Technical Evaluation Report

Ed Pendleton
AFRL / USAF
2210 Eighth Street
WPAFB, Ohio 45433
USA

Otto Sensburg
Consultant Aircraft Structures
Seitnerstrasse 4
82049 Pullach
GERMANY

SUMMARY

A NATO RTA AVT Workshop entitled "UAV Design Processes / Design Criteria for Structures" was held in Florence, Italy on April 15th and 16th, 2007. A variety of papers were presented by industry practitioners on the topics of UAV design and qualification. Companies with authors participating included Boeing, BAE, Dassault, EADS, Lockheed Martin, and Northrop-Grumman, along with authors from government agencies associated with aeronautical development. Presentation titles included "Airframe Certification Methods for Unmanned Aircraft" (Boeing), "Structural Design Criteria for UAVs and Differences from Manned Fighter Aircraft" (EADS), "Criteria, Processes, and Issues in Design of Unmanned Aircraft Structures at Lockheed Martin" (Lockheed), "UAV System Airworthiness Requirements (USAR) code: A Tailoring Approach for UAV Certification" (DGA), "Applicable structural regulations for different ranges and scales of UAVs" (Dassault), "Airworthiness Certification Strategy for Global Hawk" (Northrop), "Design Processes and Criteria for the X-51 Flight Vehicle Airframe" (Boeing), "ITWL's Experience in the Design, Flight Tests, and Certification of UAV System's Components" (Poland's Air Force Institute of Technology), "Design Criteria / Approach for Small, Unmanned Aerial Vehicles" (NASA LaRC). Also "Structural Health Monitoring / Event Monitoring for UAVs" (EADS), "Safety Management System for an Unmanned Aerial Vehicle (UAV)" (BAE), "Design Considerations for a UCAV Wing for Subsonic and Transonic Aeroelastic and Flight Mechanic Wind Tunnel Tests" (DLR), "Electrical Driven General Systems for UAVs" (EADS), "Adaptive Actuators Allocation for Fault Tolerant Overactuated Autonomous Vehicles" (University of Calabria) Falco Air Vehicle Low Reynolds Number Multi-Component Airfoil Design and Testing at Galileo Avionica, and Lessons Learned from the Helios Prototype Vehicle Mishap (NASA LaRC).

Thorough discussions were held during the course of the workshop and these discussions were further expanded and summarized upon during the round table event. By the end of the workshop, all its participants came away with an increased awareness of the UAV design issues facing the NATO alliance in the coming years.

INTRODUCTION

An RTA workshop took place in April 2007 in Florence, Italy. Papers were well selected and the workshop was efficiently organised. The following subjects were covered:

- Health Monitoring / Event Monitoring for UAVs;
- Wind Tunnel Tests for UAVs;
- Electrically Driven Actuators for UAVs;
- Adaptive Actuators Allocation; and
- Lessons learned from the HELIOS prototype mishap.

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The authors talked frankly and openly to an audience of about 50 specialists. In the round table discussion at the end, design and qualification issues were mostly discussed.

Since the majority of presentations were dealing with design and qualification, this evaluation paper also concentrates on this theme.

1.0 GENERAL UAV DESIGN REQUIREMENTS

Design for UAVs essentially follows the same rules as for manned Air Systems, but:

- Requirements may be narrowed down or relaxed because:
  - No safety requirements for a crew or passengers;
  - Specialized usage;
  - Possibly restricted flight areas;
  - Small fleets of A/C;
  - Orientation to all composite structures (⇨ fatigue, corrosion); and
  - Autonomous flight control systems.
- Requirements might be more demanding because there is no pilot intelligence:
  - Bird strike, icing, lightning; and
  - CAT 2 & 3[1] certification, i.e. flying over populated area / participation in civil airspace.

2.0 STRUCTURAL DESIGN CRITERIA

Structural design criteria have been developed over decades for manned air vehicles, serving a variety of missions, service requirements and environmental conditions. These criteria used have been evolved and advanced for large fleets of manned platforms using the experience from ground and flight tests and thousands of mission flight hours for different usage scenarios.

Acceptable structural safety levels required for peacetime operations and mission performance in war times have been ensured through extensive qualification processes and specified military certification requirements.

[1] Definitions according to LTF 1550-001, Issue 1*

CAT 1: Flying in restricted areas only → test areas without population:
- experimental UAVs / prototypes
- flight test activities structural qualification by analysis only
- structural qualification tests are not necessary except GRT (SCT)
- but flight test results can be used for structural qualification possibly authorities not really involved in UAV clearance process:
- provide evidence to the authorities only that the UAV cannot leave the restricted area (e.g. flight abortion system)

CAT 2: Flying in restricted airspace over populated areas:
- “full” structural qualification / certification process necessary?
- provide evidence to the mil. / civil authorities that the UAV can fly safely
- comparable level of safety as for manned air systems

CAT 3: Participation in civil airspace without restrictions (sense and avoid)
- “full” structural qualification / certification process necessary
- provide evidence to the mil. / civil authorities that the UAV can fly safely
- comparable level of safety as for manned air systems

* German Aerospace Regulation

New systems like unmanned air vehicles are now in various stages of conceptual design, development or production. These unmanned systems may use either variations of the design criteria for manned air vehicles to fulfil similar requirements where applicable and new design criteria where specific unique weapons system capabilities are demanded, along with certification guidelines being formulated by authorities to operate the vehicle in various classes of airspaces.

As an example for the different requirements on UAVs three different uninhabited military air system classes are presented here.

MALE – **M**edium **A**ltitude **L**ong **E**ndurance Air Vehicle

HALE – **H**igh **A**ltitude **L**ong **E**ndurance Air Vehicle

- low speed: sailplane respective transport aircraft attributes
- mission altitude: max. altitude > 40000 ft
- long endurance time: ≥ 20 h
- low manoeuvre load factors (g), low roll velocity
- structural design is driven by gust conditions
- geometrical design: driven by mission payload requirements mainly?
- fatigue requirements: high sortie rate per year life time ≥ 20 years

URAV – **U**nmanned **R**econnaissance **A**ir **V**ehicle

- low altitude missions: ≥ 1000 ft
- subsonic flight envelope
- more agile air system: increase of g and roll velocity compared to MALE, HALE
- structural design: driven by manoeuvre loads
- geometrical design: driven by mission payload requirements mainly
- fatigue requirements: low sortie rate per year life time ≥ 20 years
- first combat capability: external stores and/or internal weapon bay / small weapons only (no missiles?)
- stealth requirements: RCS, IR?

UCAV – **U**nmanned **C**ombat **A**ir **V**ehicle

- Design for
  - subsonic / transonic / supersonic flight envelope
  - multifunctional structures[2], morphing structure
- Agile air vehicle
  - equivalent to manned fighter aircraft: air to air and/or air to surface role
  - or even higher agility required: nz, roll velocity, etc.
  - geometrical design is driven by mission performance
- High combat capability: external weapons and/or internal weapon bay

[2] See also Design Aspects from AVT141: integration of Sensors and Antenna.

- Fatigue requirements
    - very low sortie rate per year
    - or use of UCAVs in war times only: fatigue loads are occuring in the short period during war time missions
    - special storage requirements
- Stealth requirements: RCS, IR ?

In addition to accelerated development and entry into service schedules one important element in UAV's platform design are the cost aspects both in terms of acquisition and in-service usage. Projected cost advantages of UAVs can be compromised if "traditional" design criteria and certification requirements are imposed upon them, leading to production costs increase or delays in acquisition and vice versa. Relaxation of qualification levels without adequate technical substantiation followed by unacceptable failure rates in service will also compromise system cost advantages over manned vehicles.

During the workshop UAV design aspects and structural design criteria for current projects were presented. Initial proposals for UAV regulations (e.g. CS23 / USAR) emphasizing the importance of UAV specific Structural Design Criteria, i.e. definition of limit / ultimate load conditions (factor of safety – no pilot in the loop), structural safety provisions for UAVs, aspects of flight envelope definition (e.g. FCS controlled / "protected" envelope, etc.) were also shown.

Also, possible future design drivers with pilot based restrictions removed for high agile manoeuvring for UCAVs are considered together with new aspects like transport requirements (sea, road, air).

3.0 SPIRAL DEVELOPMENT AS A NEW DESIGN CONCEPT

Spiral Certification approach is more aligned with the process of aircraft development than that of structures development.

Conventional	**Spiral Certification**
Builds up to Full Scale	*Begins with Full Scale*
From Materials	Flight Qualification
To Coupons	Life Extension
To Critical Details	Then Critical Details and Allowables
To Subcomponents	
To Components	
To Full Scale Test	

The above table shows that the Spiral Certification approach is run almost as the reverse of the conventional certification approach.

Because the first aircraft is assumed to be a prototype or development aircraft it is assumed that it will be qualified for flight using a test of the flight vehicle. Subsequently the next stage uses a dedicated airframe to establish load limits and life times beyond those intended for limited operational usage. Then the final

Spiral takes this airframe (or one more like the final production design) and runs it through the full envelope of loads required to certify the production vehicle. Subsequently it would test the fatigue life and damage tolerance of the design in the same airframe.

Spiral development is possible even if the requirements for certain future capabilities cannot be formulated at the time being. It leads to a more rapid procedure to put air vehicles into service and profits by future technological developments.

Constantly developing avionic equipment and varying requirements for missions make UAVs a favourable candidate for spiral development.

The customers should rethink their requirements:

- Not to overload the specifications.
- Cost against performance has to be established between manufacturer and customer.

Spiral developments cycles will provide faster time to operational service with less than spec-optimums, but steeper "learning curve" with close link between field experience and design upgrades.

It can be observed that a role change or at least adaptation (common in manned combat aircraft) takes also place in mid and large size UAVs. UAVs designed as pure reconnaissance platforms are adapted to carry weapons, while UCAV designs are adapted to reconnaissance missions.

4.0 FACTOR OF SAFETY – RE-EVALUATION FOR UAVS

The Factor of Safety (FoS) has been under discussion since manned air systems began flying. Cost saving, i.e. mass reduction, is the main driver to reduce the FoS.

The possibilities for FoS reduction are based on better design tools, more accurate load calculation, effective flight control systems (e.g. FCS as a load limiting system) and extensive structural health / event monitoring.

For unmanned air systems the simple but crucial argument is that the protection of the pilot is not an issue - but probably pilot skill will be missing when flying over populated areas.

Today the military regulations (e.g. Mil. Spec., Air 2004, Def. Stan.) and civil regulations (e.g. CS23, CS25) for manned air systems are generally requiring a FoS of 1.5 with some deviations. The USAR 3.0 (derivation from the civil regulation CS23) a first European (French) regulation for unmanned air systems basically requires a FoS of 1.3[3] with some additional safety factors (e.g. fitting factors) for critical design areas (e.g. wing attachments).

5.0 STRUCTURAL HEALTH AND EVENT MONITORING

Health and event monitoring (real time) could be more important than in manned air systems, i.e. extension of health and event monitoring to areas usually observed by the pilot may be necessary (pilot also working as a "sensor system" in manned air systems):

- Bird strike;
- Lightning strike;

[3] Recent USAR Versions are requiring also a FoS of 1.5.

- Monitoring of general vibrations, acoustic noise (high cycle fatigue);
- Dynamic loads, e.g. monitoring of local accelerations from gust, buffet, dynamic landing impact; and
- Pilot observed aging effects (wear and tear): change of maintenance concept, e.g. additional inspections may be necessary.

Care should be taken with such automatic systems that too much reliance is not placed on the processed data – there is the potential issue that without sight of some raw data systems could be declared unusable for incorrect reasons.

6.0 PRODUCTION NUMBERS, COST AND REPAIRABILITY

The limited production numbers of UAVs and their (comparatively) low price implies that no major qualification processes can be performed.

Therefore dual use materials or materials qualified in other projects will be the materials of choice.

Hence the cost share of the airframe for the single A/C is expected to be considerably lower than for a manned A/C, the money is spent primarily for sensors and electronics and not for the structure itself.

Likewise repairability has to be handled differently compared to manned A/C: it should be possible to exchange components and perform minor repairs on deployment bases, without major facilities. Rapid simplified repair concepts are also needed.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Excellent papers were given at the workshop, discussing openly the experiences of industry in developing UAVs.

The majority of presentations was dealing with design processes, requirements and qualification issues and concrete proposals were made as to how to tailor these issues to UAVs.

Following is a condensed version of proposals and explanations:

Qualification / Certification

Today most UAV certification rules and procedures adopt civil regulation documents and processes like JAR/CS 23 & 25, depending on the maximum takeoff weight and aeroplane category, often tailored to serve one specific product.

With the traditional certification rules, evolutionary improved, based on decades of service experience in civil operations, new, global standards are needed for UAVs. They must include UAV-specific features like FCS protected loads- and flight envelopes to assure a comparable level of safety as manned aircraft in peacetime operations.

Structural Integrity (i.e. Static Strength, Durability, Damage Tolerance etc.) of a vehicle structure must be assured throughout its specified usage without imposing an unacceptable threat to safety or economic burden through failure of structural components to the customer.

Structural integrity must be demonstrated to the customer through an agreed validation and acceptance program for all structural significant items.

Structural Qualification Process for UAVs

A definition of a new Structural Qualification Process for UAVs seems to be necessary, such as:

- Reduced / limited number of Production Aircrafts.
- Spiral development process.
- Shorter and overlapping development cycles: e.g. concept definition: production.
- Very low sortie rate per year for UCAV respective use of UCAV in war times only.
- Use of FCS as "load limiting system": reduction of FoS for FCS controlled flight loads.
- Last but not least: no pilot has to be protected.

The potential to reduce the amount of structural/system qualification tests must be investigated. As an example, structural qualification test steps are transferred from ground to flight test:

- Up to limit loads: flight test with improved real time flight loads instrumentation; and
- Up to ultimate conditions qualification is performed by analysis (see also AVT Working Group 092, 'Qualification by Analysis').

A comparable level of safety as for manned air systems is required because the UAV will be flying over populated areas (CAT 2 / 3).

Recommendations

During the round table discussion it was proposed to have another UAV activity at RTO (maybe a working group) to come up with recommendations for the issues mentioned above.

This was also proposed during the Working Group meeting of AVT 092.

If such an activity was to take place specialists of Government Agencies, UAV users and Industry should be nominated to ensure success.