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TITLE: NACA 0015 Data [Nominally Two-Dimensional]

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ADP010704 thru ADP010735

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**22E(2) NACA 0015 DATA (NOMINALLY TWO-DIMENSIONAL)**

**INTRODUCTION**

The tests described were carried out in the University of Glasgow's 'Hardley Page' wind tunnel, which is a closed-return, low-speed type with a 2.13m x 1.61m octagonal working section. The model span was 1.61m, and its construction was of a fibre glass skin filled with an epoxy foam bonded to an aluminium spar. The model was pitched about the quarter chord by a linear hydraulic actuator and crank mechanism. The actuator was a Unidyne 907/1 type with a dynamic thrust of 6.1kN controlled by a MOOG 76 series 450 servo valve. Thirty Kulite 093-5 PSI O ultra-miniature pressure transducers were installed below the skin in a removable pod at the centre-span of the model. The transducers were of the vented gauge type with one side open, via tubes, to ambient pressure outside the tunnel. Each transducer was fitted with a temperature compensation module to minimize changes in the zero-offset and sensitivity. Model incidence was determined using an angular potentiometer geared to the model's main spar. This provided feedback to the hydraulic actuator control system and the angle of incidence signal for the data recording system. The model incidence waveform was provided by a PC fitted with an ANALOGUE DEVICES RT 1815 input/output board. The dynamic pressure in the working section was determined by measuring the difference between the static pressure in the working section, just upstream of the model leading edge, and the static pressure in the settling chamber. These pressure tappings were connected to a Furness FC012 micromanometer which provided an analogue signal for the data acquisition module.

Two NACA 0015 models were tested, namely a "full" chord, low aspect ratio model, and a "short" chord, high aspect ratio model. The former, of 0.55m chord was tested as part of the research programme at the time to investigate the dynamic stall over a family of aerofoil profile shapes. The latter model, of 0.275m chord was tested with a view to an investigation of the dynamic stall vortex convection speed anomaly (reference 2, 4 and 10). Each model was instrumented with 30 pressure transducers placed symmetrically over the upper and lower surfaces at the mid-span of the model. Four motion types were considered, namely static, ramp-up, ramp-down and oscillatory (sinusoidal). The models were both rotated about the quarter chord point. In static tests each model was positioned at an incidence of -10° and pitched to 30° and back down to -10° in 1° increments allowing a settling time for each new incidence. For the ramp-tests the models were pitched over a preset arc at a constant pitch rate. At low pitch rates excellent ramp-profiles were obtained, but at higher pitch rates acceleration and deceleration of the model produced non-linearities. For ramp tests each test case was performed 5 times, and the data were phase averaged to produce the results presented here. For the sinusoidal tests 10 cycles of motion were recorded, and again the data were phase averaged.

**FORMULARY**

1 General Description of model

<table>
<thead>
<tr>
<th>1.1 Designation</th>
<th>Full Chord</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short Chord</td>
<td>Model 12</td>
</tr>
<tr>
<td>1.2 Type</td>
<td>Nominally two-dimensional</td>
<td></td>
</tr>
<tr>
<td>1.3 Derivation</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>1.4 Additional remarks</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>1.5 References</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

2 Model Geometry

<table>
<thead>
<tr>
<th>2.1 Planform</th>
<th>Nominally two-dimensional</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 Aspect ratio</td>
<td>Full Chord</td>
</tr>
<tr>
<td></td>
<td>Short Chord</td>
</tr>
<tr>
<td>2.3 Leading edge sweep</td>
<td>None</td>
</tr>
<tr>
<td>2.4 Trailing edge sweep</td>
<td>None</td>
</tr>
<tr>
<td>2.5 Taper ratio</td>
<td>No Taper</td>
</tr>
<tr>
<td>2.6 Twist</td>
<td>No Twist</td>
</tr>
<tr>
<td>2.7 Wing centreline chord</td>
<td>Full Chord</td>
</tr>
<tr>
<td></td>
<td>Short Chord</td>
</tr>
<tr>
<td>2.8 Semi-span of model</td>
<td>0.805m</td>
</tr>
<tr>
<td>2.9 Area of planform</td>
<td>Full Chord</td>
</tr>
<tr>
<td></td>
<td>Short Chord</td>
</tr>
</tbody>
</table>
2.10 Location of reference sections and definition of profiles
NACA 0015 profile nominal ± 0.05mm accuracy

2.11 Lofting procedure between reference sections
Constant section

2.12 Form of wing-body junction
None

2.13 Form of wing tip
Not applicable

2.14 Control surface details
None

2.15 Additional remarks
None

2.16 References
9

3 Wind Tunnel
3.1 Designation
University of Glasgow 'Handley-Page'

3.2 Type of tunnel
Closed section, closed return, atmospheric

3.3 Test section dimensions
2.13m (width) x 1.61m (height) x (length)

3.4 Type of roof and floor
Closed - vented at downstream end of working section

3.5 Type of side walls
Closed - vented at downstream end of working section

3.6 Ventilation geometry
60 rectangular slots (0.028m x 0.055m) on floor, roof and walls downstream of working section. 13 rectangular slots (0.028m x 0.105m) at same section on angled surfaces.

3.7 Thickness of side wall boundary layer
Unknown

3.8 Thickness of boundary layers at roof and floor
Unknown

3.9 Method of measuring velocity
Working section and settling chamber static pressure tappings related to wind tunnel speed calibration

3.10 Flow angularity
Not available

3.11 Uniformity of velocity over test section
Dynamic pressure constant to within 1% over a 1.5m² reference plane normal to the flow axis in the working section

3.12 Sources and levels of noise or turbulence in empty tunnel
Not available

3.13 Tunnel resonances
Not available

3.14 Additional remarks
None

3.15 References on tunnel
8

4 Model motion
4.1 General description
Four motion types: Static, Linear Ramp Up, Linear Ramp Down and Sinusoidal. All incidence variations about quarter chord.

4.2 Natural frequencies and normal modes of model and support system
Not available

5 Test Conditions
5.1 Model planform area/tunnel area
Full Chord 0.258
Short Chord 0.129

5.2 Model span/tunnel height
0.756

5.3 Blockage
Full Chord Function of angle of attack 3.9% - 16.6%
Short Chord Function of angle of attack 1.9% - 8.4%

5.4 Position of model in tunnel
Vertical on tunnel centre-line. Mounted through floor. (see Fig. 3)

5.5 Range of velocities
45 m/s to 55 m/s

5.6 Range of tunnel total pressure
Approximately 102.5kPa to 103kPa

5.7 Range of tunnel total temperature
Approximately 293K to 306K

5.8 Range of model steady or mean incidence
-5° to 42°

5.9 Definition of model incidence
Deviation of chord line from tunnel centreline

5.10 Position of transition, if free
Not available
5.11 Position and type of trip, if transition fixed

- Full Chord
- Short Chord

When applied, grit layer from leading edge to 2% chord on upper and lower surfaces.

5.12 Flow instabilities during tests

Not available

5.13 Changes to mean shape of model due to steady aerodynamic load

Not available

5.14 Additional remarks

None

5.15 References describing tests

9

6 Measurements and Observations

6.1 Steady pressures for the mean conditions

Yes

6.2 Steady pressures for small changes from the mean conditions

No

6.3 Quasi-steady pressures

No

6.4 Unsteady pressures

Yes

6.5 Steady section forces for the mean conditions by integration of pressures

Yes

6.6 Steady section forces for small changes from the mean conditions by integration

No

6.7 Quasi-steady section forces by integration

No

6.8 Unsteady section forces by integration

Yes

6.9 Measurement of actual motion at points of model

No

6.10 Observation or measurement of boundary layer properties

No

6.11 Visualisation of surface flow

No

6.12 Visualisation of shock wave movements

No

6.13 Additional remarks

None

7 Instrumentation

7.1 Steady pressure

7.1.1 Position of orifices spanwise and chordwise

Chordwise only. See Table 6.

7.1.2 Type of measuring system

- Full Chord
  - 30 Individual Kulite sensors mounted close to wing surface connected to DEC MINC parallel channel data acquisition system.
- Short Chord
  - 30 Individual Kulite sensors mounted close to wing surface connected to Bakker Electronics BE256 parallel channel data acquisition system.

7.2 Unsteady pressure

7.2.1 Position of orifices spanwise and chordwise

Chordwise only. See Table 6.

7.2.2 Diameter of orifices

1.0mm

7.2.3 Type of measuring system

- Full Chord
  - 30 individual Kulite sensors mounted close to wing surface connected to DEC MINC parallel channel data acquisition system.
- Short Chord
  - Individual Kulite sensors mounted close to wing surface connected to Bakker Electronics BE256 parallel channel data acquisition system.

7.2.4 Type of transducers

Kulite CJQH-187 differential

7.2.5 Principle and accuracy of calibration

Steady state sensitivity from applied reference and calibration procedures. Accuracy as stated by manufacturer.

7.3 Model motion

7.3.1 Method of measuring motion reference co-ordinate

Quarter chord location specified by manufacture
7.3.2 Method of determining spatial mode of motion Feedback from potentiometer geared to shaft.

7.3.3 Accuracy of measured motion 0.1°

7.4 Processing of unsteady measurements

7.4.1 Method of acquiring and processing measurements

Full Chord 30 individual Kulite sensors mounted close to wing surface connected to parallel channel DBC, MINC sample and hold modules. Signal conditioning modules on each individual channel. Gain and offset removal manual. Acquired data downloaded to PC.

Short Chord 30 individual Kulite sensors mounted close to wing surface connected to parallel channel Bakker Electronics BE256 sample and hold modules. Signal conditioning modules on each individual channel. Gain and offset removal manual. Acquired data downloaded to PC.

7.4.2 Type of analysis Phase averaging of cycles. Five cycles for ramp function tests, ten cycles for oscillatory function tests.

7.4.3 Unsteady pressure quantities obtained and accuracies achieved Basic unsteady pressure signal. Cycle repeatability variable depending on amplitude and reduced pitch rate.

7.4.4 Method of integration to obtain forces Trapezoidal rule

7.5 Additional remarks None

7.6 References on techniques None

8 Data presentation

8.1 Test cases for which data could be made available Full Chord Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. Tests cover a range of reduced pitch rate, mean incidence and amplitude and reduced frequency. In total 479 test cases. All incidence variations about quarter chord.

Short Chord Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. Tests cover a range of reduced pitch rate, mean incidence and amplitude and reduced frequency. In addition ramp and oscillatory tests with leading edge sand strip. In total 240 test cases. All incidence variations about quarter chord.

8.2 Test cases for which data are included in this document Full Chord Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. 10 test cases as detailed in Table 7. A series of plots are also presented which are illustrative of the data supplied in electronic form. Figure 5 shows a sample upper surface pressure distributions, \( C_j \), \( C_m \) and incidence histories for a ramp-up case.

Short Chord Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. 16 test cases as detailed in Table 8. A series of plots are also presented which are illustrative of the data supplied in electronic form. Figure 6 shows a sample upper surface pressure distributions, \( C_n \), \( C_m \) and incidence history for a ramp-up case.

8.3 Steady pressures For static case

8.4 Quasi-steady or steady perturbation pressures No

8.5 Unsteady pressures For all dynamic cases

8.6 Steady forces or moments For static case

8.7 Quasi-steady or unsteady perturbation forces No
8.8 Unsteady forces and moments
For all dynamic cases

8.9 Other forms in which data could be made available
None

8.10 Reference giving other representations of data
N/A

9 Comments on data

9.1 Accuracy

9.1.1 Mach number ±0.5%

9.1.2 Steady incidence ±0.1°

9.1.3 Reduced frequency ±0.5%

9.1.4 Steady pressure coefficients ±0.5%

9.1.5 Steady pressure derivatives Not estimated

9.1.6 Unsteady pressure coefficients ±0.5%

9.2 Sensitivity to small changes of parameter N/A

9.3 Non-linearities N/A

9.4 Influence of tunnel total pressure Not examined

9.5 Effects on data of uncertainty, or variation, in mode of model motion N/A

9.6 Wall interference corrections None

9.7 Other relevant tests on same model None

9.8 Relevant tests on other models of nominally the same shapes None

9.9 Any remarks relevant to comparison between experiment and theory None

9.10 Additional remarks
The electronic data supplied with this report comprises two file types. The first type of file contains the transducer co-ordinates. There is only one file of this type, and it is identified by the name naca0015_xducers.dat. The second type contains the test data. The first 128 parameters are the run information data (described in table 5), and the remaining parameters are blocks each comprising the dynamic pressure, pressure coefficients (30 values) and angle of incidence. The number of blocks depends upon the motion type. A MATLAB program to read in the data is listed in appendix B. The pressure transducer locations correspond to the order contained in the file naca0015_xducers.dat, which is the same as in table 6.

9.11 References on discussion of data 2, 5, 4, 10

10 Personal contact for further information

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