AN EXAMINATION OF THE FACTORS CONTRIBUTING TO THE CHANGE IN ESTIMATED PERFORMANCE OF THE ARROW 2 - FROM REPORT NO. 10, DECEMBER, 1956, to REPORT NO. 12, NOVEMBER, 1957.

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28 November 57

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An Examination of the Factors Contributing to the Change in Estimated Performance of the ARROW 2 - from Report No. 10, December, 1956, to Report No. 12, November, 1957.

E. N. Lindley,
Chief Engineer.

28 November 57.

SUMMARY

AIR BLEED

IR INTAKE

INTERNAL TANKAGE

NOZZLE

IROQUOIS 2 REVISED

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COMPARISON OF ARROW PERFORMANCE REPORTS 10 & 12

We have recently completed a re-estimate of the ARROW 2 performance and this has been detailed in our Periodic Performance Report No. 12 (Ref. 1). This is the first major re-estimate that has been completed in the present calendar year and incorporates revised data on engine performance and engine installation details, and, of course, the current weight situation. Prior to this the last complete performance report was our Periodic Performance Report No. 10 (Ref. 2) which was published in December of last year.

During 1957 two letters (Ref. 2a) and Ref. (2b) were transmitted to the RCAF. Both letters assured the RCAF that performance deterioration to be expected was "not significant."

The revised estimate shows degraded performance on practically all aspects when compared with Report No. 10. Most significantly the radii of action on full internal fuel and the ferry mission range has deteriorated very considerably. A brief summary of the situation is as follows:

Also letter of 5 Nov not passed to DPE

	Report #10 Dec. 1956	Report #12 Nov. 1957	Specification
Supersonic Mission Radius of Action (Full Int. Fuel)	302 n.m. 297	249 n.m.	200 n.m.
Subsonic Mission Radius of Action (Full Int. Fuel)	450 n.m. 435	355 n.m.	300 n.m.
Ferry Mission	1460 n.m. tanks retained	-80 m. 1254 n.m. tanks dropped!	1500 n.m.
Combat Factor at M = 1.5, 50,000 ft.	1.63	1.56	2.00
Combat Factor at M = 2.0, 50,000 ft.	1.99	1.60 *	No requirement
Ceiling	63,300 ft.	60,500 ft.	60,000 ft.
Combat Weight	51,500 lb.	53,796 lb.	---

The chart appended shows on a chronological basis the major inputs to which the performance changes are ascribed. The chart also shows weight variations through the period and an indication of the variation of combat performance and ferry range as a result of the different inputs. It must be emphasized that these performance variations are the result of very preliminary calculations and the actual values of the increments should not be considered as accurate. However, the variations are of the right order and when taken together do, of course, correspond to the values of report No. 12. Furthermore, the performance variations are shown assuming a capability for instantaneous calculation of performance data. Although in many cases a rough approximation could have been obtained as a result of a relatively small

* The maximum g which can be obtained is 1.70 at M.N. 1.80.

AIR BLEED | AIR INTAKE | INTERNAL TANKAGE | NOZZLE | IROQUOIS 2 REVISED

UNCLASSIFIED

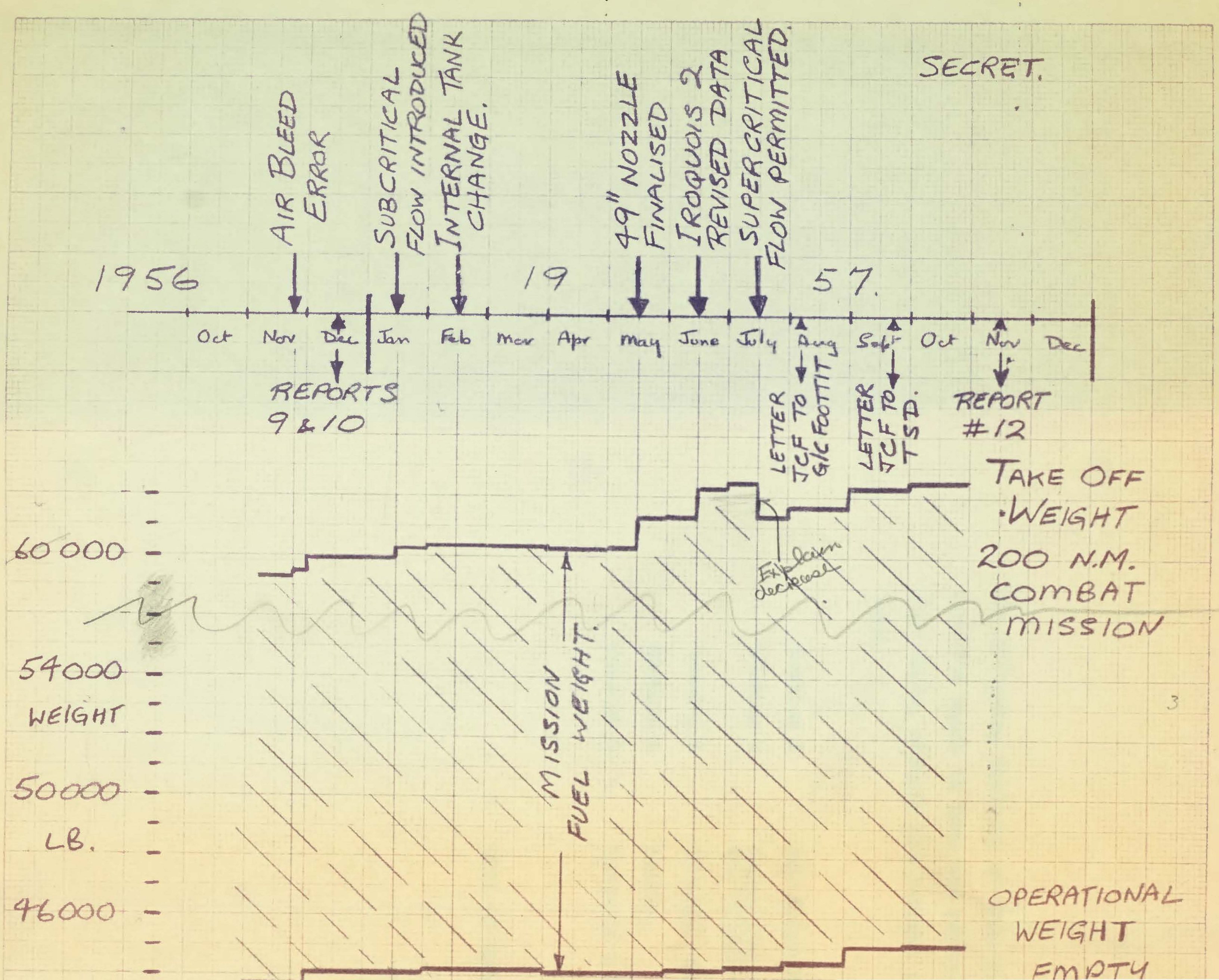
output of effort, accurate calculation would have taken up to as long as three months. Since many of the changes are small the need for accurate calculation is apparent. Throughout the period in question the Chief of Technical Design monitored ARROW performance by means of a running check on the combat g at 1.5 M.N. and 50,000 ft. This performance point has, throughout the history of the project, been that over which there has been the most contention. No corresponding check was made on radius of action or on ferry range.

It will be seen from the curve that no significant change in combat g occurred except as the result of weight change prior to the firming up of the nozzle configuration. Even at this time combat performance is not directly affected by nozzle performance but rather the aircraft weight at combat is increased as a result of the additional fuel for cruise which must be carried. Since the firming up of the nozzle configuration, the change in combat performance has again been as a result of weight growth, except for the dip caused by the use of the revised Iroquois 2 data, which was almost immediately cancelled by the decision to operate with super-critical flow in the inlet. As has already been stated, no running check was maintained on either combat radius of action with full internal fuel or ferry range. The recent issue of Performance Report No. 12 revealed considerable reduction in the values predicted for these missions. As may be seen from the chart the major inputs which resulted in this degradation were all known by May of this year. The question is, how did it come about that the effect of these inputs on these particular missions was not assessed and, in consequence, how did the Company come to inform the RCAF that the performance changes expected were not significant? The only explanation that can be given is that these missions were not considered significant by the Technical Design Dept. The combat missions with full internal fuel are not specification requirements and, certainly in the eyes of the Technical Design, the additional tankage which permits these larger radius missions to be performed is there as insurance against degradation of airplane performance resulting in inability to meet the specified combat missions (Ref. 3). This opinion was known to the RCAF and was, in fact, contested in the interests of minimum weight (Ref. 4).

Technical Design appear to have considered the ferry mission to be unimportant. In consequence they have focused all attention on the combat performance at the design point and it is apparent that design decisions taken within the Department have always supported this combat performance, in many cases at the expense of other aspects of performance.

As a result of this preoccupation with combat performance no attention was paid to the "long range" performance and thus when asked for an opinion of the state of the performance at any given time, Technical Design were convinced that no significant change was imminent. This is borne out by the plot of combat performance, which shows that, at least prior to the weight increase of September, this aspect of performance has been held remarkably well. Can't agree

Company Management has, of course, been well aware of interest in the long range performance of the ARROW, and in many cases has taken steps to engender interest in this aspect of the performance, particularly with USAF. However, the long range application of the ARROW has in practically all cases been with a specialized version of the aircraft. There is no reason to believe that the recent change in the performance estimates for the ARROW 2 makes impossible the development of a specialized long range version of the aircraft, and we are in fact doing preliminary work on such a version which shows a good capability in this direction (Ref.5).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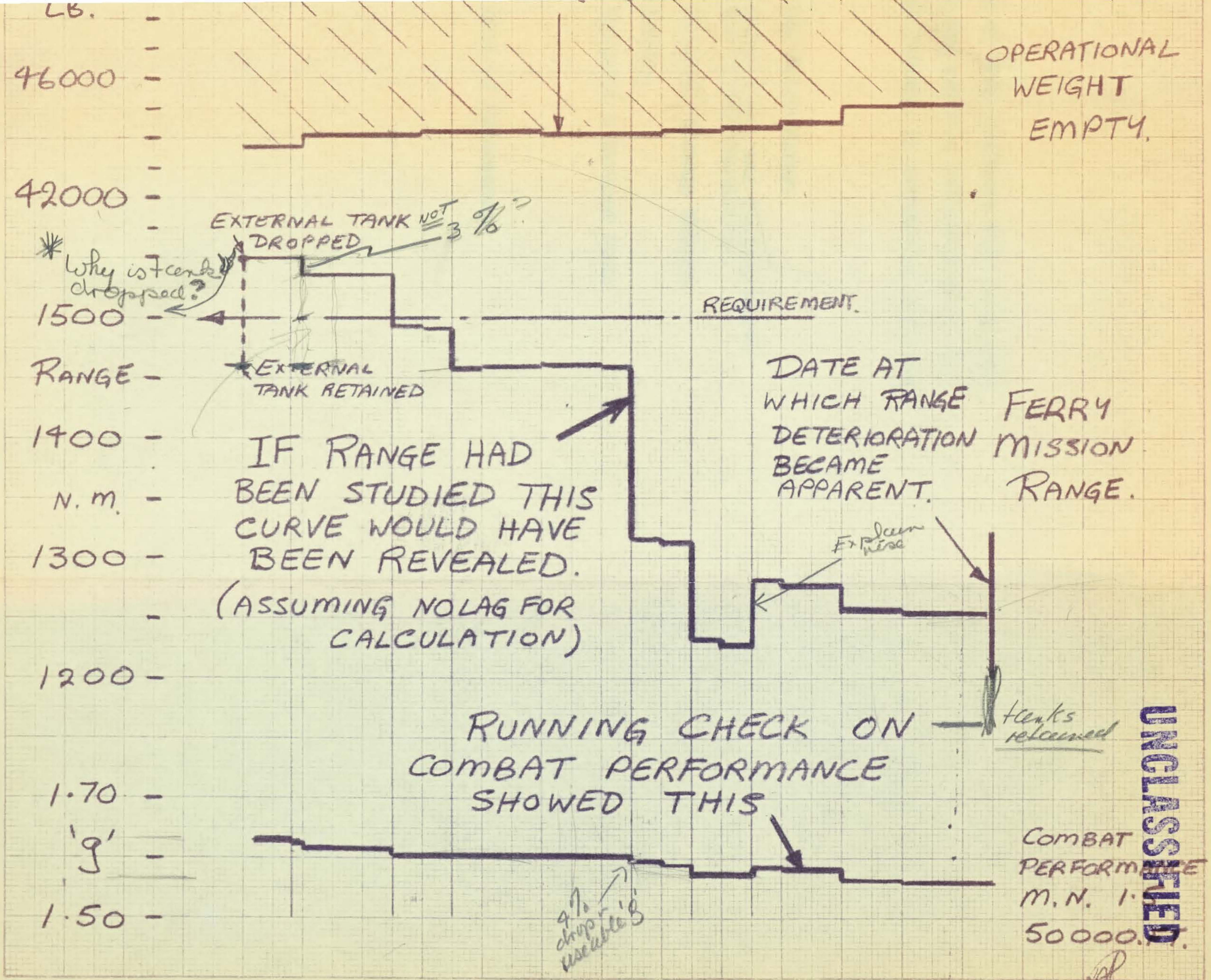
1956 19 57.
AIR BLEED ERROR
SUBCRITICAL FLOW INTRODUCED
INTERNAL TANK CHANGE.
49" NOZZLE FINALISED
IROQUOIS 2 REVISED DATA
SUPERCRITICAL FLOW PERMITTED.
Oct Nov Dec Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec
REPORTS 9 & 10
LETTER JCF TO G/C FOOTTIT
LETTER JCF TO TSD.
REPORT #12
TAKE OFF WEIGHT
200 N.M. COMBAT MISSION
Explain decrease
MISSION FUEL WEIGHT.
60000
54000
WEIGHT
50000
LB.
46000
OPERATIONAL WEIGHT EMPTY
3



27th Nov 1957.

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The following Sections of this document deal with each specific input in turn and present information on the time scale, effects and reasons in connection with each input:

AIR BLEED

AIR INTAKE

INTERNAL TANKAGE

NOZZLE

IROQUOIS 2 REVISED

UNCLASSIFIED

AIR BLEED ERROR

High pressure air is bled from the compressors of the Iroquois engines in the ARROW to provide air for the air conditioning system and other services. The effect of this air bleed on engine performance is to reduce thrust without changing fuel consumption with a consequent apparent increase in engine specific fuel consumption. In the ARROW, with its large air conditioning load, the effects of air bleed on engine performance are significant.

In Performance Report No. 8 dated May, 1956, (Ref. 6) the corrections for air bleed were made with some slight degree of approximation by applying dimensional engine performance data with respect to the effect of air bleed to the basic installed engine performance calculations which themselves had been based on non-dimensional data. In preparing Reports 9 (Ref. 7) and 10 it was decided to incorporate the correction for air bleed into the basic engine non-dimensional performance so that the effects of the bleed would be accurately reflected in the calculations of installed engine performance. It became apparent just prior to the issue of Reports No. 9 and 10 that a portion of the correction for bleed involving jet pipe pressure ratio had been incorrectly applied and that, therefore, the mission performance figures in Reports 9 and 10 were to some extent incorrect. The Performance Group made a rapid check of the effect of this error on the ferry mission range, this mission being the one most sensitive to the effect of the error. It was determined that a correction amounting to a reduction of some 3% of this range had to be applied and this correction was incorporated in Reports 9 and 10.

In view of the opinion within Technical Design that combat missions with full internal fuel were not significant, no attempt was made to correct these missions. Within the last day a rough estimate has been made of the corrections that should have been applied. The supersonic mission with full internal fuel, estimated in Reports 9 and 10 to be of 302 N.M. radius, should have been 297 N.M. radius when the proper correction for air bleed was made. The subsonic combat mission with full internal fuel, estimated in Reports 9 and 10 at 450 N.M. radius, is reduced to 435 N.M. radius when the air bleed correction is made.

In preparing the installed engine data for Report No. 12 use has been made of Iroquois 1 air bleed corrections, as the information on Iroquois 2 air bleed corrections (Ref. 8) was not received until November 4th of this year, too late for incorporation in the calculations. A comparison of the air bleed corrections for the two engines indicates that the method used is sufficiently accurate.

UNCLASSIFIED

SUBCRITICAL AND SUPERCRITICAL AIR INTAKE CONDITIONS

Towards the end of 1956 Technical Design had been undertaking detail analysis of the results of two series of intake tests. The first of these with a 6/10th scale intake model powered by two Orenda engines had been undertaken at Avro in conjunction with Orenda (Ref. 9). The second was undertaken with a 1/6th scale model of the intake at the NACA Lewis Laboratory (Ref. 10). In particular the analysis considered the test data from the viewpoint of distortion of flow velocity at the engine face. Under certain flight conditions it was known that the intake throat would choke and the resulting supercritical flow would produce increased distortion at the engine face. It was considered desirable to maintain subcritical flow, i.e. below the choking flow, with a consequent favourable distortion pattern.

During January, 1957, Technical Design discussed with Orenda the nozzle area schedule for the Iroquois 2 and this reinforced the opinion that, as matters then stood, it was necessary to cut back the maximum r.p.m. and/or nozzle area of the engine to achieve subcritical flow for the cruise condition at Mach .92 and 40,000 ft. It was obvious that an unsophisticated approach to this reduction would give unacceptable engine performance. Since, at that time, Orenda was showing remarkably little interest in the Iroquois 2 (Ref. 11), Avro undertook the study of the control

INTERNAL TANKAGE

NOZZLE

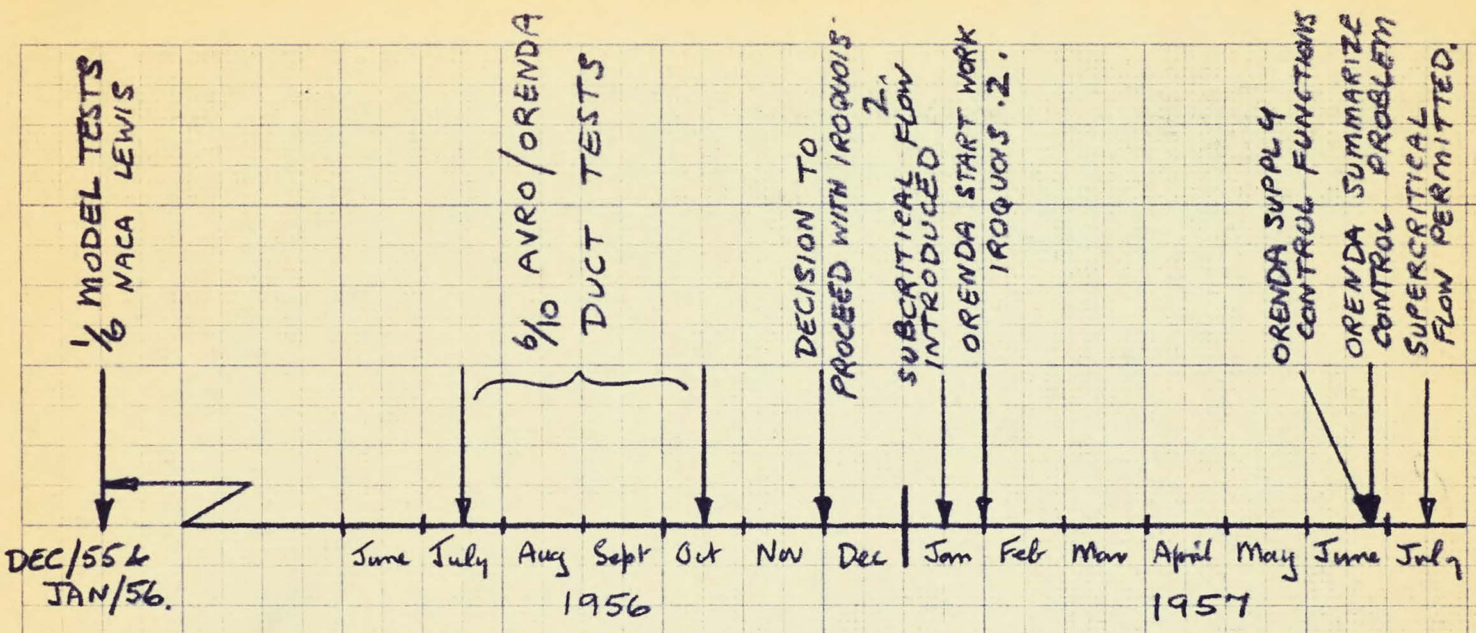
IROQUOIS 2 REVISED

REFERENCES

problem and made a number of proposals to Orenda for the types of control which would maintain subcritical flow at the inlet and, at the same time, minimize the performance penalty. Assurance had been received from Orenda on January 24th (Ref. 12) that they would provide an engine control which would in fact meet this requirement.

On June 28th Avro received from Orenda the Iroquois MK. 2 control functions (Ref. 13). This data did not include the control necessary to achieve the subcritical flow. // However, during this month Orenda carried out a re-assessment of the whole problem and soon after assurance was given verbally by Harry Keast that, as a result of the review of the test data, and analysis of compressor tests made at Nobel with distorted flows, it was Orenda's opinion that operation of the Iroquois at full throttle with the intake supercritical would not produce a hazardous situation and it was, therefore, decided to permit the intake to operate supercritical when required.

What were direct effects on performance?



CHRONOLOGY — SUBCRITICAL & SUPERCRITICAL AIR INTAKE CONDITIONS

UNCLASSIFIED

INTERNAL TANKAGE CHANGE

During the detailed engineering of the ARROW 2 an attempt was made to clear up many of the RCAF criticisms of ARROW 1 features. One feature which came in for re-design at this time was the routing of the ducts which feed hot air from the engines to the air conditioning system and other services.

In the ARROW 1 these ducts are located in the centre fuselage structure in a space between the fuselage fuel tanks and the air intake ducts. Once built into the aircraft they are to all intents and purposes inaccessible. This feature was criticized at the ARROW 1 Mock-Up Conference in February, 1956, and it was requested (Ref. 14) that over-temperature sensing devices be provided adjacent to these ducts. This matter was referred to the Maintenance Sub-Committee and this committee raised a requirement (Ref. 15) for re-location of the ducts should satisfactory heat sensing not be possible. This requirement was confirmed at a meeting of the Co-Ordinating Committee (Ref. 16).

The Project Office decided that the difficulty of providing satisfactory heat sensing was sufficient to justify re-location of the ducts. The only feasible re-location was in the dorsal fairing in the section which, in the ARROW 1, forms the upper lobe of the fuselage fuel tanks. The desirability of such a change was discussed with Technical

Design and an agreement was reached, as it was considered that this small volume of tankage (some 50 Imp. Gals.) was not essential for adequate performance against specification requirements. In view of the position at that time on ferry mission range, it is difficult to understand why this decision was made in this way.

The proposed re-location of the ducts was described in a letter to the T.S.D. (Ref. 17) and a drawing of the installation accompanied the letter. The change of location was approved by the Co-Ordinating Committee (Ref. 18).

Although this matter was the subject of so much discussion between the Company and the Air Force, it appears that at no time did we write to the Air Force to bring their attention specifically to the reduction in tankage in the ARROW 2 or to the reduction in long range performance implied by this change. The officers taking part in the discussions were familiar with the detail of the ARROW 1 design in the area in question and there can be no doubt that they were aware of the fact that re-location of the ducts would reduce the fuel tank capacity. The estimate of the revised fuel tankage was made during February (Ref. 19) and was specifically noted in the March edition of the ARROW 2 Weight Report (Ref. 20). Additionally, the ARROW 2 Model Specification (Ref. 21) describes the tankage of the aircraft. This was transmitted to the RCAF in draft form in August, 1957 (Ref. 22).

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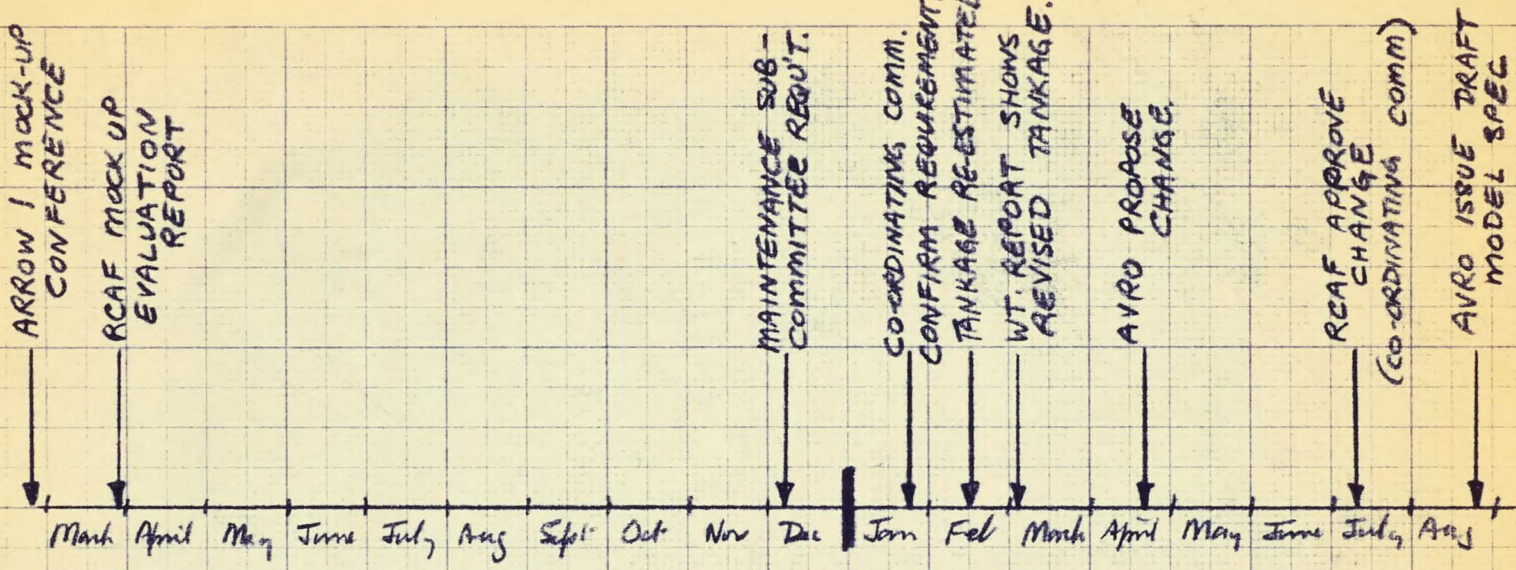
IROQUOIS 2 REVISED DATA

REFERENCES



CHRONOLOGY — INTERNAL TANKAGE CHANGE.

28th Nov 1957.

NOZZLE

IROQUOIS 2 REVISED DATA

REFERENCES

UNCLASSIFIED

NOZZLE

The re-analysis of ARROW performance made during late 1956 and incorporating the results of free flight and NACA testing had shown significant deterioration, particularly in terms of combat g. It was decided at a meeting of Company Management that this position could be at least partially retrieved by the introduction of a variable area nozzle in place of the fixed moderate divergent ejector in use at that time. Although this feature would not improve performance at the specified design point of Mach 1.5 at 50,000 ft., it would, when combined with moderate engine over-speeding permit vastly improved performance at Mach 2.0 and, in fact, a prediction made at that time on the basis of preliminary data (later included in Performance Report No. 10) indicated that it was almost possible to meet the specification requirement of 2 g at 50,000 ft. but at Mach 2.0 instead of Mach 1.5. Accordingly it was decided to propose that the aircraft and engine be modified in this manner and the performance of this configuration was presented to the Chief of the Air Staff at a Briefing at AFHQ on December 6th (?).

The decision to change the aircraft and engine configurations was confirmed to AMTS in a letter from Mr. Floyd in December, 1956 (Ref. 24). Enclosed with this letter were copies of Performance Report No. 9 and 10, Report No. 10 containing the information on the version of the aircraft with the variable area nozzle. It must be emphasized that Report No. 10 was based on a very brief analysis of the performance and, in fact, the performance in that report below M.N. 1.5 is identical to performance quoted in Report No. 9 as it was intended that the nozzle in closed position should have the same configuration as the fixed nozzle used in Report No. 9 (Ref. 7).

Detail design studies of the nozzle proceeded through late 1956 and the early part of 1957 and a generalized report on nozzle performance (Ref 25) was prepared in February. Almost at the start of these studies it was apparent that the complications resulting from the adoption of the variable area nozzle introduced weight penalties which would penalize the design point performance at Mach 1.5 and 50,000 ft.

IROQUOIS 2 REVISED DATA

REFERENCES

However, it appeared possible that the use of a fixed divergent ejector would give the performance improvements desired above Mach 1.5 with no deterioration at Mach 1.5 and with no significant deterioration subsonically (Ref. 25), and that the change in boat tail shape resulting from the adoption of such a nozzle could result in very significant supersonic drag reduction (Ref. 26).

Although the report (Ref. 25) concluded that there was no significant penalty to be paid in using a fixed nozzle subsonically, it became apparent as a result of analysis of Performance Report No. 12 that a large proportion of the reduction in subsonic cruise economy had to be charged to nozzle performance.

A recheck of the data contained in the report (Ref. 25) shows that a deterioration in this performance parameter was in fact predictable at that time. It can only be assumed that Technical Design, with their obsession with supersonic combat performance,did not give full weight to the significance of this data.

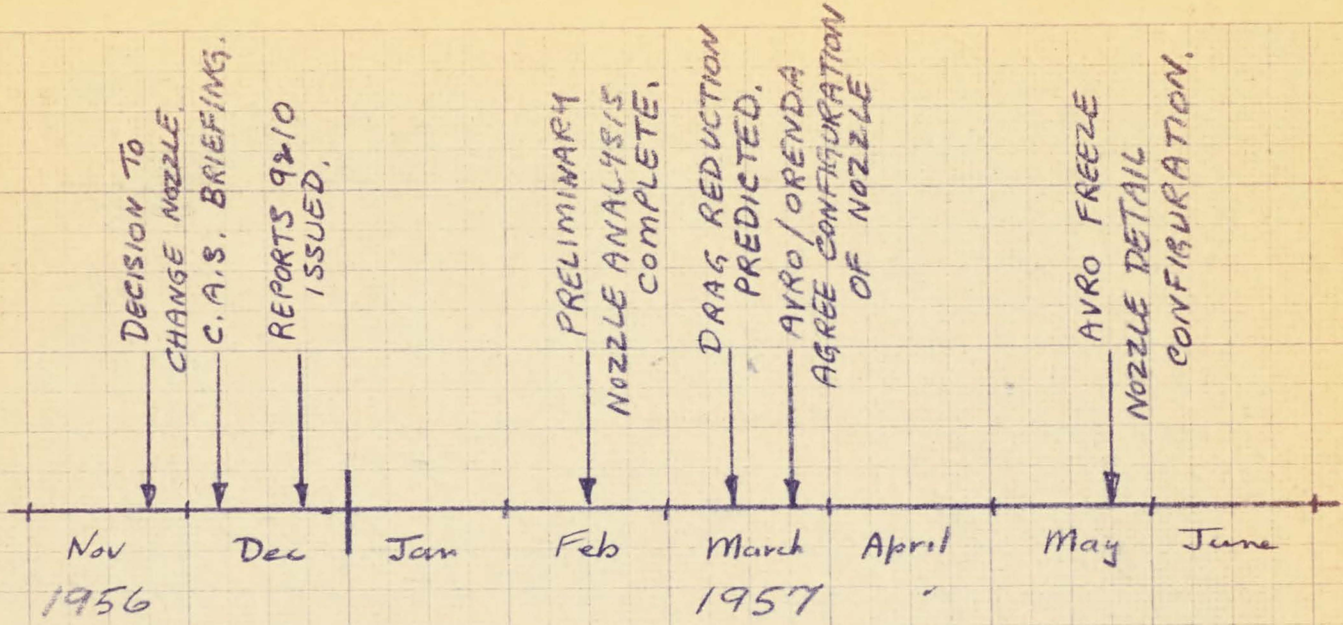
It was found difficult to obtain agreement with Orenda on the detail of the divergent nozzle. Although Technical Design had firmed up their requirement in February, Orenda Engines had been slow to finalize details of the Iroquois 2 and the compatability of engine and nozzle was in doubt. It appears that nozzle areas given by Orenda in January (Ref. 12) were theoretical areas and that some increase was necessary to

IROQUOIS 2 REVISED DATA
REFERENCES

ensure adequate, practical design. This matter was discussed at a meeting between Avro and Orenda in February (Ref. 27) and deadlines were set for Orenda to provide the missing information. It was not until 21st of March that an agreed configuration was reached (Ref. 28). This configuration was the subject of further negotiation in the following two months, and finally on May 24th Technical Design were able to freeze the present configuration.

IROQUOIS 2 REVISED DATA

REFERENCES



CHRONOLOGY — NOZZLE

28/12 Nov/57.

IROQUOIS 2 REVISED DATA

REFERENCES

UNCLASSIFIED

IROQUOIS 2 REVISED DATA

Performance Report No. 10 was essentially a repeat of Report No. 9 with amended performance in the Mach 1.5 to Mach 2.0 speed range, with the amendment being based on a scaling of Iroquois 1 engine data as agreed between Orenda and Avro. A memorandum summarizing this engine performance data was received from Orenda on January 24th (Ref. 12). This memorandum confirmed the engine data used for Report No. 10, stated that the control would be such as to permit the inlet to run subcritical (see Section on Subcritical and Supercritical Air Intake Conditions) and, additionally, gave information on more advanced versions of the engine. Subsequent to the receipt of the Orenda memorandum, attempts were made to obtain more specific and more detailed engine performance for the Iroquois 2. This matter was discussed at a meeting between Orenda and Avro on February 27th (Ref. 27) and in this it was agreed that the Iroquois 2 Model Specification would be provided to Avro not later than April 30th. We have no record of receipt of a Model Specification on the Iroquois 2 from Orenda. However, engine information was transmitted to Avro in accordance with the following:

May 9th - Non-dimensional Performance Curves (Ref. 29).

June 6th - Engine Performance Curves (Ref. 30).

June 14th- Afterburner Combustion Efficiencies, Control Schedules, Fuel Flows. (Ref. 31).

REFERENCES

UNCLASSIFIED

June 27th - Function of Iroquois MK. 2 Control System from Performance Standpoint (Ref. 13).

Nov. 1st - Air Bleed Correction Data (Ref. 8).

Since the calculation of installed engine performance is one of the most involved and laborous aspects of performance calculation (Ref. 32), involving as it does intake and duct performance, bypass performance and ejector performance, cooling losses, etc., in addition to the basic engine performance, and since these traditionally secondary effects are, in an aircraft of the type of the ARROW, assuming a very real significance, it was decided that the calculation of installed engine performance should be undertaken in great detail making use of Avro's newly acquired 704 computer. The requirement for computing time on this problem was made known to the Computing Dept. on May 6th, 1957 (Ref. 33). Performance calculations, identified as Problem A-21 appear in all Computing Dept. progress reports from that date to the present day. Complete data became available on a progressive basis as shown in the attached schedule (Ref. 35) and sufficient data was in the hands of the Performance Group by November 8th to permit them to complete the preparation of Performance Report No. 12. In considering the apparently long flow

REFERENCES

time for this problem through Computing, it must be recognized that this was the first time that we had undertaken the programming of this engine performance problem The problem is complex (Ref. 32) and in the early days was particularly complicated by the difficulties being experienced with regard to engine control as a result of the belief that subcritical operation was essential. We believe that now that this problem has been successfully programmed, variations in engine performance can be assessed in a most expeditious manner.

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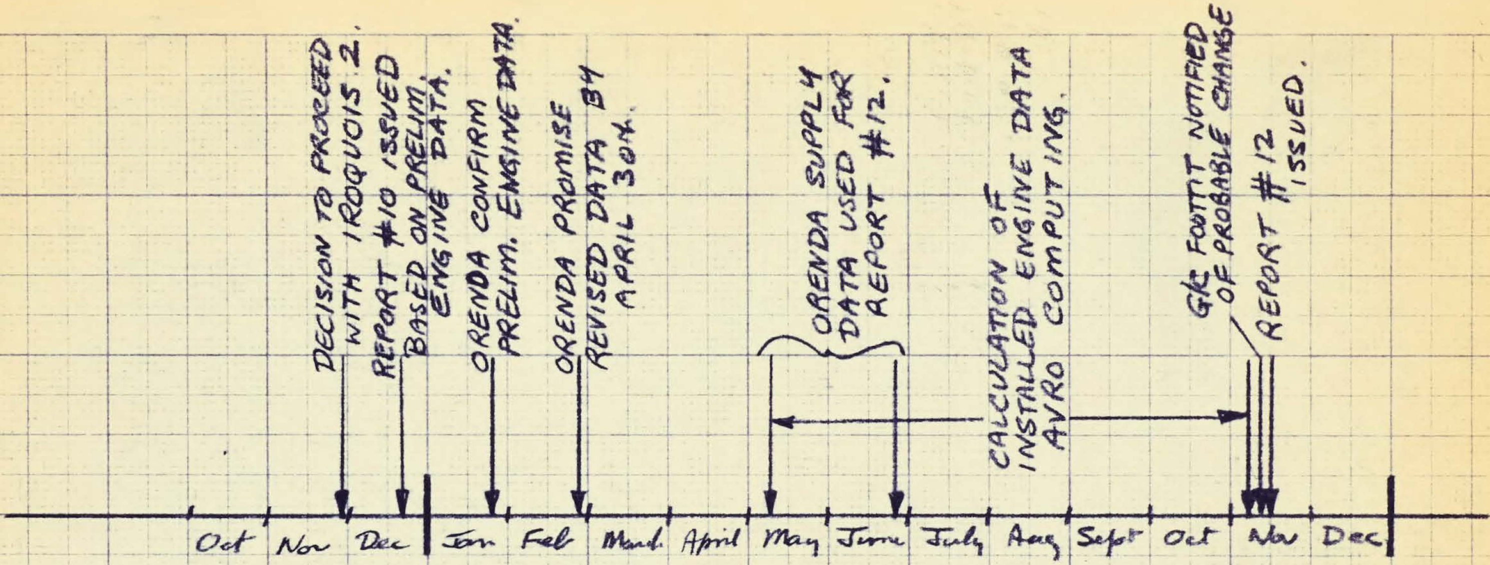

CHRONOLOGY — IROQUOIS 2 REVISED DATA

25th Nov 1957.

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UNCLASSIFIED

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Ref. 2	ARROW Periodic Performance Report No. 10, December, 1956.
Ref. 2a	Letter J. C. Floyd to G/C H. R. Foottit, 2nd August 1957.
Ref. 2b	Letter J. C. Floyd to O/C, TSD's 23rd September 1957 - ARROW Performance.
Ref. 3	C 104/2 Minimum Weight Study, April 30th, 1953.
Ref. 4	Minutes of the Fourth Meeting of the CF105 Co-Ordinating Committee held at AV Roe Canada Limited on 11 and 12 May, 1954.
Ref. 5	A Preliminary Note on the Performance of the ARROW 2A -J. H. Lucas, Nov. 28/57.
Ref. 6	CF-105 Monthly Performance Report No. 8 May, 1956
Ref. 7	CF-105 Periodic Performance Report No. 9, December, 1956.
Ref. 8	ARROW 2/Iroquois Installation - Air Bleed Correction to $\frac{P7}{PI}$ - A. W. Smallwood, November 1, 1957.
Ref. 9	C105 Model Duct Tests Iroquois Installation - D. H. E. Cross - July 31, 1957.
Ref. 10	Performance of the Inlet Duct to the 5/5 as Determined at the NACA Lewis Laboratory, Final Configuration - April, 1956.
Ref. 11	"Overspeed Iroquois" - January 30, 1957.
Ref. 12	Summary of Iroquois Performance Data Transmitted to Avro Aircraft up to January 15, 1956 - C. A. Grinyet.
Ref. 13	Function of Iroquois Mark 2 Control System from Performance Standpoint. June 27, 1957.

Ref. 14 Royal Canadian Air Force Division of Air Member for Technical Services Development Study - CF-105 Mock-Up Evaluation, March 27, 1956.

Ref. 15 Minutes of the Twenty-Second Meeting of the CF-105 Maintenance Sub-Committee Held at AVRO - December 4, 1956.

Ref. 16 Minutes of the Thirty-Second Meeting of the CF105 Co-Ordinating Committee held at AVRO - January 24, 1957.

Ref. 17 ARROW Fire Protection - April 23, 1957. ?

Ref. 18 Minutes of the Sixth Ad Hoc ARROW Development Co-Ordinating Committee Meeting to discuss the ARROW Fire Zones Held at AVRO - July 10, 1957.

Ref. 19 C105 MK. 2 Fuel Tank Capacities - February 14, 1957.

Ref. 20 Weight Summary & C. G. Position, March 1, 1957.

Ref. 21 Model Specification for ARROW 2 Interceptor Aircraft - July, 1957.

Ref. 22 AVRO ARROW MK. II Model Specification Draft Issue #1 - August 29, 1957.

Ref. 24 Performance of the CF-105 - December 18, 1956.

Ref. 25 The Optimization of Ejector Geometry for the CF-105 Incorporating the Iroquois Engine - February 1, 1957.

Ref. 26 Free Flight Model Zero Lift Drag Comparison - March 12, 1957.

Ref. 27 Minutes of Liaison Meeting Held in Mr. Floyd's conference room February 27, 1957.

Ref. 28 Iroquois Afterburner 1075/550 Variable Nozzle - March 20, 1957.

Ref. 29 Iroquois/CF105 Installation - Non dimensional Performance Curves - May, 1957.

Ref. 30 ARROW Iroquois Installation - June 6, 1957.

Ref. 31 Iroquois/ARROW Installation - Performance Curves - June 14, 1957.

Ref. 32 Some Comments on the Magnitude of Performance Calculation Problems - November 28, 1957.

Ref. 33 Computing Department - Problem Description Form - Title: Engine Thrust A/C C-105 - May, 1957.

Ref. 35 Extracts from Digital Computing Department Progress Reports - Job A-21, ARROW 2 Engine Thrust - May, 1957.