocities.

vi. Effect of Inlet Shaft Total Head Loss Coefficient

The jet velocity for these tests was kept constant at 18.5 m/sec. The leakage characteristics for various head loss coefficients are shown in Fig. 13. The various total head loss coefficients were obtained by inserting various screens in the inlet shaft. The coefficients were determined by blocking off the tunnel entrance close to the inlet bend and measuring the static head, at the tunnel walls 5 hydraulic diameters downstream of the inlet bend outlet tangent, with respect to atmosphere. As anticipated the results indicate a lower leakage flow from the station for a lower inlet total head loss coefficient at the higher train induced flows (> 70% $Q_{t\ max}$) There is little effect of loss coefficient at low train induced flows (< 40% $Q_{t\ max}$).

Generally the effect of reducing the head losses is similar to increasing the jet velocity, above 60% $Q_{t\ max}$. However, between 40 and 70% $Q_{t\ max}$ the lower the head loss coefficient the more irregular the variation. This irregularity is due to the changes in "back spillage"/entrainment rates mentioned earlier.

vii. Jet Pumping Effect

The jet pump action of the air curtain is shown on Fig. 14 compared with a theoretical curve and some experimental data, obtained for the inlet duct plus bend plus 5 hydraulic diameters of tunnel with the tunnel entrance blocked off close to the bend. The pumping action could probably be improved by shaping the wall opposite the inlet duct thus helping the deflected air curtain to pass smoothly down the running tunnel. At low train induced flows there was a tendency for the flow out of the air curtain cavity to be incident on the inside wall which, after reflection towards the outlet of the bend, set up a reverse flow circulation in the inlet duct. The difference between the theoretical curve and the jet pump characteristics is a minimum at about 67% when the 'back spillage" is a maximum. As the curtain is deflected out of the cavity and leakage occurs the difference between the theoretical inlet head loss and actual inlet head loss with air curtain flow is increased.

Discussion

With configuration 4 b the relatively high value of leakage flow at 30% $Q_{t\ max}$ was mainly due to the location of the beginning of the cavity. This leakage could probably be reduced by moving the start of the cavity slightly further away from the air curtain nozzle exit plane towards the station. Bearing this in mind, the geometry of configuration 4 b has been rationalised and shown in Fig 5 where dimensions are also given for a full size cavity.

It should be noted that the minimum ventilation flow of 25 m^3/sec, is 14% of the maximum train induced flow whilst the air curtain flow (0.174 m^3/sec in the model) is 22% of the maximum train induced flow. Even though this inlet, and the outlet air curtains tested earlier, help induce flow through the tunnel it will still be necessary to have pressure raising devices as mentioned in Ref. 1 to overcome the head loss past a stopped train with the minimum ventilation flow.

Ref. 1	J. Simper T. Ward	Model Tests on Some Aspects of a Ventilation System for an Underground Railway. BHRA Working Report, June, 1973.
Ref. 2	J. Simper T. Ward	A Feasibility Study of Various Methods of Isolating the Running Tunnels from the Station Areas on the Hong Kong Mass Transit System. BHRA CR 1175 (March, 1973).

T. Ward
J.I. Simper

15th August, 1973

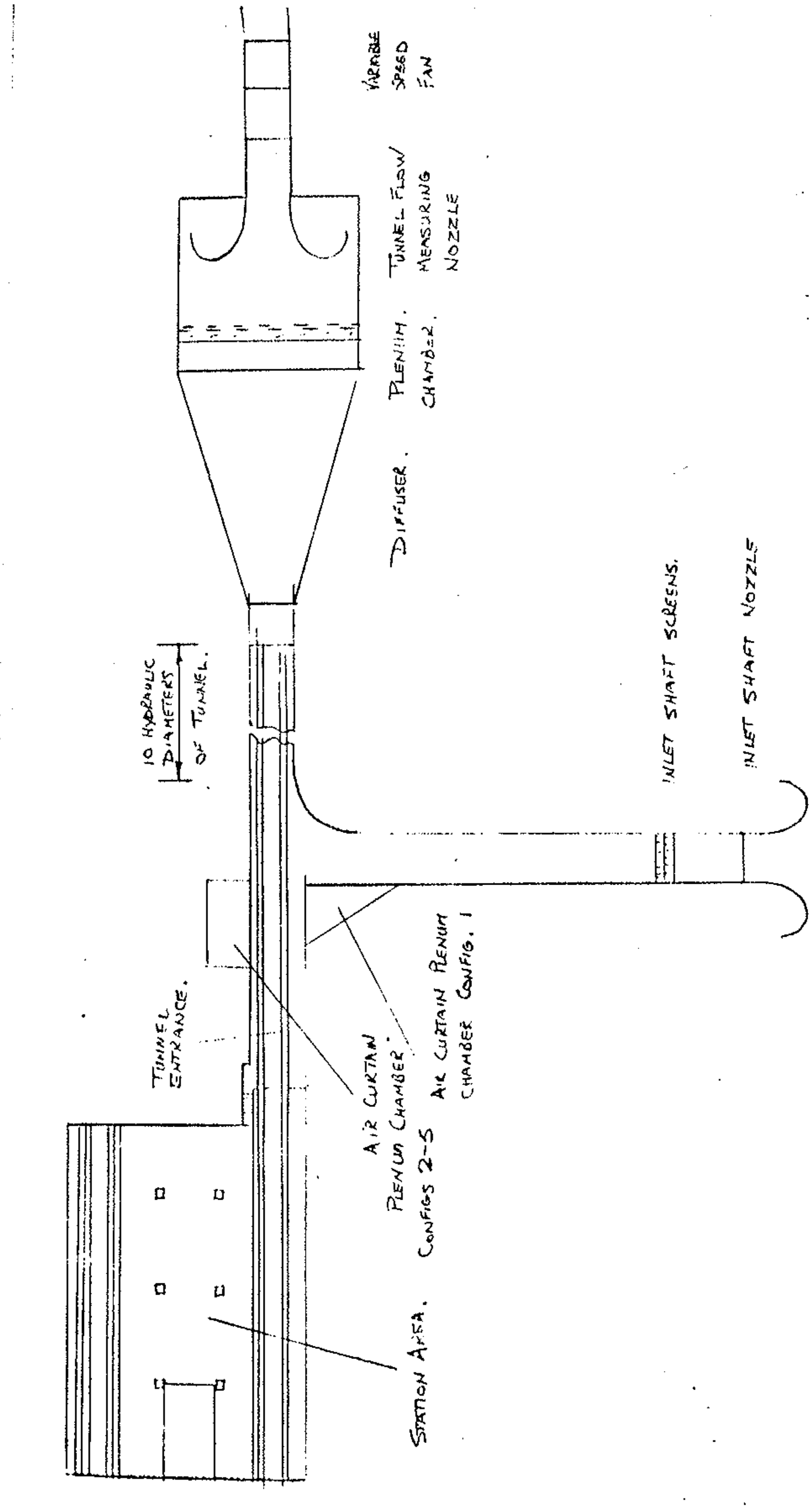
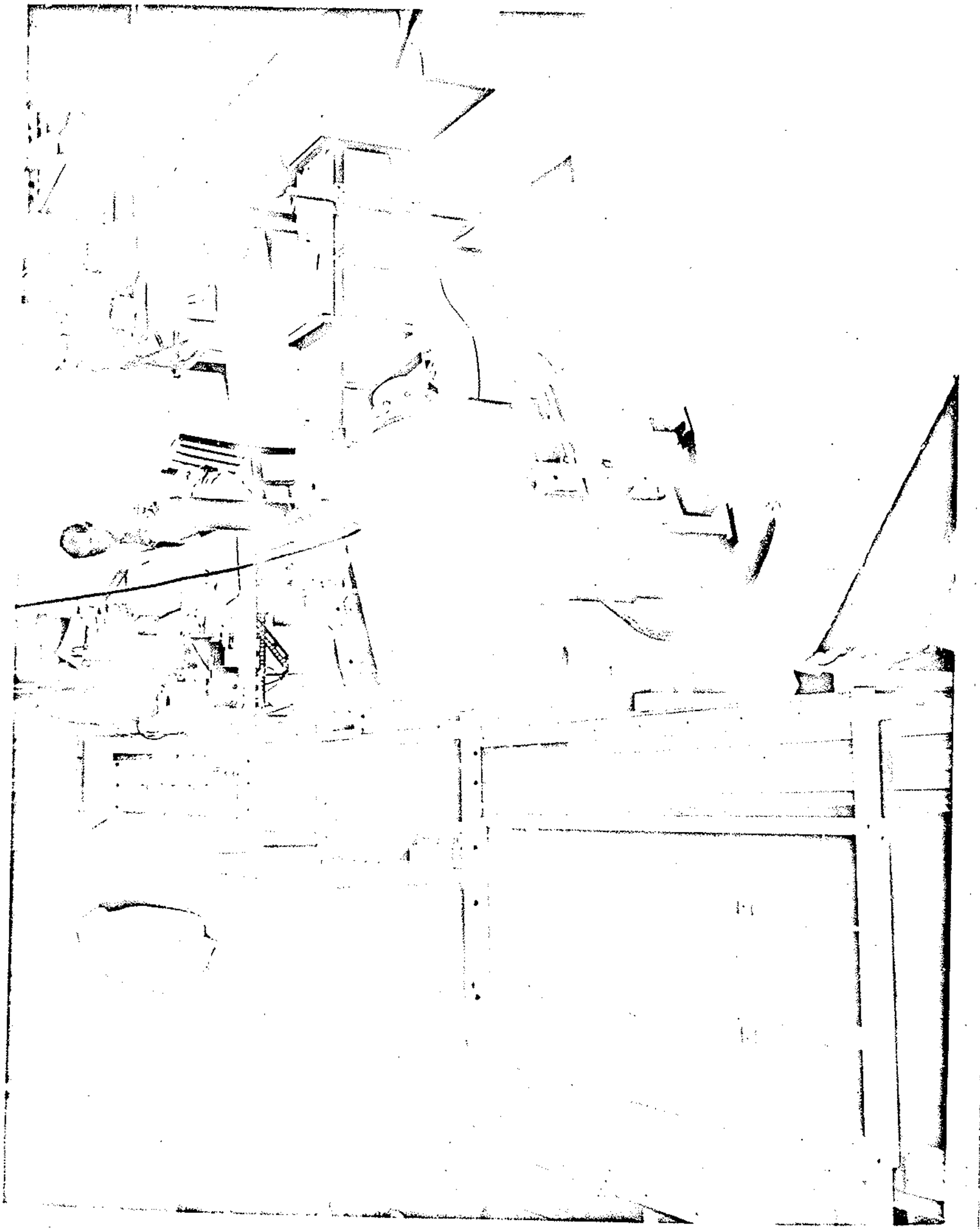
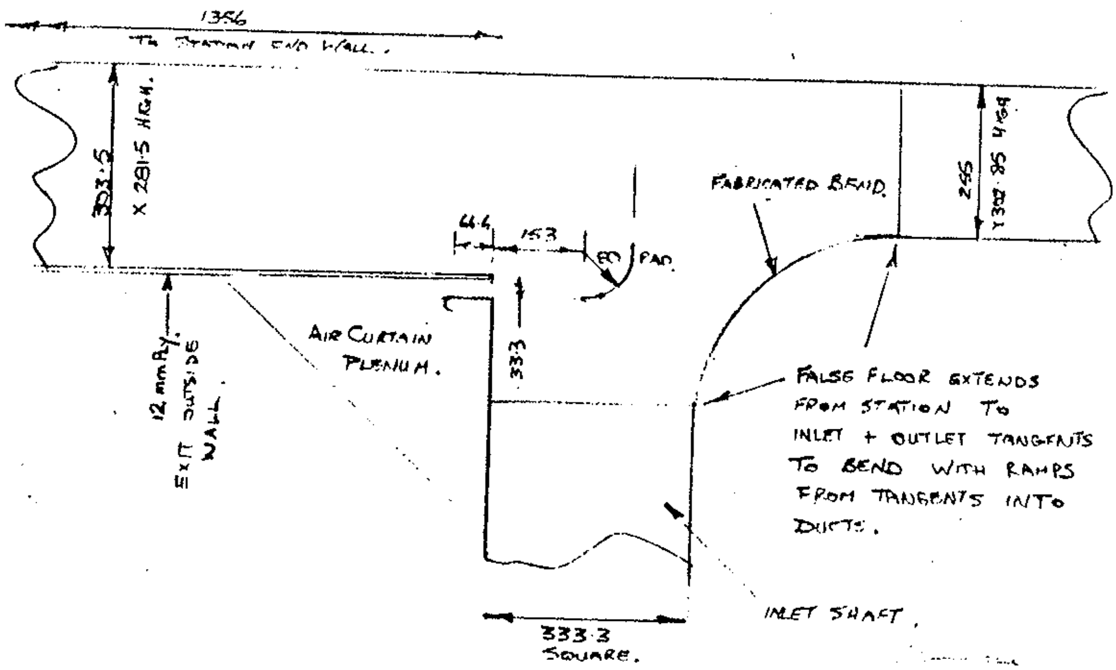


FIG. 1a GENERAL ARRANGEMENT FOR GENERALISED INLET DRAUGHT RELIEF SHAFT MODEL TESTS.



(P 1856/A/2)

FIG. 1 b GENERAL VIEW OF MODEL



CONFIGURATION 1

FIG 1C.

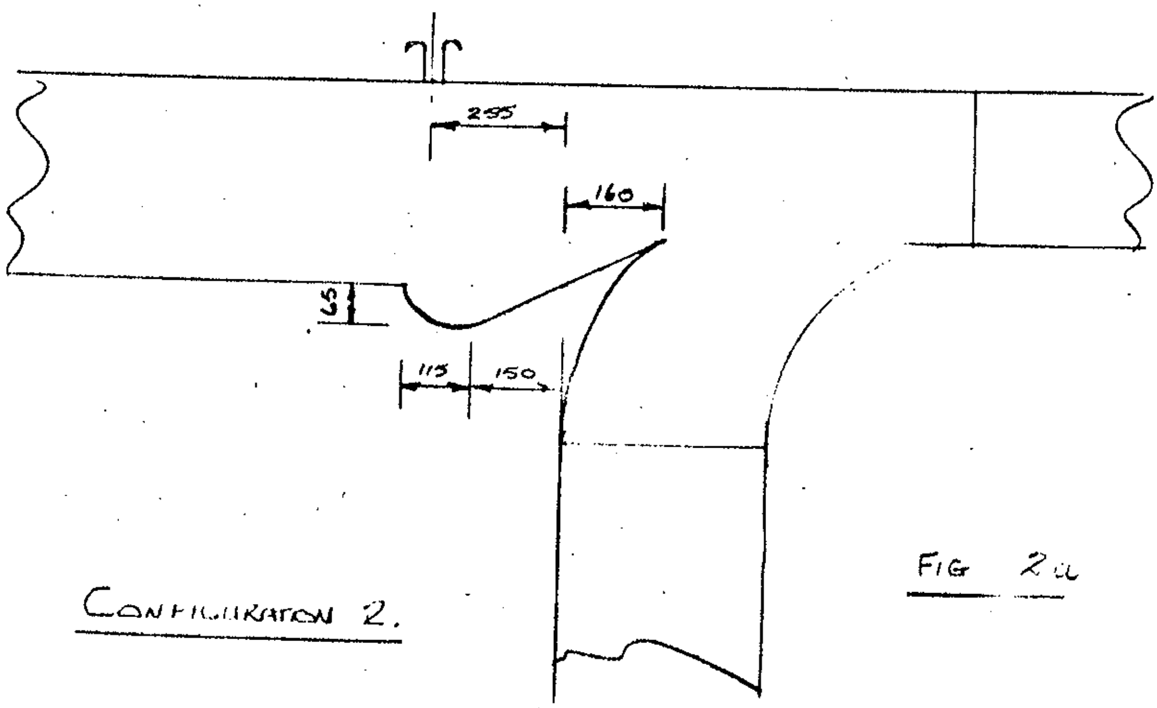
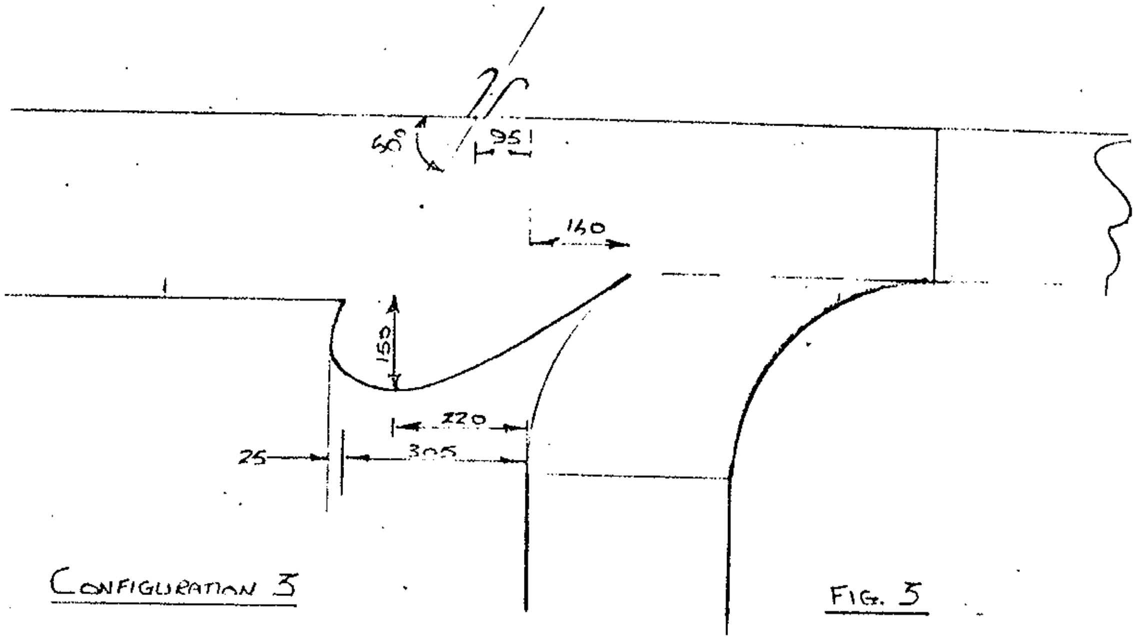


FIG 2a

CONFIGURATION 2.

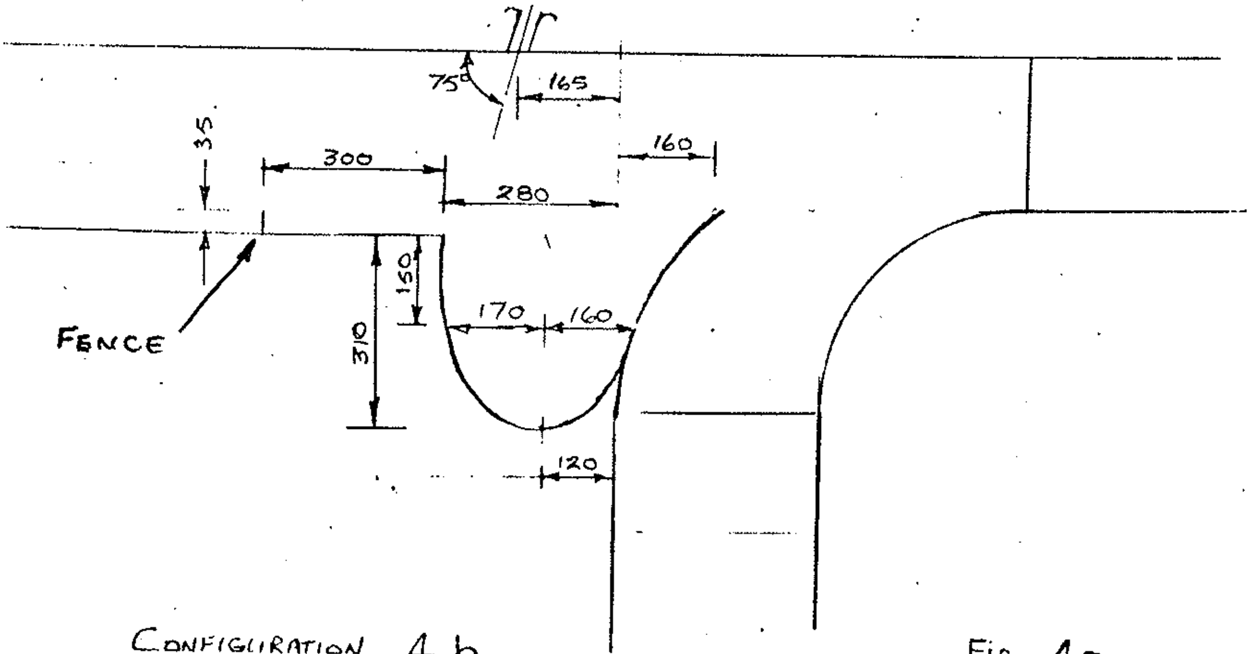
(P 1856/A/4)

FIG. 2 b CONFIGURATION 2



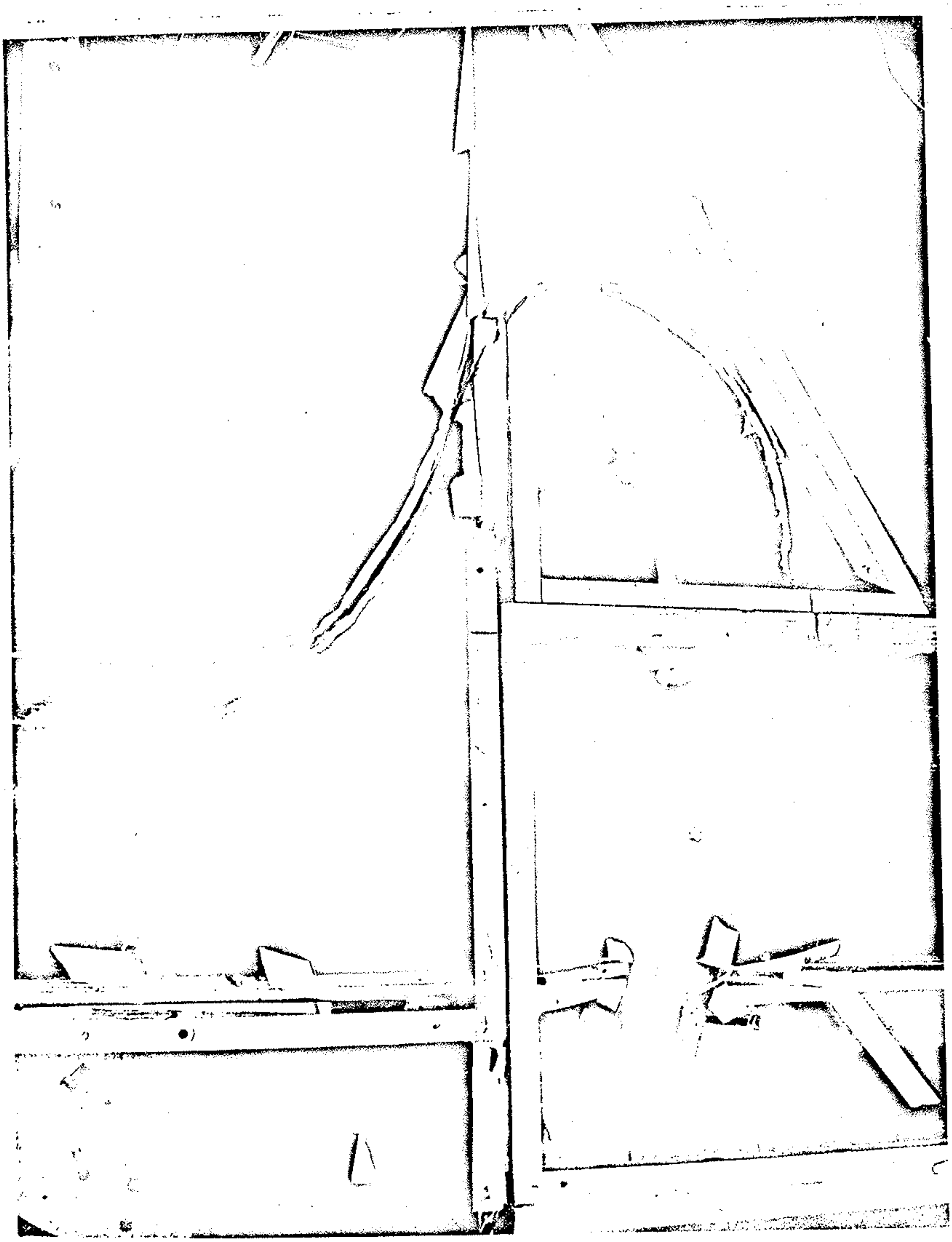
CONFIGURATION 3

FIG. 5



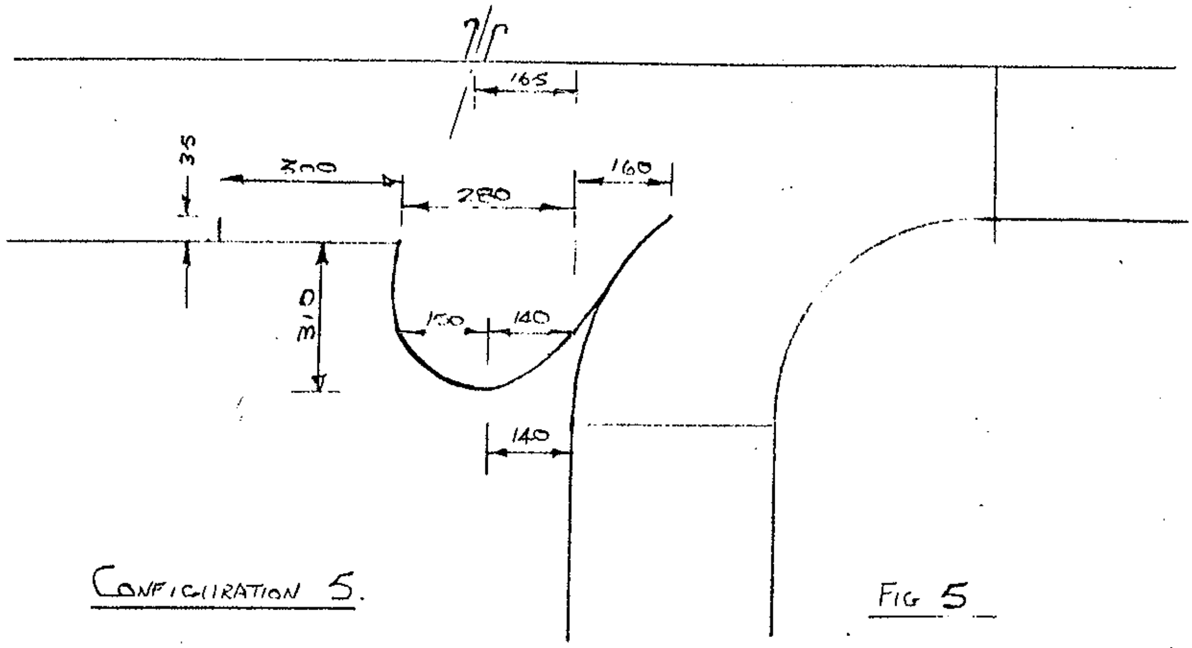
CONFIGURATION 4 b

FIG 4a



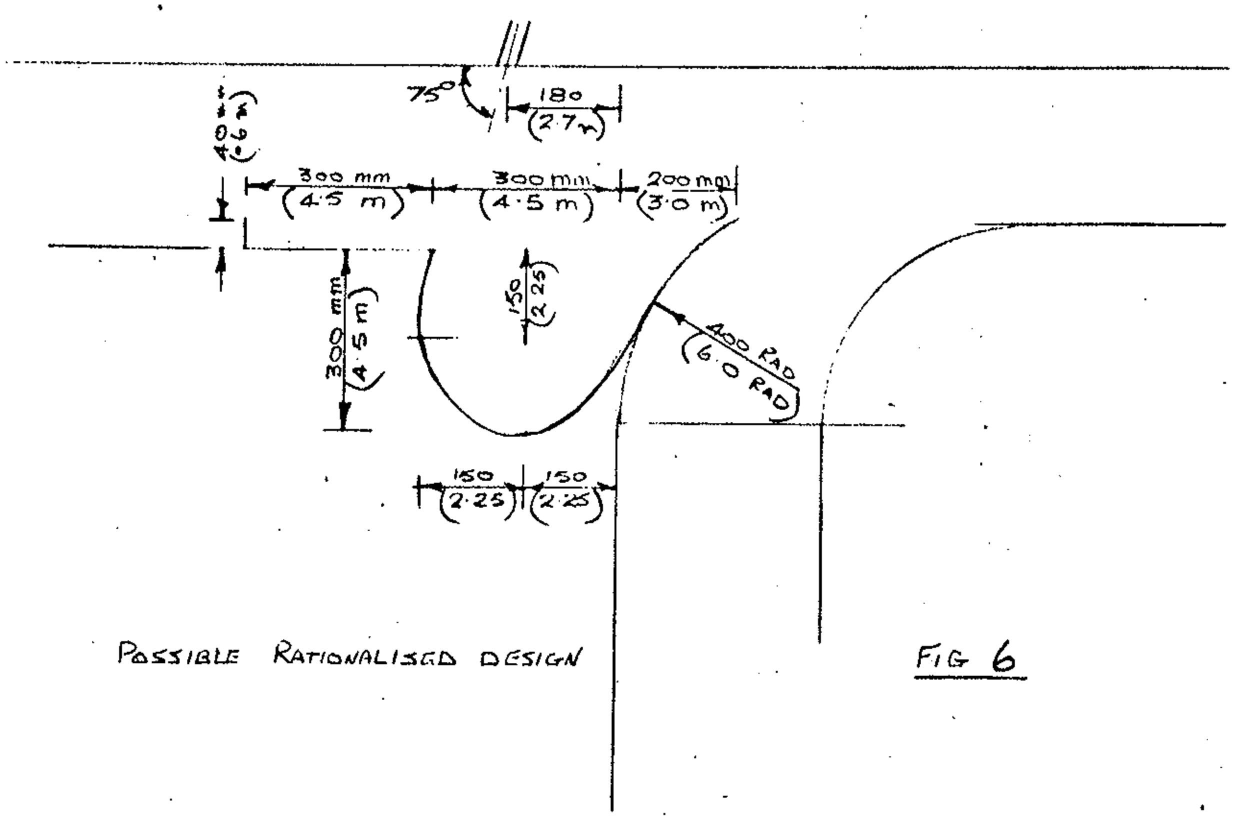
(P 1856/A/5)

FIG. 4 b CONFIGURATION 4 b



CONFIGURATION 5.

FIG 5



POSSIBLE RATIONALISED DESIGN

FIG 6

Technical Report prepared for KENNEDY AND DONKIN

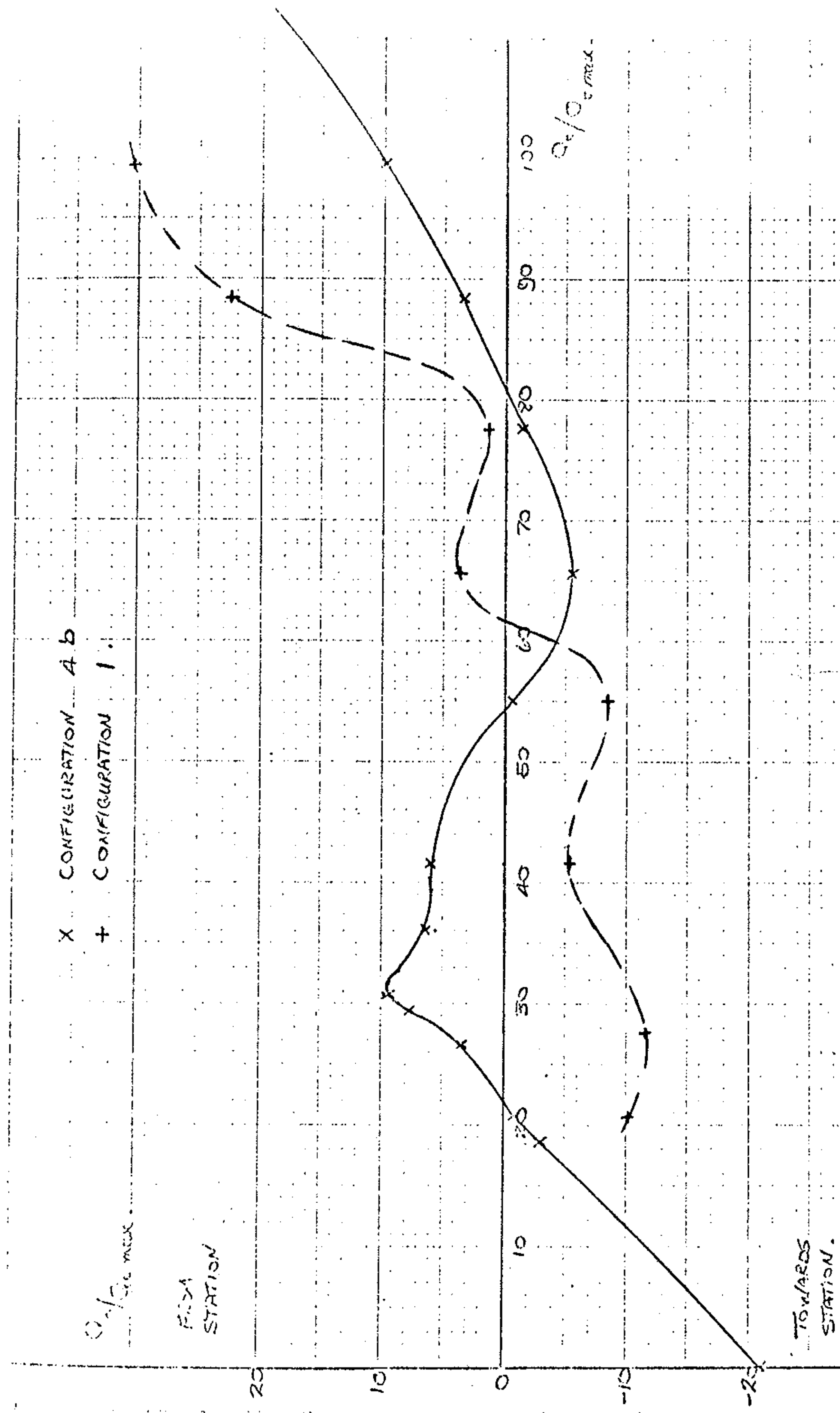


Fig 7 Leakage Characteristic for Configuration 1.

Technical Report prepared for KENNEDY AND DONKIN

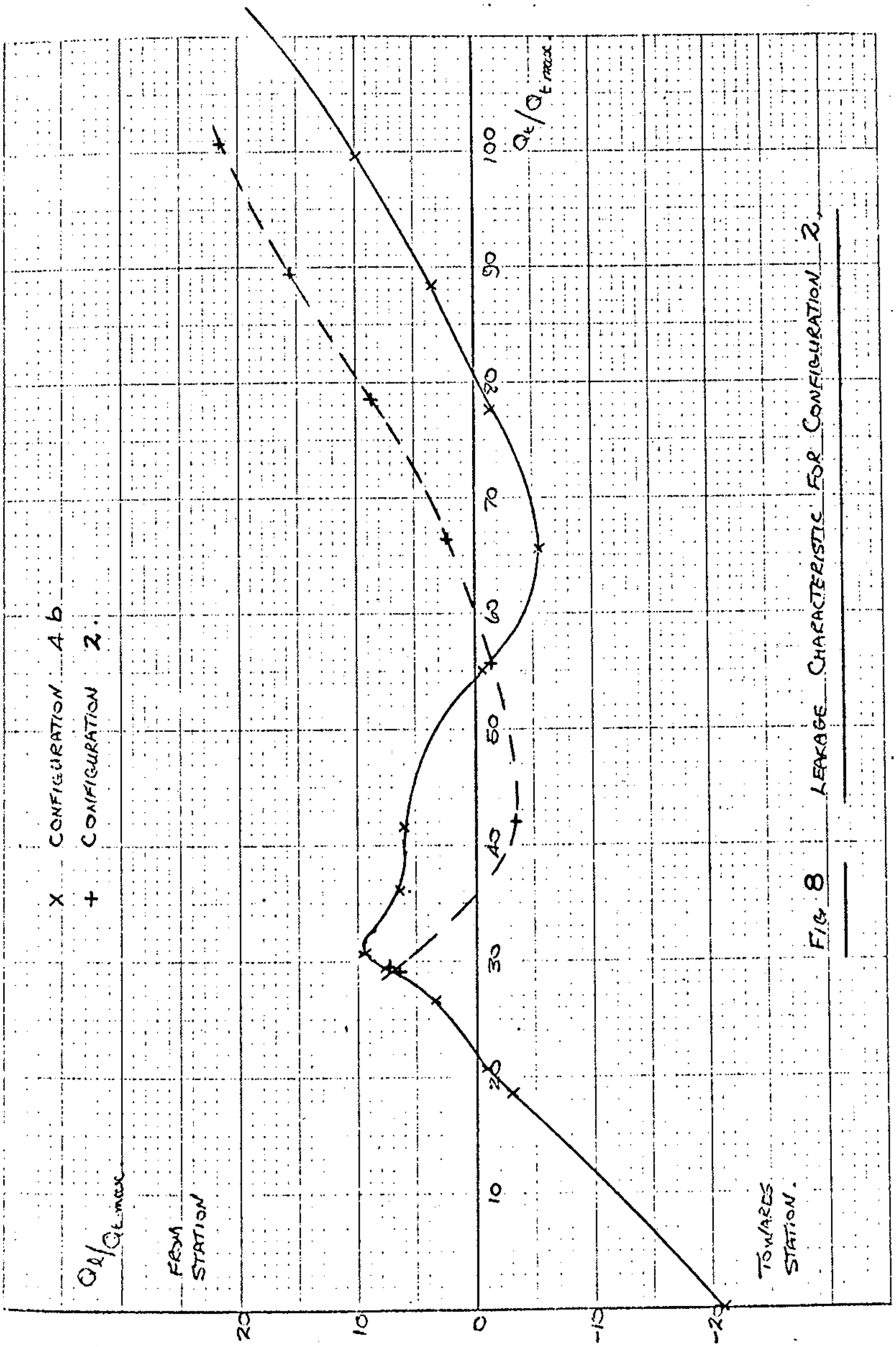


FIG 8 LEAKAGE CHARACTERISTIC FOR CONFIGURATION 2.

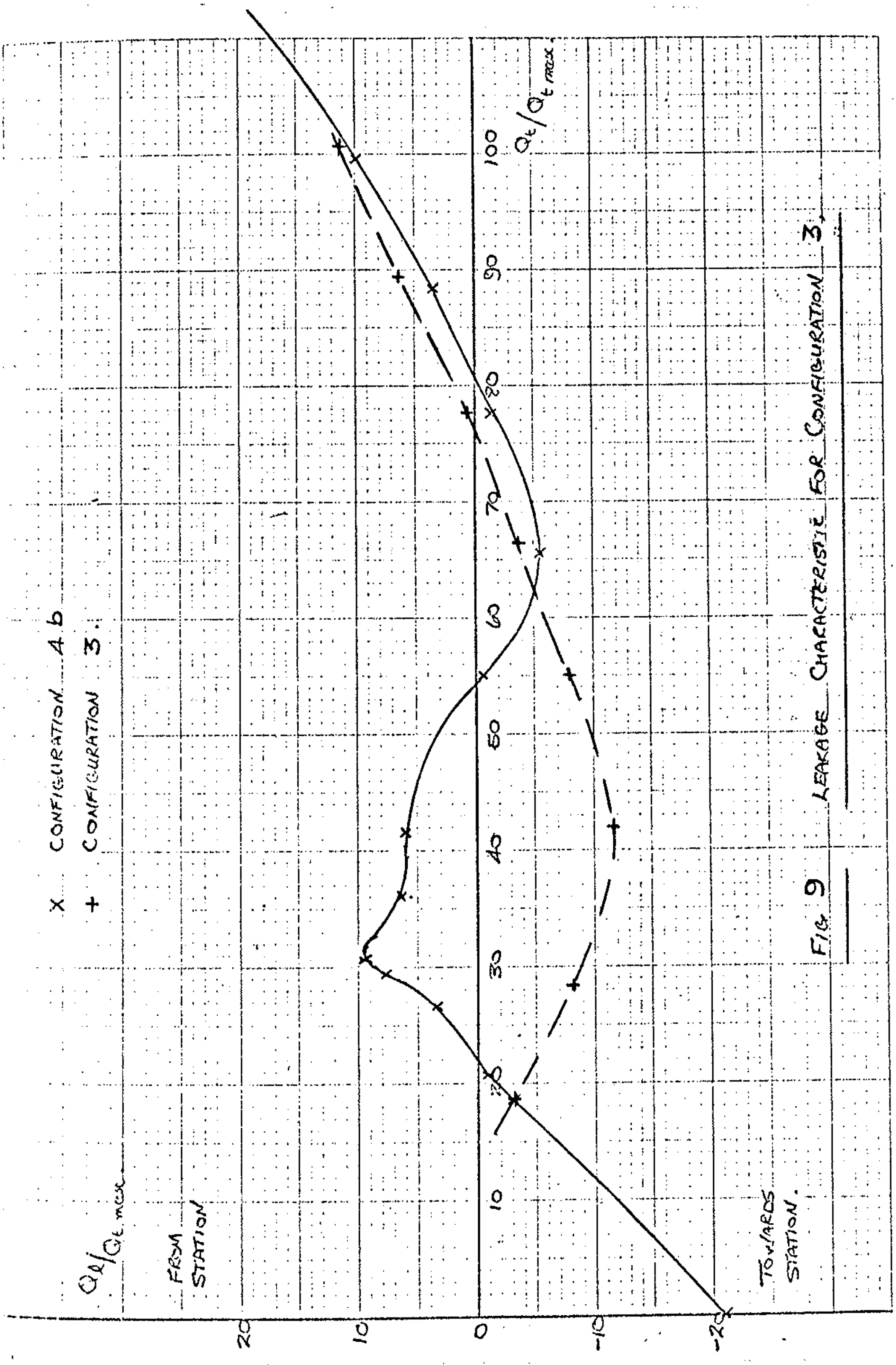


FIG 9 LEAKAGE CHARACTERISTIC FOR CONFIGURATION 3.

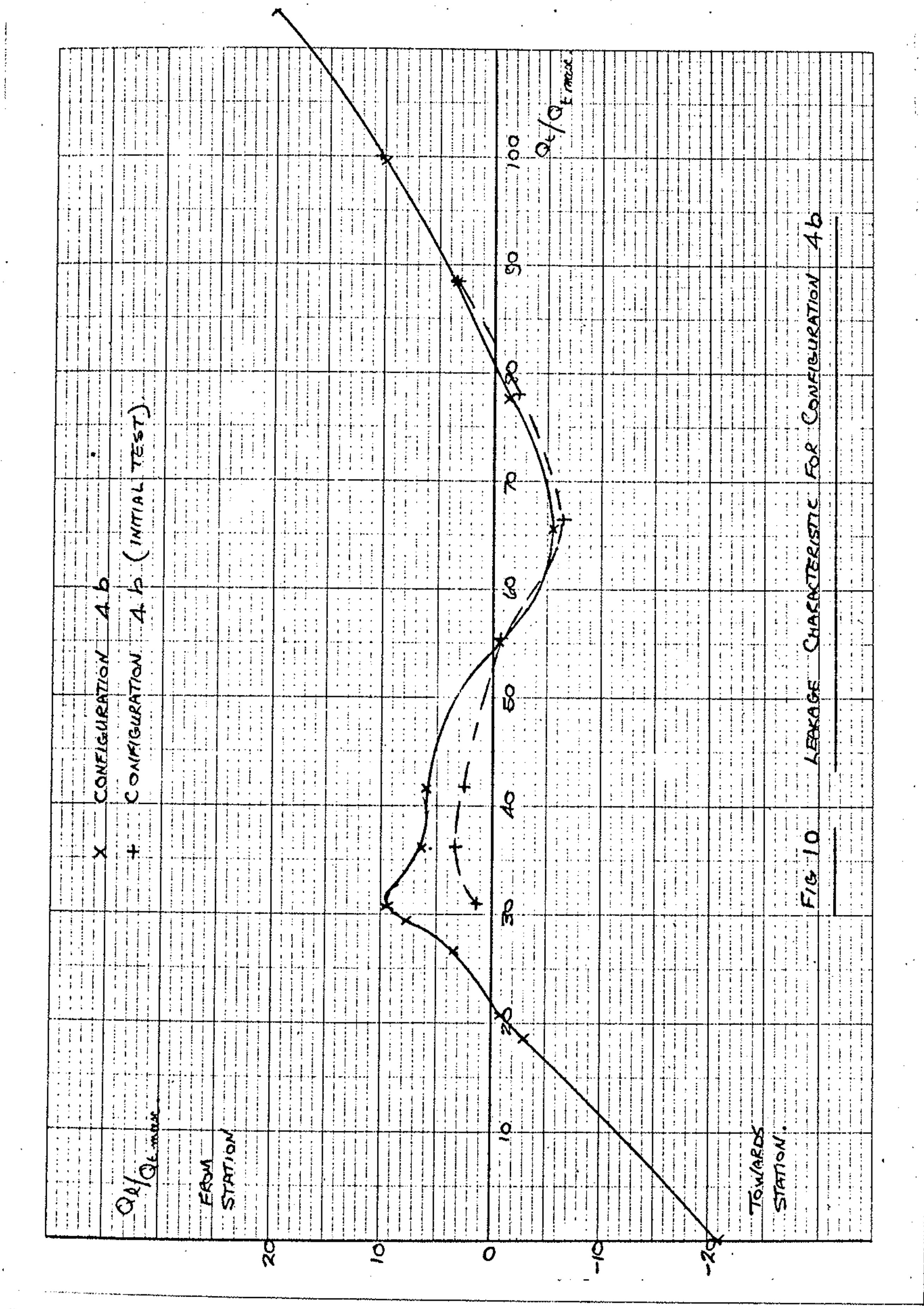


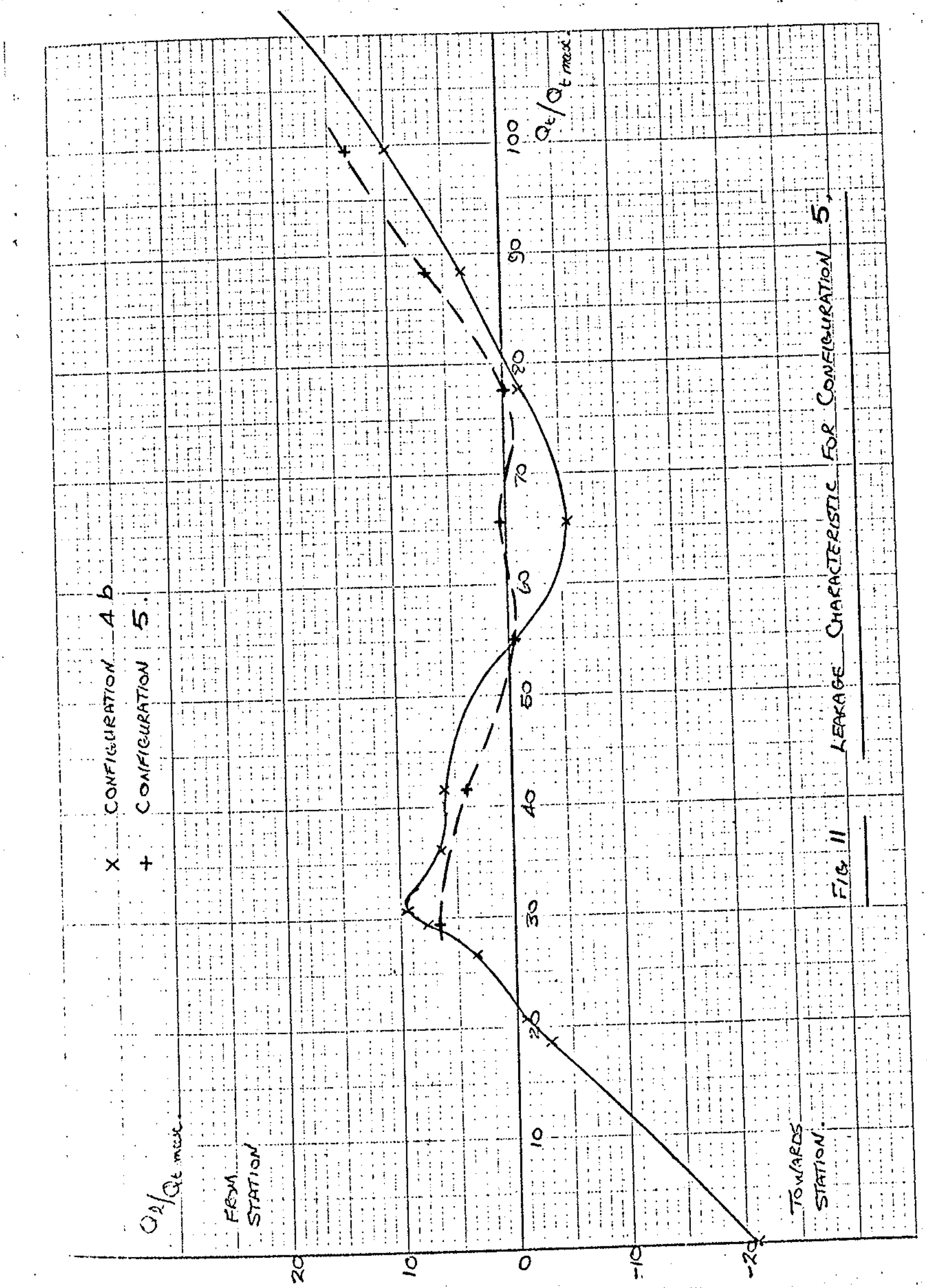
FIG 10 LEAKAGE CHARACTERISTIC FOR CONFIGURATION 4b

TRC No. 1009

Sheet 17 of 20

RP No 1856/A Date AUGUST 1973

Technical Report prepared for KENNEDY AND DONKIN



Technical Report prepared for KENNEDY AND DONKIN

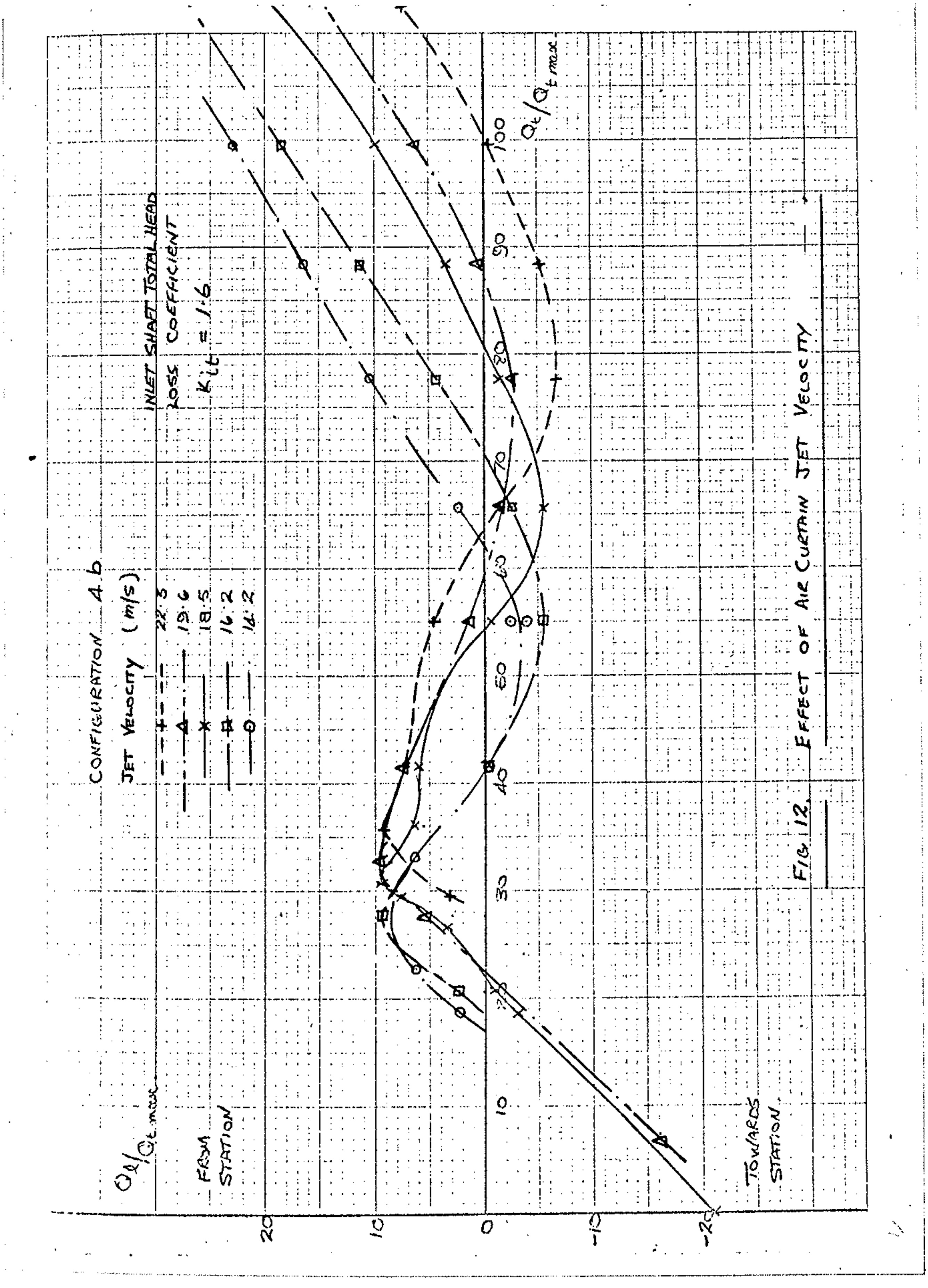


FIG. 12. EFFECT OF AIR CURTAIN JET VELOCITY

Technical Report prepared for KENNEDY AND DONKIN

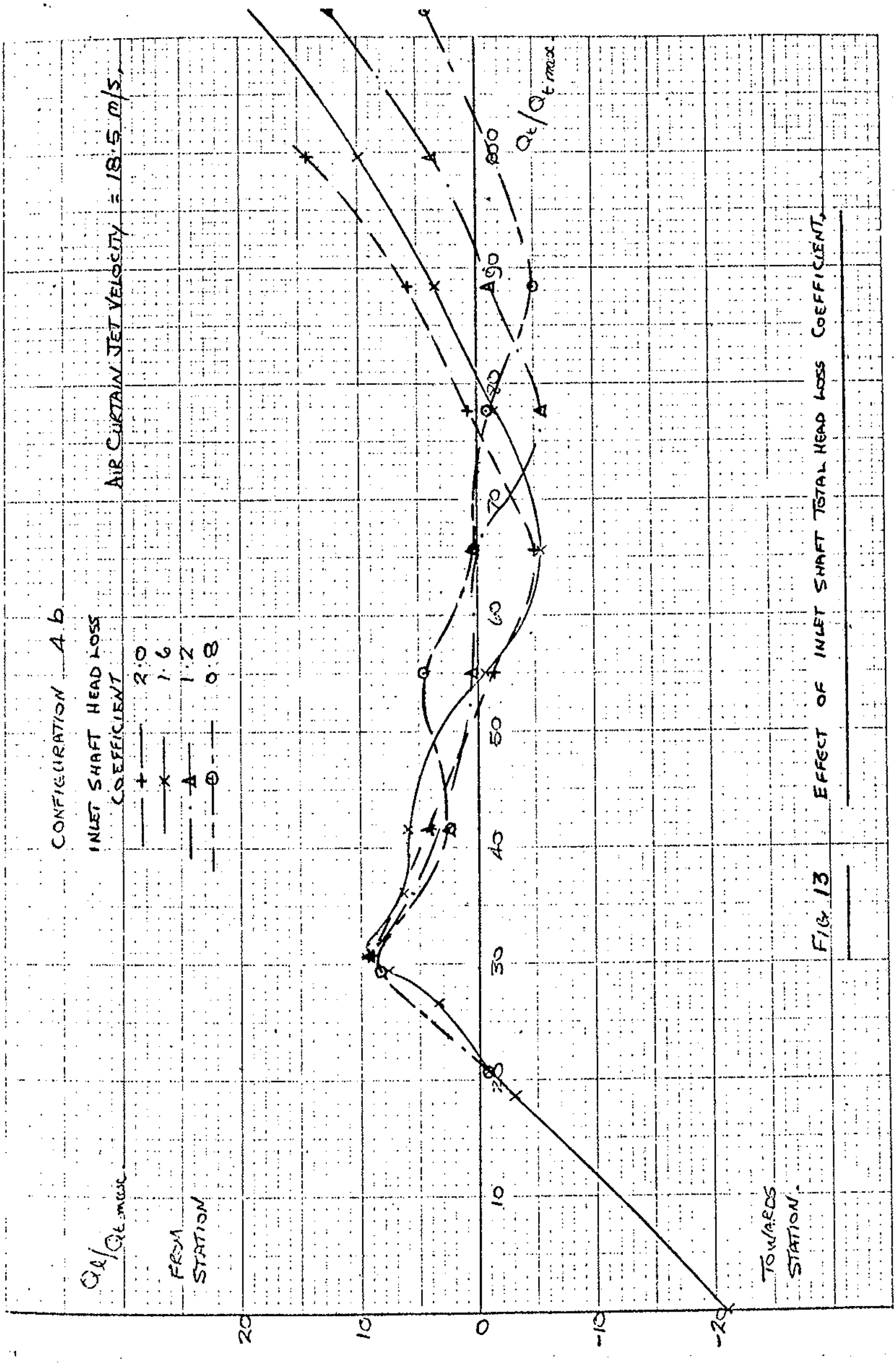


FIG 13 EFFECT OF INLET SHAFT TOTAL HEAD LOSS COEFFICIENT

Technical Report prepared for KENNEDY AND DONKIN