C 105 AERODYNAMIC TEST PROGRAM

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Due to the extremely large commitments involved in the overall program, it would be false economy to use anything but the best test facility for each particular job. Accordingly, it is appropriate to plan the program so that all the available facilities are used to the best advantage with due regard to the priority of the resulting data in the design program.

With these things in wind, the logic of the program can be developed. Since, as stated above, there is no point in testing generalised models, as this has already been done, the first thing is to develop external lines with due regard to the details of the internal structure and the processes involved in manufacture.. As the result of several months study, it is now possible to define suitable contours for further study. Having got to this point, it appears that there is great incentive to use a cambered airfoil, but there is no satisfactory data to base the design on. Accordingly it is expedient to resolve this problem by ad hoc testing.

The data required are a reliable and accurate estimate of the C_{M_O} of the aircraft in the transonic regime. To get these data a transonic tunnel is obviously required using very sensitive balances to detect very small quantities involved in C_{M_O}. Also it is evident that tunnel corrections must either be known accurately or be zero to give the necessary quantitative flavor to the results. Fortunately these requirements can be met by the model transonic throat at Cornell. The feature of this tunnel is that it functions by using porous walls with suction. This gives a uniform velocity field free from any shock reflections from the walls. Also the use of a sting mounting to position the model symmetrically with respect to the tunnel removes any other sources of anxiety over the corrections, which should be negligible. This situation is more felicitous than with the conventional NACA slotted throat where the corrections are open to question, especially with reflection plane models. Antoher feature of the Cornell set-up is that the balances are designed along with the model to give the maximum possible sensitivity.

Correlation of data from this tunnel with that from other sources appear to be excellent, and even the effect of Reynolds number does not appear to be preponderant.

One of the main features of this program is that it can be done relatively quickly. From May 12 when authority to proceed was given, it should be possible to complete the design and construction of a model with two wings and special balances by the middle of August, so that it can be calibrated and ready for running by the first of September. The running time for the preliminary program required for the evaluation of camber will be about three days. The main qualitative results will be known as the runs progress, but it will take one month to fully analyse the data.

From these results, it should be possible to determine by interpolation the proper amount of geometric camber. This then fixes the external lines and the rest of the program can be proceeded with, after making a new wing with the optimum camber.

The next order of priority is to obtain the most reliable data on the principal aerodynamic coefficients throughout the high subsonic and supersonic regime. From a thorough study of NACA reports it appears that the most suitable technique for this purpose is to telemeter data from rocket propelled missiles. Since CARDE have set up range facilities suitable for this type of test and have developed the necessary knowhow on the electronic techniques-involved, it will certainly be advantageous to rely on their experience.

The Reynolds number obtained in these tests is sufficiently large to remove all doubts on this score. Since the tests are done in free flight, there are no tunnel wall corrections to be applied. The only correction is a relatively small one for the basic drag of the rocket motor. This is unimportant for stability tests. Besides giving the most accurate source of steady state derivates, it is the only source of damping derivates.

Since this is a new technique, the effort required to design and manufacture the models including instrumentation is very large. Hence it is necessary to start preliminary work at an early date in order to get answers in time to be of value for design.

Because the models are expendible, at least three will have to be constructed to ensure that a complete set of data can be secured. More models would be desirable so that additional though non-essential data can be obtained by extra firings. This program is a very major one as far as model making facilities are concerned. Although it exceeds anything of the kind so far attempted at Avro by a considerable margin, it is felt that this is the only place to make the model due to the necessity for very close technical liaison with the model shop throughout. It will, of course, be necessary to obtain considerable assistance and advice from CARDE on the telemetering package. There is no doubt that a program of this magnitude will fully occupy the model making facilities at Avro during the period when it is essential that models for the tunnel programs be also under construction. Hence arrangements must be made to make the tunnel models elsewhere.

A 1/20 scale sting mounted model for the Cornell tunnel provides the only possible source for high speed directional and lateral data including the coupling terms which are very necessary for the design of the autopilot. Also it provides the only vehicle suitable for the program suggested by Dr. A. Puckett on the launching of missiles, which has been discussed at length in another report. The techniques developed by Cornell for making very small accurate strain guage balances to suit every requirement are essential for both these programs. Hence it is fairly obvious that there is no alternative but that they construct the model and the instrumentation. One of the features of this are the balances in the model missiles which have a diameter of about one half inch.

Longitudinal data of high quality can also be obtained with this model at all subsonic Mach numbers and at M = 1.2 by the use of a special liner. At the lower speeds the tunnel can be pressurized up to 2½ atmos. to give relatively high Reynolds numbers.

At the N.A.E., the most useful tunnel for this program is the 16" x 30" intermittent supersonic tunnel. This however can be arranged to operate in any speed range. It is best suited to a relection plane model. Its range of operation is thus such that it can give data which overlaps that from both models in the Cornell tunnel and the free flight model. This should provide both a useful and valuable check on the continuity of the data. However it cannot be used to supplant the other models, since each in its own sphere provides superior data, some of which cannot be obtained in this tunnel due to restrictions involved in the mounting method. Of the N.A.E. models, the models for this tunnel should receive the highest priority, and should be started immediately after the optimum camber is found for the wing.

Tests on the intake at several supersonic Mach numbers are very desirable. While pressure recovery data is useful, the most important deductions can be secured from an examination of Schlieren or other types of pictures of the shocks. This requirement restricts one to the N.A.E. 10" x 10" supersonic tunnel. To get a reasonably sized model, it would be necessary to use a partial reflection plane model. However, the problem of the boundary layer and Reynolds number is such as to render a test in this tunnel virtually meaningless. A detailed discussion with the N.A.E. on how to overcome the difficulites did not result in any improvement in the picture. Accordingly it is felt that although results from these tests should be accepted with the utmost reserve in view of the unreliability of some NACA data done at a similar scale, they are probably better than nothing. Accordingly a model should be constructed and tests proceeded with at low priority.

Low speed tests can be done in the N.A.E. No. 3 tunnel. These will overlap some of those done in the Cornell pressurized tunnel. However there are several miscellaneous tests which it is much more economical to do in this tunnel. The most important program of this kind are test with undercarriage down, and with and without a ground board. Also some work may be necessary on the streaming of a tail parachute. This program depends on work on this subject being carried out at Manchester. It may also be necessary to study the jettisoning of missiles and such things. For these purposes, the normal three point support system is indicated rather than a reflection plane. Although this later system would provide a higher Reynolds number, it would not be enough higher than that achieved in Cornell to warrant making a special model in view of the very limited scope of the tests that could be undertaken.

In general, data from the Avro 707 series and from the very large NACA tunnels seems adequate to ensure the basic soundness of the design from the low speed point of view. Accordingly this program to supply certain detailed information should not be regarded as of the highest priority, but should take its place after the high speed programs.

Tests in a spinning tunnel are mandatory for a fighter aircraft. Accordingly these tests will be undertaken in the N.A.E. spinning tunnel which is one of the best of its kind. Since no great apprehension is felt as to the success of this program, the priority need not be high.

It is assumed that all models to be tested at N.A.E. would have to be made in their shops, since the Avro facilities will be fully occupied in making free flight models and the full scale mock-ups which are also required for the overall program.

It is accordingly felt that the program outlined above and of which details are given in the the Appendices represents an adequate and balanced program using all the available facilities to the best advantage.

APPENDIX A

C.105 AERODYNAMIC TEST PROGRAM

SPEED REGIME	TYPE OF TEST	FACILITY	TYPE	SIZE OF TUNNEL	MODEL	R ×10⁻⁶	COMMENTS
LOW SPEED	(1) GENERAL	N.A.E.	LOW SPEED	6'-7" × 10'-0"	3 PT SUPPORT APPROX 1/12 SCALE	5.6	DATA AT HIGH R DUBIOUS DUE TO SUPPORT INTERFERENCE & BLOCKAGE.
		CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	7.1	2.5 ATMOS. NO SUPPORT INTERFERENCE OR BLOCKAGE. REASONABLY RELIABLE
	(2) TAIL PARACHUTE	N.A.E.	LOW SPEED	6'-7" × 10'-0"	3 PT. SUPPORT APPROX 1/12 SCALE	5.6	MINOR PROGRAM. MAY NOT BE REQUIRED.
	(3) SPINNING	N.A.E.	SPIN TUNNEL	15'-0" DIA.	APPROX. 1/24 SCALE	2.0	MANDATORY PROGRAM
HIGH SUBSONIC	(1) LONGITUDINAL	CORNELL	HIGH SPEED V.D.T	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	2.5	EASY TO COMBINE WITH (2) & (3), WHICH CANNOT BE DONE ELSEWHERE
		N.A.E.	INTERMITTENT SUPERSONIC	16" × 30"	REFLECTION PLANE.	1.5	PROGRAM REDUNDANT BUT USEFUL AS A CHECK
	(2) DIRECTIONAL & LATERAL.	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.5	DATA IMPORTANT FOR DELTA. CANNOT BE DONE ELSEWHERE.
	(3) ARMAMENT	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	2.5	LARGE STING MODEL REQ. FOR MISSILE INSTALL^N. CANNOT BE DONE ELSEWHERE
TRANSONIC	(1) LONG. TRIM DATA	CORNELL	TRANSONIC THROAT	3'-0" × 4'-0"	STING MOUNT .03 SCALE	1.5	FOR DEVELOPMENT OF CAMBER
	(2) DIRECTIONAL & LATERAL	CORNELL	TRANSONIC THROAT	3'-0" × 4'-0"	STING MOUNT .03 SCALE	1.5	DATA VERY IMPORTANT CANNOT BE DONE ELSEWHERE.
SUPERSONIC	(1) LONG. (a) STATIC	CARDE	R.P. MISSILE	FREE FLIGHT	1/8 SCALE 11 CHANNELS	36.0	BEST SOURCE OF SUPERSONIC DATA AVAILABLE
		CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LINER GIVES M=1.2 ONLY
		N.A.E.	INTERMITTENT SUPERSONIC	16" × 30"	REFLECTION PLANE	1.5	ONLY SOURCE OF TUNNEL DATA AT SUPERSONIC SPEEDS OVER 1.2
	(b) DYNAMIC	CARDE	R.P. MISSILE	FREE FLIGHT	1/8 SCALE 11 CHANNELS	36.0	ONLY SOURCE OF DAMPING DATA
	(2) DIRECTIONAL & LATERAL	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LINER GIVES M=1.2 ONLY CANNOT DO TESTS ELSEWHERE
	(3) ARMAMENT	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LARGE STING MODEL REQ^D TO HOUSE INSTRUMENTATION
	(4) INTAKE	N.A.E.	INTERMITTENT SUPERSONIC	10" × 10"	REFLECTION PLANE. PARTIAL MODEL.		MUST USE 10" TUNNEL FOR SCHLIEREN R. TOO LOW TO BE OF MUCH VALUE

MODELS REQ^D FOR ABOVE PROGRAM

N.A.E.
(1) LOW SPEED
(2) HIGH SPEED
(3) SPINNING
(4) INTAKE.

CORNELL
(1) TRANSONIC (.03 SCALE)
(2) SUBSONIC & M=1.2 (1/20 SCALE)

C.A.R.D.E.
(1) R.P. MISSILE (1/8 SCALE)

APPENDIX B

PROPOSED PROGRAMME FOR C-105

WIND TUNNEL TESTING AT CORNELL AERO. LAB.

I. Transonic Wind Tunnel 3' x 4'

(a) Preliminary Test

Purpose: (1) To determine basic longitudinal stability and control characteristics.
(2) To determine the effect of camber on the control.

Model: .03 Scale Sting Model
(1) Uncambered wing
(2) Cambered wing (camber is so chosen as to bracket expected design requirement).

Test: (1) Uncambered wing
Mach number: .5, .7, .8, .85, .9, .92, .95, .98, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25 (14)
Elevator deflections: +10°, 0°, -5°, -10°, -20°, -30°, (6) 14 x 6 = (84)

(2) Cambered wing (14)
Mach number: As above
Elevator deflections: 0°

At M = .5 it is required to reach the stall which will call for an angle of attack of about 30°

Instrumentation:

(1) Force data giving C_L, C_M, C_D, C_{H_e}

(2) Pressure data (if possible) only on $\delta_e = 0°$ runs.

Number of orifices: 9

(b) Final Test

Purpose: To determine complete stability and control characteristics about the 3 axes.

Model: .03 Scale sting model cambered wing.
The amount of camber will be chosen in view of the knowledge derived from data of the preliminary test (a).

Test: (1) Longitudinal Stability and Control

Mach number: .5, .7, .8, .85, .9, .92, .95, .98, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25 (14)
δ_e : 0, 2, 5, 10, -2, -5, -10, -15, -20, -25, -30 (11)
14 x 11 (154)

(2) Lateral Control

M = As above
δ_a = 2, 5, 10, -2, -5, -10, -15, -20 (8)   14×8 = 112

(3) Directional Stability and Control

M = As above   14×7 = 98
ψ = 2, 4, 6, 8, 10, -4, -8 (7)   14×7 = 98
Fin and rudder on and off

(4) Dive Brakes

20 - 20, 40 - 40, 60 - 60 (L - U)
M = .9, .95, .98, 1.0, 1.05, 1.10, 1.20 (7)   (21)

581 runs

Instrumentation:

(1) Six component main balance: L, D, Y, M, N, ℓ.
(2) Two component fin balance: Y_F, N_F,
(3) Hinge moments of elevator, aileron and rudder.
(4) For dive brakes runs: hinge moments of dive brakes.
(5) No pressure data required.

II. Subsonic Wind Tunnel 8'6" x 12"

Purpose:
(1) Extensive armament test.
(2) Dive brake design (differential movement).
(3) Low speed, high R.N. effects.
(4) Stability and control test to check on and correlate the results from transonic wind tunnel which is a completely new technique.
(5) Limited pressure data (cockpit and side of nacelle).

Model: 1/20 Scale sting model

Test:
(1) High R.N. at 2.5 atm.
δ_e = 0, -10, -20, -30 (4)
M = .3

(2) Longitudinal Stability and Control
M = .5, .6, .7, .75, .8, .85, .9, .92, .95 (9)
δ_e 0, 2, 5, 10, -2, -5, -10, -15, -20, -25, -30 (11)

(3) Lateral Control
M = As above (9)
δ_a = 2, 5, 10, -2, -5, -10, -15, -20 (8)

(4) Directional Stability and Control
M = As above (9)
ψ = 2, 4, 6, 8, 10, 15, -4, -8 (8)
Fin and rudder <u>on</u> and <u>off</u>
δ_r = 2, 5, 10, 15, 20, 25, 30 (7)

Effect of elevator on Directional Stability

ψ = 4, 8, 12 (3)

δ_e = -20, -30 (2)

M = .5, .8, .9, .95 (4)

(5) Blanketing Losses

(a) In elevator effectiveness

M = .5, .8, .9, .95, (4)

$\psi = 8^o$

δ_e = -10, -20, 10 (3)

Repeat above at ψ = 0, 8 with dive brakes open 60 - 60 at M = .8, .95

(b) In rudder effectiveness

M = .8, .95

Dive brakes 60 - 60

ψ = 0, 8

δ_r = 5, 10, 20

(6) Falcon Missiles

Six missiles to be tested in several longitudinal and chordwise locations and combinations, possibly with partly open doors on some of the missiles. Investigation is to cover effects of incidence and side slip angles at M = .95 .

(7) Dive Brakes L = Lower U = Upper

L	U	L	U	L	U
0	10	10	10	10	0
10	20	20	20	20	10
20	30	30	30	30	20
30	40	40	40	40	30
40	50	50	50	50	40
50	60	60	60	60	50

M = .8, .85, .9, .92, .95

Instrumentation:
(1) Six component main balance: L, D, Y, M, N, ℓ
(2) Two component fin balance: Y_F, N_F,
(3) Hinge moments: elevator, aileron, rudder, lower and upper dive brake.
(4) For missile runs: forces and moments on the missiles.
(5) Pressure data from 9 orifices.

III. <u>Supersonic Wind Tunnel 8'8" x 12' with liner</u>

Purposes of this test are exactly the same as subsonic test (II) and so the same measurements are to be repeated at M = 1.2 (the only Mach Number for which a liner is available).

APPENDIX C

C-105 ROCKET MODEL TEST PROGRAMME

Purpose: (1) To obtain data, throughout transonic and supersonic range, leading to the evaluation of static and dynamic longitudinal stability and control. Data pertaining to control operating forces and control effectiveness will be particularly valuable in view of the very high Reynold's Number of the test ($\simeq 36 \times 10^6$)

(2) To investigate the drag increase due to control deflection.

Model: (1) Three 1/8 scale models equipped with square wave operated elevator. Two of these are required for tests at two different c.g. positions. The third one will be built as a stand by in case of failure of one of the other models.

(2) Several 1/8 scale models equipped with a pre-set elevator. These will carry much less electronic equipment and will be built only if a cheap method of manufacture (such as large unit casting) is developed.

Test: The model will be accelerated to required top Mach number by a booster rocket. Then a sustainer rocket built into the model will take over and ascertain a positive separation. The data will be obtained from transient records of model motion in response to square wave push-downs and pull-ups of the elevators. Mach Number range: .7 to 2.5

Instrumentation: (a) Longitudinal stability and control models

(1) Telemetering on eleven channels supplying following data:
- longitudinal acceleration.
- transverse acceleration
- normal acceleration
- elevator hinge moment
- aileron hinge moment
- elevator position
- aileron position
- angle of attack
- total pressure
- reference static pressure
- pitch angle with reference to a fixed datum

(2) High speed photography from the ground

(3) Radiosonde

(b) Drag Models

(1) Telemetering on six channels
- longitudinal acceleration
- transverse acceleration
- normal acceleration
- angle of attack
- total pressure
- reference static pressure

(2) Photography

(3) Radiosonde

Results: From the recorded data following aerodynamic information, covering the entire Mach range, will be derived:

(1) Aerodynamic centre

(2) C_{L_α}

(3) C_{L_δ}

(4) Elevator incremental centre of pressure

(5) C_{M_α}

(6) $C_{h_{\delta_e}}$ } Elevator

(7) $C_{h_{\alpha_e}}$ }

(8) $C_{h_{\alpha_a}}$ Aileron

(9) $C_{M_{\dot{\alpha}}} + C_{M_q}$

(10) C_D

(11) Buffet boundary

APPENDIX C

PROPOSED PROGRAM OF C 105

WIND TUNNEL TESTING AT N.A.E.

1. Low Speed Tunnel

Purpose: (1) To determine the basic longitudinal stability and control characteristics at low speed.

(2) To determine the lateral and directional characteristics and aileron effectiveness at low speeds.

(3) To determine the ground effect by the use of a ground board.

(4) To study the [illegible] of missiles and external tanks.

(5) To study the streaming of the tail parachute.

Tests:

Elevator deflection +10, 0, -5, -10, -20, -25, -30
Aileron deflection 10, 5, 0, -5, -10, -15, -20
Rudder deflection 10, 5, 0, -5, -10, -20, -25, -30

Longitudinal tests to be done with and without a ground board with landing gear extended.
With the ground board in place, the streaming of the tail parachute will be studied with reference to the oscillations that may develop.

2. High Speed Tunnel (16" x 30")

Purpose: (1) To determine the basic longitudinal stability, elevator and aileron effectiveness at transonic and supersonic speeds.

Tests: Elevator deflection +10, +5, 0, -5, -10, -20, -25, -30
Aileron deflection 20, 15, 10, 5, 0, -5, -10, -15, -20
Mach range Subsonic to 2.0

Instrumentation:
Six component balance to give L, D, M, ℓ,
Elevator and aileron hinge moments

3. High Speed (10" x 10")

Purpose: (1) To determine the efficiency of the intake by direct measurement and Schlieren photography.

Tests: Pressure recovery
Schlieren photography
Tests to be done with various ramp angles at all supersonic Mach numbers up to 2.0 [illegible] which throats are available.

Instrumentation:
[illegible] and [illegible] [illegible] rakes.

4. <u>Spinning Tunnel</u>

Purpose: (1) To check the spin recovery characteristics under various loading conditions.

Tests: Routine spinning tests to be carried out at conditions corresponding to various fuel loads. The effect of rudder, elevators, and aileron on the spin recovery to be noted.

Instrumentation:
Photographic record of spins.

APPENDIX E

Comparison of running time required to complete an identical programme in N.A.E. and Cornell.

Proposed programme for C-105 for Cornell Transonic Wind Tunnel is taken as the basis for comparison as it is possible to run such a programme at both facilities.

From Appendix B, I (a) and (b)

Total number of runs required	581
Average number of points per run	10
Cornell output based on past tests in transonic wind tunnel	3 runs/hr.
N.A.E. output [Quarterly Bulletin 1952 (4)]	4 points/hr.
Utilization time assumed	
Cornell 3 seven hour shifts	21 hrs./day
N.A.E. 2 seven hour shifts	14 hrs./day

Based on these data estimated required running time for this programme is -

Cornell	9.2 days
N.A.E.	4.8 months (104 days)

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In general, the aerodynamic data on which the C 105 design has been based is both excellent and copious, especially when compared with that used for the design of the C 100. Thus there are numerous NACA test at a very large scale both at low and high speeds of wings whose thickness and planform resemble those proposed for the C 105 very closely. This does not in anyway lessen the need for large quantities of ad hoc data on points specific to the design in question. However, it is evident that tests using facilities which are not of very high calibre, and specially suited to the object in view, will not produce results which are of much value compared to what can be gleaned from the analysis of existing data.

Due to the extremely large commitments involved in the overall program, it would be false economy to use anything but the best test facility for each particular job. Accordingly, it is appropriate to plan the program so that all the available facilities are used to the best advantage with due regard to the priority of the resulting data in the design program.

With these things in wind, the logic of the program can be developed. Since, as stated above, there is no point in testing generalised models, as this has already been done, the first thing is to develop external lines with due regard to the details of the internal structure and the processes involved in manufacture.. As the result of several months study, it is now possible to define suitable contours for further study. Having got to this point, it appears that there is great incentive to use a cambered airfoil, but there is no satisfactory data to base the design on. Accordingly it is expedient to resolve this problem by ad hoc testing.

The data required are a reliable and accurate estimate of the C_{M_0} of the aircraft in the transonic regime. To get these data a transonic tunnel is obviously required using very sensitive balances to detect very small quantities involved in C_{M_0}. Also it is evident that tunnel corrections must either be known accurately or be zero to give the necessary quantitative flavor to the results. Fortunately these requirements can be met by the model transonic throat at Cornell. The feature of this tunnel is that it functions by using porous walls with suction. This gives a uniform velocity field free from any shock reflections from the walls. Also the use of a sting mounting to position the model symmetrically with respect to the tunnel removes any other sources of anxiety over the corrections, which should be negligible. This situation is more felicitous than with the conventional NACA slotted throat where the corrections are open to question, especially with reflection plane models. Antoher feature of the Cornell set-up is that the balances are designed along with the model to give the maximum possible sensitivity.

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Because the models are expendible, at least three will have to be constructed to ensure that a complete set of data can be secured. More models would be desirable so that additional though non-essential data can be obtained by extra firings. This program is a very major one as far as model making facilities are concerned. Although it exceeds anything of the kind so far attempted at Avro by a considerable margin, it is felt that this is the only place to make the [illegible] due to the necessity for very close technical liaison with the model shop throughout. It will, of course, be necessary to obtain considerable assistance and advice from CARDE on the telemetering package. There is no doubt that a program of this magnitude will fully occupy the model making facilities at Avro during the period when it is essential that models for the tunnel programs be also under construction. Hence arrangements must be made to make the tunnel models elsewhere.

A 1/20 scale sting mounted model for the Cornell tunnel provides the only possible source for high speed directional and lateral data including the coupling terms which are very necessary for the design of the autopilot. Also it provides the only vehicle suitable for the program suggested by Dr. A. Puckett on the launching of missiles, which has been discussed at length in another report. The techniques developed by Cornell for making very small accurate strain gauge balances to suit every requirement are essential for both these programs. Hence it is fairly obvious that there is no alternative but that they construct the model and the instrumentation. One of the features of this are the balances in the model missiles which have a diameter of about one half inch.

Longitudinal data of high quality can also be obtained with this model at all subsonic Mach numbers and at M = 1.2 by the use of a special liner. At the lower speeds the tunnel can be pressurized up to 2½ atmos. to give relatively high Reynolds numbers.

At the N.A.E., the most useful tunnel for this program is the 16" x 30" intermittent supersonic tunnel. This however can be arranged to operate in any speed range. It is best suited to a relection plane model. Its range of operation is thus such that it can give data which overlaps that from both models in the Cornell tunnel and the free flight model. This should provide both a useful and valuable check on the continuity of the data. However it cannot be used to supplant the other models, since each in its own sphere provides superior data, some of which cannot be obtained in this tunnel due to restrictions involved in the mounting method. Of the N.A.E. models, the models for this tunnel should receive the highest priority, and should be started immediately after the optimum camber is found for the wing.

Tests on the intake at several supersonic Mach numbers are very desirable. While pressure recovery data is useful, the most important deductions can be secured from an examination of Schlieren or other types of pictures of the shocks. This requirement restricts one to the N.A.E. 10" x 10" supersonic tunnel. To get a reasonably sized model, it would be necessary to use a partial reflection plane model. However, the problem of the boundary layer and Reynolds number is such as to render a test in this tunnel virtually meaningless. A detailed discussion with the N.A.E. on how to overcome the difficulites did not result in any improvement in the picture. Accordingly it is felt that although results from these tests should be accepted with the utmost reserve in view of the unreliability of some NACA data done at a similar scale, they are probably better than nothing. Accordingly a model should be constructed and tests proceeded with at low priority.

Low speed tests can be done in the N.A.E. No. 3 tunnel. These will overlap some of those done in the Cornell pressurized tunnel. However there are several miscellaneous tests which it is much more economical to do in this tunnel. The most important program of this kind are test with undercarriage down, and with and without a ground board. Also some work may be necessary on the streaming of a tail parachute. This program depends on work on this subject being carried out at Manchester. It may also be necessary to study the jettisoning of missiles and such things. For these purposes, the normal three point support system is indicated rather than a reflection plane. Although this later system would provide a higher Reynolds number, it would not be enough higher than that achieved in Cornell to warrant making a special model in view of the very limited scope of the tests that could be undertaken.

In general, data from the Avro 707 series and from the very large NACA tunnels seems adequate to ensure the basic soundness of the design from the low speed point of view. Accordingly this program to supply certain detailed information should not be regarded as of the highest priority, but should take its place after the high speed programs.

Tests in a spinning tunnel are mandatory for a fighter aircraft. Accordingly these tests will be undertaken in the N.A.E. spinning tunnel which is one of the best of its kind. Since no great apprehension is felt as to the success of this program, the priority need not be high.

It is assumed that all models to be tested at N.A.E. would have to be made in their shops, since the Avro facilities will be fully occupied in making free flight models and the full scale mock-ups which are also required for the overall program.

It is accordingly felt that the program outlined above and of which details are given in the the Appendices represents an adequate and balanced program using all the available facilities to the best advantage.

APPENDIX 'A'

C.105 AERODYNAMIC TEST PROGRAM

SPEED REGIME	TYPE OF TEST	FACILITY	TYPE	SIZE OF TUNNEL	MODEL	R ×10⁻⁶	COMMENTS
LOW SPEED	(1) GENERAL	N.A.E.	LOW SPEED	6'-7" × 10'-0"	3 PT SUPPORT APPROX 1/12 SCALE	5.6	DATA AT HIGH α DUBIOUS DUE TO SUPPORT INTERFERENCE & BLOCKAGE
		CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	7.1	2.5 ATMOS. NO SUPPORT INTERFERENCE OR BLOCKAGE. REASONABLY RELIAB…
	(2) TAIL PARACHUTE	N.A.E.	LOW SPEED	6'-7" × 10'-0"	3 PT. SUPPORT APPROX 1/12 SCALE	5.6	MINOR PROGRAM. MAY NOT BE REQUIRED.
	(3) SPINNING	N.A.E.	SPIN TUNNEL	15'-0" DIA.	APPROX. 1/24 SCALE	2.0	MANDATORY PROGRAM
HIGH SUBSONIC	(1) LONGITUDINAL	CORNELL	HIGH SPEED V.D.T	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	2.5	EASY TO COMBINE W… (2) & (3), WHICH CANNOT BE DONE ELSEWHERE
		N.A.E.	INTERMITTENT SUPERSONIC	10" × 30"	REFLECTION PLANE.	1.5	PROGRAM REDUNDAN… BUT USEFUL AS A CHECK
	(2) DIRECTIONAL & LATERAL.	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.5	DATA IMPORTANT FOR DELTA. CANNOT BE DONE ELSEWHERE.
	(3) ARMAMENT	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE.	2.5	LARGE STING MODEL REQ… FOR MISSILE INSTALLN. CANNOT BE DONE ELSEWHERE
TRANSONIC	(1) LONG. TRIM DATA	CORNELL	TRANSONIC THROAT	3'-0" × 4'-0"	STING MOUNT ·03 SCALE	1.5	FOR DEVELOPMENT OF CAMBER
	(2) DIRECTIONAL & LATERAL	CORNELL	TRANSONIC THROAT	3'-0" × 4'-0"	STING MOUNT ·03 SCALE	1.5	DATA VERY IMPORTAN… CANNOT BE DONE ELSEWHERE.
SUPERSONIC	(1) LONG. (a) STATIC	C.A.R.D.E.	R.P. MISSILE	FREE FLIGHT	1/8 SCALE 11 CHANNELS	36.0	BEST SOURCE OF SUPERSONIC DATA AVAILABLE
		CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LINER GIVES M=1.2 ON…
		N.A.E.	INTERMITTENT SUPERSONIC	10" × 30"	REFLECTION PLANE	1.5	ONLY SOURCE OF TUNNEL DATA AT SUPERSONIC SPEEDS OVER 1.2
	(b) DYNAMIC	C.A.R.D.E.	R.P. MISSILE	FREE FLIGHT	1/8 SCALE 11 CHANNELS	36.0	ONLY SOURCE OF DAMPING DATA
	(2) DIRECTIONAL & LATERAL	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LINER GIVES M=1.2 ON… CANNOT DO TESTS ELSEWHERE
	(3) ARMAMENT	CORNELL	HIGH SPEED V.D.T.	8'-6" × 12'-0"	STING MOUNT 1/20 SCALE	2.3	LARGE STING MODEL REQD TO HOUSE INSTRUMENTATION
	(4) INTAKE	N.A.E.	INTERMITTENT SUPERSONIC	10" × 10"	REFLECTION PLANE. PARTIAL MODEL.		MUST USE 10" TUNNEL FOR SCHLIEREN. R. TOO LOW TO BE OF MUCH …

MODELS REQD FOR ABOVE PROGRAM

N.A.E.
- (1) LOW SPEED
- (2) HIGH SPEED
- (3) SPINNING
- (4) INTAKE

CORNELL
- (1) TRANSONIC (·03 SCALE)
- (2) SUBSONIC & M=1.2 (1/20 SCALE)

C.A.R.D.E.
- (1) R.P. MISSILE (1/8 SCALE)

APPENDIX B

PROPOSED PROGRAMME FOR C-105

WIND TUNNEL TESTING AT CORNELL AERO. LAB.

I. Transonic Wind Tunnel 3' x 4'

(a) Preliminary Test

Purpose: (1) To determine basic longitudinal stability and control characteristics.
(2) To determine the effect of camber on the control.

Model: .03 Scale Sting Model
(1) Uncambered wing
(2) Cambered wing (camber is so chosen as to bracket expected design requirement).

Test: (1) Uncambered wing
Mach number: .5, .7, .8, .85, .9, .92, .95, .98, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25 (14)
Elevator deflections: +10°, 0°, -5°, -10°, -20°, -30°, (6) 14 x 6 = (84)

(2) Cambered wing (14)
Mach number: As above
Elevator deflections: 0°

At M = .5 it is required to reach the stall which will call for an angle of attack of about 30°.

Instrumentation:

(1) Force data giving C_L, C_M, C_D, C_{H_e}

(2) Pressure data (if possible) only on $\delta_e = 0°$ runs.

Number of orifices: 9

(b) Final Test

Purpose: To determine complete stability and control characteristics about the 3 axes.

Model: .03 Scale sting model cambered wing.
The amount of camber will be chosen in view of the knowledge derived from data of the preliminary test (a).

Test: (1) Longitudinal Stability and Control

Mach number: .5, .7, .8, .85, .9, .92, .95, .98, 1.00, 1.05, 1.10, 1.15, 1.20, 1.25 (14)
δ_e : 0, 2, 5, 10, -2, -5, -10, -15, -20, -25, -30 (11)
14 x 11 (154)

(2) Lateral Control

M = As above
δ_a = 2, 5, 10, -2, -5, -10, -15, -20 (8)
14×8 = (112)

(3) Directional Stability and Control

M = As above
ψ = 2, 4, 6, 8, 10, -4, -8 (7)
Fin and rudder on and off
14×7 = (98)
14×7 = (98)

(4) Dive Brakes

20 - 20, 40 - 40, 60 - 60 (L - U)
M = .9, .95, .98, 1.0, 1.05, 1.10, 1.20 (7)
(21)

581 runs

Instrumentation:

(1) Six component main balance: L, D, Y, M, N, ℓ.
(2) Two component fin balance: Y_F, N_F,
(3) Hinge moments of elevator, aileron and rudder.
(4) For dive brakes runs: hinge moments of dive brakes.
(5) No pressure data required.

II. Subsonic Wind Tunnel 8'6" x 12"

Purpose: (1) Extensive armament test.
(2) Dive brake design (differential movement).
(3) Low speed, high R.N. effects.
(4) Stability and control test to check on and correlate the results from transonic wind tunnel which is a completely new technique.
(5) Limited pressure data (cockpit and side of nacelle).

Model: 1/20 Scale sting model

Test: (1) High R.N. at 2.5 atm.
δ_e = 0, -10, -20, -30 (4)
M = .3

(2) Longitudinal Stability and Control
M = .5, .6, .7, .75, .8, .85, .9, .92, .95 (9)
δ_e 0, 2, 5, 10, -2, -5, -10, -15, -20, -25, -30 (11)

(3) Lateral Control
M = As above (9)
δ_a = 2, 5, 10, -2, -5, -10, -15, -20 (8)

(4) Directional Stability and Control
M = As above (9)
ψ = 2, 4, 6, 8, 10, 15, -4, -8 (8)
Fin and rudder on and off
δ_r = 2, 5, 10, 15, 20, 25, 30 (7)

Effect of elevator on Directional Stability
ψ = 4, 8, 12 (3)
δ_e = -20, -30 (2)
M = .5, .8, .9, .95 (4)

(5) Blanketing Losses
(a) In elevator effectiveness
M = .5, .8, .9, .95, (4)
$\psi = 8^\circ$
δ_e = -10, -20, 10 (3)

Repeat above at ψ = 0, 8 with dive brakes open 60 - 60 at M = .8, .95

(b) In rudder effectiveness
M = .8, .95
Dive brakes 60 - 60
ψ = 0, 8
δ_r = 5, 10, 20

(6) Falcon Missiles
Six missiles to be tested in several longitudinal and chordwise locations and combinations, possibly with partly open doors on some of the missiles. Investigation is to cover effects of incidence and side slip angles at M = .95.

(7) Dive Brakes L = Lower U = Upper

L	U	L	U	L	U
0	10	10	10	10	0
10	20	20	20	20	10
20	30	30	30	30	20
30	40	40	40	40	30
40	50	50	50	50	40
50	60	60	60	60	50

M = .8, .85, .9, .92, .95

Instrumentation:
(1) Six component main balance: L, D, Y, M, N, ℓ
(2) Two component fin balance: Y_F, N_F,
(3) Hinge moments: elevator, aileron, rudder, lower and upper dive brake.
(4) For missile runs: forces and moments on the missiles.
(5) Pressure data from 9 orifices.

III. Supersonic Wind Tunnel 8'8" x 12' with liner

Purposes of this test are exactly the same as subsonic test (II) and so the same measurements are to be repeated at M = 1.2 (the only Mach Number for which a liner is available).

APPENDIX C

C-105 ROCKET MODEL TEST PROGRAMME

Purpose: (1) To obtain data, throughout transonic and supersonic range, leading to the evaluation of static and dynamic longitudinal stability and control. Data pertaining to control operating forces and control effectiveness will be particularly valuable in view of the very high Reynold's Number of the test ($\simeq 36 \times 10^6$)

(2) To investigate the drag increase due to control deflection.

Model: (1) Three 1/8 scale models equipped with square wave operated elevator. Two of these are required for tests at two different c.g. positions. The third one will be built as a stand by in case of failure of one of the other models.

(2) Several 1/8 scale models equipped with a pre-set elevator. These will carry much less electronic equipment and will be built only if a cheap method of manufacture (such as large unit casting) is developed.

Test: The model will be accelerated to required top Mach number by a booster rocket. Then a sustainer rocket built into the model will take over and ascertain a positive separation. The data will be obtained from transient records of model motion in response to square wave push-downs and pull-ups of the elevators. Mach Number range: .7 to 2.5

Instrumentation: (a) Longitudinal stability and control models

(1) Telemetering on eleven channels supplying following data:
- longitudinal acceleration
- transverse acceleration
- normal acceleration
- elevator hinge moment
- aileron hinge moment
- elevator position
- aileron position
- angle of attack
- total pressure
- reference static pressure
- pitch angle with reference to a fixed datum

(2) High speed photography from the ground

(3) Radiosonde

(b) Drag Models

(1) Telemetering on six channels
- longitudinal acceleration
- transverse acceleration
- normal acceleration
- angle of attack
- total pressure
- reference static pressure

(2) Photography

(3) Radiosonde

Results: From the recorded data following aerodynamic information, covering the entire Mach range, will be derived:

(1) Aerodynamic centre

(2) C_{L_α}

(3) C_{L_δ}

(4) Elevator incremental centre of pressure

(5) C_{M_α}

(6) $C_{h_{\delta_e}}$ } Elevator

(7) $C_{h_{\alpha_e}}$ }

(8) $C_{h_{\alpha_a}}$ Aileron

(9) $C_{M_{\dot{\alpha}}} + C_{M_q}$

(10) C_D

(11) Buffet boundary

APPENDIX D

PROPOSED PROGRAM OF C 105

WIND TUNNEL TESTING AT N.A.E.

1. Low Speed Tunnel

Purpose: (1) To determine the basic longitudinal stability and control characteristics at low speed.

(2) To determine the lateral and directional characteristics and control effectiveness at low speeds.

(3) To determine the ground effect by the use of a ground board.

(4) To study the jettisoning of missiles and external tanks.

(5) To study the streaming of the tail parachute.

Tests:

Elevator deflection	+10, 0, -5, -10, -20, -25, -30
Aileron deflection	10, 5, 0, -5, -10, -15, -20
Rudder deflection	10, 5, 0, -5, -10, -20, -25, -30

Longitudinal tests to be done with and without a ground board with landing gear extended.
With the ground board in place, the streaming of the tail parachute will be studied with reference to the oscillations that may develop.

2. High Speed (16" x 30")

Purpose: (1) To determine the basic longitudinal stability, elevator and aileron effectiveness at transonic and supersonic speeds.

Tests:

Elevator deflection	+10, +5, 0, -5, -10, -20, -25, -30
Aileron deflection	20, 15, 10, 5, 0, -5, -10, -15, -20
Mach range	Subsonic to 2.0

Instrumentation:
Main balance to give L, D, M, $\mathcal{L}$,
Elevator and aileron hinge moments

3. High Speed (10" x 10")

Purpose: (1) To determine the efficiency of the intake by direct measurement and Schlieren photography.

Tests: Pressure recovery
Schlieren photography
Tests to be done with various ramp angles at all supersonic Mach numbers up to 2.0 for which throats are available.

Instrumentation:
Pitot and static rakes in the duct.

4. Spinning Tunnel

Purpose: (1) To check the spin recovery characteristics under various loading conditions.

Tests: Routine spinning tests to be carried out at conditions corresponding to various fuel loads. The effect of rudder, elevators, and aileron on the spin recovery to be noted.

Instrumentation:

Photographic record of spins.

APPENDIX E

Comparison of running time required to complete an identical programme in N.A.E. and Cornell.

Proposed programme for C-105 for Cornell Transonic Wind Tunnel is taken as the basis for comparison as it is possible to run such a programme at both facilities.

From Appendix B, I (a) and (b)

Total number of runs required	581
Average number of points per run	10
Cornell output based on past tests in transonic wind tunnel	3 runs/hr.
N.A.E. output [Quarterly Bulletin 1952 (4)]	4 points/hr.
Utilization time assumed	
Cornell 3 seven hour shifts	21 hrs./day
N.A.E. 2 seven hour shifts	14 hrs./day

Based on these data estimated required running time for this programme is -

Cornell	9.2 days
N.A.E.	4.8 months (104 days)

4. Spinning Tunnel

Purpose: (1) To check the spin recovery characteristics under various loading conditions.

Tests: Routine spinning tests to be carried out at conditions corresponding to various fuel loads. The effect of rudder, elevators, and aileron on the spin recovery to be noted.

Instrumentation:
Photographic record of spins.