Adaptive Buckling-Driven Composite Structures for Next Generation Aircraft

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Outline

- Introduction
- NABUCCO project
- Buckling-driven mechanisms for composite adaptive structures
- Concluding remarks

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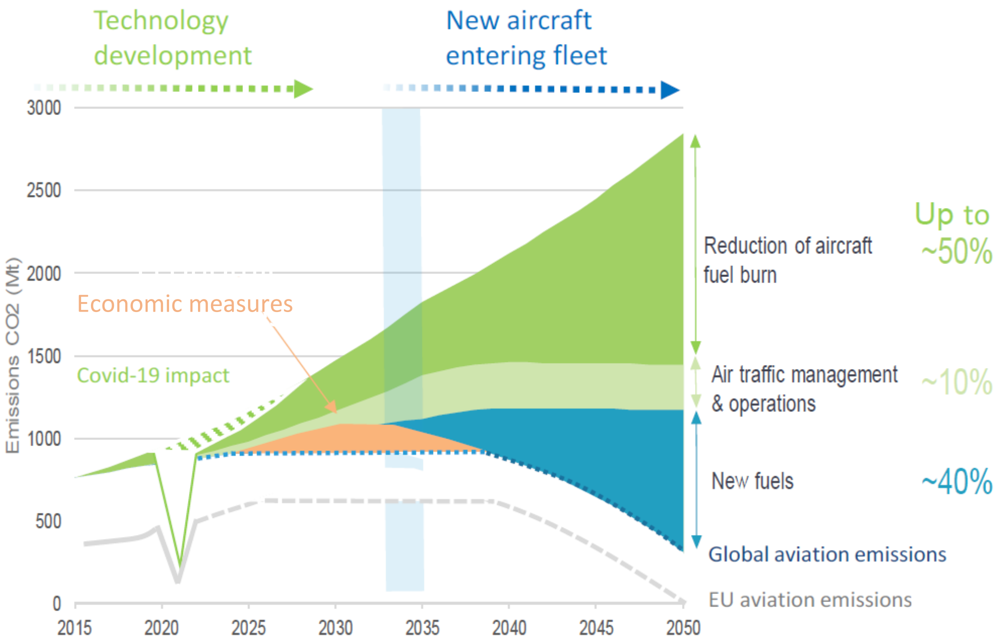
Future Aircraft Configurations

Do aircraft structures still represent a design challenge?

Aeronautics Vision for Achieving Carbon Neutrality



The European Green Deal, COM (2019) 640

Strategic Research and Innovation Agenda, EU (2020)

Destination 2050, A Route to Net Zero European Aviation, 2021

Design Challenges for Aircraft Structures

Weight reduction is still one of the major drivers

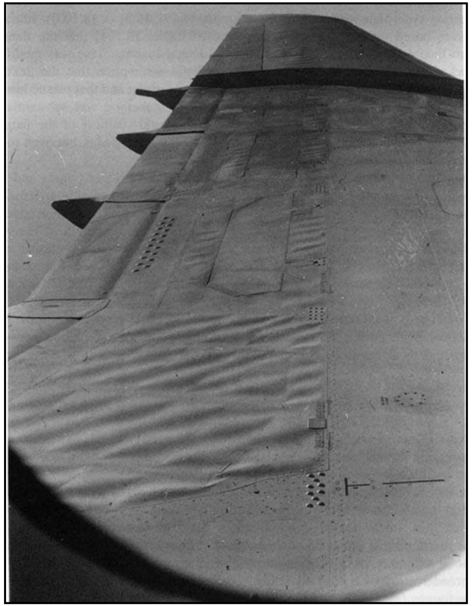
How to get it?

- Advancements on **design tools and processes** (multidisciplinary, validated…)
- Circular economy – modular vehicle architecture and remanufacturing, **greening industry**
- New lightweight and easily recyclable **materials**
- **Relaxation of well-established and historically consolidated design constraints**

“Strategic Transport Research and Innovation Agenda (STRIA) - Vehicle Design and Manufacturing”
Malkin P., **Bisagni C.**, Golinska P., Schmitt D., van den Bossche P., Salvato F.
European Commission, Directorate-General for Research and Innovation, Directorate H - Transport, Unit H.1 - Transport strategy, EUR KI-01-17-930-EN-N, 2017

Buckling of Primary Structures

https://shellbuckling.com/index.php
Photograph by Connie Indrebo, Crazy Creek Air Adventures, Middletown, California



J. Singer, J. Arbocz and T. Weller, *Buckling Experiments*, Vol. 1, 1998.

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NABUCCO - A Paradigm Shift for Aerospace Structures

Research funded by **ERC Advanced Grant**
(May 2023 - April 2028)

NABUCCO *- New Adaptive and BUCkling-driven COmposite aerospace structures*

Funded by the European Union
European Research Council
Established by the European Commission

Traditional approach

Buckling avoided:

- Stiffness reduction
- Nonlinear response
- Snap-through
- High variability (imperfections)

NABUCCO approach

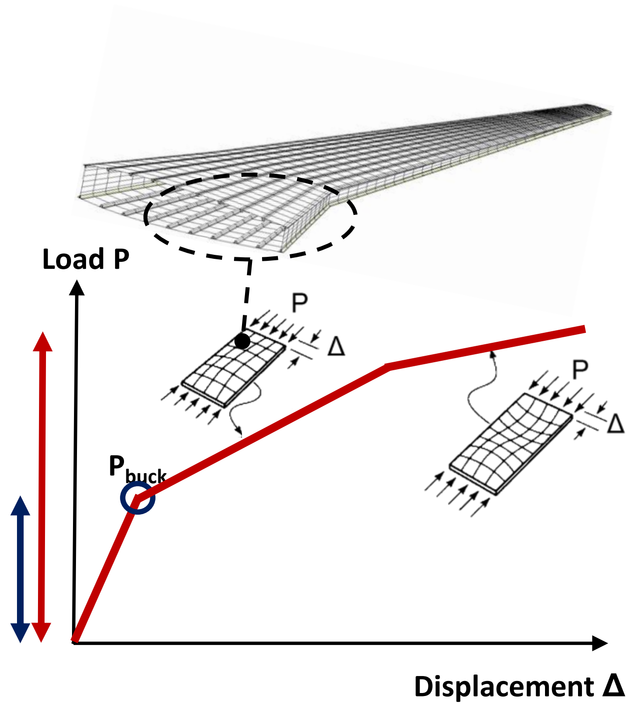
Buckling exploited:

- Load redistribution
- Shape variation
- Fast response
- Large design space

NABUCCO - A Paradigm Shift for Aerospace Structures

NABUCCO approach:
Design ***for*** buckling

Traditional approach:
Design ***against*** buckling



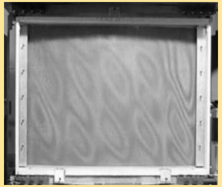
NABUCCO - A Paradigm Shift for Aerospace Structures

Goal	Develop new concepts of adaptive buckling-driven composite structures for next generation more efficient and sustainable aircraft
Challenge	Buckling: from phenomenon to be avoided to a design opportunity
Results	Adaptive structures for aircraft morphing wings

NABUCCO - Methodology

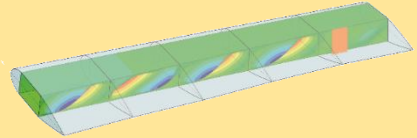
Objective 1

Explore buckling for novel, lighter and flexible structures



Objective 2

Conceive adaptive buckling-driven multi-stable structures



Computational-experimental framework

Imperfections + manufacturing variabilities

Analytical formulation

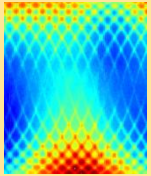
Optimization and AI techniques

Advanced test techniques

High-fidelity simulations

Objective 3

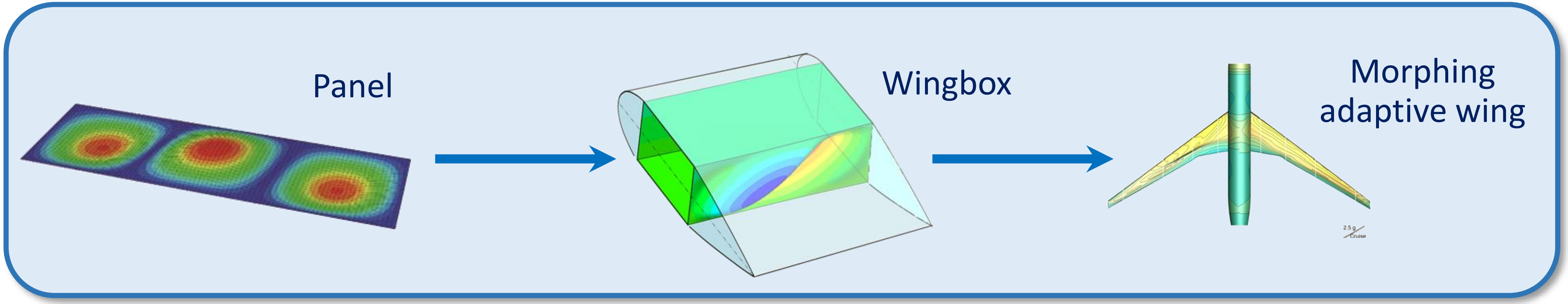
Exploit optimal material and advanced manufacturing



Objective 4

Design wings with morphing capabilities

NABUCCO - Building Block Approach



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Buckling-driven Multi-stable Adaptive Structures

Study of **buckling-driven mechanisms** implemented in a composite wing to be used for shape morphing application

3. Feasibility in a wing

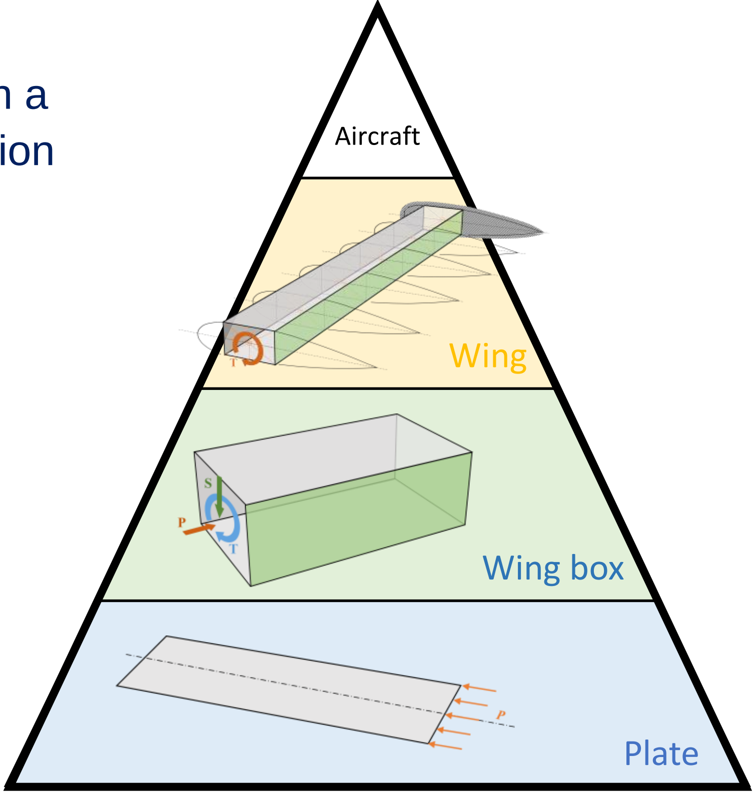
- Design parameters
- Experimental validation

2. Implementation in a wing box

- Load case
- Selective stiffness variation
- Shear center modification

1. Buckling-driven mechanisms

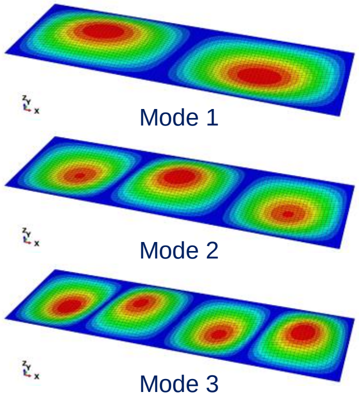
- Onset of buckling
- Post-buckling stiffness



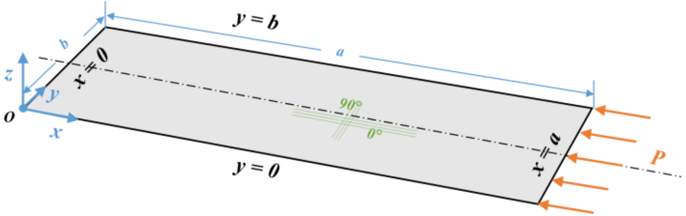
Zhang J. and Bisagni C., "Buckling-driven mechanisms for twisting control in adaptive composite wings", *Aerospace Science and Technology*, 118(2021)107006, 2021.

Buckling-driven Mechanisms

First 3 eigenmodes

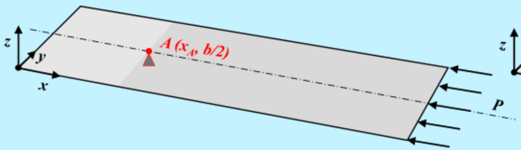


Uniaxial-loaded quasi-isotropic plate

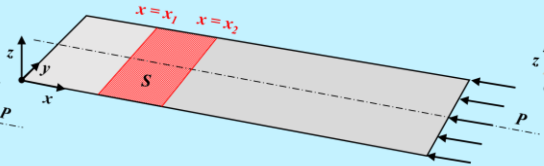


- IM7/8552 composite, lay-up $[0/45/-45/90]_s$
- Simply-supported on all edges

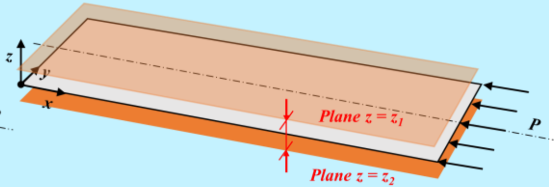
Point constraint



Area constraint



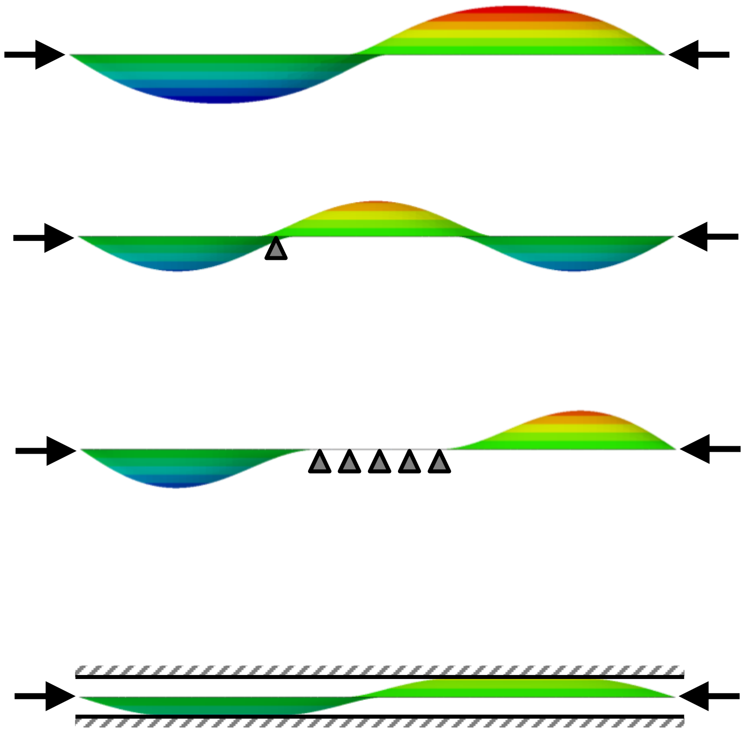
Maximum displacement constraint



Zhang J. and Bisagni C., "Buckling-driven mechanisms for twisting control in adaptive composite wings", *Aerospace Science and Technology*, 118(2021)107006, 2021.

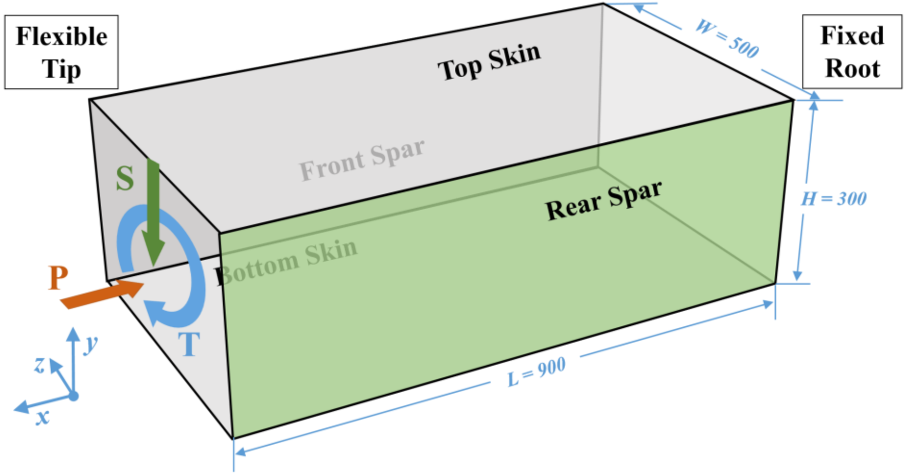
Buckling-driven Mechanisms

- Baseline
- Point constraint
  - P_{cr} 12% ↑
  - K_{post} -12% ↓
- Area constraint
  - P_{cr} 37% ↑
  - K_{post} +19% ↑
- Max displacement constraint
  - K_{post} +102% ↑

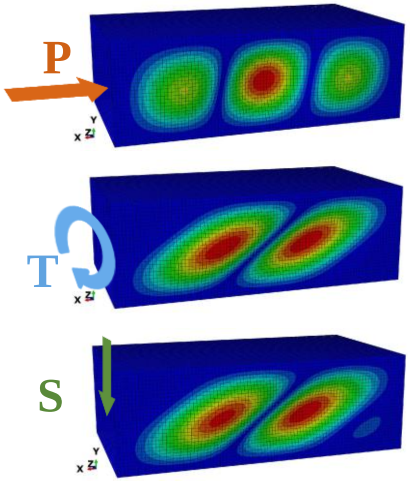


Implementation in a Simplified Wing Box

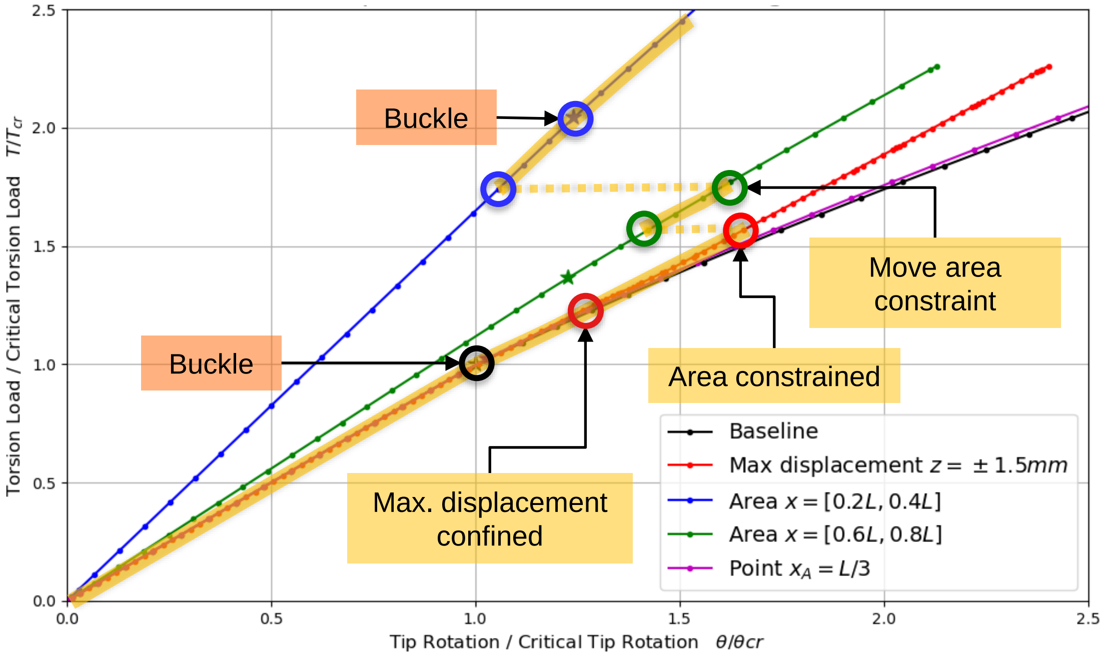
- Rectangular wing box section between two ribs
  - L / H = 3
  - Rear spar: $[0/45/-45/90]_s$
  - Front spar, top and bottom skin: $[0/45/-45/90]_{3s}$

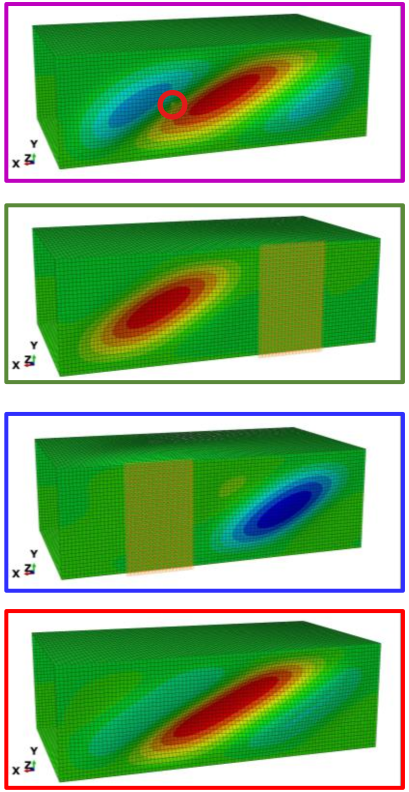


First eigenmode



Implementation in a Simplified Wing Box





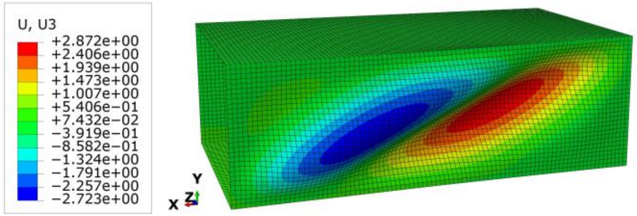
Zhang J. and Bisagni C., “Buckling-driven mechanisms for twisting control in adaptive composite wings”, *Aerospace Science and Technology*, 118(2021)107006, 2021.

Implementation in a Simplified Wing Box

Effects of buckling

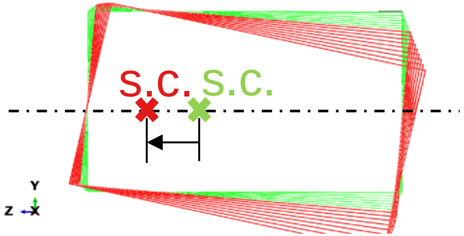
- Selective **stiffness variation**

  Buckled rear spar



- **Shear center**

  Shifts forward 12%



- **Stress distribution**

  May change the failure mode thus may play a beneficial role in structural design

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Concluding Remarks

- The next generation aircraft will require to be **lighter, more flexible and sustainable**, with the same or increased level of safety.
- The relaxation of some of the established design constraints, together with the use of **new lightweight and recyclable materials**, can contribute to the development of new breakthrough technologies and design philosophies.
- Structures able to work in the post-buckling field and able to adapt their shape during flight conditions will act on **two of the biggest levers for the future of clean aviation: reduced weight and increased efficiency**.
- **Advanced modelling and design tools** (multidisciplinary, validated…) are needed to predict the behavior of flexible and sustainable structures, including damage initiation and propagation until final failure.

Acknowledgement

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Thanks for your attention!

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