# SUMMARY RECORDS

## 50th Meeting of

## GARTEUR Group of Responsables for

## Structures and Materials

The meeting was held at National Aerospace Laboratory (NLR), Amsterdam on 22-23 April 2004

## Contents

ATTENDANCE LIST

**FRANCE**

| | | |
|---|---|---|
| T. Khan | ONERA, Châtillon | |
| R. Ohayon | CNAM, Paris | |

**GERMANY**

| | | |
|---|---|---|
| H. Schnell | EADS AIRBUS, Bremen | IPoC |
| J. Dee | Airbus UK | IPoC, replacing H. Schnell |
| K. Rohwer | DLR, Braunschweig | |

**ITALY**

| | | |
|---|---|---|
| A. Riccio | CIRA, Capua | |

**THE NETHERLANDS**

| | | |
|---|---|---|
| H. Ottens | NLR, Marknesse- Noordoostpolder | chairman |
| L. Hootsmans | Fokker, Papendrecht | IPoC |

**SPAIN**

| | | |
|---|---|---|
| J. Maroto Sanchez | INTA, Madrid | |

**SWEDEN**

| | | |
|---|---|---|
| S. Nilsson | FOI, Stockholm | |
| H. Ansell | Saab AB, Linköping | IPoC |

**UNITED KINGDOM**

| | | |
|---|---|---|
| P. Curtis | DstL, Salisbury | |

**Secretary**

| | | |
|---|---|---|
| Th.M.C. van der Helm | NLR, Marknesse -Noordoostpolder | |

**Excused**

| | | | |
|---|---|---|---|
| GERMANY | J. Bühlmeier | EADS-M, Ottobrun | IPoC |
| ITALY | A. Minuto | Alenia, Pomigliano d'Arco | IPoC |

**Absent without notice**

| | | | |
|---|---|---|---|
| FRANCE | M. Mahé | AIRBUS France, Toulouse | IPoC |
| UNITED KINGDOM | S. Willocks | BAE Systems Airbus, Filton | IPoC |

# GoR - Structures and Materials,
## 50th Meeting held at NLR, Amsterdam - The Netherlands, on 22/23 April 2004
**23 April 09:00 a.m.**

**AGENDA**

1. Opening remarks and adoption of Agenda

2. Summary Records 49th GoR meeting

3. Action Items

| | | |
|---|---|---|
| 49.1 | H. H. Ottens | Send an invitation to Dr Hentschel for next meeting |
| 49.2 | T. Khan | Send an Email to M. Mahé inquiring whether he wants to stay in the GoR as an IpoC or not |
| 49.3 | F. Roudolff | Ask the GARTEUR secretary if it is possible for the SM-GoR Website to be hosted by the GARTEUR Website |
| 49.4 | All | Study the presentation made by F. Roudolff on “Smart structures and materials” one year ago. |
| 49.5 | F. Roudolff | Send the presented viewgraphs on “Smart structures and materials” to new partners |
| 49.6 | H. Schnell | Report about the internal meeting on nanotubes during the next GoR meeting |
| 49.7 | P. Curtis | Organise a meeting on “Interchangeability” and report to the GoR during the next meeting |
| 49.8 | All | Study the National programs on UAV’s and see if there is any interests |
| 49.9 | P. Curtis, K. Rohwer, T. Khan, R. Ohayon | Send a small report for AG 24, AG 25, AG 27, AG 28, EG 26 and EG 27 with good quality figures before end of November |
| 49.10 | R. Ohayon | Make a presentation on the subject of ‘Morphing wing’ during next meeting |

4. Progress reports and status on current AG's

| | | |
|---|---|---|
| AG 24 | *Bird Strikes* | P. Curtis |
| AG 25 | *Postbuckling and Collapse Analysis* | K. Rohwer |
| AG 27 | *Fractographic Aspects of Fatigue Failure in Complex Composites* | P. Curtis |
| AG 28 | *Impact Damage and Repair of Composite Structures* | K. Rohwer |

5. Progress reports on current EG's

| | | |
|---|---|---|
| EG 27 | *Friction Stir Welding* | T. Khan |
| EG 28 | *Material Properties during curing* | H.G.S.J. Thuis |

6. New activities

| | | |
|---|---|---|
| *AG 29* | *Interchangeability composite materials* | P. Curtis |
| *AG 30 ?* | *Birdstrike* | P. Curtis (M. Willows) |
| *AG 31 ?* | *Results EG 28* | H.G.S.J. Thuis |

## 7. Presentations

- H. Schnell : Nanotubes (action 49.6)
- R. Ohayon : Morphing wing (action 49.10)

## 8. Possible new activities

- Smart materials and structures
- Structural & material requirements for UAV's

## 9. Website

## 10. Any other business

## 11. Date and place of the next meeting

Closure of the meeting on 23 April at 14:30 hours

# Summary Records

## 1. Opening remarks – Adoption of agenda

The Chairman, Harold Ottens, opened the meeting and welcomed the participants, in particular **Jonathan Dee** from Airbus UK who will in future replace H. Schnell (EADS Airbus Germany).

The agenda was adopted without any amendments or changes.

## 2. Summary Records 49th GoR meeting

The Summary Records of the 49th GoR meeting were approved. Harold Ottens expressed his thanks to Florence Roudolff who made good record of the meetings over the past 2-year period.

## 3. Action Items 49.1 up to 49.10

***AI 49.1:***

Harold Ottens contacted Klaus Rohwer regarding the invitation for Dr. Hentschel as possible replacement for mr. Bühlmeier. Klaus Rohwer stated that Dr. Hentschel could not come and will not be able to join the GoR.

AI is closed.

Harold further mentioned that Mr. Buhlmeier could not come and asked whether GARTEUR GoR needs a new IPoC? Klaus Rohwer will try to find this out . **(Action Item 50.1 ⇒ K. Rohwer).**

Harold stated that Hilmar Schnell was IPoC for Germany. Jonathan Dee from Airbus UK will replace Hilmar Schnell.
Klaus Rohwer said that Hilmar Schnell as well as Jonathan Dee are from Airbus (GE and UK).
Hilmar Schnell explained how this situation arose.
Among the 4 Airbus nations the research budget was divided over certain technology areas. For the IPoC of this GoR it was decided that the IPoC will come from the Structures & Materials area, in this case from Airbus UK.
Up till now the GoR members are nominated by the participating countries. The Airbus decision is logical, but not conform the original GARTEUR rules.
Harold will discuss this matter in the next GARTEUR Council meeting. **(Action Item 50.2 ⇒ H. Ottens).**

***AI 49.2:***

M. Mahé from Airbus France did not answer to the invitation for the meeting in Amsterdam. Tasadduq Khan has sent two e-mails to M. Mahé (Airbus Toulouse) but did not get a reply whether he still wants to stay in the Group of Responsables as an IPoC. He will try to contact him again and inform the GoR. **(Action Item 50.3 ⇒T. Khan).**

AI is closed.

***AI 49.3:***

Harold informed the GoR that he received all the web-site documents from Florence Roudolff and that those will have to be added to the central website of GARTEUR. This central GARTEUR web-site will be moved from INTA to NLR. This is not yet done. The website should be available within 1-2 months. **(Action Item 50.4 ⇒ H. Ottens).**
For the time being the SM-GoR Website still has the following address: http://www.onera.fr/garteur/gor-sm/

The user “gor-sm” and the password “r0ud0lff” (with some zero (0) instead of o) must be entered.

AI is closed.

***AI 49.4:***

The topic “Smart structures and materials” will be discussed under agenda item 8.

AI is closed.

***AI 49.5:***

The presented viewgraphs “Smart structures and materials” were sent to the new GoR partners by Florence Roudolff.

AI is closed.

***AI 49.6***

The report on "nanotubes" will be presented by Hilmar Schnell under agenda item 7.
AI is closed.

***AI 49.7***

The report on "interchangeability" will be presented by Paul Curtis under agenda item 6.

AI is closed.

***AI 49.8***

The National programs on UAV's will be discussed under agenda item 8.
AI are closed.

***AI 49.9***

Harold stated that all the information on AG24, AG25, AG27, AG28, EG26 and EG27 was sent by everyone to establish the annual report 2003.
AI is closed.

***AI 49.10***

Roger Ohayon will give a presentation on "Morphing wing" under agenda item 7.
AI is closed.

## 4. Progress reports and status on current AG's

**SM-AG 24** *Bird Strikes*

Paul Curtis presented the conclusions and recommendations on Action Group 24 : Bird Strikes (Michelle Willows). This document was already sent to the GoR members in the mail and also handed out during the meeting. The viewgraphs are presented in **Appendix A-1**.
Harold asked which members are in the International Bird Strike Group? Paul Curtis will find out more about that.
**(Action Item 50.5 ⇒ P. Curtis).**
Klaus Rohwer asked whether impact due to foreign objects or hail could also be included.
Paul Curtis wanted to restrict to bird strike.

As discussed during the last GoR meeting a proposal for a new similar topic for a new Action Group was sent to the members of the SM-GoR by e-mail **Appendix A-2**.
The GoR proposes to first have the final report on Action Group 24 ready. Then start up a new EG29 Birdstrike2 by M. Willows, whereafter the GoR will decide whether to form an Action Group. Roger Oyahon will be the monitoring responsable.

Paul Curtis will inform the existing group and ask M. Willows to chair the EG29 and to derive the Terms of Reference for the new Action Group before the next GoR meeting.
**(Action Item 50.6 ⇒ P. Curtis).**

**SM-AG 25** *Postbuckling and Collapse Analysis*

The Monitoring Responsable, Klaus Rohwer, mentioned that the main work is finished for quite a while. The final report is still pending.
Chairman of this Action Group was Adam Zdunek (FOI), but he left FOI and the Action Group. The Vice chairman, Rien van Houten (NLR) has taken on the duty to write the final report which should now be ready by June 2004. **(Action Item 50.7 ⇒ K. Rohwer).**
Klaus Rohwer stated that, as a follow-on a new EU-program called "Cocomat" is now running.

**SM-AG 27** *Fractographic Aspects of Fatigue Failure in Complex Composites*:

Paul Curtis, the Monitoring Responsable, presented the activities of Action Group 27. The activities are 9 to 12 months behind schedule. Harold Ottens asked whether the activities could be accelerated. Paul Curtis stated that the delay was caused by the poor deliverance of the material. The materials are coming in now!

The relevant viewgraphs are presented in **Appendix B**.

**SM-AG 28** *Impact Damage and Repair of Composite Structures*

The Monitoring Responsable, Klaus Rohwer, reported on the activities of the Action Group. The presentation was co-authored by Florence Roudolff.
A new partner in this project is ESA-ESTEC. Furthermore a report was issued on Literature survey (GARTEUR TP-146). The viewgraphs are presented in **Appendix C.**

The damage that can be repaired is 4 layers deep. Hilmar Schnell thought that damage in 4 layers is too large to apply a cosmetic repair.
The delamination growth is predicted with a Paris-like law. Roger Ohayon stated that the Paris law is applicable for metals, but not necessarily for composites.
Delamination growth prediction based on an energy criterium should be better. Aniello Riccio stated that he did a lot of work on this subject 'static behaviour'. He will give a presentation on delamination growth based on energy criteria at the next GoR meeting. **(Action Item 50.8 ⇒ A. Riccio).**

Roger Ohayon further asked about the speed of the delamination growth. Are there dynamic effects to be expected. Paul Curtis showed a slide on predicting damage growth. It happens that he is discussing this subject with a student and he explains that it is difficult to predict damage growth. This is very challenging for most current researchers. Harold acknowledged that this is still an interesting subject.

## 5. Progress reports on current EG's

**SM-EG 27** *Friction Stir Welding (FSW)*

Tasadduq Khan had pushed this activity over 1,5 years now. The original idea was the thermal mechanical modelling of the FSW process. ONERA would do the modelling and NLR and DLR the experimental validation. However DLR was not really interested and NLR had some difficulties in making their FSW-machine operational.

Also a second topic: corrosion of Friction Stir Welds did not get enough interest.

Hilmar Schnell stated that one is working on FSW at Airbus and that this is a very important project. But apparently it is not an Action Group for GARTEUR?
He showed a slide on the 'organisation of FSW core team' **(see Appendix D).** The core-team leader is Daniela Lohwasser.
Items of interest are e.g.:
1. Center wingbox application
2. Fuselage application
3. Wing application

A 5 FP proposal on FSW has been accepted. Machines are available at Airbus.

Paul Curtis remarked that this work is done on aluminium. Hilmar Schnell answered affirmative on the question of Luc Hootsmans whether this was also done on thin layers , .3 and .4 mm thickness.

Tasadduq Khan asked about the status on FSW work at NLR and Harold answered that the person in charge, Arij de Koning has retired. A special instrumented machinehead is designed and manufactured.

Tasadduq Khan suggested to close this EG. He will give it a month and then report on the next GoR meeting. **(Action Item 50.9⇒ T. Khan).**

**SM-EG 28** *Material Properties during curing*

Harold sent around the Minutes of the Meeting on 'Material properties during curing', which was held in Amsterdam, chaired by Bert Thuis (NLR), on 15 April. Mr. Zarrelli has left CIRA and therefore did not attend the meeting.
Interest was shown by INTA and QinetiQ. Antonio Riccio is not sure whether CIRA can participate in this exploratory project. Klaus Rohwer stated that from DLR side no contribution can be provided.
Tassaduq Khan stated that no work on curing is going on at ONERA.

Hans Ansell mentioned SICOMP and INTA will find out whether Spanish universities are interested.

The GoR agreed that a follow-up meeting is required before they can decide whether to form a new Action Group. **(Action Item 50.10 ⇒ All).**

Hilmar Schnell said that there are a lot of activities on Structural Health Monitoring (SHM) at EADS, but there is no budget (acoustic emission?)

## 6. New Activities

**AG29 Interchangeability composite materials**

Paul Curtis presented the background and objectives on the proposal for "Development of a probabilistic method for rapid interchange of composite materials in the design of composite structures"; as shown in **Appendix E-1.** An outline was given on the Statement of Work and a definition on the various Work Packages. Viewgraphs are presented in **Appendix E-2.**
Paul asked the GoR if there are any others interested in membership because it is a very important program. France and Germany are missing.
Tasadduq Khan mentioned that ONERA will not participate in this Action Group. He said that one is working on a national project in France called "AMERICO". He will ask someone from ONERA to come in and give a report on the AMERICO project (Jean-François Maire) at a next meeting (but not *the* next meeting).
**(Action Item 50.11 ⇒ T. Khan).**
Hans Ansell (SE) mentioned that there is a lack of aircraft manufacturers. He did not succeed in getting people interested at SAAB but will do his best. **(Action Item 50.12 ⇒ H. Ansell).**
Luc Hootsmans (NL) said that Fokker is interested but has to find the budget. At the moment they are contributing to the DIALFAST project.
Klaus Rohwer (GE) stated that DLR is interested but money is the main issue.
Hans Ansell asked about the materials manufacturers? Paul Curtis will check with the materials manufacturers. **(Action Item 50.13 ⇒P. Curtis).** Paul will circulate the final proposal which should be ready by the end of June. Then the activities can start after summer.

Klaus Rohwer confirmed to set up a new Action Group 29. Harold Ottens will inform the Council accordingly. **(Action Item 50.14 ⇒ H. Ottens).**

**AG30 ? Birdstrike Results EG 29**

This topic was already discussed under agenda item 4 (AG24).

**AG31 ? Results EG28**

The Exploratory Group 28 was already discussed under agenda item 5.

## 7. Presentations

- **Nanotubes**

Hilmar Schnell (EADS-Airbus) reported on the Nanotechnology meeting which was organised by Airbus in Hamburg on 25 November. Viewgraphs are shown in **Appendix F.**

Harold asked if there was further need to discuss this topic. Tasadduq Khan said there is no need at the moment.
Klaus Rohwer stated that the next Action Group should be on this specific topic.
Jonathan Dee noted that there is a development on this subject at EADS.
Tasadduq Khan then stated that a lot of work on nanotubes is done at ONERA.
All GoR members should inform each other on a regular basis about the developments on nanotubes.
**(Action Item 50.15 ⇒All).**
In spring 2005 Jonathan Dee will give a presentation on this subject. **(Action Item 50.16 ⇒J. Dee).**

- **Morphing wing**

Roger Ohayon presented the latest news on 'Morphing Wing' . The viewgraphs are presented in **Appendix G-1 and Appendix G-2.**
Tassaduq Khan mentioned that one is setting up a program in the GARTEUR Flight Mechanics Panel. GoR should find

out more on Morphing Wing from the chairman of the Flight Mechanics Panel. **(Action Item 50.17 ⇒ H. Ottens)**
It is also important to deal with structures and materials and not only with aerodynamics.

Apparently the USA and South-Korea show great interest in this project, which runs from 2002-20012?

Paul Curtis mentioned that there is also great interest in Europe. He knows from such activities at:
Imperial College, BAe Systems, Cranfield University (Neil McDougall), IA(E)M and INEGI.

## 8. Possible new activities

- **Smart structures and materials**

Sören Nilsson works already 15 years on Health Monitoring for composite structures; 'shape control actuators'. He will prepare a short presentation on shape control actuators for the next GoR meeting. **(Action Item 50.18 ⇒ S. Nilsson).**

Tasadduq Khan is interested in actuators. He will ask D. Osmont (ONERA) to give a presentation at the next GoR meeting. **(Action Item 50.19 ⇒ T. Khan).**

Harold Ottens and Tasadduq Khan will give a presentation on the work that was done at NLR/ONERA regarding Structural Health Monitoring on composite structures. **(Action Item 50.20 ⇒ H. Ottens/T. Khan).**

- **In-house topics of interest**

Harold then proposed to discuss interesting topics of in-house work as suggested by Paul Curtis.
*Paul Curtis, DSTL (UK )*
* Materials by design (unusual behaviour) : – metallics , - non-metallics
* Bio – inspiral (nature) mechanic materials
* Life extension ageing structures
* Corrosion ext. coatings

*Klaus Rohwer , DLR (GE)*
* Work especially for shape control on improving electric acuators
He stated that he rather waits for some new ideas.

*Aniello Riccio, CIRA ( IT)*
* Damage propagation in space application area's (fibre, metrics, composites)
* Starting activities on thermo mechanical loading
* Structures around the engine?
Airbus interested?

*Harold Ottens, NLR (NL)*
* Modelling, crack initiation
* "Casting"
* Replacement of chromium in paint systems
* Environmental issues

In the field of Aerostructures : development and integration, trailing edge, skin, leading edge.

*Hans Ansell, SAAB (SE)*
* UAV: 3 projects: 1. Autonomic, stealth, UCAV (with Dassault). Focus on cheap assembly of structures. Australian specifications used for design and certification.
* Integrated composite structures
* Damage tolerance of complex integrated metal structures
* Damage tolerance of systems
* Load monitoring of systems
Hans Ansell will prepare a presentation on the various topics for the next GoR meeting in Stockholm, Sweden.
**(Action Item 50.21⇒ H. Ansell).**

*José Maroto Sanchez, INTA (SP)*
* Replacement of chromium

*Hilmar Schnell, Airbus (GE), Jonathan Dee, Airbus (UK)*
* Damage tolerance of Integrated metal structures
* New Al alloy, new developments at manufacturers
* Testing; we do not know what we are testing e.g. effect of testing frequency in salt spray environment
* Hybrid structures

*Luc Hootsmans, Fokker (NL)*
* Thermoplastics
* Glare, especially for leading edges. Good bird impact resistance

*Sören Nilsson, FOI (SE)*
* No subjects. He does not know how long structures will exist in FOI

Harold Ottens asked every country to give an overview of the requirements for UAV's which are used.
**(Action Item 50.22⇒All).**

- **Structures and materials requirements for UAV's**

Hans Ansell has already said that Sweden is using Australian specifications for design and certification of UAV's.

## 9. Website

The status on the website was already discussed under agenda item 3.

## 10. Any Other Business

- **New basic document Council**

Harold Ottens mentioned that there has been a discussion to improve the Council organisation.
The GoR now has the authority to approve Action Groups.
Harold will distribute the final version of the new basic document (including the Letter of Adherence and Letter of Admittance) to the GoR members stating the change.
**(Action Item 50.23 ⇒ H. Ottens).**

- **More IPoC's?**

Hans Ansell asked if we need some more IPoC's? There used to be an IPoC for Dassault, for EADS and one for BaeS Warton.
At this moment the GoR has only 3 IPoC's: Hans Ansell (SAAB), Jonathan Dee (Airbus UK) as a replacement for Hilmar Schnell and Luc Hootsmans (Fokker).
The GoR agreed that more IPoC's are very welcome.

Tasadduq Khan will try to ask Dassault for a new IPoC. **(Action Item 50.24 ⇒ T. Khan).**

Paul Curtis stated that he has contacted Stewart Willocks at Warton but he does not seem to have the time.

- **Update of the Co-ordinates list**

Dr. Bühlmeier can be removed from the list.

## 11. Date and place of the 51st meeting

The 51st GoR meeting will be held on 21/22 October in Stockholm, Sweden.
Jonathan Dee might not be able to join.

The 52nd meeting is planned in Spring and should be hosted by Italy (CIRA) in 2005. The date is set on 21 and 22 April.

## Closure of the meeting at approximately 14.30 hours

**Action Item List**

At this 50th meeting of the GoR SM on 23 April 2004 at NLR, Amsterdam, the following action items were recorded:

| Action Item | Responsibility | Action |
|---|---|---|
| 50.1 | Klaus Rohwer | Find out if a new IPoC can be found in place of Mr. Bühlmeier. |
| 50.2 | Harold Ottens | To discuss the matter of more persons from one company joining the GoR with the Council. Garteur is a collaboration between countries and not between companies. |
| 50.3 | Tasadduq Khan | To send the GoR an e-mail regarding the participation of M. Mahé |
| 50.4 | Harold Ottens | To get the information for the website from INTA to NLR. The website should then be available in 1-2 months. |
| 50.5 | Paul Curtis | To find out more about the members in the international birdstrike group (Europe + US?) |
| 50.6 | Paul Curtis | Will ask Mrs. M. Willows to inform the existing group and have the final report on AG24 ready first. |
| 50.7 | Klaus Rohwer | Rien van Houten will finalise the report on AG25 within 2 weeks. |
| 50.8 | Aniello Riccio | Will give a presentation on delamination growth based on energy criteria at the next GoR meeting. |
| 50.9 | Tasadduq Khan | Before closing down EG27 Friction Stir Welding, get in direct contact with the right person at Airbus via Hilmar Schnell and then report on this in the next GoR meeting. |
| 50.10 | All | Decide whether to form a new AG after a follow-up meeting of EG28. |
| 50.11 | All | AG29 proposal 'Interchangeability composite materials'' will be accepted; all participants to send information before end of May to Paul Curtis and to Harold Ottens. |
| 50.12 | Hans Ansell | Will do his best at SAAB for participation in AG29. |
| 50.13 | Paul Curtis | Check materials manufacturers. He will circulate the final proposal which should be ready by the end of June. |
| 50.14 | Harold Ottens | Inform the Council about the forming of new Action Group 29. |
| 50.15 | All | All GoR members should inform each other on a regular basis about developments on nanotubes. |
| 50.16 | Jonathan Dee | Give a presentation on Nanotubes in Spring 2005. |
| 50.17 | Harold Ottens | To check with Flight Mechanics Panel chairman on 'Morphing wing' program. |
| 50.18 | Sören Nilsson | Prepare a short presentation on shape control actuators for the next GoR meeting. |
| 50.19 | Tasadduq Khan | Ask D. Osmont (Onera) to give a presentation on Smart Structures and Materials at the next meeting. |
| 50.20 | Harold Ottens / Tasaddug Khan | Will give a presentation on what work was done at NLR and ONERA regarding 'Structural Health Monitoring' on composite structures |
| 50.21 | Hans Ansell | Prepare a presentation on the various topics for the next GoR meeting in Stockholm, Sweden. |
| 50.22 | All | To give an overview of the requirements which are used for UAV's. |
| 50.23 | Harold Ottens | Send the final Basic Document to the GoR members (this includes Letter of Adherence, Letter of Admittance which should be sent to Harold Ottens and to Paul Curtis). |
| 50.24 | Tasadduq Khan | Try to contact Dassault for a new IPoC. |

**Appendix A-1**

## Conclusions and recommendations AG24 Birdstrike

**by**

**Paul Curtis**

## 1. Comparison of Achievements Against Original Aims of Research Programme

The original aims of this research programme, as described in the proposal, were three-fold, to:

- undertake a round-robin activity to assess state-of-the-art birdstrike modelling techniques,
- identify ways to produce birdstrike tolerant structures and design, fabricate, test and model such a structure, and
- establish a standard birdstrike modelling methodology that could be used for attaining certification.

The objectives of the round-robin exercises centred around the evaluation of different bird modelling techniques as used by all the partners. Comparisons of impact behaviour and damage sustained were made between the simulation results and the test results as caused by real birds on various structures. These structures were generic e.g. a flat panel or a typical blunt or sharp leading edge, etc. and representative of 'real' aircraft structures that are normally subject to birdstrike. Unfortunately not all partners could undertake all tasks so direct comparisons are limited, however all tasks have been attempted to some extent, by at least one or more partners.In addition,a new birdstrike tolerant structure was designed which incorporated a novel tensor concept that effectively 'catches' the bird. This was fabricated and tested as part of the work programme.
Numerical modelling was performed to develop a representative numerical bird that resulted in comparable damage to that generated in the birdstrike tests by real birds. This has been achieved and a standard numerical bird has been defined, although the exact way in which the bird is best modelled (i.e. the methodology) depends upon the specific bird impact problem being analysed.
To date, verification that certain structures can withstand specified birdstrike events with no or minimal damage being sustained has always been by very costly and time consuming experimental test programmes. The group has shown that substantial monetary and time savings can be made by employing finite element techniques, in particular, to simulate a wide variety of birdstrikes and limiting the number and breadth of experimental tests to those only required to 'prove' the simulation predictions.
Over the duration of the GARTEUR programme investigation into birdstrike modelling research has shown it to be fairly limited as most companies still tend to rely heavily on extensive experimental test programmes to certify their new structural designs. However, companies are now beginning to see the value in modelling the effect of birdstrikes on their new structures early on in the design process, when modifications to their designs are easier and cheaper to implement, and this has lead to fewer experimental tests being performed. Some experimental tests are still required to attain certification, but with growing confidence in birdstrike modelling techniques these are becoming limited in number. Within these forward looking companies experimental testing is becoming viewed as being primarily for the benefit of the Certifying Authorities, certainly by the Civil Aviation Authority, who understandably still require absolute proof that a structure will withstand a specified birdstrike.
The utilisation of a synthetic or dummy bird, which has been shown to exhibit the same behaviour as a 'real' bird when impacted, again would have considerable cost savings, and health and safety benefits. Real birdstrike tests are rarely repeatable or reproducible. Repeat testing using 'real' birds has shown that there is a wide variation in every parameter of impact loading measured. These variations are due to marked differences in bird material properties, structure and geometry, which are not controllable in 'real' birds, but are not a problem with dummy birds. Although this was an objective listed in the original proposal it was not pursued as CSL, BAe SYSTEMS and QinetiQ are currently engaged in a collaborative programme (under the auspices of the International Birdstrike Research Group, IBRG) comparing physical substitute birds with real birds. The collaboration has since grown world-wide and plans are underway to start a test programme on the various substitute materials.

## 2. Partner Collaboration

A considerable amount of time and effort has been expended by all the partners over the years in the field of birdstrike. Collaborative groups have already been set up to examine specific areas such as bird characteristics and habits, and the compilation of databases of birdstrike statistics, etc. Individual

companies and institutes have looked at birdstrike testing and modelling in isolation but it has been driven by the short-term needs of the industry. This GARTEUR group has enhanced European collaboration and has brought researchers together to exchange ideas, problems, and achievements.
The involvement of each partner in the work programme has been tabled below (Table 1).

| | Phase 1 | | | | Phase 2 | | Phase 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Task 1: Rigid Panel | Task 2: Metallic components | Task 3: Trans-prances | Task 4: composite panels | Task 1: sharp & blunt metallic LE's | Task 2: sharp & blunt composite LE's | Task 1: Fabricate novel LE | Task 2: Perform test | Task 3: Simile-ate test |
| QinetiQ | X | X | X | X | X | X | | | X |
| BAe | | X | X | | X | X | | | X |
| CAA * | | | | | | | | | |
| CSL ** | | | | | | | | | |
| DLR | X | X | | X | | X | X | | X |
| EADS | X | X | | X | X | X | | | |
| Imperial College | X | X | | X | X | X | | | |
| ONERA | X | X | X | X | X | X | | | |
| NLR | X | | | X | | X | X | | X |
| Rolls-Royce | X | | | X | X | X | | | |
| SAAB | | | X | | | | | | X |

*CAA will not be undertaking any technical work. They will oversee the project and contribute to the substantiation and certification issues raised.
** The Central Science Laboratory's Birdstrike Avoidance Team (BAT) provides research and consultancy services (e.g. aerodrome related advice to civil airport authorities and airforces throughout the world) on the birdstrike problem. In particular, they routinely review birdstrike records and ornithological data to derive operation birdstrike risk levels for the CAA. They are also often requested to identify the species of bird struck from the remains found on the aircraft, by examination of the whole carcass if possible or by microscopic examination of feather fragments or even DNA analysis of blood smear remains.

Table 1: Partners Technical Involvement in each Task

## 3. Conclusions and Recommendations

### 3. 1 Numerical Bird Parameters

***Mass***
The current bird mass to be used for military aircraft is 1kg. For civil applications the weight varies depending upon the potential impact site (part of aircraft) under consideration for birdstrike assessment and the certifying authority.

***Diameter***
The damage caused in an impact is related to the impacting mass per unit area of contact, consequently the diameter of the Dummy Bird is critical. If the mass is kept constant, varying the density and length of the Dummy Bird will not affect the force per unit area.
When a bird strikes an aircraft, its wings will be outstretched and therefore it is the under-wing diameter that is most relevant. However, during testing, the wings are generally folded and essentially become part of the torso, as the bird is often contained in a bag to maintain its integrity during firing and flight. Thus,

for modelling purposes, the over-wing diameter is more appropriate, as the test results are used to validate the modelling predictions.

***Density***

There are a number of options:

- use the average density of birds with masses similar to the 1kg requirement,
- assume a worst case scenario and use the density of the densest bird with a mass similar to the 1kg requirement,
- use the average density of all birds.

The density of a plucked bird is proportional to its mass, but the relationship should be interpreted with care. It is likely that the density of a bird is dependent on its lifestyle; waterbirds which have large reserves of fat and high buoyancy have low densities while passerines, requiring a lot of muscle for constant flapping flight, have high densities.

The average feathered density across all birds is approximately 0.72g/cm$^3$ and the average plucked density is 0.97 g/cm$^3$. The feathers make up, on average 6.4% of the mass of a bird and have a density of 0.14g/cm$^3$, the majority of which is air, either trapped between individual feathers, or within the feather shafts themselves. Though a "real" bird has feathers, they contribute little to the mass of a bird but have a large influence on its overall density. In effect, one is including a surrounding pocket of air with the bird when measuring its density.

Therefore, if the feathered density were used, the numerical bird would have a reduced density, assuming the diameter is derived from a plucked bird. Whereas, if the plucked density is used, the density is higher but this is conservative and it is considered better to represent the bird torso accurately, because this is what causes the damage.

A plucked density of 0.9343 g/cm$^3$ is to be used.

***Shape***

Bird species show considerable variation in shape and indeed, the shape is generally constrained by the bagging and sabot arrangement used in testing. The three most typical shapes are given in Figure 123 below.

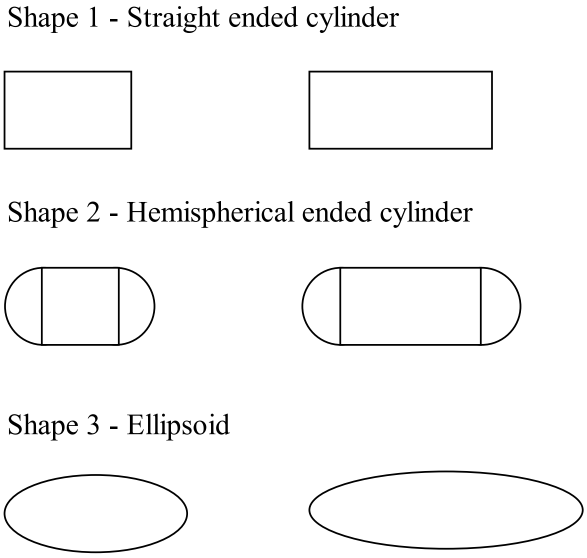


Figure 123: Typical bird shapes

Diagrams of two bird species showing the approximate bird torso shape are given in Figure 124.

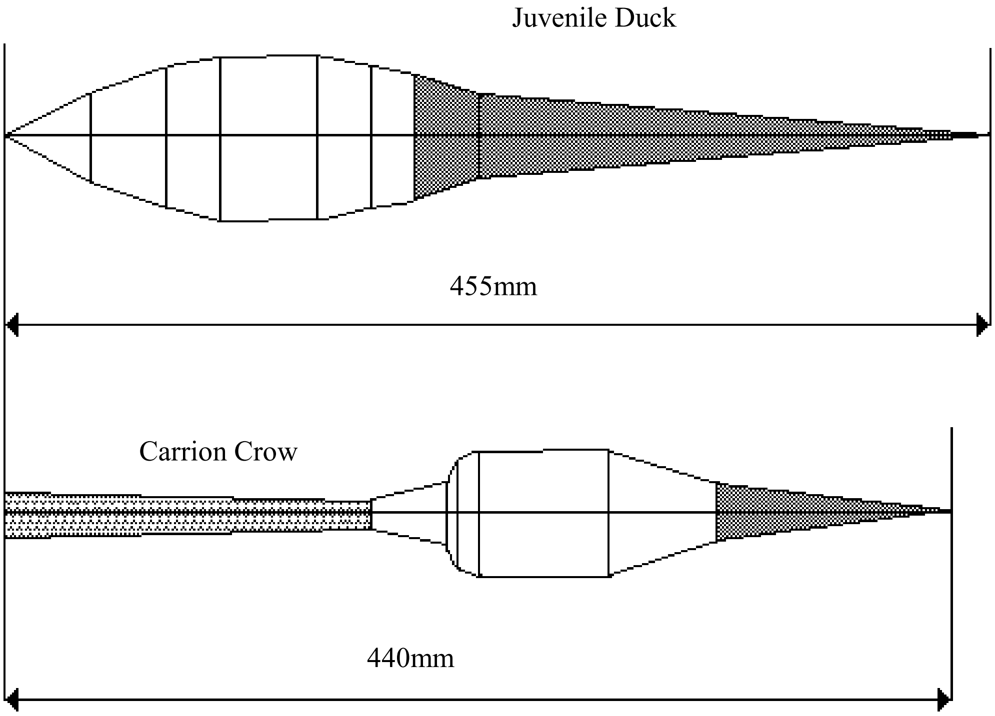


Figure 124: Diagrammatic representation of two bird species to show approximate torso shape, for comparison with Figure 123.

Clearly, the ellipsoid is closest to the shape of the real birds as depicted in Figure 124, but this shape is rather long and too unstable for use in testing with a high mass, low density Dummy Bird.
A detailed survey was performed to find the optimum shape and material composition for a simulated bird model. A shape with two hemispherical ends and a central cylindrical body, as depicted in Figure 125 below, was considered the optimum material and geometrical shape for numerical simulations. (All dimensions are in cm.)

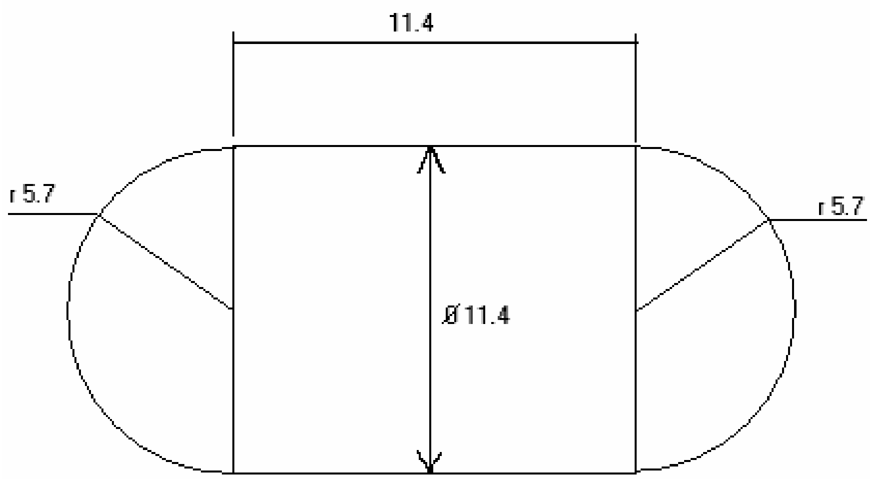


Figure 125: Bird model geometry

The volume of a hemispherical-ended cylinder is given by:

$$v = r^2h + 4/3\ r^3$$

and substituting m / ρ for v:

$$h = (m/\rho r^2) - (4r/3)$$

***Length***

The length is based on the total volume (as derived from the mass and density), diameter and shape. As above, the plucked mass is used.

***Material***

A hydrodynamic material model based on a water and air mixture was considered the optimum material for numerical simulations.
The effects of other physical characteristics of the Dummy Bird, such as toughness, have not been addressed in this study. We have assumed that the toughness of bird tissue is negligible compared to that of a fan blade and variations in toughness will have little effect on impact damage, though this has not been verified experimentally.

### 3.2 Bird Modelling Approach

The bird geometrical model, based on previous work of Wilbeck and Niering, should have the following properties. The model should have a length to breadth ratio of 2 and should consist of a cylindrical type structure with rounded ends. A simple cylinder, when fired end-on, generates the highest pressure on the circumference rather than the centre, which physical tests have shown to be incorrect.
The bird material model should be based on a hydrodynamic EOS formulation with a 90% water and 10% air mixture. A shock EOS should be used for the loading part of the pressure density curve and if available, an adiabatic EOS for the unloading part. The modelling strategies usually assume a homogenous material behaviour, i.e. the water and air are not treated as single materials within the analyses. If further accuracy is required, then it's recommended that an investigation should be performed to determine the importance of the water and air distributions within the bird structure. To accomplish this, the bird could be modelled with different geometrical distributions of air and water in a realistic manner (i.e. should the bird model be mostly air in the centre of the bird, and mostly water in the outside part of the bird?). MRI data from the IBRG could be used to identify actual distributions in real birds.
To overcome problems with severe deformation of the bird during impact in Lagrangian Finite Element codes, techniques based on Eulerian, Arbitrary Lagrangian-Eulerian (ALE) and Smooth Particle Hydrodynamics (SPH) have been developed. The most promising recent development is the use of SPH based birds, which use Lagrangian particles to interact via contact logic to traditional Lagrangian Finite Element models. This technique is now available in most commercial hydrocodes. Such a technique can have a significant advantage over more traditional approaches especially when the bird splits, such as bird impact against a sharp leading edge or fan blade. It also has a major advantage when perforation on the leading edge is important and impact on the front spar needs to be determined.

### 3.3 Target Modelling Approach

The simulation of birdstrike onto woven glass composite panels has shown the importance of using reliable composite failure models, especially when rate sensitivities are important [18]. Results indicate that incorrect modelling could predict either a grossly conservative perforation velocity, or provide misleading failure mechanisms. The use of Johnson-Cook type models for metallic structures appears to yield reasonable accuracy, however, reliable rivet and fracture modelling needs to be confirmed prior to simulation of the structure or component. Similarly, modelling of transparencies requires the use of failure models which can accurately model the physics of the impact problem i.e. fracturing of the material.
The proposed methodology reflects a state-of-the-art technique directed towards the development of a numerical certification route. Such an approach can be used for the large-scale numerical simulation of damage initiation and propagation in both metallic and composite structures and components, subjected to

high velocity impacts. The modelling of birdstrike onto metallic leading edges is relatively straight forward, and good correlation can be achieved with experimental test results. However, more validation is required for modelling birdstrike onto composite leading edges.

### 3.4 Validation

The following steps are necessary to validate any birdstrike modelling capability:

- Validate the bird finite element material and geometrical model by simulating experimental birdstrike tests on a rigid target and comparing the results with high speed film and pressure transducer results.
- Independently validate the material failure model used to simulate the response behaviour of the aircraft component for each damage mode. In metallic components which use an elastic-plastic material stress-strain relationship the proposed mesh density must be validated against experimental tests, if penetration effects are to be investigated using erosion (element deletion) type algorithms. Composite materials require detailed experimental test results to validate each of the failure modes associated with the experimentally observed composite damage.
- Validate the birdstrike modelling capability by reproducing damage observed in a simplified (but representative) structural component subject to impact and comparing the simulations with detailed results obtained from experimental tests.

In addition, to provide a good birdstrike modelling capability, a number of other important parameters need to be addressed, such as finite element mesh sensitivity, correct slide line definitions, and incorporation of material strain rate effects (particularly important when modelling glass based composites). The use of a damage mechanics approach that can be used to model energy dissipation correctly, for the amount of damage produced, is an important parameter in such high-energy impact events.

### 3.5 Conclusions

Over the duration of the GARTEUR group investigation into birdstrike modelling research has shown it to be fairly limited as most companies still tend to rely heavily on extensive experimental test programmes to certify their new structural designs. However, companies are now beginning to see the value in modelling the effect of birdstrikes on their new structures early on in the design process, when modifications to their designs are easier and cheaper to implement, and this has lead to fewer experimental tests being performed. Although at least one experimental test with a real bird is still required to attain certification. Within these forward looking companies experimental testing is becoming viewed as being primarily for the benefit of the Certifying Authorities, certainly by the Civil Aviation Authority, who understandably still require absolute proof that a structure will withstand a specified birdstrike.

To make this design process even simpler companies are now considering developing a synthetic or dummy bird, which has been shown to exhibit the same behaviour as a ‘real’ bird when impacted. This is partly because of the considerable cost savings, but also because of the greatly improved health and safety benefits. Real birdstrike tests are rarely repeatable or reproducible which adversely effects the risk assessment. Repeat testing using ‘real’ birds has shown that there is a wide variation in every parameter of impact loading measured. These variations are due to marked differences in bird material properties, structure and geometry, which are not controllable in ‘real’ birds, but are not a problem with dummy birds. Although this was an objective listed in the original proposal it was not pursued as CSL, BAe and QinetiQ are currently engaged in a collaborative programme (International Birdstrike Research Group, IBRG) comparing physical substitute birds with real birds. However, the collaboration has since grown world-wide and plans are underway to start a test programme on the various substitute materials. It is hoped that this should be linked in with the follow-on GARTEUR programme.

It is clear from all the simulation work undertaken within the group that a number of representative bird models are available and it is possible to simulate birdstrike onto metallic structures with confidence. However, for birdstrikes onto composite structures, although much progress has been made, the

simulations are not truly predictive and preliminary tests are still required to 'calibrate' the models before there is adequate confidence in the numerical results.
The round robin exercises during Phases 1 and 2 have allowed a number of optimum birdstrike numerical modelling methodologies to be identified. The group has been able to standardise particular aspects of the bird, for example in terms of its shape and size, but the best modelling approach depends upon the birdstrike problem that is being analysed. For bird impact against a sharp leading edge or fan blade whereby they bird 'splits' or is 'cut' then the sph method has distinct advantages over the more traditional lagrangian methods.
Specifically the modelling results have shown that the type of composite failure models and the availability of suitable composites failure data is the constraining factor for successful birdstrike simulations on composite structures. In addition conclusions from the HICAS, CRAHVI and other European funded research programmes support the view that further research is needed to predict successfully impact failures in composite structures. In high velocity impact of soft bodies on composite structures both delamination and fibre failure are found to be important, depending on the impact energy levels. Improved composites failure models, which include ply damage and interply delamination models, were developed in HICAS and by several members of the GARTEUR group. However, the work concluded that further validation studies are still required before these models can be used as the basis of design and certification tools for composite structures in the aircraft industry.
Phase 3 involved the design, fabrication and testing of a new impact tolerant leading edge. For this a novel tensor concept was devised, which can be embedded within a composite leading edge. The tensor deploys on impact, effectively 'catching' the bird as it penetrates.
This work has gone a long way to address the issue of attaining birdstrike certification by modelling rather than testing however, it is clear that birdstrike modelling is very complex because of the impact speeds involved and the structure/fluid interactions. The Civil Aviation Authority will accept birdstrike modelling of new metallic structures based on older 'similar' designs which have previously undergone birdstrike testing. However, regarding birdstrike against composite structures there is still more effort needed in developing progressive composite damage models and subsequently validation on a wider range of generic composite structures is still required.

### 3.6 Recommendations

Firstly the scope of the GARTEUR group should be widened to include impact, not only from birds, but also from other 'foreign' object or projectile e.g. concrete, bulk heads, wheel rims, stones, rubber tyres, hailstones, lightening, fan blade debris, etc. Impacts from approximately 60 m/s upward to just below ballistic should be considered.
Regarding the impacted structure, more consideration should be given to composite materials. To develop design and certification tools for the aircraft industry for structures under severe loads, ideally more validation of composites failure modelling under impact loads by careful testing of idealised structures coupled to materials test programmes and simulation studies is necessary. But this would be very costly so the preference is for materials and test data to be exchanged freely amongst partners, as has been the case so far.
The woven carbon leading edges manufactured by QinetiQ are still available to the consortium for future use. If Birdstrike AG24 programme is allowed to continue for a further 3 years then DLR have colleagues that may like to join the consortium and be able to birdstrike test these leading edges, providing useful data for simulation purposes.
Future key aspects to be investigated include:

- *Scaling of impact*
  Determination of a relationship that would allow manufacturers to test higher impact weights at lower impact velocities (and conclusive evidence that straightforward scaling does not work) would be useful to industry, as full-scale birdstrike testing is so costly and facilities are so limited.
- *Pre-stressed structures*
  Impacted structures should actually be preloaded to represent the aircraft in flight, which adds even more complexity to the birdstrike modelling. One example could be birdstrike against a pressurised