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NOTES ON AERODYNAMIC AND CONTROL PROBLEMS IN THE DESIGN OF AVRO ARROW

NEGATIVE CAMBER

Negative camber very efficiently eliminates trim drag for the design conditions but, however, produces undesirably large positive (nose down) trim angles at high E.A.S. in low altitude supersonic flight, as shown by flight test.

This trend was not unexpected since free flight model tests have shown rather large positive C_{m_0} at low altitudes which did not check very well with tunnel results at low Reynolds numbers.

NOTCHES

Notches are quite effective in relocating the pitch up tendencies at transonic Mach numbers into regions of high lift coefficients.

LEADING EDGE DROOP AND EXTENSIONS

The most significant effect of both of these modifications is that flow over the top of the wing is improved in such a way that fin effectiveness is significantly higher.

HINGE MOMENTS

The hinge moments measured in flight on the elevator were generally lower than estimates.

DIRECTIONAL STABILITY

Flight with very low directional stability (practically neutral) is quite feasible as an emergency procedure, even in approach conditions without artificial stabilization in regions where roll angle to sideslip angle ratio does not exceed approximately 5 - 6. Above that value control difficulties are encountered. Artificial stabilization system based on accelerometers can be designed and produce very good and reliable results in flight regions where φ/β ratio does not exceed approximately 15 to 20. Above that value rudder power requirements become excessive and only extremely high response system is able to cope with it to pilot's satisfaction.

LONGITUDINAL DYNAMIC STABILITY

Results on pitch damping obtained from free flight models were quite reliable, but somewhat conservative as compared with full size aircraft. The configuration showed good damping throughout the flight range with usual low, but not critical, reduction in the transonic range. Phugoid oscillations were of no practical significance.

PROBLEMS IN DAMPING SYSTEM DESIGN

A high performance system utilizing either gyros or accelerometers is very sensitive to interference from vibration modes of the airframe. Location of sensors in relation to nodal lines of the various modes is critical and an analogue computer was found to be extremely useful in finding the correct locations for the sensors, using information provided by flutter groups. In some cases where high gains were utilized relocation was not successful in curing the problem and electrical filtering (notch type filters tuned to one particular frequency) were used.

In a yaw augmentation system utilizing an accelerometer, it is important to locate the accelerometer at a point which is the percussion centre for the rudder. If location is not exact, oscillations will result, e.g. in the case of the Arrow, these were approximately 1 cycle per second; this was easily cured by relocation to a point determined experimentally.

The following paragraphs give references to Avro reports on subjects related to aerodynamics.

1. Aerodynamics

The following reports describe aerodynamic aspects of supersonic design:

P/Aero Data/99	Rigid Lateral Derivatives
P/Aero Data/98	Rigid Longitudinal Derivatives
P/Aero Data/97	Elastic Lateral Derivatives
P/Aero Data/96	Elastic Longitudinal Derivatives
P/Aero Data/95	Elastic Factors on Lateral Derivatives
P/Aero Data/85	Summary of Gust Data and its Application to Design Problems.
P/Aero Data/79	Comparison of C-105 with Requirements of Spec. MIL-8785 (ASG).
P/Aero Data/75	Variation of Longitudinal Derivatives with α at Low Speed.
71/Aero Data/1	Effects of Canopy, Missiles, Bleeds etc. on Stability Derivatives.

1. <u>Aerodynamics</u> (Continued)

71/Stability/53	Duty Cycles and Fatigue Life of Aileron Jacks
71/Stability/42	Control Duty Cycles
71/Stability/40	Determination of Flow Around the Fuselage using Associated Legendre Functions of the 2nd Kind.
71/Stability/35	Trim Angles, All Weights and C.G. Positions
71/Stability/29	A Method for Flight Measurements of Control Surface Duty Cycles.
71/Stability/27	Longitudinal Stability of the Elastic Aircraft
71/Stability/15	Arrow Lateral Dynamic Stability
P/Stability/132	Dynamic Equations Relative to Body Axes.
P/Stability/120	Estimated Pressure Lags, Time Lags in the Air Pressure Data System.
P/Stability/116	Estimated Position Errors of Air Data Nose-Boom
P/Stability/108	Phugoid Characteristics
P/Stability/104	Lateral Dynamic Stability at Approach Conditions
P/Stability/102	Lateral Dynamic Stability in 2 'g' Flight
P/Stability/100	Lateral Dynamic Stability in 4 'g' Flight.

2. <u>Wind Tunnel</u>

Wind tunnel tests carried out on the Avro Arrow are described in report no. P/W. Tunn/131 "Summary of Wind Tunnel Testing of the CF-105". This includes:

1. Tests at Cornell Aeronautical Labs. in a 3' x 4' transonic tunnel at Mach No.'s from .5 to 1.23 of several variants of the basic configuration and series of tests of armament.

2. Tests at N.A.C.A., Langley, in 4' x 4' supersonic tunnel - M = 1.41, 1.6, 1.8 and 2.0.

3. Tests at N.A.E. in low speed tunnel including ground effects.

4. Intake tests at N.A.C.A. Lewis Laboratory.

2. Wind Tunnel (Continued)

Plots of basic data are available in reports referenced in P/W. Tunn/131, issued by C.A.L. and in the following Avro reports:-

P/W. Tunn/111 to 114)
P/W. Tunn/122 to 125) - N.A.C.A., Langley, Tests
P/W. Tunn/158 to 163)

P/W. Tunn/88 to 99)
P/W. Tunn/115 to 120) - N.A.E. Low Speed Tests
P/W. Tunn/170 to 174)

P/W. Tunn/137 to 139 - Jettison Tests, Armament and Tanks

3. Free Flight Models

Information is available on design of free flight models for supersonic speeds, instrumentation and range requirements, launcher design, data analysis and reduction techniques.

Validity of dynamic data has been partially verified by full scale tests at supersonic speeds on Arrow aircraft. The method is suitable for obtaining drag data, checking of static longitudinal derivatives, measurement of damping in pitch, directional stability, rotary lateral derivatives and cross-coupling effects.

The following Avro reports describe in general the techniques utilized and contain references to approximately 50 detail reports on various aspects of the free flight model program:-

P/F.F. Model/47	Summary of Free Flight Model Tests and Results
P/F.F. Model/57	Free Flight Stability Model Results
P/Stability/135	Time Vector Analysis of Free Flight Model Lateral Results.
P/Stability/140	Time Vector Analysis of Free Flight Model Longitudinal Results.

4. Digital Programmes

Digital programmes are available for automatic data handling, e.g. calculate aircraft derivatives from flight recorded parameters in a manner avoiding any by-hand data reduction. In practice, it was difficult to achieve a fully working system on this basis, due to instrumentation problems. However, digital programs listed below were utilized extensively with good results and time saving. Two methods were generally used:

(1) If sufficient number of flight recorded parameters was successfully recorded in flight during a manoeuvre, the parameters were digitized by hand in intervals of 1/20 of a second and fed into the program which calculated derivatives automatically.

(2) If the number of parameters recorded was not sufficient to use Method (1), a modified digital programme was used into which estimated derivatives and measured initial conditions were fed, producing response curves. By trial and error method applied to the derivatives, it was generally possible to reproduce the manoeuvre on the computer and thus assess the differences between estimates and flight data. Since this method does not produce an explicit answer, and a bit of guesswork is involved, it was necessary to analyze more flight conditions in order to obtain reliable answers.

71/Stability/31	Digital Computation Method of Analysis of Lateral Motion with Moving Lateral Controls.
71/Stability/37	Digital Computation Response Prediction in Seven Degrees of Freedom.
71/Stability/17	Digital Computation and Analysis of Arrow Longitudinal Response in Emergency Mode.
71/Stability/16	Digital Computation and Analysis of Arrow Leteral Response in Emergency Mode.

5. Analogue Computer

The most useful contribution of the analogue was its ability to simulate exactly not only aerodynamics and dynamics of the airframe, but also of components of the mechanical and automatic control circuits. Design of a sophisticated automatic system is virtually impossible without a large installation. The simulator was found to be extremely useful in trouble-shooting during flight tests since it was able to work with full size mechanical and electrical hardware by connecting it to the aircraft. Predictions of flying qualities were in reasonable agreement with flight test but somewhat conservative.

5. Analogue Computer

Simulation of detail problems was usually quite accurate and always led to a practical solution.

An accurate representation of aerodynamics with practically all non-linearities was found to be extremely useful, in spite of the complexity and time taken to design the simulator.

Evaluation of stability derivatives by comparison of flight recorded traces with analogue traces and application of trial and error procedures was found to be impractical mostly due to complex representation of aerodynamic quantities. Digital methods were used instead.

The following reports describe details of simulator and damping system design.

70/Stability/14	General Information on the Arrow Flight Simulator
P/Stability/139	Stability Augmentation in the C-105
P/Stability/137	Damping System Development
71/Simul/9	Lateral Dynamic Stability of the Flight Simulator
71/Simul/10	Longitudinal Dynamic Stability of the Flight Simulator.

6. Flight Test

Flight test experiences are related in the following reports.

71/FAR/27	Summary of Preliminary Analysis of Flight 1 to 9 - 25201.
71/FAR/43	Preliminary Stability and Damper Analysis of First Seven Flight - 25202.
71/FAR/44	Technical Design Report on Flight Test - August.
71/FAR/45	Preliminary Stability and Damper Analysis Flights 8 - 15 - 25202.
71/FAR/50	Technical Design Report on Flight Test - September
71/FAR/55	Quantitative Analysis of Flights 1 to 22 - 25202
71/FAR/57	Technical Design Report of Flight Test on Arrow No. 3
71/FAR/61	Stability and Control Report on Flights 12 to 23 - Arrow 25201.