ARROW W.B. McCarter April 1959

INTRODUCTION

This note contains an abstract of the many contributions to the aerodynamic design of the Arrow propulsion system.

Part I	P/Power/x
Part II	x/Int Aero/y
Part III	Miscellaneous

INDEX & ABSTRACT

P/Power/37 — Total Pressure Losses, C105 Duct.
October, 1954 W.B. McCarter

Considers mean total pressure recovery for both constant area duct and diffusers. Includes discussion of friction factor and effect of reduced Reynold's Number with altitude.

P/Power/41 — Duct Area Variation and Bypass Air with J75-A24 and J75-B20.
Feb. 1955 W.B. McCarter

Estimate of minimum inlet throat area required for duct leading to J75 and the amount of secondary (bypass) air required to match the intake at supersonic speeds. Includes estimate of limiting bypass entry area.

P/Power/43 — Shock Structure, C105 Intake.
March, 1955 W.B. McCarter

Estimate of total pressure recovery at inlet throat due to shock losses developed by nose cone and ramp. Indicates advantage of small nose cones angles and determines optimum ramp angle at supersonic speeds. Includes charts of local flow angles and local Mach Numbers forward of inlet throat.

P/Power/45 — Total Pressure Recovery at Sea Level, Static.
March, 1955 W.B. McCarter

Following a remark by E.B. Greatrex of Rolles-Royce in the R.Ae.Soc. Journal of October 1952, all available experimental evidence was correlated on the basis of contraction in area from lip station to throat. The consistency is felt to be excellent.

Comparisons of theory to experiment, for extreme cases of sharp lip and bellmouth entry is excellent.

The inlet internal contour is definitely a secondary effect, with the elliptic profiles having a slight edge on flow coefficient.

P/Power/48

Theoretical Analysis of Optimum Ramp Angle for Mach 2 Aircraft Fitted with Side Intakes Incorporating the J75.
July, 1955 W.B. McCarter

Consideration was given to three losses in order to find the maximum thrust-less-drag.

a) Loss in total pressure due to shock structure giving a lower net thrust.
b) Spillage drag due to the free stream tube area being less than the inlet area.
c) Ramp pressure drag.

The analysis was confined to the J75 engine operating at the tropopause at supersonic speeds, afterburner lit.

P/Power/49

Theoretical Analysis of Optimum Double Ramp Angle for a Mach 2 Aircraft Fitted with Side Intakes Incorporating the J75.
July, 1955. W.B. McCarter

It seemed logical that the next step from the analysis of P/Power/48 should be consideration of the possible benefit of a double ramp.

P/Power/52

Differential Static Pressure at the Compressor Face, Sea Level, Static.
July, 1955 W.B. McCarter

Includes the differential static pressure at the compressor face for stressing purposes at sea level static for the J67, J75 and PS13. The maximum negative differential static pressure appears in the overchoked inlet condition which occurs on a maximum cold day.

* P/Power/54

C105 Engine Duct Static Pressure Differential at Sea Level with J67, J75 and PS13 Engines.
August, 1955 W.B. McCarter.

Estimate of the variation of internal static pressure down the engine duct at sea level, static, maximum cold day for both subcritical and supercritical operation.

* P/Power/57

Summary Report, Selection of the Side Inlet Configuration for a Mach 2 Aircraft Incorporating the J75.
November, 1955 W.B. McCarter

A brief outline of the methods used to determine the optimum inlet configuration. This analysis, which is essentially aerodynamic, is confined to the case of side intakes with blunt lips and two-dimensional compression ramps for a Mach 2 aircraft.

P/Power/58

Spillage Drag for Side Intakes with Blunt Lips and Two-Dimensional Compression Ramps.
November, 1955 W.B. McCarter

Development of contribution to aircraft drag due to spilled air around intake at reduced RPM and comparison with experiment on similar configurations.

P/Power/64

Comparison of Theory and Experiment, J75 Inlet Performance.
April, 1956 W.B. McCarter

Comparison of theoretical prediction and experimental data from Lewis Laboratory. Includes comparison of total pressure recovery, onset of buzz, spillage drag.

Comparison deemed excellent with marked exception of spillage drag where experiment indicated greater drag at transonic speeds.

P/Power/65

Performance of the Inlet Duct to the J75 as Determined at the NACA Lewis Laboratory, Final Configuration.
April, 1956. W.B. McCarter

This report is a collection of data obtained in test of the C105-J75 inlet at the Lewis Laboratory in December 1955 and January 1956. Data for the final configuration only was abstracted from their respective reports.

The final configuration consisted of the following geometry:

Bypass inlet area 98 sq.in., ramp bleed open area 98.7 sq.in., ramp bleed side vent attached, 30° included nosecone, 12° fixed ramp, 5.6 sq.ft. fixed inlet throat area, forward diffuser of 26.3% area expansion, inlet contraction of 22.0%.

P/Power/66

C105 Buzz Threshold, J75, Iroquois.
August, 1956 W.B. McCarter

This report discusses the phenomena of inlet buzz, its cause and cure. Charts are included which show the limitation on the Arrow flight envelope should the engine be throttled to idle or windmilling RPM.

P/Power/71

Analysis of Bypass Performance, Lewis Laboratory.
May, 1956 L. Allen, S.L. Naylor
W.B. McCarter

A series of tests were performed on the 1/6 scale C105 intake model at the Lewis Laboratory. Four bypass configurations were tested.

The Mach Number range was .65 to 2.1 with, generally, zero angle of yaw and attack for the bypass tests.

Flow coefficients for the different bypass configurations are presented in graphical form along with bypass mass flow and its affect on total pressure recovery at the compressor face.

P/Power/73

Fuselage Diverter Bleed.
June 1956 W.B. McCarter

The total pressure recovery is of the form given by theory assuming a normal stock immersed in a fully turbulent boundary layer with a 1/7 power velocity profile. However, a flow coefficient must be applied varying from 1.0 at subsonic speeds to approximately .70 at M 2.0.

The boundary layer thickness is that given by Prandtl for a flat plate factored by 1/√2 for that portion of the fuselage of conical form.

The fuselage diverter bleed is a small 25 sq. in. inlet beneath the ramp sized to take a mass flow approximately equal to 1% of the engine flow to be used in the airconditioning system. Attention must be paid to ensure the NSW off the bleed lips does not stand upstream of the ramp leading edge.

P/Power/94

Effect of Divergence Angle of a Divergent Ejector on Thrust.
January, 1957 W.B. McCarter

An empirical curve is developed in this report to show the loss in ejector thrust with increased divergence angle. This empirical curve does follow, reasonably well, the available experimental results.

* P/Power/95

Performance Characteristics of a Series of Divergent Shroud Ejectors.
January, 1957 D.P.Hughes, K,G.Tadman

The curves drawn are a carpet plot of tests on divergent ejectors given in NACA RM E55021a by W.K. Greathouse.

* P/Power/97

The Optimisation of Ejector Geometry for the C105 Incorporating the Iroquois Engine.
February, 1957 W.B. McCarter

The ejector geometry was optimized on the basis of total net thrust of the installed engine less spillage drag and bypass momentum drag. This is the total excess thrust of the propulsion system as a whole.

Consideration was given to cooling flows in the bypass to overcome thermodynamic problems, consideration was given to the maximum external profile with existing primary structure and finally to the minimum take-off ground angle satisfying RCAF requirements.

* 73/Int Aero/5

Mark III Intake Design, Part. I.
February, 1958 L.Allen, W.B.McCarter

Progress made through 1957 on a proposed Mach 3 intake for the Mk.III C195 is presented and an indication is given of some of the remaining problems.

The intake consists of a swept nose configuration of roughly elliptical projection. The inlet capture area will be about 12 sq.ft. There are three fixed ramps of 7.5, 3.7 and 3.7° and a final ramp variable from 5 to 19°. The throat area will range from 3.4 sq.ft. to 6.5 sq.ft. The compression surfaces are placed outboard and the cowl faired into the fuselage. The inlet duct downstream of the start of the constant area section is similar to that of the Mk.II aircraft. Two boundary layer bleeds will be required - a fuselage diverter bleed (similar to that on the Mk.II) and the inlet lip bleed. Air from the diverter bleed will be ducted into the cavity between the fuselage and ramp wall and air from the inlet lip bleed will be used in the air-conditioning system.

The inlet will operate subcritically up to a Mach Number of 2.4 and supercritically at Higher Mach Numbers. A variable bypass will be required in the duct to position the NSW for supercritical operation at full RPM and to pass sufficient flow at reduced RPM to prevent intake buzz.

Estimated pressure recoveries and thrusts are included.

* 72/Int Aero/6

Method for Calculation of Propulsion System Net Thrust (Revised P/Power/97).
December, 1957 K.G.Tadman, L.Allen
W.B. McCarter

The method of calculation for the Iroquois Mk.I engines characteristics has been given in P/Power/97, but since it was issued, some of the curves and charts have been revised for the Mk.2 and modified methods of calculation have been evolved in order to adapt for programming on the IBM 704.

72/Int Aero/8 — Windmilling Buzz.Boundaries.
March, 1958 K.G.Tadman, W.B. McCarter

The general mechanism of buzz due to separation of the turbulent boundary layer at the duct wall or on the ramp has been discussed fully in P/Power/66. The buzz boundaries were obtained using the windmilling mass flows estimated at that time. However, the windmilling mass flows have been investigated by Orenda and the earlier figures revised. In addition, the trim angles of attack have been revised necessitating recalculation of the buzz threshold.

* 73/Int Aero/10 — Mk.III Intake Design, Part II.
March, 1958 L.Allen, W.B.McCarter

An investigation has been made of the effect of capture area and ejector geometry on thrust and fuel consumption for the Mk.III aircraft. Various ejector configurations have been considered and comparison with a convergent-divergent nozzle plus door arrangement is included.

* 72/Int Aero/12 — An Expendable Ejector Insert to Improve Arrow 2 Subsonic Cruise Performance.
April, 1958 W.B. McCarter

In order to meet the RCAF requirements for 1500 NM ferry range with the Arrow 2, a study was made to find the optimum ejector geometry for M .92 at 40000' at cruise RPM, and full RPM, no afterburner.

In addition, for the same flight conditions, the effect on the existing large 40-49 divergent ejector, of changes in engine control schedule, reduced bypass entry area, and reduced engine bleed were assessed.

A reasonable compromise between cruise and full RPM which meets the ferry range requirement and cooling requirements is a 31-33 divergent ejector. Because this geometry is off-design at all supersonic speeds an expendable plug nozzle released when the afterburner is turned on has been recommended.

* 72/Int Aero/13

Performance Calculations at Subsonic Cruises for Arrow 2 with Three Ejectors of Small Throat Diameter Ratio.
April, 1958 L. Allen

Some performance calculations at M.92 cruise at 40000' has been made using one NACA and two Rolles Royce ejectors, all with small throat diameter ratios. These calculations were made to verify the predictions of thrust and cooling flow given for a 31-33 divergent ejector configuration in 72/Int Aero/12.

* 73/Int Aero/17

Arrow 3 Propulsion System, A Summary.
June, 1958 W.B. McCarter

The Arrow 3 propulsion system is a combination of variable geometry side intake, variable bypass, and fixed geometry divergent ejector.

The basic aerodynamic philosophy was a workable solution to the following requirements:

a) High total pressure recovery.
b) Flow stability range from windmilling to maximum RPM.
c) Low additive drag and no interference effects to increase the aircraft external drag.
d) Minimum changes to existing Arrow 2 structure.
e) No deterioration in performance in comparison to Arrow 2 below M 2.0.

72/Int Aero/20

Revised Bypass Restrictor Geometry and Spring Characteristic.
July, 1958 W.B.McCarter, L.Allen K.G.Tadman

Compliance with the Orenda request to reposition the restrictor forward in the bypass gave an opportunity to do an intensive reassessment of its geometry, the spring characteristic, restrictor loads, and bypass pressures by means of an IBM 704 program.

The final configuration was optimised on the basis of:

a) SFC at subsonic and supersonic cruise.
b) Maximum thrust with afterburner at M =.9 through to M 2.3.
c) Distortion levels, at both equilibrium and transient flight cases to be = 12% on an ICAO standard cold day.
d) Bypass pressures to be no greater than presently issued.

<u>70/Int Aero/21</u>

Comparison Between J75-A25, J75-B23, and Iroquois 2 on Basis of Uninstalled Net Thrust and Specific Fuel Consumption.
July, 1958 W.B. McCarter

This report compares the uninstalled net thrust (i.e. with 100% pressure recovery) and specific fuel consumption of the Pratt and Whitney J75 series A25 and B23 with the Orenda Engines Ltd. Iroquois series 2.

Neither air bleed or power extraction corrections are included, nor is any ejector contribution considered.

<u>71/Int Aero/22</u>

Thrust Derivatives.
July, 1958 W.B. McCarter

Enclosed are the thrust derivatives at flight speeds requested by Stability and Control Group. Included are rate of change of thrust with yaw, angle of attack, altitude, and forward velocity. In addition the thrust moment derivative through yaw axis has been estimated.

<u>71/Int Aero/25</u>

Comparison of Performance of the Arrow 1 with J75-A25 to the Arrow 1 with the Over-speeded J75, the J75-A27.
September, 1958 W.B. McCarter

This report contains a brief assessment of the overspeeded J75, the J75-A27 in the Arrow 1. Comparison is made throughout with the J75-A25, the present engine in the Arrow 1.

The report is divided into three parts:

a) Uninstalled net thrust and TSFC.
b) Acceleration times and fuel consumption at 45000'.
c) Comparison of mass flows at the tropopause.

<u>70/Int Aero/27</u>

A Description of the Rumbling, Buzzing, and Banging Within the Arrow Propulsion System.
October, 1958 W.B. McCarter.

The noises emanating from the Arrow propulsion system are due to aerodynamic flow-breakaway. Rumbling is the separation of airflow from the outboard lips of the intake, buzzing is initiated by the separation of the turbulent boundary layer from the ramp surface and internal lip profile, and banding is initiated by the separation of engine airflow from the compressor bleeding.

Each can be heard by the pilot and vary from the low intensity rumble to the high intensity crack of an explosion.

* P/Perf/80

Escape from C105.
March, 1954 W.B. McCarter

The list of problems associated with escape discussed are:

a) Explosive decompression.
b) Tolerance to acceleration and deceleration forces.
c) Windblast.
d) Clearance of fin.
e) Tumbling.
f) Impact forces of an opening parachute.
g) Survival in a low pressure, low oxygen content, low temperature atmosphere.
h) Bends.
i) Impact with ground.
j) Survival in a crash.

P/Equip/52

Design of Shock Ramp Air and Air-Conditioning Exhaust Nozzles.
November, 1954 W.B. McCarter

The boundary layer air from the shock ramp and air conditioning air are exhausted through outlets in the aircraft spine aft of the canopy. This report considers the exit geometry such that separation of the fuselage surface boundary layer is prevented.

* OEL/Aero/17

C105 Intake Duct Tests.
June, 1955 H.C. Eatock

This report records the test of an 0.6 scale model duct and three inlets. The configuration tested include the original design inlet for the J67, a bellmouth version of this inlet to simulate in-flight performance, and a sharpened leading edge version to conform more closely to the supersonic area-rule distribution.

C100/Aero/563

Suggested Modification to C100 Nacelle Inlet to Improve High Speed, High Altitude Performance.
May, 1955 W.B. McCarter

Nacelle inlet lip modification to improve high speed performance. With existing information, a subsonic pitot intake can be tailored to fit any design point. The optimum geometry, however, is sensitive to off-design cases and the gain at a particular point may cost heavily at another.

The design point for the C100 Mk.IV, modified for high altitude interception, was assumed to be M .7 at 50000 feet.

* Arrow Propulsion System.
June, 1958 W.B. McCarter

This report contains a brief description of the design philosophy behind the Arrow propulsion system. It was compiled to assist J.C. Floyd in his Commonwealth Lecture to the Royal Aeronautical Society.

P16/Prelim.Design/1 A Summary of a Preliminary Study for a Supersonic Jet Transport Investigated in 1956.
July 1958 K.J.Barnes, G.B.Sampson

The following report is a summary of an unfinished study made in early 1956 to determine the feasability of a supersonic transport using existing components and present-day 'state of the art'.

The aircraft was designed around an 80 passenger, 20,000 lb. payload, and four Gyron engines since these had the highest thrust available at the time. The design Mach Number was 1.75.

The configuration was optimized using Area Rule as a guide to locate various components on the fuselage and also to 'coke bottle' the original parallel fuselage so that the total transferred area at the design point represented a minimum drag Sears-Haack body of revolution.

* 71/Aero Data/12 The Spillage Drag and External Drag Coefficient, Arrow 1, 1A.
November, 1958 W.B. McCarter

Included in this composite report is a new revised spillage drag characteristic which shows good agreement with both the Arrow 1 intake tests results and for the Vigilante, an aircraft with similar intake geometry.

In addition, a new external drag curve is suggested which is consistent with all available WTM and FFRM tests of the Arrow 1 and is in good agreement with that of the Hustler, an aircraft with definite family characteristics.

Gen/Int Aero/1

The Aerodynamics of the Propulsion System for a Supersonic Transport.
February 1959 W.B. McCarter

Using only conventional gas dynamic principles it is possible to indicate in non-dimensional form the net thrust, specific fuel consumption, and nautical air miles per pound possible with JP4 fuel in a jet engine.

From this, one can predict the feasability of air transport at supersonic speeds.