# REVIEW OF THE EUROPEAN RESEARCH PROJECT "ACTIVE AEROELASTIC AIRCRAFT STRUCTURES"(3AS)

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## 1. Astract

Active Aeroelastic Aircraft Structures (3AS) is a research project funded by the European Union under the Key Action Aeronautics of the "Competitive and Sustainable Growth" RTD Programme FP5. Its main objective is the development of new aircraft design concepts that exploit aeroelastic effects in a beneficial way. The project consortium consists of these partners: ALENIA (Italy), EADS-CASA (Spain), EADS-Defence & Security (Germany), GAMESA DESARROLLOS AERONÁUTICOS (Spain), Saab AB (Sweden), Centro Italiano Ricercha Aerospaziali S.C.p.A., CIRA (Italy), Deutsches Zentrum für Luft- und Raumfahrt e.V. , DLR(Germany), Instituto Nacional de Tecnica Aerospacial, INTA (Spain), Vyzkumny a zkusebni letecky ustav, a. s., VZLU (Czech Republic), Kungl Tekniska Höskolan, KTH (Sweden), Instituto Superior Técnico, IST (Portugal), The University of Manchester, UMAN (United Kingdom), Politecnico di Milano (Italy), TECHNION research and development foundation Ltd. (Israel), and, as a major subcontractor, the Central Aerohydrodynamic Institute, TsAGI (Russia).

The project started in April 2002 with a total duration of three years. It is aiming to cover a wide range of potential Aeroelastic Concepts. For this reason, the different designs could only be analysed and optimised in a preliminary manner, rather than investigating all aspects of all involved disciplines in depth, as it would be required for a real airplane design. In order to have at least a look at all important design aspects, a so-called "experts panel" with members from the different disciplines reviews the different

concepts at important phases of the design process and for the planned tests. The following different types of airplanes were investigated in 3AS, depicted in fig. 1, 2, 3 and 4.

Fig. 1. Aeroelastic wind tunnel model of the long range transport aircraft "EuRAM"

Fig. 2. Three-surface commuter jet "X-DIA"

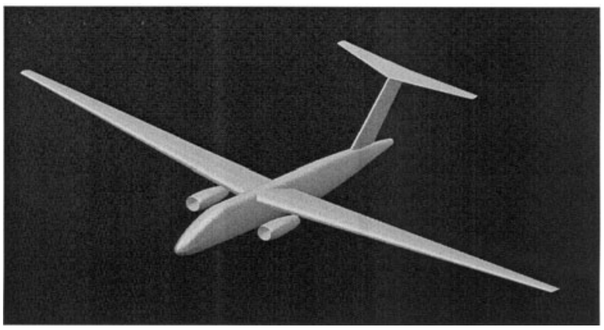


Fig. 3. High aspect ratio wing "HARW" for a HALE-UAV

Fig. 4: RPV model

The target and demonstration airvehicles are

- a long range, wide-body, 4-engine transport airplane, designated the "European Research Aeroelastic Wind Tunnel Model" (EuRAM),
- a 3-surface commuter jet, the X-DIA configuration,
- a high aspect ratio wing(HARW) for a high altitude, long endurance unmanned air vehicle
- a small remotely piloted vehicle (RPV).

The exemplified aircraft integrate a broad variety of new aircraft design concepts where active and new passive aircraft control and structural design approaches are used to improve performance goals in areas such as:

- Aerodynamic drag reduction,
- Structural weight reduction,
- Advanced sizing design and exploitation,
- Manoeuvrability enhancement,
- Load reduction,
- High aeroelastic effectiveness,
- Improved aeroelastic stability (flutter) and
- Dynamic loads suppression.

Except for the HARW configuration, the basics of the other experimental models already existed at the beginning of the project. Still, the complexity of studied integrated systems and configuration options quickly necessitated a wealth of hardware and computational model evolvement. As an exmaple, in the case of the RPV six different wing builds evolved and a new model aircraft inspired, at 6m scale, the size of the EuRAM.

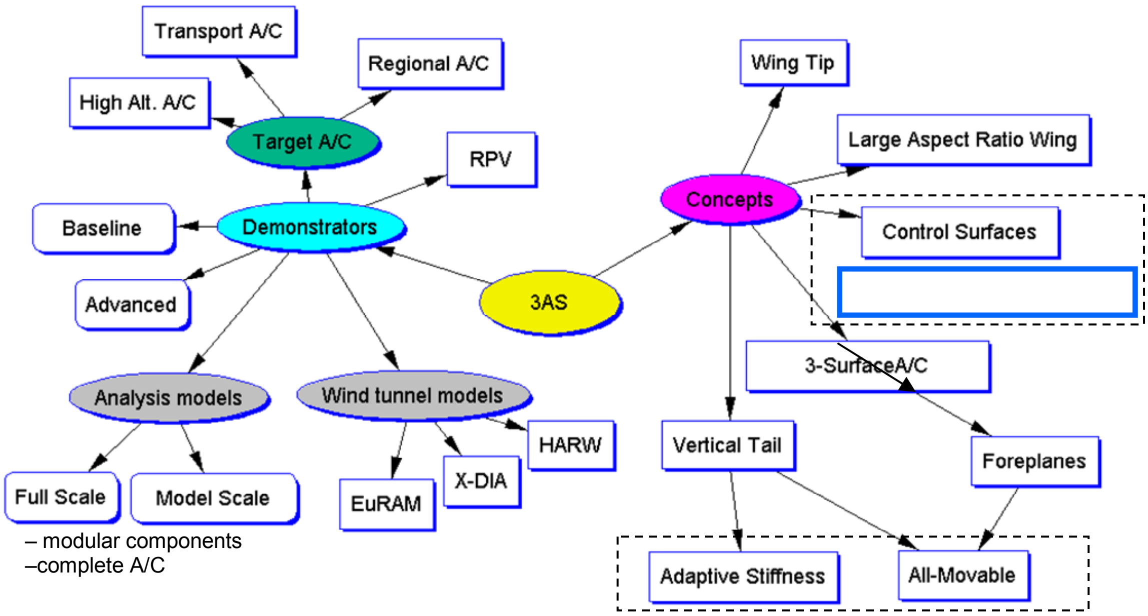



Fig. 5. 3AS technology structure

The aeroelastic design concepts are subdivided into three different groups, based on the method that is used to initiate the desired aeroelastic deformations:

- Aerodynamic control surface concepts,
- Concepts for all-movable control surfaces with variable stiffness attachments,
- New active and passive structures concepts.

These methodologies are highlighted in the technology plan view in fig. 5 by dashed boxes.

In order to assess the potential improvements from Aeroelastic design concepts, negative aeroelastic impacts on current aircraft designs were assessed in a dedicated work package.

Whereas the Aerodynamic control surface concepts need no new technologies to apply them, the adaptive stiffness attachment devices require extra efforts within the project and from outside resources. This applies to the

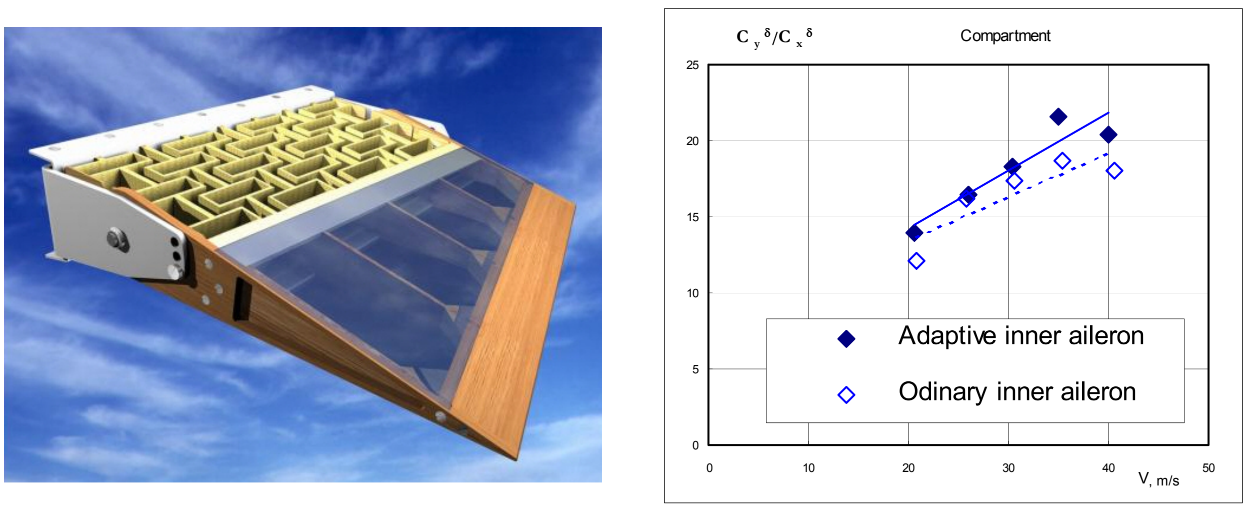



Fig. 6. Selective Deformable Structures concept: arrangement and Lift-over-Drag improvement for inboard aileron on complete EuRAM aircraft, c.f. [10]

"New Structures" concepts, active or passive, which are subdivided into three groups:

- A new passive structural design concept, that allows large continuous deformations of a load-carrying structure. This concept is called "Selective Deformable Structure" (SDS). It is applied to the inboard aileron of the EuRAM model as well as to a full scale static test article fig. 6.
- Active structures concepts applied to the external structure (wing skins).
- Active internal structures concepts.

The analytical studies were conducted hand in hand with detailed component and complete model aircraft tests coverring static, vibration and wind tunnel testing. The Wind tunnel tests were performed at:

- the VZLU institute in Prague (EuRAM half wing model, X-DIA foreplane with fuselage)
- the Politecnico di Milano (X-DIA),
- the Royal Technical University in Stockholm (HARW half wing model),
- the Instituto Superior Tecnico in Lisbon (RPV model), also preparatory wing testing at UMAN.
- and at the Central Aerohydrodynamic Institute (TsAGI) in Zhukovsky near Moscow.

So far, the project has met all important objectives. The efficiency of the different concepts to improve aircraft efficiency was verified, and required future efforts for applications on flying demonstrators were identified.

Besides direct exploitation of 3AS results within the project itself, the created analytical and hardware models as well as theoretical and experimental results are a valuable basis with versatile opportunities for future research activities in Europe.

## 2. Review

### *2.1 The EuRAM*

This demonstrator platform captures the aeroelastic challenges of large transport aircraft, specifically the wide bodies with MTOWs beyond 200 tons, where the market is very competitive. In ref. [1] a characterization and etymology of this "multi-funtional" model is given. Ref. [2] summarizes many of the analytical investigations. It is the main focus of work between TsAGI and the other 3AS partners.

Of note is that the aircraft is modular regarding the baseline wing and a baseline plus wing which includes winglets, bringing the full scale aircraft span to almost 60m. If it is desirable to include winglets, then it has been shown that the stability of the configuration must tolerate a depreciation. Evenmore so if larger winglets were contemplated. Typically at the wing tip a trailing edge(T/E) aileron is integrated. One is fond of this control surface but it is prone to loss of effectiveness at high speed. This has implications too for the dynamic control behaviour as will be stated further on.

At least we should note already what is meant by effectiveness, $\eta$

$$\eta = \frac{\text{augmented equilibrium forces}}{\text{rigid input forces}} \qquad (1)$$

In this definition, a modifying effect on applied forces on the structure is stipulated. Through elastic and full dynamic factorization of the structural behaviour there is at least a readjustment to the balance of forces given. If the factor is over one then the structure introduces a servo effect involving the influx of more aerodynamic load, it is beyond rigid response, greater values can be interpreteted as the structure diverging unstably from its loaded equilibrium if not cared for!

The other direction of the matter, as in the case of the aileron acting behind the elastic axis of the wing box, is the aforementioned lessoning of effectiveness with increasing dynamic pressure. Against this, new active wing tip controls were developped that counteract this elastic deficiency even on a swept back wing, providing about four times greater efficiency than the conventional T/E aileron per unit surface. In fig. 1 two dagger type active wing tip controls(AWTC) are installed in-plane at the wing

Fig. 7. Right EuRAM half wing in VZLU wind tunnel, arrow AWTC installed in-plane at tip chord

tip. The aircraft in this case is in the baseline plus configuration showing the basic fin-rudder. Control surfaces of significance were “styled” orange in the campaign. In a preliminary stage the double sized arrow variants were also tested, c.f. fig. 7. Here the the wing component is balanced in the VZLU wind tunnel facilities.

In [3] analysis for validation and updating puposes is given. In fig. 8 various streamwise functions of the deformed aerodynamic mesh versus half wing span are depicted. Each function depends on the selcted AWTC configuration{small surface, its shape, its position relative to the outer wing}.

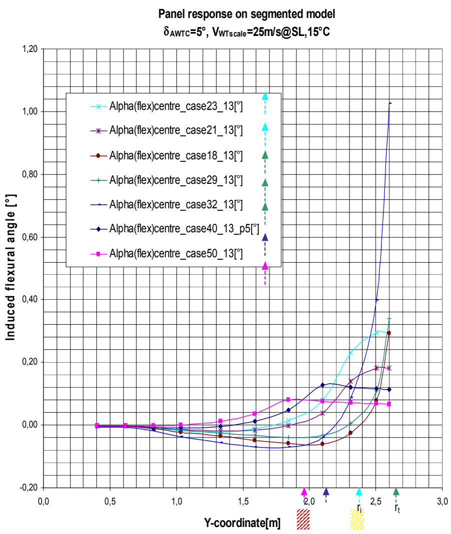



Fig. 8. streamwise angular twist deformation of aerodynamic panel system versus half span for various AWTC nfigurations

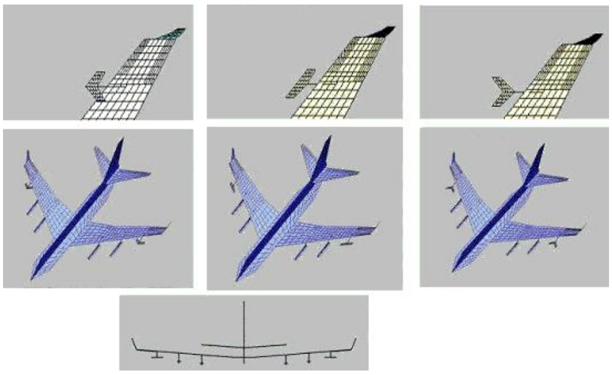


Fig. 9. AWTC surfaces, attached out-of-plane on pylons

Considerable difficulties had to be overcome in discerning the angular structural displacements from the accompanying vertical deflections. Residual angular deflections i.e. in balance of the momentary wing wing weight and wash out of the airload of the swept wing can be actively compensated.

A static or dynamic stability problem, for instance involving AWTC wing structure and basic trialing edge aileron within the flight envelope was not found.

A picture of the various configuration options, further in from the wing tip is given in fig. 9. These are even installed out-of-plane.


Fig. 10. Example of out-of plane AWTC implementation in model

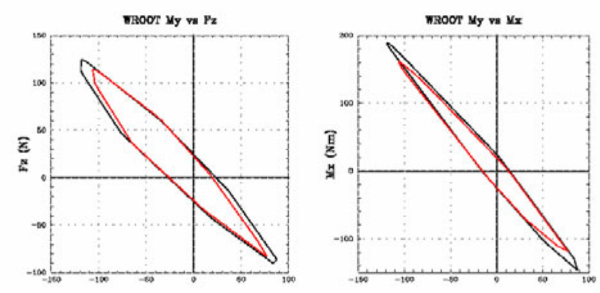



Fig. 11. Example of closed-loop loads reduction at the wing root station using the AWTC

Depending also on the variable engine positions, variable improved flutter speed margins were found for the baseline plus aircraft.

Dynamic loads reduction is specifically highlighted in [4].

Following the trend of the static analysis, the AWTC could be shown to reduce gust loads by 7 to 20%. By trend we mean that only a fraction of the T/E aileron's surface in the AWTC design again is necessary to achieve these reductions. In figures 10 & 11 a view of the calculations model and typical potatoe curves are given. The inner curves show the reduced structural load in closed-loop control.

Whereas many aircraft design concepts based on the exploitation of beneficial aeroelastic effects so far show their advantages only with increasing speed of flight, the adaptive stiffness concept for all-movable surfaces exploits the full effectiveness throughout the entire flight envelope as demonstrated in fig. 12.

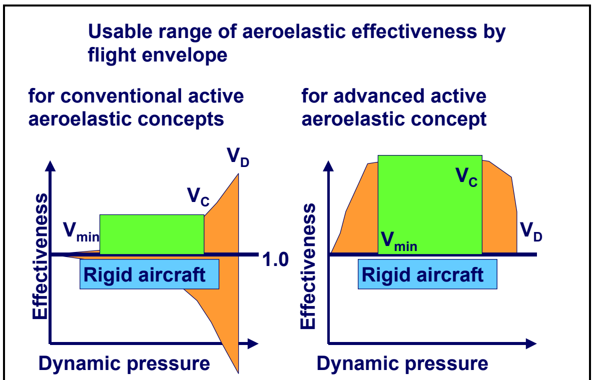



Fig. 12. Adaptive Attachment Stiffness concept for all-movable aerodynamic surfaces

Fig. 13. Tested all-movable vertical tail versus conventional fin with rudder, size comparison on EuRAM empennage

The point of the matter is to control the diverging nature of the reduced size fin, see size comparison in fig. 13.Various systems were devised to provide the adaptive stiffnes, c.f. [5].

For the augmentation of the fin efficiency giving greater side load on the smaller, lighter surface, one devises an attachment point and elastic structural bearing line aft of the aerodynamic pressure point. Such a feasible result is characterised in fig. 14 producing the scaled down requirement for the variation of attachment stiffness.

Final analyses rested on 40% mean aerodynamic chord reference position after scanning options between 25% and 60%. As described in [5], various systems managed to achieve the variable stiffness requirement and were integrated to the complete aircraft model. Various upscaling studies are being completed to the end of the project. This includes preliminary fullscale aircraft flight control system impacts.

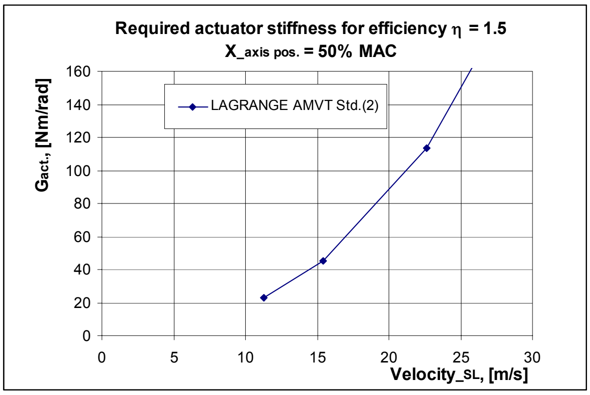
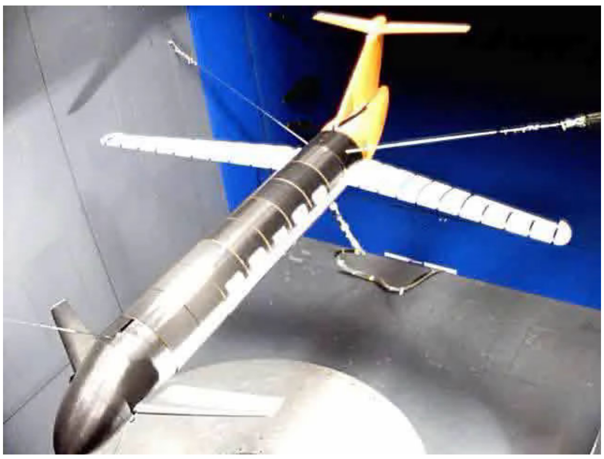



Fig. 14. 50% CMAC reference position design point-model variable stiffness specification

The most promising EuRAM concepts have been integrated and wind tunnel tested through the whole flight envelope to dive speed and beyond to factually capture stability critical speeds. Valuable spin-off insights in safety issues have been gained.

## *2.2 The X-DIA*

This aircraft has been equally challenging, see very recent installation of the complete model in the wind tunnel and previous fuselage componet wind tunnel test with forward swept foreplane in figures 14 & 15 respectively. Some results exploiting active control are reported in [6] and [7].



Fig, 15. Complete X-DIA wind tunnel integration

Fig. 16. X-DIA fuselage component with forward swet foreplanes in wind tunnel

Due to planning, complete aircraft tests will not have been attempted till this publication. In particular though such a list of achievements can be reported

- A variable camber wing has been integrated.
- Modularity for controllable forward and aft swept foreplanes assured, and appropriate
- new fuselage and tail design accomplished.
- Advanced active control for flight mechanics, aeroelastics and vibration has been treated.

The four metre aircraft is capable of remote free-flight piloting control. In 3AS the studies are limited to analysis and WT testing because of time limitations.

## *2.3 The HARW*

This application was totally developped from scratch by Saab, resting on a characteristic HALE mission profile. The tenth scale baseline wing of 1.6m span was then built and tested by KTH, c.f. fig. 17.

There is little sweep to it and it is quite slender with an aspect ratio A of 15. An increased ratio variant with A = 25 was further designed based on the foundations and preliminary test findings of the baseline.

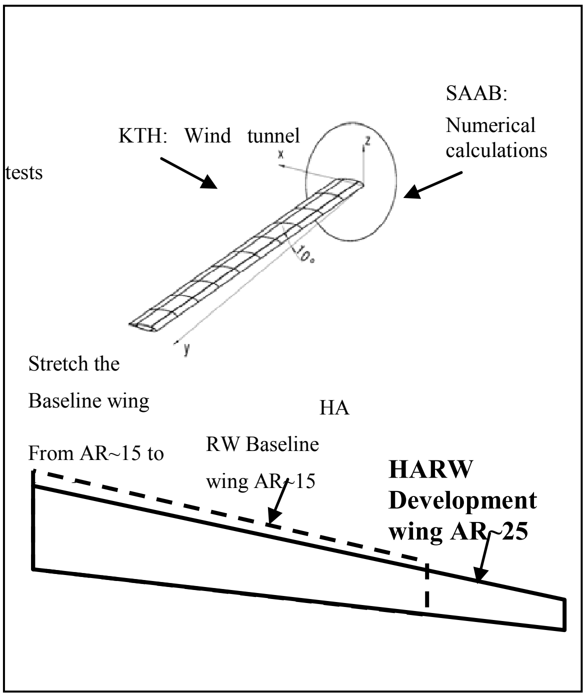



Fig. 17. HARW wing concept

With small absolute chord and high slenderness, a sensible shape response tailoring is done by multiple controls. As can be seen on fig. 17, 10 controllable tabs on repective segments were architectured. Research findings are reported exemplarily in [9].

Here too, active aeroelastic adaptions allow a new design space beyond fixed nominal or compromise flight points, beyond endorsed jig-build wing incidence and twist

## *2.4 The RPV*

In the case of this aircraft the studies were directed to flight applications whenever possible. This can be said for several concepts c.f. [8]. It has paid off well for the project that such an approach often throwing ponderous research avenues overboard was possible. If necessary, considerable risks and crude solutions were allowed. Conversely, it is also beneficial to see the performance of a sophisticated system operating in a crude environment. As in for example a piezo zirconate titanium (PZT) controlled carbon fibre spar integration.

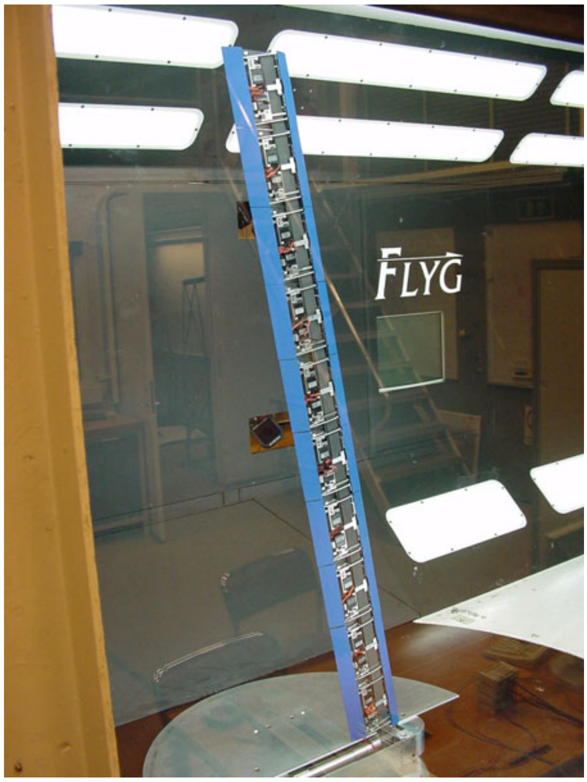



Fig. 18. Close-up of built multi-controls HARW half wing

The direct benefits on coping hands-on with specialistic avionics and miniturization therof have been apparent.

The confinements wrt. the small model have probably meant more discipline to weight and geometry from the outset compared to the other 3AS vehicles, but admittedly this also depends on how you relate respective stability requirements etc. Building on the realised compact sys-

Fig. 19. 2,4m and 6m span RPVs

tems design, an outlook will be to transfer the active aeroelastic concepts form the 2.4 m span aircraft to a new 6m span one. For this case newer adaptive pneumatic control concepts should also have found their flight readiness.

## 3. Summary

Unusual control surface concepts, some of them from forgotten past military applications, e.g. allmovable fin but augmented in 3AS by adaptive stiffness, have been fortuitously designed and demosntrated on model civilian aircraft platforms for flight.

State-of-the-art standard materials, even some "artistic" materials, PZT has been mentioned, applied to intelligent passive structures design platforms can bring about aeroelastic performance benefits.

The 3AS knowledge base probably spans most aeroelastic issues on all present flying aircraft. All aircraft platforms are accessible to far reaching modular component changes with complete aircraft design and testing evaluation.

Further investigations, including more full scale integration studies should find competitive interest in aircraft industry.

## 4. Aknowledgements

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3AS is benefited by the International Science and Technology Cooperation(ISTC) link as EU collaboration in the ISTC#2050 project.

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