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THE SCALING OF MODEL TEST RESULTS TO PREDICT INTAKE HOT GAS REINGESTION FOR STOVL AIRCRAFT WITH AUGMENTED VECTORED THRUST ENGINES

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ABSTRACT

The difficulties of modelling the complex recirculating flow fields produced by multiple jet STOVL aircraft close to the ground have led to extensive use of experimental model tests to predict intake Hot Gas Reingestion (HGR). Model test results reliability is dependent on a satisfactory set of sealing rules which must be validated by fully comparable full-scale tests.

Scaling rules devised in the U.K. in the mid 60's gave good model/full scale agreement for the BAe P1127 aircraft. Until recently no opportunity has occurred to check the applicability of the rules to the high energy exhausts of current ASTOVL aircraft projects. Such an opportunity has arisen following tests on a Tethered Harrier powered by an early standard Pegasus engine with Plenum Chamber Burning.

Comparison of this full-scale data and results from tests on a model configuration approximating to the full-scale aircraft geometry has shown discrepancies between HGR levels. These discrepancies although probably due, in part, to geometry and other model/full scale differences indicate some re-examination of the scaling rules is needed.

This paper reviews the scaling practices adopted in the U.K. in the light of the recent results, describes further scaling studies planned and suggests potential areas for further work.

INTRODUCTION

STOVL aircraft supported by multiple jet lift in operation close to the ground are susceptible to ingestion by the engine of hot exhaust gases reflected, on impingement with the ground, into the engine intake. This can produce a thrust loss and may induce engine surge. The extreme complexity of the jet induced recirculating flow fields, which are highly aircraft configuration dependent, poses a severe challenge to the flow modeller and has led to extensive use of experimental model tests to predict the intake hot gas reingestion (HGR) characteristics of candidate STOVL aircraft.

For model test results to be reliable a satisfactory set of scaling rules is necessary which must be validated by fully comparable full-scale tests.

Simulation of the recirculating flow fields has been undertaken by many experimenters notably in the U.K., U.S. and West Germany. U.K. studies, to date, have been undertaken employing scaling rules formulated from fundamental theoretical and experimental considerations by Cox and Abbott at RAE Pyestock in the mid sixties (Refs 1 and 2). The studies, including simulated aircraft vertical motion, have adhered to a flow buoyancy relationship which requires model jets to be tested at pressure ratios significantly lower than full-scale. U.S. and West German researchers (Refs 3-5) have ignored the buoyancy rules and tested at full-scale pressure ratios but with no aircraft motion represented.

The validity of the 'Cox and Abbott' rules was investigated by comparison of model and full-scale results for the BAe P1127 aircraft (Ref. 6) where good agreement was obtained. The agreement, it should be noted, was obtained for cold front, hot rear jet configurations with no central hot gas fountain control.

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It has for some time been realised that the rules adopted in the U.K. have not been checked for applicability to ASTOVL projects employing augmented vectored thrust engines with high pressure/high temperature front and rear jets, maybe with inwards splay, and with mechanical deflectors for HGR fountain control (CADS/LIDS), where flow mechanisms may be radically changed.

The first opportunity to compare model and full-scale results for an augmented vectored thrust aircraft has been provided by the Tethered Harrier test rig at Shoeburyness, England. The rig comprises a Harrier aircraft fitted with an early standard Pegasus engine with Plenum Chamber Burning (PCB) installed on a hydraulic ram to afford vertical motion.

Results from full-scale tests on this rig and on model tests approximating to the full-scale configuration have recently become available. These show discrepancies between HGR levels for model and full-scale although it should be noted that these may be partly due to geometry and other differences between the model and the full-scale aircraft rather than to fundamental scaling law shortfalls.

This note reviews the scaling laws in the light of the recent results, describes further scaling studies planned in the U.K. and suggests candidate items where support from U.S. and other agencies would be valuable.

2. SYMBOLS

D	-	Diameter
g	-	Gravitational Constant
$K'_{1,2,3,4,5}$	-	Scaling Constants
L	-	Length
P	-	Total Pressure

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p	-	Static Pressure
q	-	Dynamic Head
Re	-	Reynold's Number
R^*	-	Radial Separation Distance of Ground Jet due to Buoyancy
Rs	-	Radial Separation Distance of Ground Jet due to Headwind
T	-	Total Temperature
$\theta = T - T_\alpha$	-	Temperature rise above ambient
t	-	time
u	-	ground jet velocity
V	-	velocity
W	-	Mass Flow
Cp	-	Specific Heat
ρ	-	Density
μ	-	Kinematic Viscosity
$\overline{T}_{360}$	-	Mean Intake Temperature at Engine Face
$\overline{T}_{120}$	-	Mean Temperature in the 120^o Segment at the engine face producing the highest mean temperature in any 120^o segment.
Tc_{120}	-	Intake Temperature Distortion Coefficient $= \dfrac{\overline{T}_{120} - \overline{T}_{360}}{\overline{T}_{360}}$

continued/.......

Subscripts

α	-	ambient
o	-	free stream
I	-	intake
J	-	Jet
m	-	model
FS	-	full-scale
HGR		Hot Gas Reingestion
PCB		Plenum Chamber Burning
CAD/LID		Cushion Augmentation Device/Lift Improvement Device

3. RECIRCULATION FLOW PATHS

Extensive theoretical, model and full-scale experiments have identified three ways in which the jet exhaust flows might recirculate back to the engine inlets. These are shown on Fig. 1 and comprise:-

1) Near Field Reingestion

Near Field Reingestion is caused by the flows from separate lift jets meeting on the ground creating an upward or fountain flow which impinges on and is redirected by the aircraft undersurface. Some travels directly on a short time scale to the engine inlets with little opportunity for mixing thereby retaining a high percentage of jet exit temperature and potentially causing severe HGR. Some success has been achieved in redirecting this flow away from the inlets by mechanical deflectors (CAD's/LID's).

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2) Intermediate Thrust Reverser or Mid Field Reingestion

This is caused when:-

a) Some of the recirculating flow in the ground jet and the forward moving part of the fountain is blown back by headwind into the intake after some opportunity for mixing with ambient air.

3) Far Field Reingestion

Far Field Reingestion is caused when the ground flows travel radially outwards mixing progressively with exhaust air to recirculate into the intake on a much longer time-scale driven by the effects of buoyancy and entrainment. The reingested air temperature is then relatively low so Far Field Reingestion is not usually a serious problem.

4. SIMILARITY AND SCALING

Scaling rules are required fundamentally for two main purposes:

1) To set up a consistent set of test conditions which will produce geometric and dynamic similarity between the model and full-scale test conditions.

2) To scale the results from model to full-scale conditions using, where necessary, interpolation or extrapolation of model data to relate to full-scale conditions outside the envelope of conditions examined at model scale.

4.1 Similarity

Geometric and Dynamic Head similarity, Fig. 2 are generally accepted, practice in the U.K. being to express dynamic head in the dynamic pressure (total-static) form, as recommended in Ref. 1 , rather than the kinetic pressure ($\frac{1}{2}\rho V^2$) form.

continued/......

Simple excess temperature similarity Fig. 2, designated the 'old' rule, has also been widely used although recent studies at Rolls-Royce, Ref. 7, pursued at BAe Kingston (Ref. 8), have identified an "alternative rule" based on hot gas transport. The justification and evidence supporting the old and alternative rules are discussed in more detail in Section 4.3.2.

4.2 Scaling

Fundamental considerations of factors to be considered when scaling model test conditions can identify many scaling options and a selection is shown on Fig. 3. The first five relationships were identified by Cox and Abbott and have been adhered to in all U.K. originated HGR model tests.

Test conditions can, in fact, be fully defined by three relationships:-

1) Geometry scaling, limited by rig size and capacity

2) Temperature scaling, limited by rig constraints

and

3) Either Buoyancy (generally used in the U.K.) or Full-Scale Nozzle Pressure Ratio (U.S. and WG practice) or Other parameters as shown on Fig. 3.

Time Ratio is fully defined by geometric and dynamic head scaling.

It is clear from Fig. 3 that not all relationships can be satisfied at the same time and some concessions have to be made. In fact, adoption of full-scale nozzle pressure satisfies, or closely approximates to, most other transport parameters. This ignores buoyancy and places severe demands on rig/model supplies and capabilities as discussed in Section 4.3.4.

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Adherance to dynamic pressure and excess temperature scaling allows, for simple cases, satisfaction of the buoyancy criteria implying tests at nozzle pressure ratios much lower than full-scale conditions. However, where different jet conditions exist, as in the front and rear jets of an augmented vectored thrust engine, it is not possible to strictly satisfy buoyancy and excess temperature relationships for both jets. A compromise has to be made. In general, since it has been found that near and intermediate field recirculations tend to dominate the HGR problem it has been the practice to satisfy buoyancy for the front jets and to satisfy the excess temperature scaling and accept some departure from buoyancy scaling for the rear jets. This on the premise that buoyancy is dominant mainly in the far field, see Section 4.3.3.

4.3 Implications of Scaling

4.3.1 Geometry

Linear geometric scaling is generally accepted for model tests. Large models require large rigs with high flow and power requirements. Small models limit instrumentation density and, depending on scaling assumptions, generally imply higher time-scale factors requiring faster response instrumentation for transport measurements. Current practice is to employ models in the 1/10th to 1/15th scale regime.

4.3.2 Excess Temperature

Rig material constraints have generally limited jet exhaust temperatures to about 800K, which are fully representative for early P1127/Harrier aircraft conditions, but which impose increasingly severe scaling requirements for advanced STOVL aircraft projects operating at jet exhaust temperatures in the range 1000K-1800K.

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It had been assumed until recently that the recirculation temperature rise (θ_I) was a constant fraction of the jet excess temperature (θ_J) where the front jet conditions were used for multiple jet arrangements. However, recent re-examination of hot transport criteria, initially at Rolls-Royce and subsequently at BAe have identified a possible alternative rule which introduces a density term ($\propto \sqrt{T_J}$) into the scaling relationship so that

$$\left\{\frac{\theta_I}{\theta_J}\frac{\sqrt{T_J}}{\sqrt{T_\alpha}}\right\}_{FS} = \left\{\frac{\theta_I}{\theta_J}\frac{\sqrt{T_J}}{\sqrt{T_\alpha}}\right\}_{M}$$

This has been expressed in the form of a 'corrected jet excess temperature' by Milford at BAe Kingston where $\theta_J^* = \theta_J\sqrt{T_\alpha}/\sqrt{T_J}$ so that θ_I / θ_J^* is constant rather than θ_I / θ_J as assumed by Abbott and Cox.

The validity of the two rules has been investigated by reference to model HGR tests from previous experiments(Refs 8&9) covering jet excess temperatures in the range 130°C-600°C. The results are inconclusive as some data can be found to collapse better on the old rule, some better on the alternative, with the effect, if any, on some being obscured by general data scatter. Some examples are shown on Figs 4a and 4b. It may be that the two rules are each applicable in particular regimes where different modes of hot gas transport are dominant. In spite of the uncertainty as to which rule to use an examination of the relative effect on full scale intake excess temperature estimation of emplcying the alternative rule can be seen on Fig. 5. This curve shows that for jet temperatures in the region of the P1127 the change is insignificant. At high jet temperatures,circa 1400-1800K,the alternative rule would give a predicted full scale intake temperature rise $\doteqdot$ 30% less than the old rule. A similar factor applies to intake temperature distortion (TC_{120}) where Tc_{120} represents a coefficient employed at Rolls-Royce which can be related to the amount of engine available surge margin erosion caused by intake

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temperature distortion. For current projected STOVL aircraft with a target landing jet temperature of approximately 1000K the alternative rule implies estimates of intake temperature rise of $\simeq$ 10% less than the old rule.

The need for all HGR sensitive aircraft must be to reduce intake HGR to a very low level in which case the correction factor is relatively unimportant.

4.3.3 Relevance of Buoyancy

It can be argued that buoyancy scaling may have been adopted primarily for reasons of test technique. Adherance to the buoyancy rule permits model HGR tests to be carried out in a low speed wind tunnel at low model jet pressures with slow model motion and with instrumentation with moderate time response. The rule does, however, imply model tests at nozzle pressure ratios much less than full-scale where questions must be asked whether low pressure jets can correctly simulate the conditions present in high pressure choked jets.

The significance of buoyancy was originally assessed by Cox and Abbott in terms of its influence on the radial separation of a ground jet compared to the separation due to a relative headwind. Separation distance, non-dimensionalised by jet diameter D_J was found to correlate in terms of buoyancy and headwind parameters for model and full-scale, (Ref.1&10). The relationships can be used to produce carpet plots in terms of nozzle temperature and pressure ratio for buoyancy separation (Fig. 6a) and in terms of nozzle pressure ratio and headwind for headwind separation (Fig.6b). For relevant buoyancy scaled test conditions the separation distance due to buoyancy is typically 100 or more nozzle diameters. This is remote from the impingement source and from the inlet and is in

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the 'far field'. For relevant buoyancy scaled test conditions the separation distance due to headwind is typically of order 10 nozzle diameters. This is in the 'near' and intermediate reingestion fields. This suggests that buoyancy is probably not critical for near or intermediate field HGR but does not necessarily imply that buoyancy scaling is incorrect.

4.3.4 Full-Scale Nozzle Pressure Ratio NPR

While full-scale NPR satisfies or closely approximates to most transport parameters adoption of full NPR requires simulation at model scale of full-scale headwinds, pressures, motion and time response instrumentation K_1 times full-scale for a model geometry scale K_1. To the Authors knowledge tests at full NPR have yet to address the problem of model motion as all tests to date have been at fixed height. Evidence in the U.K., albeit at buoyancy scaled conditions, shows that failure to represent model motion will give incorrect levels of intake HGR during simulated aircraft landing and take-off operations for full-scale aircraft, see Fig. 7, since landing into the developing hot gas pattern is essentially a dynamic process.

5. MODEL/FULL-SCALE AGREEMENT

5.1 P1127 Results

It was realised very early on in the U.K. studies that postulated scaling rules needed to be validated by comparative full-scale information. To this end a series of full-scale aircraft tests was commissioned covering take-offs and landings for comparison with test results from a model closely simulating the full-scale aircraft geometry. (Ref. 6). Agreement, in terms of mean intake temperature rise, relative to front jet excess temperature,

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between the model and full-scale results is shown on Fig. 8 to be very good. Ref. 6 also indicated that temperature distortion contours were very close with a strong bias for hot gas to be present in the bottom portion of the intake. On the above evidence it was decided to retain the postulated scaling rules including buoyancy for all future studies. The good agreement was, of course, obtained for low temperature front jets, hot rear jets with no central hot gas fountain control.

5.2 Pegasus 2A/Tethered Harrier

Concern has been expressed for some time that the scaling rules adopted in the U.K. have not been examined in the context of the conditions relevant to current ASTOVL aircraft projects employing augmented vectored thrust engines with high pressure/high temperature front and rear jets and probably incorporating HGR avoidance devices such as nozzle convergence and/or CAD's. The Tethered Harrier Aircraft mounted on a dynamic ram on a large gantry at Shoeburyness, England has recently afforded a first opportunity to examine the applicability of the scaling rules. The full-scale installation is shown on Fig. 9.

The aircraft was fitted with an early standard Pegasus engine with PCB configured with 'TV' shaped front nozzles arranged, in the vertical nozzle setting, as shown on Fig. 10. The engine was instrumented with an array of 48 fast response thermocouples at the engine face.

The results obtained from some of the simulated landings carried out at full-scale for a range of front jet temperature augmentation up to 1400K have been analysed in terms of peak mean intake temperature rise encountered during a landing relative to front jet excess temperature,

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Figs 11 and 12 refer,and for temperature distortion, Fig. 13. Fig. 11 presents results for a 20° converged front nozzle configuration with a CAD fitted with data for the same CAD but with 10° converged front nozzles on Fig. 12. Fig. 13 presents temperature distortion data for the 10° converged nozzle with CAD. All curves are plotted with front jet mean temperature as abscissa. The mean intake temperature rise data,Fig. 11,is seen to collapse reasonably well in terms of simple jet excess temperature supporting the 'old' temperature scaling rule. Plotting the data on a 'corrected' jet excess temperature produces a significant positive gradient with increasing excess temperature.

The full-scale results can be compared with model test results obtained from tests on a model closely simulating the aircraft configuration with 10° coverged front nozzles but with circular front nozzles rather than the 'TV' shaped front nozzles on the full-scale engine. The model test conditions were set up using the scaling rules, including buoyancy, to represent maximum engine conditions at full-scale i.e. a front jet temperature of 1400K. Fig. 14 shows the scaled and full-scale conditions with, for comparison, conditions used for the P1127 tests. The necessary small departure from correct rear nozzle buoyancy scaling can be seen caused by the requirement to satisfy the excess temperature and dynamic head scaling ratios derived when applying the buoyancy rule to the front nozzles.

Model results for the 10° convergent nozzle + CAD geometry are superimposed on Figs 12 and 13 at conditions relevant to the full-scale engine conditions. It can be seen that the full-scale results for mean intake temperature rise relative to front jet excess temperature exceed the model by approximately 100%.

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Further considerations of the configurations, however, indicated that the 'TV' shaped front nozzles of the full-scale aircraft aligned with the nozzles vertical so that a major portion of the ground sheet flow travelled forwards. The magnitude of this effect in terms of intake HGR has been estimated from the work of Kotansky, Ref. 11 to be of the order of 40% increase in mean temperature rise at the intake (Fig. 15). This reduces the model/ full-scale discrepancy but a large difference still remains.

Further examination of the full-scale results indicated a severe temperature profile at the front nozzle exits - the model tests being carried out with a near uniform temperature profile. The full-scale profile contains a hot central core displaced somewhat aft of the nozzle centreline and surrounded by an annular ring of air at less than the mean temperature. It is not known how far downstream this profile persisted or the effect it might have on the intake temperature rise. It can be postulated that some gas at the mean jet temperature might enter the intake with little mixing thereby raising the mean intake temperature (as the full-scale results suggest). On the other hand the cool outer annulus flow at $<$ the mean jet temperature might be expected to shield the hot core flow from the inlets.

The model results for intake temperature distortion, Tc_{120} for the 10^{o} converged nozzles + CAD geometry, see Fig. 13 also indicate a discrepancy between model and full-scale - full-scale again exceeding the model data but this time by only about 25%. Further studies aimed at investigating this difference were made to examine the temperature contours at the engine face for model and full-scale. A typical comparison is made on Fig. 16. Where a full-scale test point, obtained at a front jet temperature of $\doteq$ 900K, is compared with a model result, at similar aircraft height, landing velocity and headwind conditions, scaled to the same

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jet temperature. In spite of differences in absolute levels for both mean temperature rise and temperature distortion the patterns exhibit similar characteristics with high temperature generally dominant in the lower portion of the intake.

A possible further factor which may affect model/full-scale agreement is that of jet turbulence. There appears to be little data in the literature but a relevant reference by Lummus, Ref. 12, suggests that fountain force on an aircraft planform in ground effect can be modified by changing jet turbulence. It can be concluded from this evidence that differences in jet turbulence might also be expected to influence intake HGR levels.

6. CURRENT POSITION

The current state-of-the-art in the U.K. on predicting full-scale HGR characteristics for STOVL aircraft from model tests set up using scaling rules originally proposed twenty years ago can be summarised:

> The rules give good model/full-scale agreement for both mean intake temperature rise and temperature distortion contours for STOVL aircraft, such as the P1127/Harrier, with cool front jets (circa 400K) and hot rear jets (950K) with no fountain control devices.
>
> Within limitations of current model/full-scale geometric similarity the rules appear to underpredict levels of mean temperature rise and temperature distortion from a 'test bed' type STOVL aircraft fitted with an augmented vectored thrust engine with front nozzle jet temperatures up to 1400K.

continued/......

Additional observations for the Tethered Harrier programme can be made:

The fu_l-scale data produces a good collapse of mean intake temperature rise with simple front jet excess temperature supporting the 'old' rule.

A greater discrepancy exists between full-scale and model predicted intake mean temperature rise than for temperature distortion.

Intake temperature distortion contours at full-scale, although higher than model predictions, exhibit the same general shape.

Accordingly it is considered that the scaling rules must be open to question and a programme of work has been outlined in the U.K. to investigate various aspects of scaling. These are discussed in the following section.

7. SUPPORTING EXPERIMENTAL PROGRAMMES

Future work plans fall into three separate categories (Fig. 17)

- Model and full-scale tests related to the Tethered Harrier Aircraft.
- Fundamental scaling law studies to be carried out with simplified aircraft configurations.
- Fundamental studies of jet wakes including entrainment and fountain flow properties.

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7.1 Tethered Harrier Related Studies

Model studies are planned to directly reproduce conditions encountered during the full-scale tests to investigate the effect on HGR of 'TV' shaped nozzles, to study temperature profile and possibly jet turbulence. These studies are aimed directly at providing answers to questions raised concerning differences identified between model and full-scale results obtained on the Pegasus 2A installation. The tests will include some studies with jet conditions approaching full-scale values thereby ignoring the buoyancy scaling relationship.

A further programme of work is planned on the Tethered Harrier using a Pegasus 11 engine offering increased nozzle pressure ratio to the Pegasus 2A (circa 2.0:1). This work will extend full-scale data towards the jet conditions expected for future ASTOVL aircraft. This full-scale programme will be supported by tests on a model closely simulating the aircraft configuration. Scaling rules to be used for this model will depend on results from fundamental jet studies and simple aircraft configuration studies identified to examine the scaling rules in a systematic way. The studies are briefly outlined below.

7.2 Simplified Aircraft Configuration

A comprehensive set of experiments is proposed to measure intake HGR on simple aircraft configurations using the full range of projected ASTOVL aircraft jet pressure ratios and temperatures for different assumptions concerning the chosen scaling laws.

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The studies will cover a far flowfield investigation for a single jet with jet pressure ratios from buoyancy scaled to full-scale simulation with variations in jet temperature to study excess temperature scaling. Studies will also be made for near field reingestion of a twin jet assembly, again over a full range of nozzle temperatures and pressures, to examine alternative scaling assumptions.

7.3 Basic Jet Flowfield Studies

Existing rigs in the U.K. used for HGR studies have been designed to buoyancy-scaled test conditions and therefore do not, at present, have sufficient capacity to test at full-scale nozzle pressure ratios. The rigs are not equipped for detailed jet flowfield surveys. Such studies have therefore been proposed using simple jets alone. Two programmes of work have been identified.

1. A study of single jet entrainment with measurements in the free jet wake and in the ground sheet after jet/ground impingement to determine the effects of jet Mach number. The study is planned to include the effects of imposed turbulence patterns on jet decay characteristics.

2. A study with multiple jets to investigate the effects of varying nozzle pressure ratio on flow behaviour in the ground jet and in the fountain regions. This study is intended to be complementary to the above single jet study.

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REFERENCES

1. Studies of the Flow Fields created by single vertical jets diverted downwards upon a horizontal surface.
   NGTE Report M390. M Cox and W A Abbott. Oct. 1964.

2. Estimation of Intake Temperatures during V/STOL Operation from Model Tests.
   NGTE Note No. NT600. W A Abbott. March 1966.

3. VTOL Reingestion Model Testing of Fountain Control and Wind Effects.
   AIAA 75-1217. H A Weber and A Gay.

4. V/STOL Aircraft Configuration Effect on Exhaust Gas Ingestion.
   AIAA 79-1284. E D Spong, J H Kamman, C L Hall, and E T Seiffertt.

5. Hot Exhaust Gas Reingestion Characteristics of a Small-Scale Harrier Type V/STOL Aircraft Model.
   McDD Report MDC A4225. Hall and Kamman. August 1977.

6. Full-Scale and Model Studies of Exhaust Ingestion on the Hawker Siddeley P1127 with Special Reference to Scaling Laws.
   NGTE Note No. NT658. A W R Allcock and W A Abbott. Oct. 1967.

7. Hot Gas Reingestion Temperature Scaling Laws.
   RR Report GN.20346. L R Harper. March 1982.

8. Scaling Factors for Hot Gas Recirculation.
   BAe Kingston Report BAe-KAD-N-GEN-2878. C M Milford. August 1981.

9. VTOL Transport Exhaust Gas Ingestion Model Tests.
   Proceedings of 7th Annual National Conference on Environmental Effects on Aircraft and Propulsion Systems.
   Princeton New Jersey. Sept. 1967. A E Harris, J A Marbert, J W Tatom.

10. Studies of Flow Fields Created by Vertical and Inclined Jets when Statiionary or Moving over a Horizontal Surface. Note. Report M391. W A Abbott. Oct. 1964.

11. Investigation of the Interaction of Lift Jets and a Ground Plane.
NASA CR152343. D R Kotansky, L W Glaze. April 1980.

12. Critically of Engine Exhaust Simulations on VSTOL Model - Measured Ground Effects.
AIAA 80-0230. J R Lummus.

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4-POSTER PEGASUS HOT GAS RECIRCULATION MECHANISMS

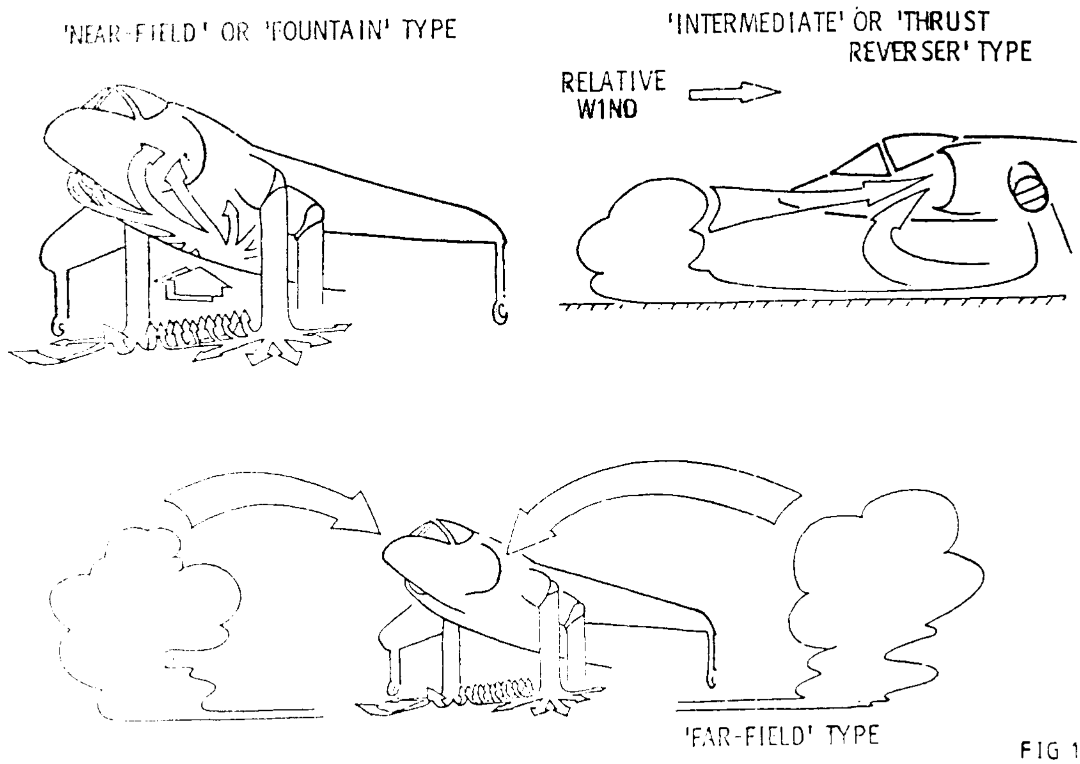


FIG 1

SIMILARITY

o GEOMETRY $\left(\frac{L1}{L2}\right)_{MODEL} = \left(\frac{L1}{L2}\right)_{FULL\ SCALE}$

o DYNAMICS $\left(\frac{q_1}{q_2}\right)_{MODEL} = \left(\frac{q_1}{q_2}\right)_{FULL\ SCALE}$

[SIMILARLY $\frac{V_{MODEL\ ASCENT/DESCENT}}{V_{WIND\ TUNNEL}} = \frac{V_{AIRCRAFT\ ASCENT/DESCENT}}{V_{HEAD\ WIND}}$]

o TEMPERATURE $\left(\frac{\theta_I}{\theta J}\right)_{MODEL} = \left(\frac{\theta_I}{\theta J}\right)_{FULL\ SCALE}$ (" OLD RULE ")

OR $\left(\frac{\theta_I}{\theta J}\sqrt{\frac{TJ}{T\alpha}}\right)_{MODEL} = \left(\frac{\theta_I}{\theta J}\sqrt{\frac{TJ}{T\alpha}}\right)_{FULL\ SCALE}$ ("ALTERNATIVE RULE")

FIG 2

SCALING RELATIONSHIPS

	ITEM	RELATIONSHIP	COMMENT
NGTE SCALING RULES	GEOMETRY	$D_m/D_{fs} = K_1$	GEOMETRY SCALE
	'DYNAMIC HEAD'	$(P-P_\infty)_m/(P-P_\infty)_{fs} = K_2^2$	$K_2^2 \ll 1$ FOR 'BUOYANCY SCALING = 1 FOR MACH NO OR NPR REPRESENTATION
	TEMPERATURE	$(T-T_0)_m/(T-T_0)_{fs} = K_3$	K_3 AS CLOSE TO 1 AS FACILITY PERMITS
	BUOYANCY	$\dfrac{\left[\dfrac{V_j^2 T_\infty}{\theta_j D_j}\left(\dfrac{T_\infty}{T_j}\right)^{1/2}\right]_{model}}{\left[\quad\right]_{fs}} = K_4$	$K_4 = 1$ FOR BUOYANCY SCALING $K_4 \gg 1$ FOR NPR REPRESENTATION
	TIME	$t_m/t_{fs} = K_1/K_2'$	TIME SCALE
	VELOCITY	$V_m/V_{fs} = K_2'$	$K_2' = K_2$ FOR CONSTANT DENSITY REGIMES
	MOMENTUM FLUX	$\left(\dfrac{WV}{D^2}\right)_m \Big/ \left(\dfrac{WV}{D^2}\right)_{fs} = K_2'^{\,2}$	$K_2' \ll 1$ FOR BUOYANCY SCALING = 1 FOR MACH NO OR NPR REPRESENTATION
	MASS FLUX	$\left(\dfrac{W}{D^2}\right)_m \Big/ \left(\dfrac{W}{D^2}\right)_{fs} = K_2'$	
	HEAT FLUX	$\dfrac{\left[\dfrac{WC_p(T-T_\infty)}{D^2}\right]_m}{\left[\quad\right]_{fs}} = K_2' K_3$	
	REYNOLDS NO.	$\left(\dfrac{\rho VD}{\mu}\right)_m \Big/ \left(\dfrac{\rho VD}{\mu}\right)_{fs} = R_{em}/R_{efs} = K_5$	$K_5 < 1$ FOR NPR REPRESENTATION $K_5 \ll 1$ FOR BUOYANCY SCALING

FIG3

TEMPERATURE SCALING

(DATA SUPPORTS OLD RULE)

Ref: Harris et al Lockheed 1967

'OLD RULE' **'ALTERNATIVE RULE'**

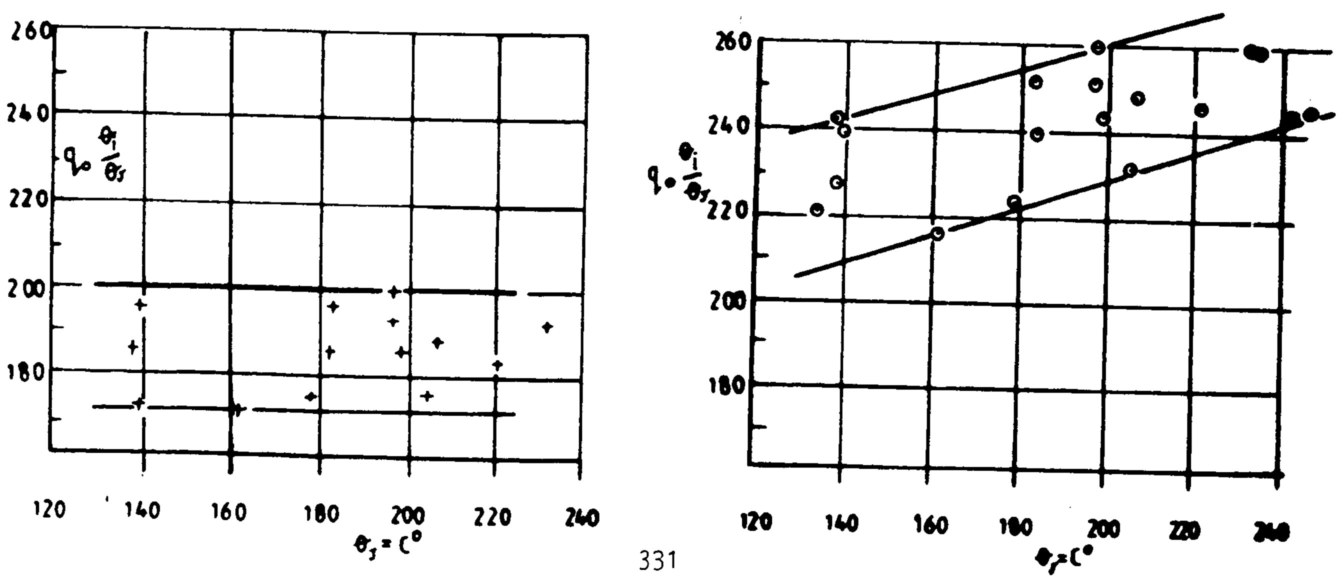
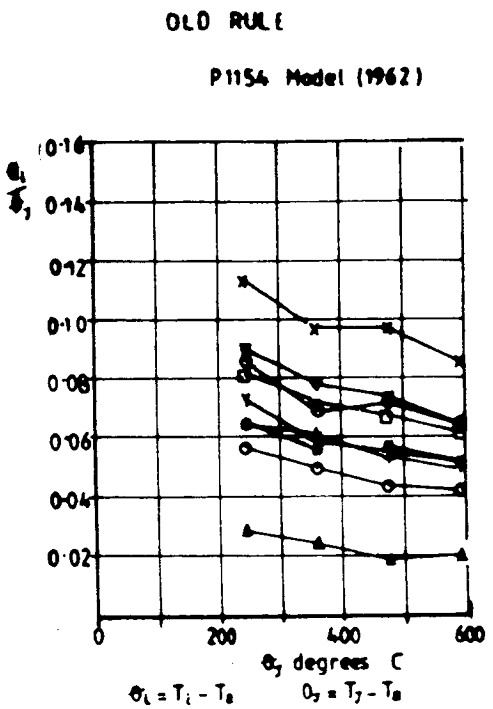


FIG 4a

TEMPERATURE SCALING

(DATA SUPPORTS ALTERNATIVE RULE)



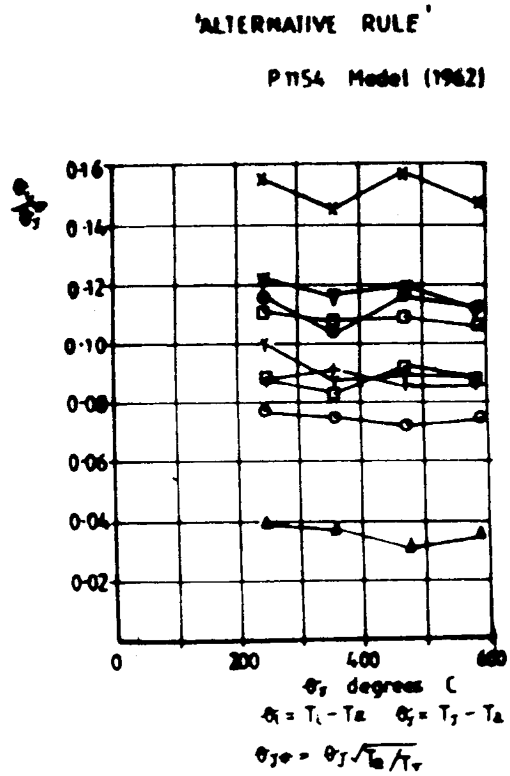
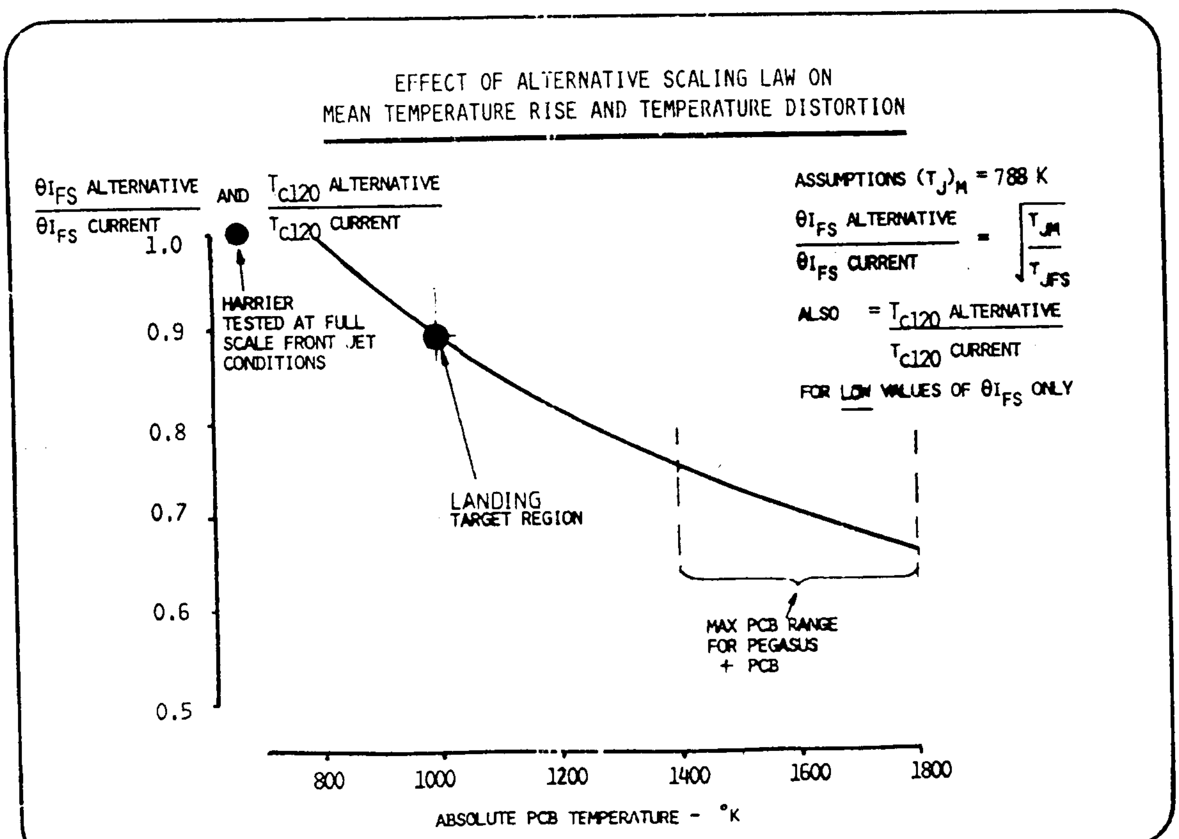


FIG 4b



PRS204

FIG 5

RADIAL SEPARATION OF GROUND JET DUE TO BUOYANCY

1/15th SCALE MODEL CONDITIONS. NOZZLE DIAMETER DJ = 1·6 INS.

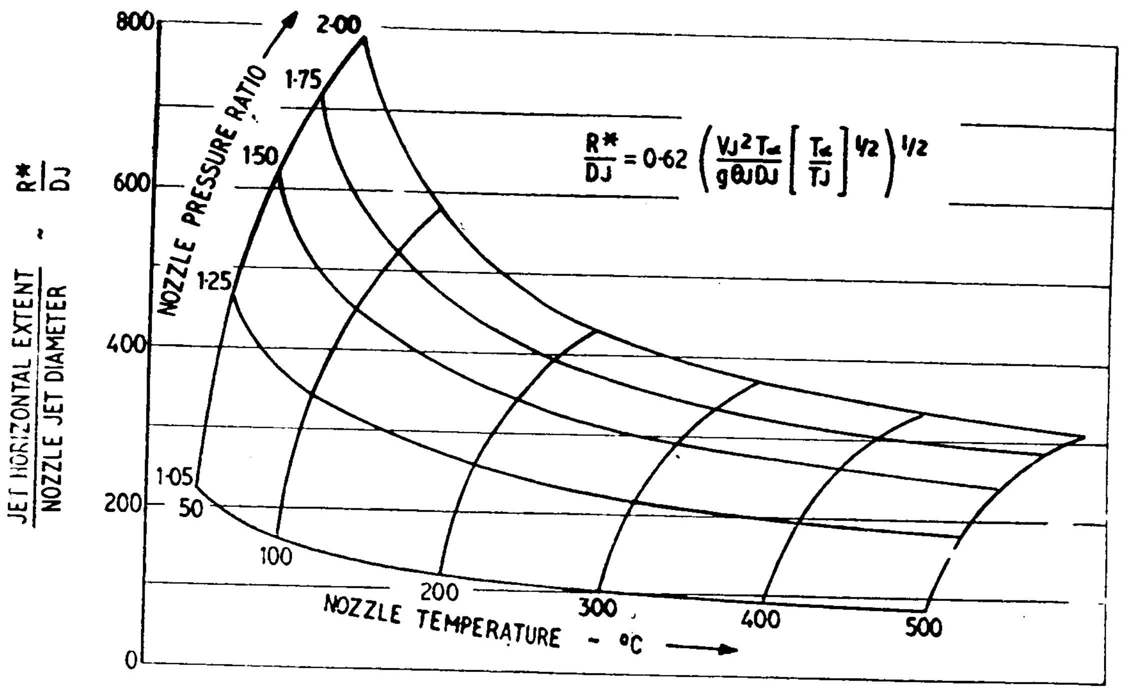


FIG 6a

VARIATION OF GROUND JET SEPARATION DISTANCE WITH HEADWIND

1/15th SCALE MODEL CONDITIONS. NOZZLE DIAMETER D_J = 1·0 TO 1·4 INS

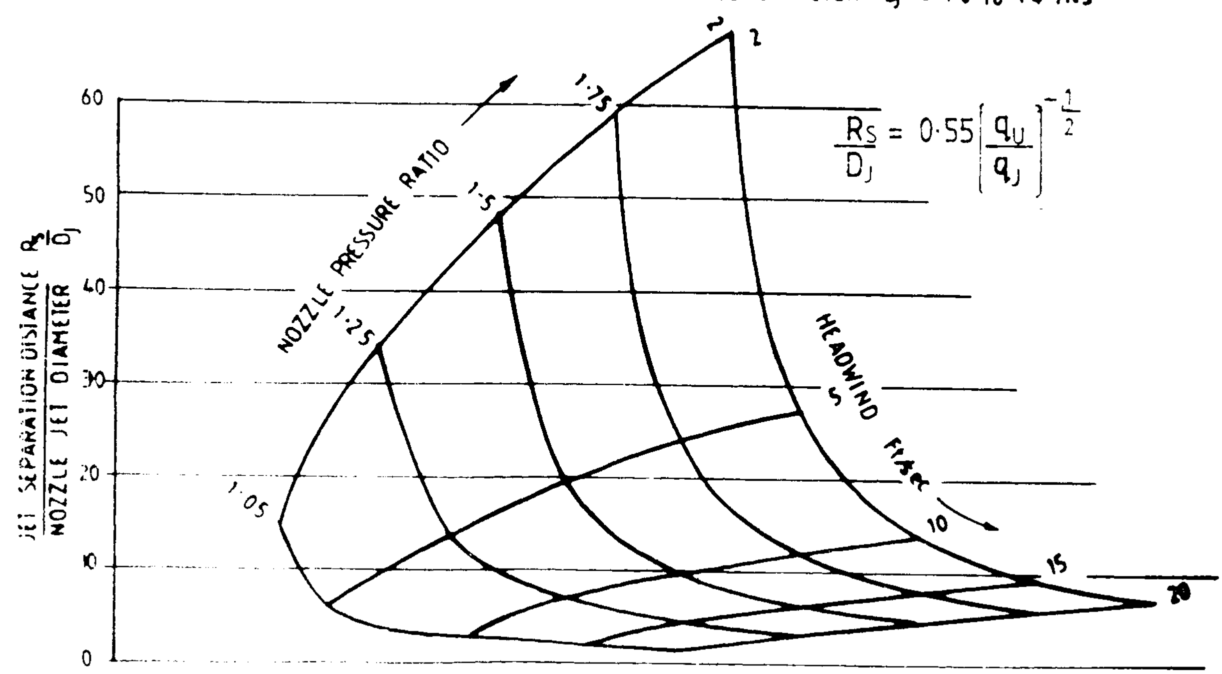


FIG 6b

COMPARISON BETWEEN PROLONGED HOVER AND MOVING MODEL TESTS

VARIATION OF PEAK MEAN INTAKE TEMPERATURE RISE WITH HEADWIND

10° CONVERGED NOZZLES CAD 'N'

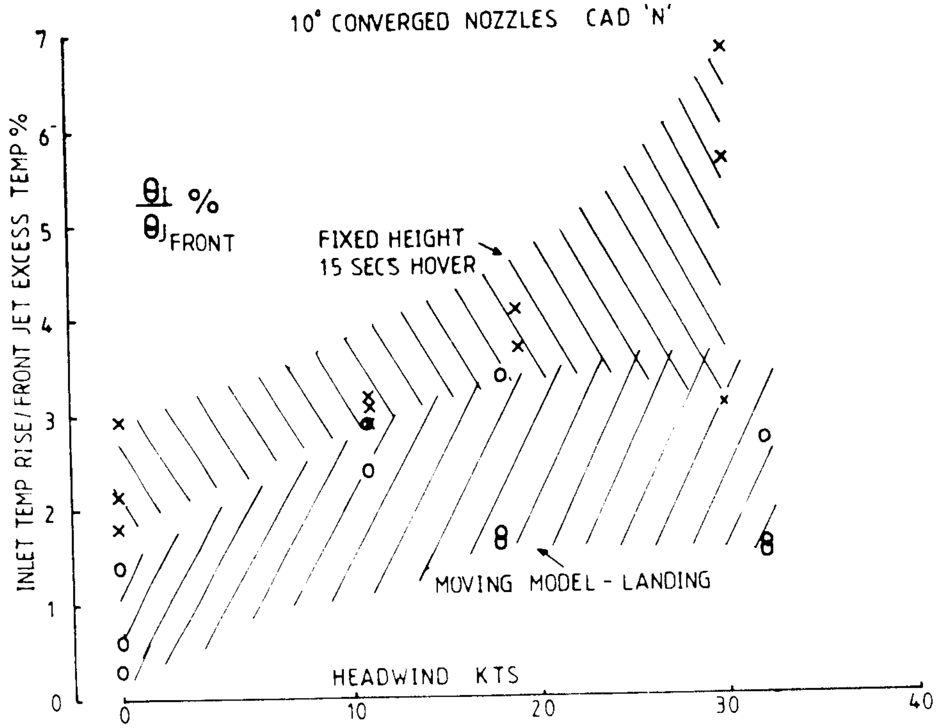


FIG 7

COMPARISON OF MODEL AND FULL SCALE RECIRCULATION TEST RESULTS (P1127 AIRCRAFT)

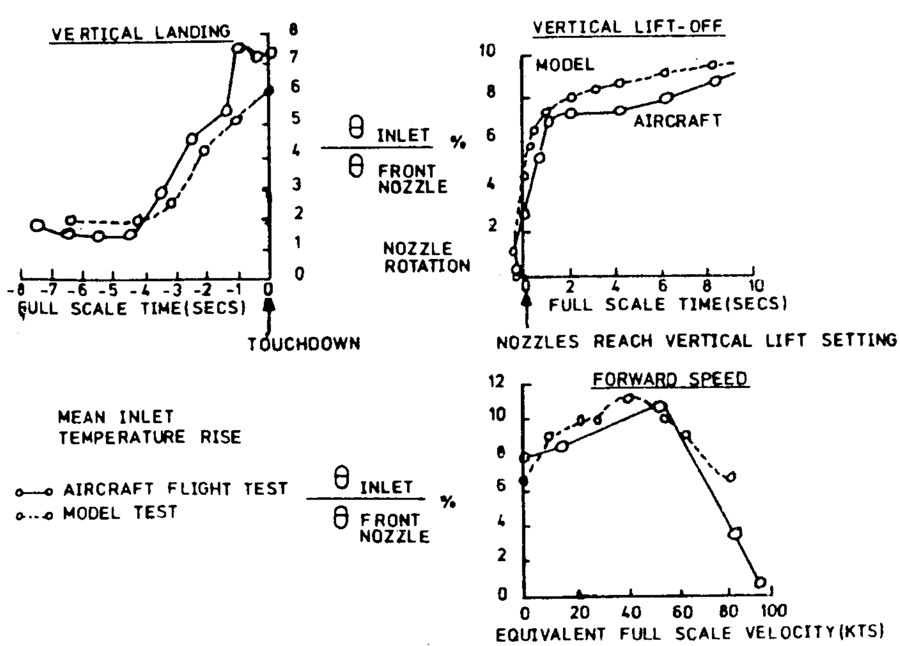


FIG 8

ORIGINAL PAGE IS
OF POOR QUALITY

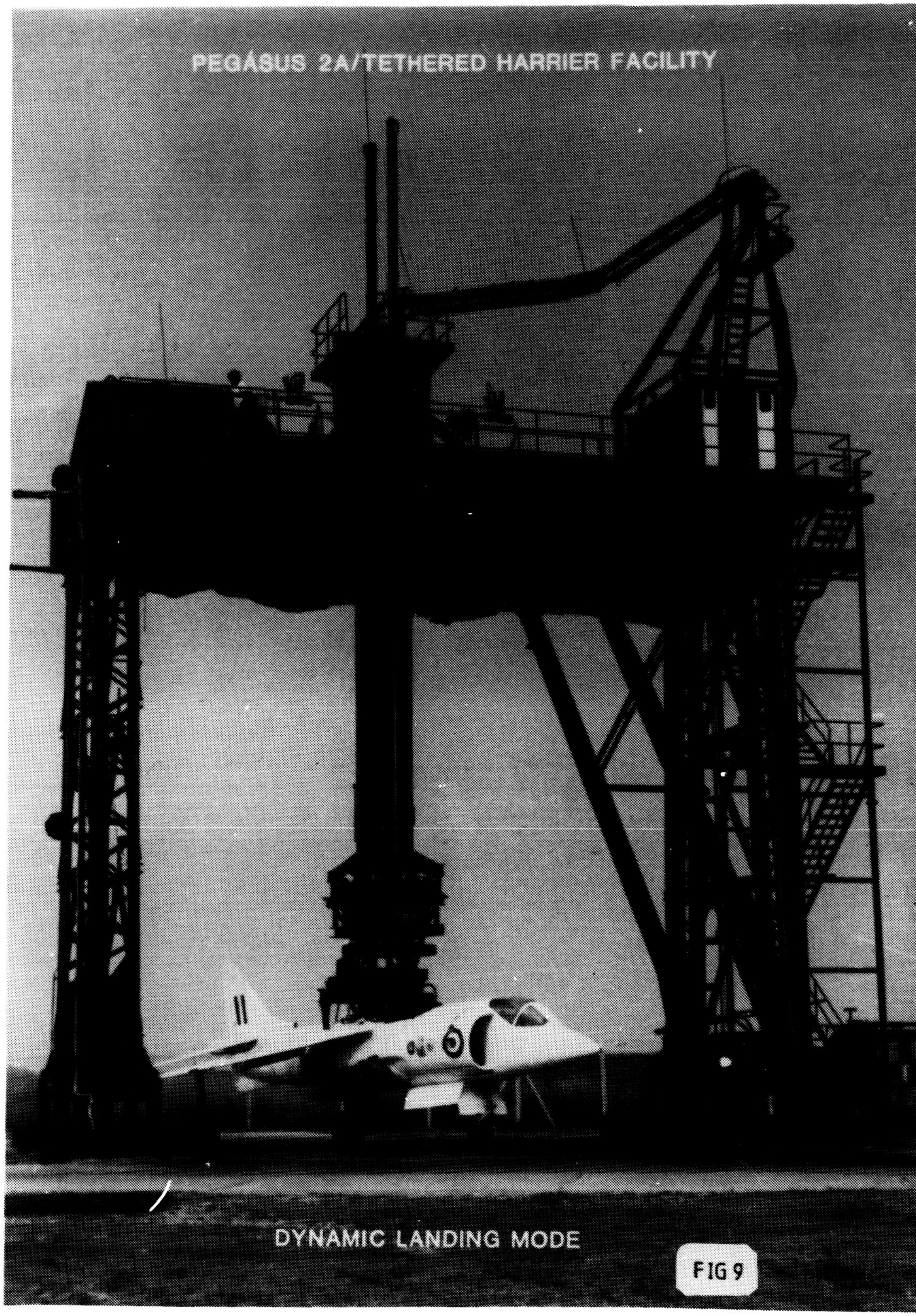


FIG 9

PEGASUS 2A / TETHERED HARRIER SIMULATED LANDING TESTS -DEC 1984
NOZZLE ORIENTATION

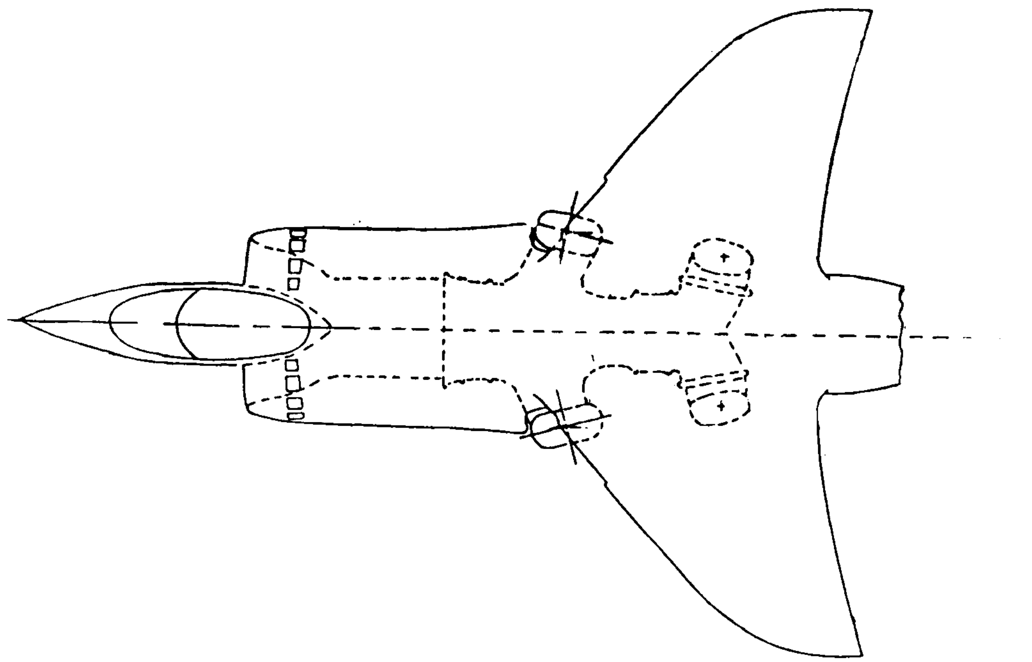


FIG 10

PEGASUS 2A / TETHERED HARRIER SIMULATED LANDING TESTS -DEC 1984
20 CONVERGED FRONT NOZZLES CAD AD + BA
MEAN INTAKE TEMPERATURE RISE / JET EXCESS TEMPERATURE

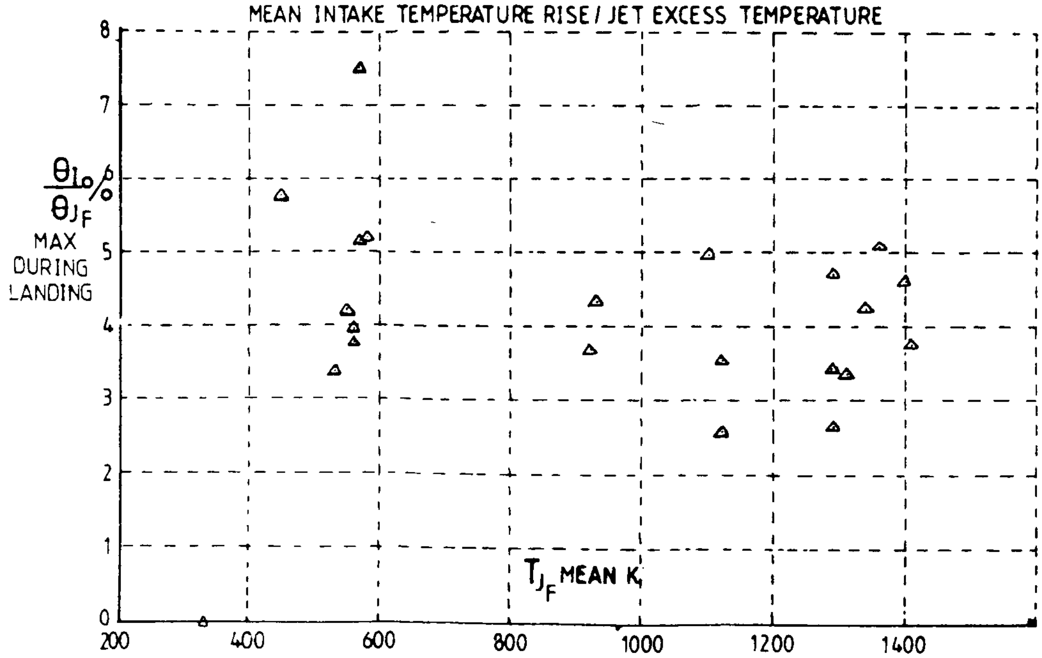


FIG 11

ORIGINAL PAGE IS OF POOR QUALITY

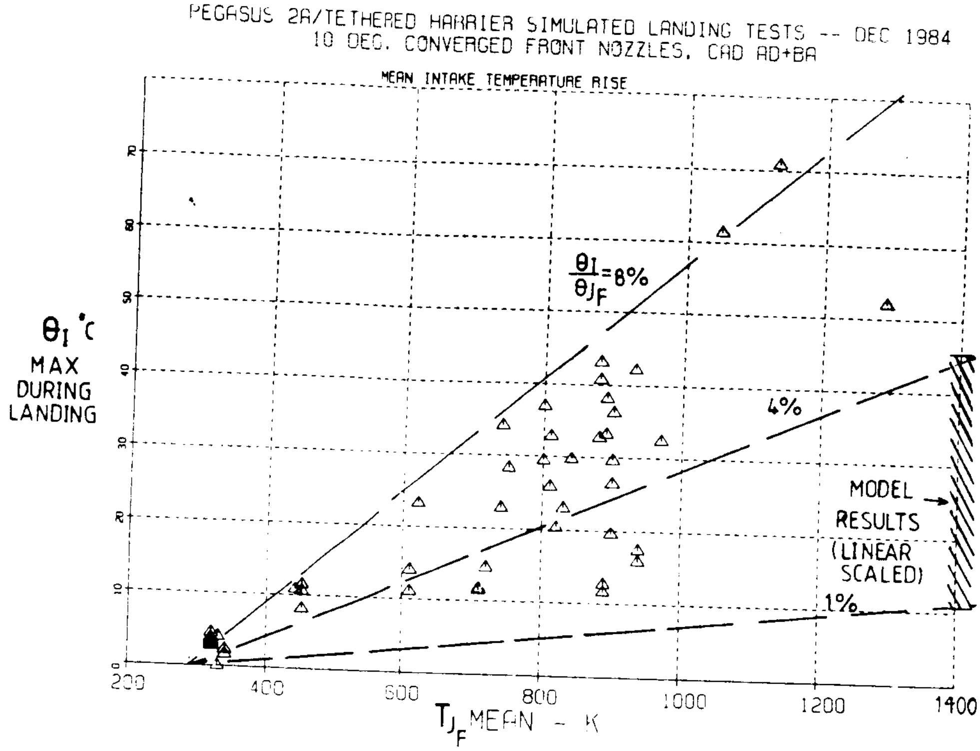


FIG 12

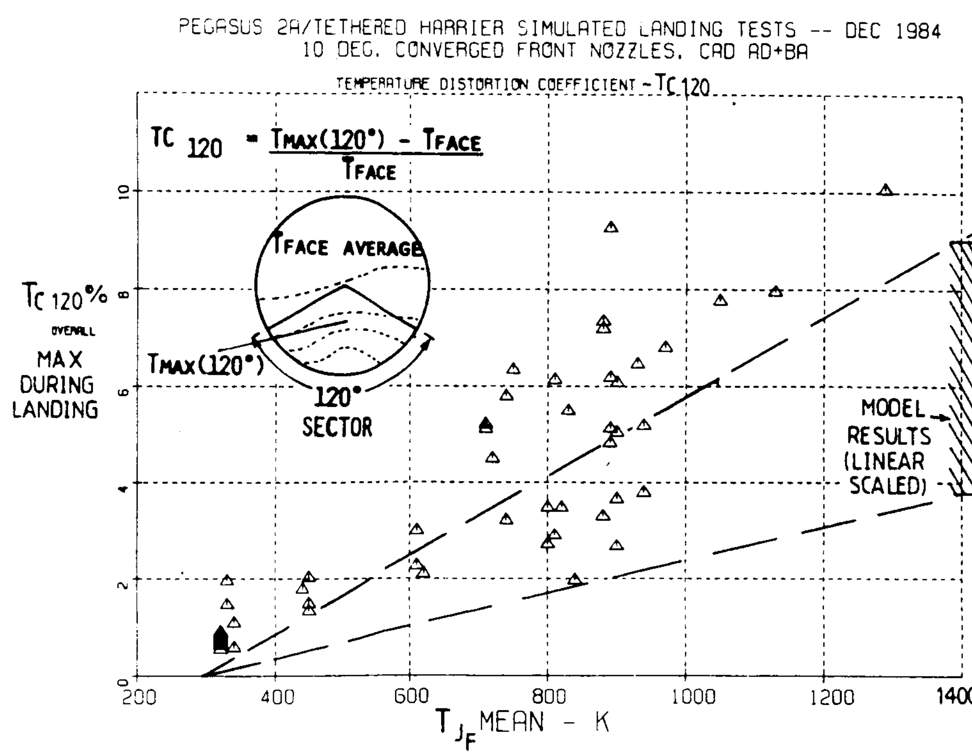


FIG 13

HGR MODEL SCALING PARAMETERS AND TEST CONDITIONS
BUOYANCY SCALED

	ITEM		P1127 FULL-SCALE	P1127 MODEL	PEGASUS 2A/TETHERED HARRIER FULL-SCALE	PEGASUS 2A/TETHERED HARRIER MODEL
SCALING PARAMETERS	GEOMETRY FS/M		1·0	10	1·0	10
	DYNAMIC HEAD RATIO FS/M	FRONT REAR	1·0	22·0 22·0	1·0	19·3 19·3
	EXCESS TEMP RATIO FS/M	FRONT REAR	1·0	2·33 2·33	1·0	2·78 2·78
	BUOYANCY RATIO FS/M	FRONT REAR	1·0	1·0 1·18	1·0	1·0 0·91
	TIME RATIO FS/M		1·0	2·13	1·0	2·28
TEST CONDITIONS	FRONT NOZZLES	P_J/P_α θ_J	1·83 70°C	1·038 30°C	1·5 1112°C	1·026 400°C
	REAR NOZZLES	P_J/P_α θ_J	1·64 575°C	1·029 250°C	1·31 512°C	1·016 184°C

FIG 14

θ_I/θ_{J_F} RATIOS RELATIVE TO SHOEBURYNESS NOZZLES
FOR THREE NOZZLE HEIGHTS

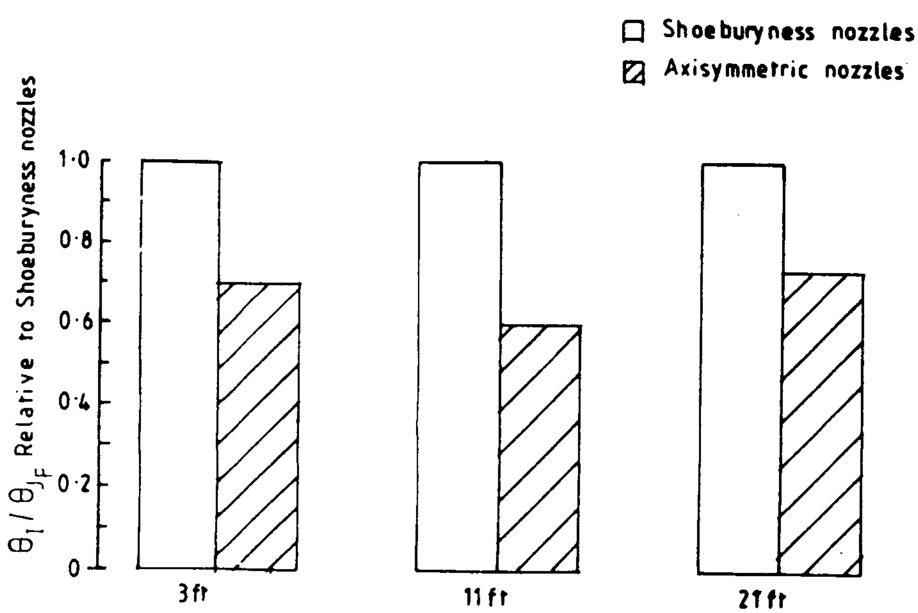
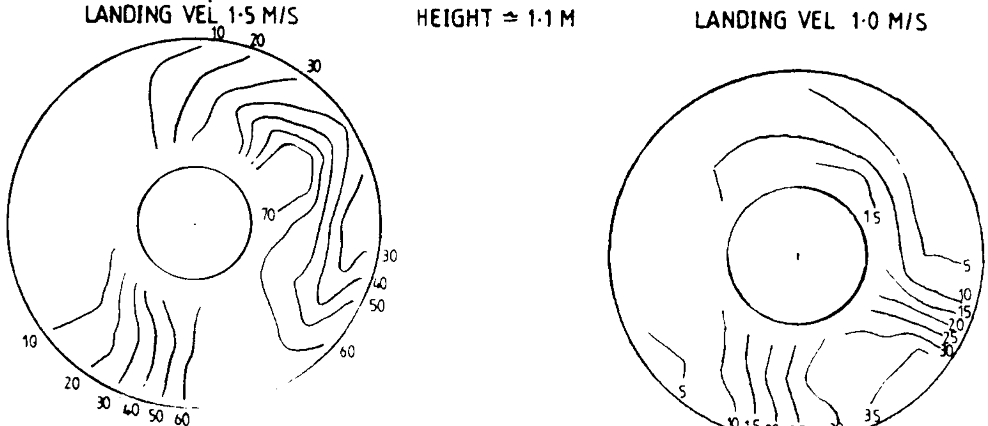


FIG 15

MODEL - FULL SCALE COMPARISON
PEGASUS 2A/TETHERED HARRIER RESULTS
INTAKE TEMPERATURE DISTORTION CONTOURS
MAXIMUM LEVELS DURING LANDING AT $T_{JF} \doteq 900$ K
10 CONVERGED FRONT NOZZLES CAD AD + BA

FULL SCALE	HEADWIND ≏ 10 KTS	MODEL
LANDING VEL 1·5 M/S	HEIGHT ≏ 1·1 M	LANDING VEL 1·0 M/S



$\theta_I = 32{\cdot}7\,^\circ C$ $\qquad$ $\theta_I = 12{\cdot}5\,^\circ C$

$T_{C\,120} = 7{\cdot}2\,\%$ $\qquad$ $T_{C\,120} = 3{\cdot}9\,\%$

FIG 16

HGR SCALING - SUPPORTING EXPERIMENTAL PROGRAMMES

o MODEL AND FULL-SCALE TESTS RELATED TO THE TETHERED HARRIER AIRCRAFT

- NOZZLE GEOMETRY } MODEL TESTS BUOYANCY AND FULL
- TEMPERATURE PROFILE } NPR SCALED
- PEGASUS 11 FULL-SCALE AND MODEL

o FUNDAMENTAL SCALING LAW STUDIES TO MEASURE INTAKE HGR FOR SIMPLIFIED AIRCRAFT CONFIGURATIONS.

- FAR FLOWFIELD
- NEAR FLOWFIELD

o FUNDAMENTAL STUDIES OF JET WAKES INCLUDING ENTRAINMENT AND FOUNTAIN FLOW PROPERTIES.

- EFFECT OF NPR
- EFFECT OF JET TURBULENCE

FIG 17