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BIRD STRIKE COMMITTEE EUROPE

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STRUCTURES WORKING GROUP

MANUAL FOR THE DESIGN OF BIRD IMPACT RESISTANT STRUCTURES AND TRANSPARENCIES

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The accompanying Paper is a copy of the Introduction to the Various Parts of the Manual for the Design of Bird Impact Resistant Structures and Transparencies. This provides a useful summary of the origins and scope of the material contained therein and describes the intended means of circulation of the manual.

BIRD STRIKE COMMITTEE EUROPE

MANUAL FOR THE DESIGN OF BIRD IMPACT RESISTANT STRUCTURES AND TRANSPARENCIES

1. FOREWORD

The attached document is one of the following Parts of this Manual : -

1. "Manual de resistance des structuresaux impacts d'oiseaux" - Parts I and II
   Published by Avions Marcel Dassault-Breguet Aviation: DTN-6175/81

2. "Bird Strike Design Manual"
   Published by British Aerospace - Aircraft Group: GEN/B44/30210

These Documents were prepared under separate contracts to the French and British Governments with the same aim of satisfying the need of Industry for such information.

The Structures Working Group of the Bird Strike Committee Europe were made aware that this work would also satisfy one of the principal aims of the Group which is

> "to assist national organisations in the production of design guidance material for bird impact resistant structures".

The French and British Governments are in agreement that free access to this design guidance material would be of mutual benefit to manufacturers, Authorities and public alike in promoting the design of bird impact resistant structures.

Thus, it has been agreed that a limited number of the copies of the total Manual would be made available through BSCE to those participating civil airworthiness authorities who have design and manufacturing industries within their control. This would be on the understanding that these Authorities would have the responsibility of bringing the contents of the Manual to their Industry on a free user basis, while keeping the Manual in their charge.

Marcel Dassault-Breguet and British Aerospace will be made aware by RSCE of the recipients of the Manual in order that arrangements can be made for forwarding any extension or update of the Manual as these become available.

At the same time, the co-operation will be sought of the design and manufacturing industry to forward, through the local holders of the Manual, any test or service data which would be of value in updating the Manual.

RSCE had hoped to integrate the separate Parts of the Manual into a common manual, since they are complementary in many respects. However it has not been possible to achieve this aim and it has been decided instead to keep the original French and British texts accompanied by a list of contents giving cross references to both French and British Parts with a view to harmonisation. The latter intention is the purpose of this introductory document.

Finally, the design guidance material contained in the Manual is based on the most comprehensive coverage of international data (particularly French, British and American) which has been made available and is believed to be the best statement of the state of art to date on the subject. It is because of this that RSCE is particularly appreciative of the French and British Governments decision to make this work freely available in the interests of promoting safety of civil aircraft with the most efficient design solutions.

NOTE: The information in these manuals is provided for design guidance purposes: it is not intended that it should be used for certification purposes without the back-up of a confirmatory test programme unless it can be shown that

a) adequate conservatism exists using the manual information, and/or

b) the design is similar to one which has been already proven by test and/or operational experience.

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2. SUMMARY OF CONTENTS OF THE FRENCH AND BRITISH MANUALS GIVING GUIDANCE ON THE DESIGN OF BIRD IMPACT RESISTANT STRUCTURES AND TRANSPARENCIES

2.1 French Manual

Title and reference "Manuel de résistance des structures aux impacts d'oiseaux" AMD-BA DTM-6175/81.

The French manual is organized in five chapters which can be independently developed.

The first four chapters essentially cover technical matters and deal with the bird impact resistance.

The fifth one is a collection of general information about regulations, test facilities, birds and bird impact statistics.

Each chapter contains its own bibliography.

2.1.1. Leading edge resistance

- Determination of the part of the mass of the bird involved in the leading edge impact.
- Formulas giving the limit velocity of penetration (CEAT.RAE).
- Kinetic energy criteria for destruction and for absence of penetration into the leading edge.
- Analysis of results of test conducted in CEAT on corvette type leading edges and aircraft components.
- Instructions for use of this kinetic energy criteria.
- Mathematical tools for this use.

2.1.2. Structural resistance against oblique bird impact

- Methodology for analysis of the test results.
- Elementary theory giving kinetic energy, forces and motion of the bird after the impact.
- Structural resistance :

.Tests analysed : aircraft components - CEAT's plates

.Type of destructions observed

.Laws giving

Energy for piercing skin

Energy for peeling of skin

Energy for destruction of structure by lateral action

Energy for destruction in the plane of webs.

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- Motion of the bird after the impact
- Distribution of the mass of bird – Trajectory – Destructions – Energetic Schedule of the shooting
- Instructions for use of test results

2.1.3 Impact resistance of transparencies

- Compilation of the test results : List of references.
- Modes of structural response
- Analytical investigations
- Experimental investigations (glass panels, acrylics, polycarbonates)

The classification of the items of this chapter is based on the general formula of Poullain Clamagirand type coupling.

Piercing velocity and thickness :

$$e^{b} = M^{a}\,v^{2}\,\cos\alpha^{\lambda}\,.\,\lambda$$

The results are divided in two parts :

a) Those which agree with the general law, even if it is under a degenerated form.

b) Those which do not agree with this law (test results of : Rangas and Pigman, RAE, Mac Naughton and Perfect.)

Design techniques of transparency components including

Material characteristics

Windshield thickness

Edge member design

Effect of panel size and contour

Transparency thickness sizing

2.1.4 Bird impact forces and pressures

- Earliest works of Mac Auley and J. Mitchell
- Review of bird impact loading investigations by Flight Dynamics Laboratory at Wright Patterson Air Force Base.
- Hydrodynamic theory of soft bodies

Initial impact (Hugoniot pressure)

Steady flow

Equation of state of the material

(influence of the porosity)

Boundaries of the theory.

- Experimental results on rigid targets
- Effects of non rigid targets
- Computer code for calculation of pressures in steady flow.

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2.1.5 General Informations

- Regulations (engines excluded)
- Bird impact test facilities at CEAT
- The birds :
  - Classification according to their mass
  - Bird impact statistics and bird strike reporting system (operational data collection)
  - Multi-language list of birdnames
  - Bird strike probability model

2.1.6 Up-dating and extension

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The main areas envisaged for up-dating and extension are :

- The use, in the pneumatic gun tests, of frozen birds recently thawed instead of birds just killed.

- The comparison of test results between wild birds ("Gulls") and domestic birds (Chickens).

- Composite material structures, including leading edges : epoxy resin impregnated glass fibre fabrics or aramid fibre fabrics.

  Test results on monolithic and multilayer shells including Nida.

- Properties of aluminium alloys at great velocity of deformation.

- Shock absorber materials.

- Detailed information given on all French facilities for impact testing.

- Information on computer code available in France and concerning the impact of a soft body (bird) on an elastic target using a finite element analysis giving a chronological dynamic description of the flow and pressures in the bird, and the motion, stresses and deformation of the impacted structure.

2.2 Bird Impact

Title of Document: "Bird strike design manual"

British Aerospace Aircraft group GEN/BAe/30210.

2.2.1 Bird strike statistics

[illegible] based on CAA analyses during 1972 through 19[illegible] [illegible] some USA documentation are reported.

2.2.2 Bird impact loading

This section investigates work which has attempted to quantify loading for a bird impact on a rigid structure. It aims to provide impact forces [illegible] for initial design purposes. A comparison is made of loads produced by various formulae documented for a 1.81 kg bird impacting at normal incidence.

As yet there is a shortage of information for assessment of impact loads on flexible structures which are complicated by coupling on a time base between loading and non-linear structural response. This problem is capable of solution by finite element computer analysis. This has been demonstrated by USA Air Force sponsored programme termed MAGNA which has produced a good correlation between calculated analysis and test results for the F16 canopy. Useful information on bird modelling, bird substitutes and the effect of bird impact orientation is given.

2.2.3 Structural design information

The aim of the chapter is to present information which can be used to assist in the design of structural and transparency components to give improved birdstrike protection. The birdstrike resistance criteria used in the empirical investigations is the maximum impact velocity without structural penetration.

In the airframe structural design section, empirical equations are presented for flat and curved panels as well as for leading edges. The bird impact investigations conducted on these structures are described together with a discussion on the problems which can be encountered in the application of leading edge equations.

The radome and front fuselage structure are reviewed with respect to bird impact resistance.

The transparency design section assesses the basic impact requirements, considers structural response and investigates the impact resistance of specific transparency materials.

Empirical equations for these materials are presented, the limitations of which are highlighted.

The loading equations, presented in chapter 3, are utilized in order to predict centre panel moments thus, knowing the failing stress, the panel thickness can be calculated.

The MAGNA finite element program is reviewed and a discussion on its possible applications is presented.

Further Design Considerations: The purpose of this chapter is to present information that will reduce structural damage resulting from birdstrike. The chapter considers both structure and transparencies. Design features which will increase birdstrike resistance are presented.

Testing Facilities: A general outline of the test methods for simulating an inflight bird impact is given. The smooth bore compressed airgun is the most widely used test method and a detailed description is presented. Other factors such as control of bird orientation, accuracy of velocity measurement are discussed with a view of increasing confidence in test results. Details of the test facilities available in the UK are presented.

Operational Data Collection: The object of this chapter is to highlight the operational information required to develop methods of reducing the strike hazard thereby increasing safety and reducing the cost of ownership of future aircraft developments.

Bibliography: The main reports used in the preparation of this manual have been summarised and are included in this chapter. A list of references gives details of those used in the preparation of the manual and also includes references which, although have not been used, may prove to be of use to those readers who wish to pursue a particular topic.

Further Work

The manual is based on test and experimental evidence accumulated over the past ten to fifteen years. It is essential that the manual is extended and updated at regular intervals as new information becomes available. Also the compendium has shown areas where additional test evidence is required.

Extension and Updating: The main areas for updating are:

- design
- birdstrike statistics
- bibliography

Further test data is required to give increased confidence in the current design methods and to provide a basis for design where none currently exists (see next section). This test data can be acquired from various sources including:

- validation tests on new and current aircraft.
- 'old' test data being made available
- Specific research and development programmes for particular components
- feedback from inservice aircraft, with associated effect of ageing of non-metallic materials.

3. LIST OF CONTENTS WITH CROSS REFERENCES TO BOTH MANUALS

This list roughly follows the general plan of the British manual.

Abbreviations :

F.M. (French manual) = Manuel de résistance des structures aux impacts d'oiseaux.

U.K.M (British manual) = Bird strike design manual.

The purpose of the F.M. and U.K.M is to provide a compendium of birdstrike information which can be used by designers to give improved bird strike protection to aircraft structural components, including transparencies.

No information on engines is included. (For requirements see paragraph 3.2 below).

3.1 The bird strike problem

3.1.1 Background to the bird strike problem

This paragraph recalls past and serious accidents with loss of aircraft and cost of bird strikes.

U.K.M - chapter 1.2 p.7

F.M. Not covered

3.1.2 Reducing the bird strike hazard

List of the various methods currently employed, other than those applicable to aircraft design.

U.K.M - chapter 1.3 p.9 and chapter 8 p.295

F.M. Not covered

Remark

For more details the reader can refer to the working groupsof the BSCE which are : (in alphabetical order) :

W.G "Aerodrome"(Study of scientific experiments to drive birds out of the airfields and Procedures to reduce the bird strike risk).

W.G "Analysis" (Analysis of bird strike reports)

W.G "Bird movement" (Bird concentrations and Maps of migrations)

W.G "Communication and Flight Procedures" (Flight Instructions for pilots to avoid bird strike - Inquiry into applications and efficiency)

W.G "Radar and other sensors" (Migration watching by radar or other means - European collaboration).

(The last working group being "structural testing of airframes").

3.1.3 Bird strike statistics

Only civil aircraft statistics are published.

F.M. Part 5 chapter 3.1 p.5.24 to 5.39

U.K.M. chapter 2 p. 12 to 48

-Statistical references Bibliography

F.M. Part 5 § 3.11 p.5.24

(BSCE Working Paper and STNA/2N Statistics)

U.K.M. chapter 2 p.47-48 and chapter 8 p.282-283 (CAA Technical notes)

-Classification of bird masses

F.M. Part 5 § 3.2 p.5.26

U.K.M. Not covered

-Strikes versus altitude

F.M. Part 5 § 3.13(a) Table 1 p.5.27

U.K.M. chapter 2.3.2 p.33

-Strikes versus flight phase

F.M. Part 5 § 3.13 Table 2 p.5.28, 5.29

U.K.M. Not covered

-Strikes versus bird masses classification

F.M. Part 5 § 3.13(b) Table 3 p.5.30 to 5.33

U.K.M. Not covered

-Impact position on aircraft

F.M. Part 5 § 3.13(c) Table 4 p.5.34 to 5.37

U.K.M. chapter 2.3.2 p.38

-Annual strike rate

F.M. Part 5 § 3.13(d) p.5.37

U.K.M. chapter 2.3.2 p.34

-Bird strike rate each month

U.K.M. chapter 2.3.2 p.34

F.M. Not covered

-Bird species struck each month

U.K.M. chapter 2.3.2 p.35

F.M. Not covered

-Bird strike by aircraft type

U.K.M. chapter 2.3.2 p.36-37

F.M. Not covered

-Accidents and serious damage to light aircraft

U.K.M. chapter 2.3.3 p.38-39

F.M. (The published statistics include light aircraft).

3.1.4 Data collection for bird strike incidents and probability models

F.M. Part 5 chapter 3.1.4 p.5.38
(Information for IBIS : ICAO Bird strike information system)
U.K.M. chapter 7 p.270 - 273

3.1.5 Bird strike probability models

F.M. Part 5 chapter 4 p.5.43 to 5.52
U.K.M. chapter 2.4 p.40 to 46

The probability models explained in the two manuals results from USAF works and may apply to all cases. However the application to civil aircraft structures is difficult because the bird density in space necessary for calculations is not well known.
The F.M. (part 5 chapter 5 § 4.3) gives the laws of distribution of the bird masses, obtained from AFWAL TR 803003, and a method to re-enter into the model with the various statistical results published.

3.1.6 Multi-language list of bird names

F.M. Part 5 chapter 3.2 pages 5.40 to 42.
U.K.M. Not covered

The BSCE multi-language list of bird names contains the bird species involved in bird strikes during the last years, with their mean mass and category.

The list of ICAO is more extensive but the mean weights are not indicated.

For the European reader the Council Directive of 2 April 1979 on the conservation of wild birds, ref 79/409/EEC, gives the list of protected bird species.

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3.2 Regulations

The French manual gives (Part 5 chapter 1 pages 5-3 to 5-10) the text of the bird impact regulations applicable to civil and french military aircraft and a summary of the U.S. requirements concerning the windshield and canopy systems.

These requirements concern only the structural point of view.

The UK Manual gives a summary of the requirements applicable to structure (chapter 4.2 P. 77), to transparencies (chapter 4.4.3.p.140) and, in chapter 5.2 p 194, a general view of the damage tolerance of the aircraft with regard to birdstrike, with consideration to the systems including externally mounted equipment (chapter 5.3.7 p 205).

But the conditions for residual strength of the surrounding structure are more severe than those of the regulations.

Listed below are the references of regulations applicable to civil aircraft.

a) European regulations JAR 25

Structure JAR 25.571 e (1)
JAR 25.631 and ACJ 25.631

Residual strength
ACJ 25.571(a) paragraph 2.7.2 (a) and (b)
ACJ 25.571(b)

Windshields JAR 25.775(b) and (c)

Systems JAR 25.1309 d (1) and ACJ 25.1309

b) FAA regulations (Part 25)

Structure 25.571 e (1)
(Empennage-structure) 25.631 (8 pound bird)

Residual strength : Notes FAA ANW112 : 8040-1-25.571/631 and Memorandum of ANW 110 Letter of December 29,1980.

Windshields 25.775(b) and (c)

Systems 25.1309 d-1

c) For Information : Engines regulations

JAR E C-3-4 paragraph 20 page 12
(in French AIR 001 3-4 paragraph 20 page 13)
FAR Part 33 - 33.77 (a) and (f).

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3.3 Bird impact loading

F.M. Part 4 pages 4-1 to 4-110

U.K.M. chapter 3 pages 49 to 74 and chapter 8 pages 300 to 321.

3.3.1 Bird modelling

U.K.M. Chapter 3.3.1 page 51

F.M. For leading edges Part 1 chapter 3 page 113

For pressure calculations : Part 4 chapter 3.3.4.4.1 p.4.73 - 75

For tests Part 5 chapter 2.2. pages 15 to 17

3.3.2 Forces by elementary evaluation

F.M. Leading edges Part 1 chapter 3 page 13

Oblique impact on structures Part 2 chapter 2.3 p.2-24 to 2-39

Works of M. GA Mac Aulay and J.Mitchell part 4 chapter 2 pages 4-5 to 4-11.

U.K.M. chapter 3.3.2 pages 53 to 57

Three methods of estimating impact loading are presented, corresponding to those of the F.M. (part 1 and 2).

The empirical expression derived by RAE gives approximately the same results as the work of GA Mac Aulay.

3.3.3 Investigations of Air Force Flight Dynamics Laboratory

(Air Force Wright Aeronautical Laboratories) and of the University of Dayton (Ohio) Research Institute.

F.M. Part 4 chapter 3 pages 4-12 to 4-110

U.K.M. chapter 3-4 pages 57 to 74

3.3.3.1 References

F.M. Part 4 chapter 3-1 page 4.12

U.K.M. Chapter 3 page 73 and summary chapter 8 p.300 to 321.

3.3.3.2 Description and explanation of the form of pressure recording in bird impact on a rigid target

F.M. Part 4 chapter 3-2 pages 4-13 4-15

U.K.M. Chapter 3.4.1, 3.4.2 pages 58 to 65

3.3.3.3 Hydrodynamic theory of soft body impact

F.M. Part 4 chapter 3.3 pages 4.16 to 4.84

U.K.M. See chapter 8 summary p. 308 - 312.

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The F.M. gives a complete development of this theory :

-Initial impact : the shock (Hugoniot Pressure) and the release waves (p. 4.19 to 4.29)

-Influence of special features : yaw of the projectile - curvature of the projectile at the impact point.

Oblique impact - Elasticity of the target material (p.4.30 to 4.38)

-Steady flow

Subsonic and supersonic flow in normal impact (p.4.39 to 4.47)

Steady flow in oblique impact (p.4.48 to 4.58)

-The termination of impact (p. 4.59)

-The state equations or characteristic equations of the bird including : shock compression p.4.60
isentropic compression p.4.63
porosity effects p.4.65
material properties p.4.73

-Boundaries of the theory p.4.83

3.3.3.4 Experimental results : Impact on rigid targets

F.M. Part 4 chapter 3-4 pages 4.85 to 4.92

U.K.M. see chapter 8 pages 300 - 301

This paragraph applies to experimental investigations on Initial impact pressure - steady flow pressure - Duration of impact - Bird impact force - Time profile.

3.3.3.5 Effect of the target compliance

F.M. Part 4 chapter 3.5 pages 4.93 to 4.106

including locally rigid target pages 4.95 to 4.103
locally flexible target pages 4.103 to 4.106

U.K.M. see chapter 2 paragraph 3.4.4. pages 68 - 71
chapter 8 pages 302-303.

PAGE

3.3.3.6. Computer code to evaluate the pressure distributions in steady flow for the bird impact on a rigid target

F.M. Part 4 chapter 3.6 pages 4.107 to 4.110

U.K.M. Not covered

3.4. Structural design information

3.4.1. Leading edge structures

3.4.1.1. Determination of the part of the mass of the bird involved in the leading edge impact

F.M. Part 1 para.2 pages 1.5 to 1.14

U.K.M. Not covered

3.4.1.2. Resistance of the leading edges

The two manuals cover only conventional metallic structures

- Bird Penetration speed : Emperical formulae

R&E formula : F.M. Part 1 chapter 4.2.1. pages 1.16 to 1.17

U.K.M. chapter 4.3.2. pages 81. to 103

CEAT formula : F.M. Part 1 para.4.2.2. page 1.18

U.K.M. chapter 4.3.2. fig 4.9 page 98

The two manuals give : the limitations for use of these formulae the effects of various design parameters and the effect of differents L.E. skin materials.

- Kinetic energy criteria for destruction and for absence of penetration into the leading edge

U.K.M. Not covered

F.M. Part 1 chapter 4.3 page 1.19 to 1.54

Summary of items of the french manual

a) The two types of L.E. destructions chap.4.3.1 page 1.19 to 1.27

b) Principles for analysis of test results with bird penetration chapter 4.3.2. page 1.28

c) Numerical values of the kinetic energy criteria for L.E. destruction and for absence of penetration
These values result from analysis of French and British tests and can be applied to L.E. with splitter plates
(F.M. page 1.34 - U.K.M. page 202)

d) Instructions for use of these criteria
chapter 4.4 page 1.46 to 1.48

e) Mathematical tools
chapter 4.5 page 1.49 to 1.54

This chapter gives the geometrical means to compute the intersection between the leading edge skin and the cylinder circumscribed to the bird. For the skin, the cases of cylindrical and straight lines generated surfaces are considered.

- Additional information for the design

- wings : U.K.M. chapter 5.3.2. pages 195 - 199
- empennage : U.K.M. chapter 5.3.3. page 199 - 202

F.M. : the structural point of view is included in part I. Considerations for certification of the systems are not covered.

3.4.2. Resistance of metallic structures in oblique bird impact

F.M. part 2 page2.1 to 2.125
U.K.M. chapter 4 page 104 to 135
chapter 5 page 202 to 204

On this subject, the French and British manuals are quite different : while the British manual concentrates on speed of penetration, the French manual considers the overall concept of energy dissipation with progressive speed/energy loss after rupture of the structure skin.

The items of the two manuals are dealt with separately.

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3.4.2.1. U.K. Manual

- Flat panels : chapter 4.3.3. pages 104-117
  speed of penetration pages 105-106
  effect of various design parameters pages 107-111
  comparison with test data pages 112-116
- Curved panels (concave) chapter 4.3.4 pages 117-122
  speed of penetration pages 118-120
  comparison with test data pages 121-122
- Air intakes chapter 4.3.5. pages 123-127 and chapter 5.3.4 pages 202-203
- Front fuselage chapter 4.3.6. pages 128-133
- Canopy roof structure chapter 4.3.7 pages 133-135 and chapter 5.3.5 pages 203-204
- Systems fairing chapter 4.3.8 page 136

3.4.2.2. French Manual (Part 2)

- Introduction chapter 1 pages 2-3
- Method of analysis of impact test results (chapter 2 pages 2-5 to 2-48)

Including :

a) Assumptions (§ 2-1 pages 2.6, 2.7)
   Bird impact test conditions at CEAT - Bird Kinetic energy distribution - The mechanical effects of the impact result from the normal component of the Bird kinetic energy.
b) Utilization of the concept of energy (§2.2 pages 2.8 to 2.23)
   - Evaluation of bird kinetic energy affecting a surface
   - Remaining kinetic energy after absorption of the normal component of the initial kinetic energy
   - Effect of the scale on the test results
c) The concept of forces during the impact (§ 2.3 pages 2.24 to 2.39)
   - Elementary evaluation of the bird impact forces
   - Bird like a fluid. Pressures in a shock on a plane or a spherical surface (convex and concave)
   - Use of this concept of force for deriving energy

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d) Analysis of the bird motion after impact (§ 2.4 pages 2.40, 2.48)

Presentation of problems - CEAT oblique impact test on stiffened panels - The problem of the determination of the remaining masses - Energy schedule.

- Resistance of the structures in oblique impact (chapter 3 pages 2.49 to 2.106)

Laws for deriving energy for

- piercing skins (§ 3.3.1 pages 2.74, 2.101)
  (tests on convex surfaces - concave surfaces (air intakes) test on plates)
- Peeling of skins (§ 3.3.2. pages 2.102, 2.105)
- Destruction of stringers (§ 3.3.3. pages 2.105 and 2.106) by lateral action and by direct impact in the plane of the web

- Bird motion after impact (chapter 4 pages 2.107 to 2.122)
  - Evaluation of the distribution of the bird mass
  - Substantiation of the deviation of the bird path observed after penetration
  - The type of destructions versus the energy schedule
- Instructions for use of the test results for the forecast of structure behaviour in oblique bird impact (chapter 5 pages 2.123 to 2.125)

3.4.3 Transparency design

Transparency design based on testing is comprehensively covered in both U.K.M. and F.M., with the latter making particular use also of the US "Guide Lines for the design of aircraft Windshield/Canopy systems" (AFWAL-TR-80-3003)

The two manuals are fully consistent .

F.M. part 3 pages 3.1 to 3.70

U.K.M. chapter 4.4 pages 139 to 192 and chapter 5.4 pages 207 to 227.

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- [illegible]
  [illegible] chapter [illegible]
  [illegible] 4 [illegible]
- [illegible] requirements
  [illegible] chapter [illegible] pages [illegible]
  [illegible]
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- [illegible]
  [illegible]
  [illegible] pages [illegible] 142
- [illegible]
  [illegible] pages [illegible]
  [illegible] pages [illegible] 170 (application of the theory of [illegible])
- [illegible]
  [illegible] of the [illegible] the two [illegible] is not the same.
- [illegible] transparency materials:

[illegible]	chapter 4.4.6	page	145
[illegible]	" 4.4.7	"	157
[illegible]	" 4.4.8	"	163
[illegible]	4.4.9	"	164

[illegible] the law of [illegible] from the use in [illegible] formula type. [illegible] coefficients of the various materials (glass, acrylics, polycarbonate) are given with the references to experimental works (see chapter 4).

- General expression of the relationship between the limit penetration speed and the thickness of the transparency (chapter 4.1 pages 3.15 to 3.17)
- all parameters are accounted for in the formula (§4.2.1, page 3.17)
- Cases in which the impact angle is not accounted for in the formula (§4.2.2, page 3.20)
- Cases in which the bird mass and the impact angle are not accounted for in the formula (§ 4.2.3 page 3.19)

- Cases in which the results do not agree with the general formula (§ 4.3 page 3.43)
  (Works of Kangas and Pigman -of RAE- and of Mac Naughton and Perfect)
- Goodyear's bird strike tests (polycarbonate or streched acrylics) (§ 4.4 page 3.51)
- Canopy design studies (§ 4.5 page 3.58)
- Equivalent thickness for multi-ply transparencies (§ 4.6 page 3.59)

- Design technique summary

F.M. part 3 chapter 5 page 3.60 to 3.69

U.K.M. chapter 4 § 4.4.12 pages 181 to 188
chapter 5 § 5.4 pages 207 to 223

- Material properties

F.M. part 3 § 5.1 page 3.60

U.K.M. § 4.4.12 page 181 gives configurations showing typical impact resistance

- Windshied thickness : Airframe (or test frame) rigidity and design

F.M. § 5. 2. 1. page 3.61

U.K.M. § 5.4.4. page 210

Edge member attachments and bolt broaching

F.M. § 5.2.2. - 5.2.3. pages 363 to 369

U.K.M. § 5.4.4. pages 210 - 217

- Bird ingression problems

U.K.M. § 5 - 4.5 page 219

F.M. Not covered

- Windshield size and contour

F.M. § 5.3. page 3.69

U.K.M. § 5.4.3. page 208

- Environmental effects on plastic windscreen materials

F.M. Not covered

U.K.M. § 5.4.6. page 223

- transparency thickness sizing

F.M. § 5.4 page 3.70

U.K.M. § 4.5 page 187

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The F.M. recommends the use of the Poullain-Clamagirand formula (U.S. Guidelines AFWAL TR 80-3003 adopt the same position because this formula is conservative.)

The computer code MAGMA, developed at the University of Dayton (Ohio) Research Institute in conjunction with the Flight Dynamics Laboratory, Wright Patterson A.F.B., is intended to give efficient solutions to non linear analysis of complex structures. At the present time, this code is applied to the studies of bird impacts on canopy systems of USAF fighters as a post bird impact test analysis tool. The coupling between bird impact forces and pressures, and the large scale deformations of the target is not yet realised. For this problem of coupling, see paragraph 2.1.6 above (works initiated in France).

3.4.4. Composite material structure (Radome)

U.K.M. chapter 439 pages 136 - 137 and chapter 536 page 204

F.M. Not yet covered but envisaged in the new release of the F.M.

See above § 2.1.6.

3.5. Externally mounted equipment

F.M. Not covered (by contract)

U.K.M. § 5.3.7; page 205 (see also chapter 5.2)

The designer should consider the consequences of a bird impact on undercarriage, lights, pressure probes, antennas, drop tanks, system fairings.

A failure analysis of the concerned system may be necessary.

3.6. Testing and facilities

F.M. part 5 chapter 2 pages 5.11 to 5.17

U.K.M. chapter 6 pages 228 to 269

- The main methods of bird impact testing

Sled testing U.K.M. § 6.3 page 231

F.M. Not covered

Smooth bore compressed air gun UK.M. § 6.4 pages 233 - 251

F.M. part 5 chapter 2 § 2.1 pages 511 - 517

including description of sabot, velocity measurements and (only in U.K. Manual) factors affecting the accuracy of results

- Bird impact test facilities

U.K. Facilities U.K.M. § 6.8 pages 256 - 267

Air compressed gun : BAE : Filton - Hatfield - Weybridge

Rolls Royce : Bristol - Bucknall

- French Facilities : F.M. part 5 § 2.1 pages 511 - 517

Air compressed guns at CEAT.

Remark : it is envisaged to publish in a new release of the F.M. information on the other main french impact test facilities, to wit :

Air compressed guns at CEP (bird ingestion tests on engines)

Air compressed guns at CEA/CESTA

Rocket sled at CEV Cazaux

Rocket sled at CEL Biscarosse (2 tracks)

- Guide for a test validation program

U.K.H. chapter 6 § 5.7 pages 252 - 255

F.H. Not covered.

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