Holistically improving screening decisions under uncertainty in aircraft conceptual design and technology assessment

Insights on bottom-up uncertainty quantification and propagation and integrated socio-technical group decision making

Graduation presentation Bram Peerlings
29/08/2019, 14:00 – 15:00 hrs
TN F005

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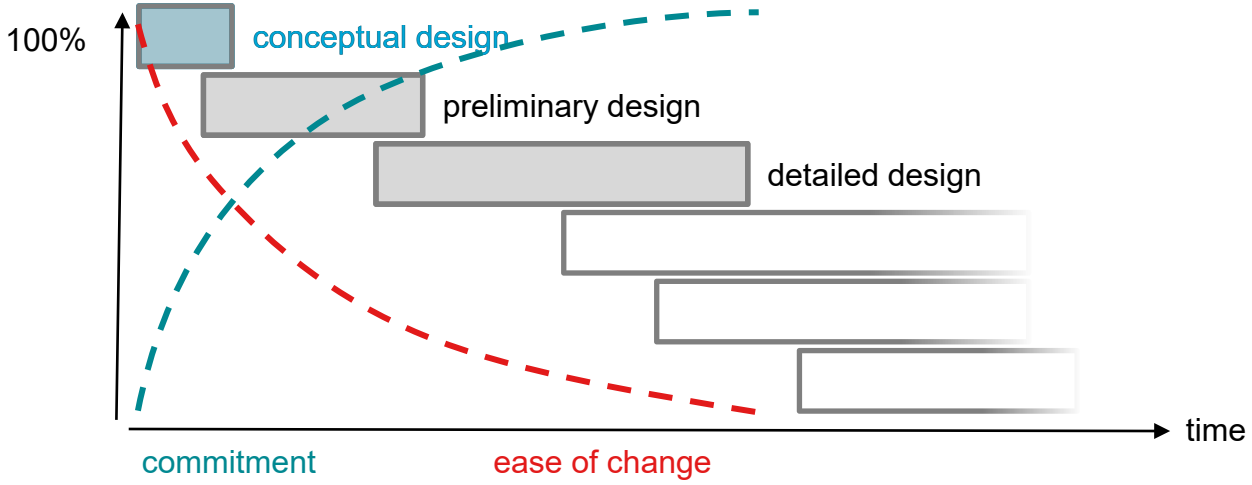
Three phases in aircraft design

"Get the aircraft right" early on



Based on Torenbeek (1982), Sadraey (2013), Jenkinson et al. (2013)

Good decisions are critically important

Make a contribution to holistically improving group decisions about technology assessment and selection under uncertainty in aircraft conceptual design

Outline

1. Decision quality
2. Technical perspective
3. Socio-psychological perspective
4. Integrated perspective
5. Closing

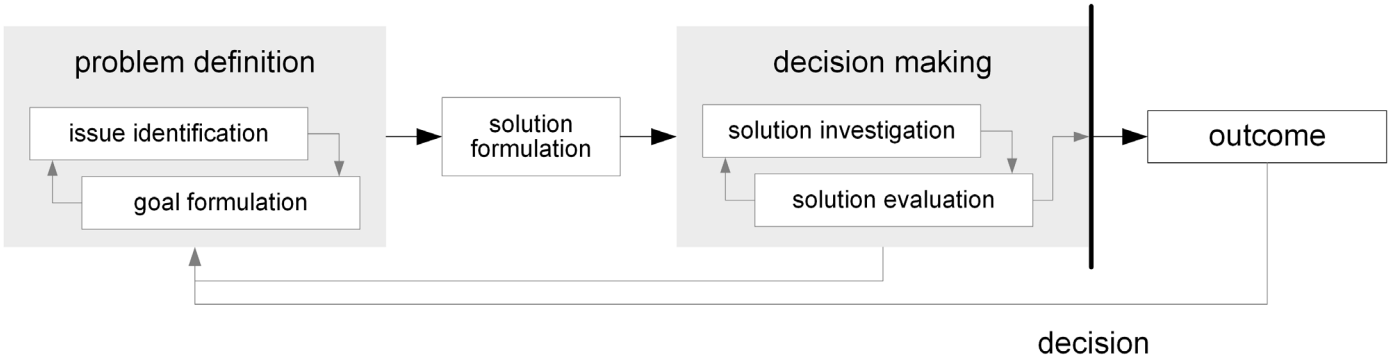
6. Questions

Decision quality

What factors contribute to high-quality group decisions?

Decisions and decision making

Within the larger problem solving process



- The process that starts with investigating and evaluating alternative solutions to some pre-set goal and ends right at the point where a decision is made and the decision makers commit to an action or approach
- The conclusion of the deliberation process

Based on Dewey (1910), Simon et al. (1987), Schulz-Hardt and Mojzisch (2012), Chang (2011), Elwyn and Miron-Shatz (2010)

Screening decisions and decision quality

- Screening decision — Go/no-go decision
- Decision quality — ……..

  No agreed-upon definition exists in literature

  Not outcome desirability

- Decision quality — The extent to which a (group of) decision maker(s) at the decision point can convince an ideal observer that the decision will yield the decision goal, insofar possible

Based on Cooper et al. (1997), Cooper (2009), Hammedi et al. (2013), Rausch & Anderson (2001), Chen & Chien (2009), Howard (1988), Baartmans and Kosolosky (2015), Kamis and Davern (2005), Amason (1996)

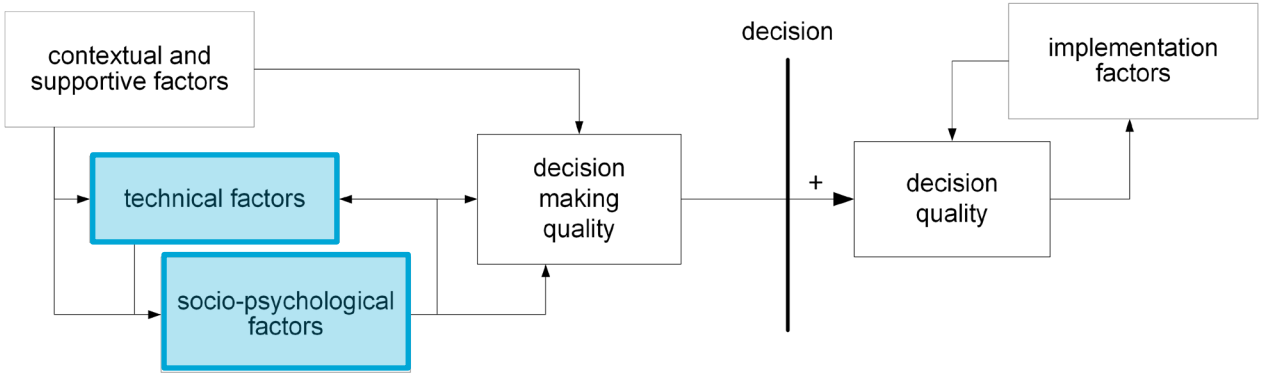
Ideal observer

- Transparent
- Independent
- Unaffected by (the outcomes of) the decision

- Balances objectivity and trust
  - Low uncertainty Objectivity
  - High uncertainty Trust

Influences on decision quality

Obtained from systematic literature review



Technical perspective

How can model uncertainty be quantified, assessed and propagated bottom-up, that is, starting from model(ling) assumptions, simplifications and limitations?

Computational aerodynamics

Determining flow characteristics without experiments

- Flow model — Physical description of a flow
- Solution method — Mathematical procedure to solve the flow model
  Tightly coupled to the flow model
  +
- Solver — Combination of flow model and solution method

- Different solvers exist, at different levels of accuracy and computational cost

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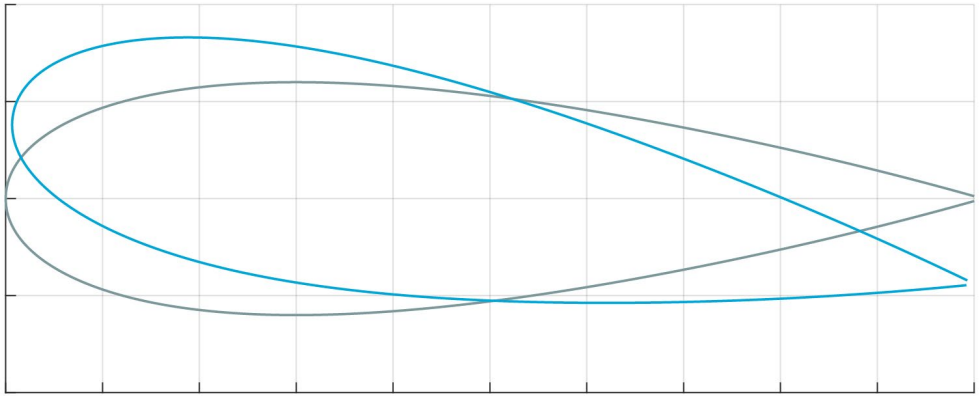
Uncertainty quantification

What uncertainties in the model output do the assumptions, simplifications and limitations of aerodynamic flow models and solution methods introduce?

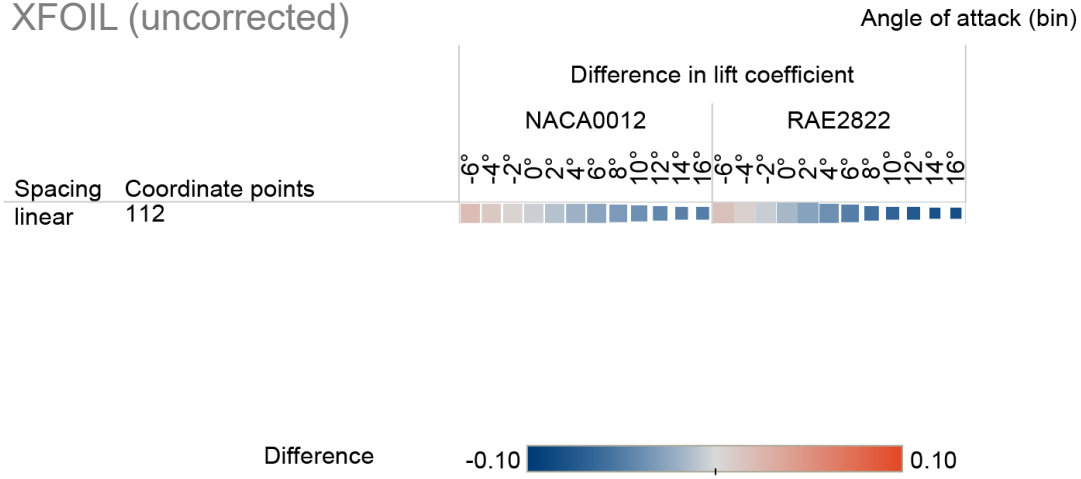
Approach



Jacobs et al. (1933), Cook et al. (1979)

Results: Influence of solution method

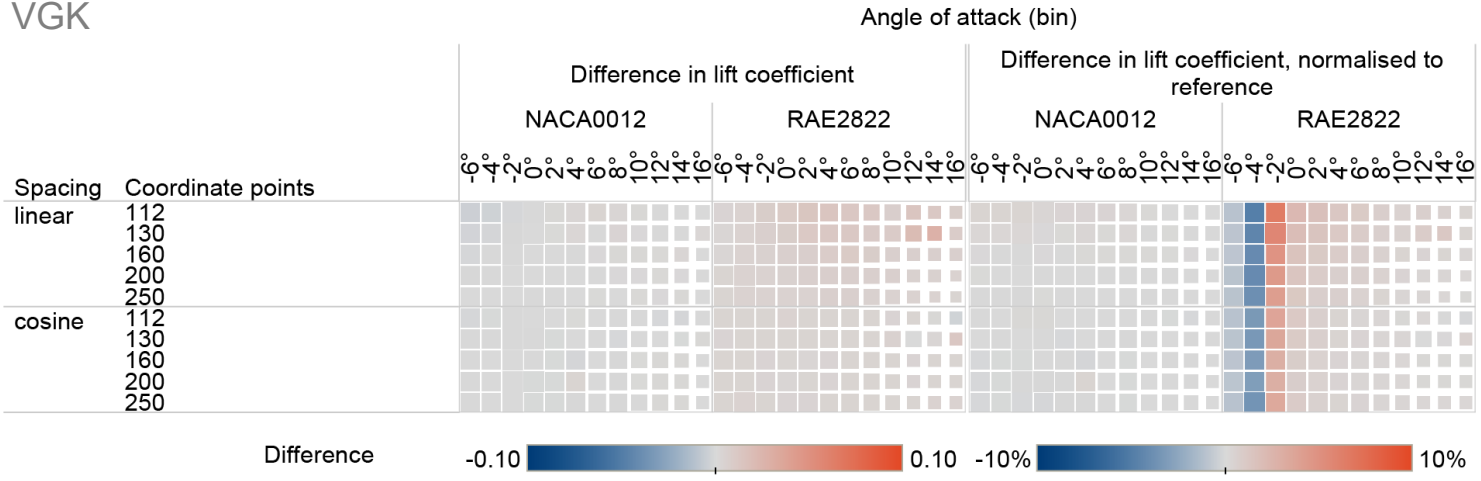
XFOIL (uncorrected)



- Clear relation with α
- Clear relation with number of coordinate points
- M_∞ only influences convergence

Results: Influence of solution method

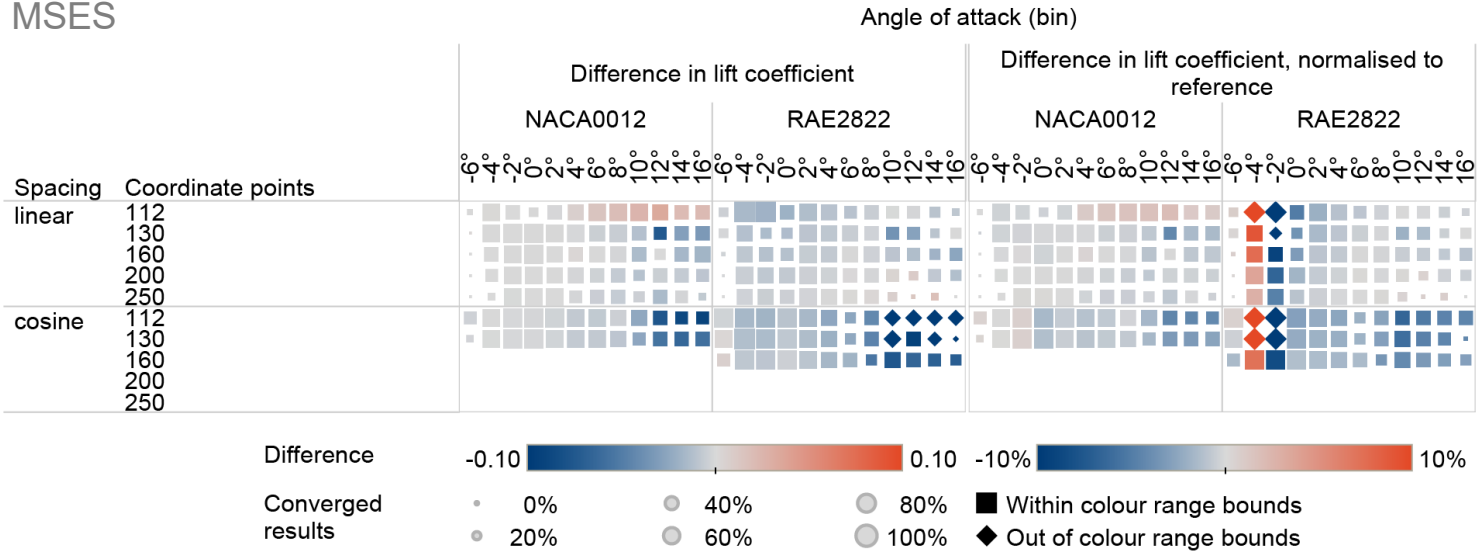
VGK



- Little influence of number of coordinate points and spacing
- Clearer dependence on geometry
- Lower influence of α, slight dependence on M_∞

Results: Influence of solution method

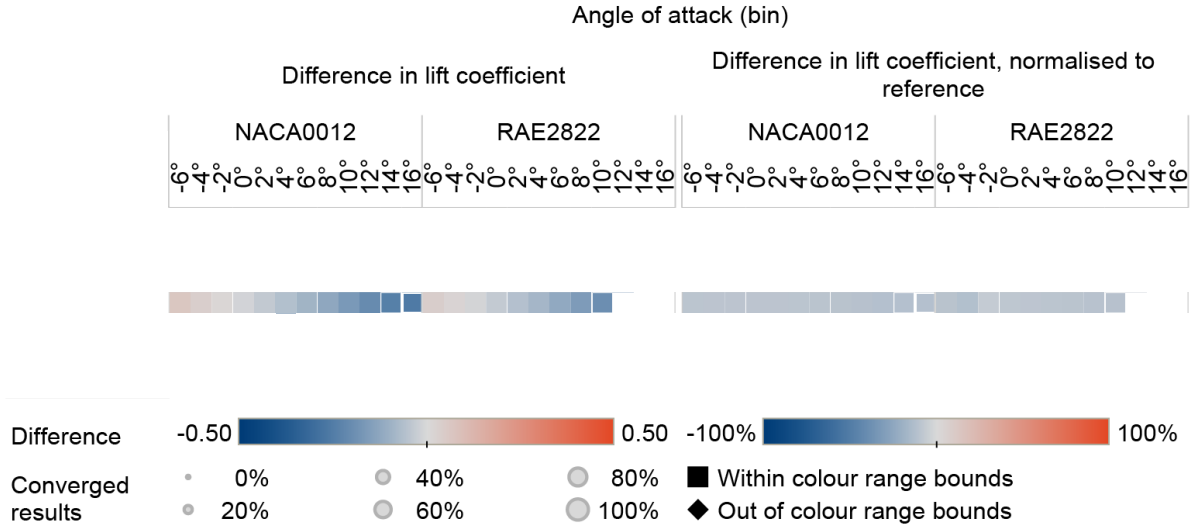
MSES



- Much more erratic results and larger differences
- Lower number of converged results, especially at higher cosine-spacings

Results: Influence of flow model

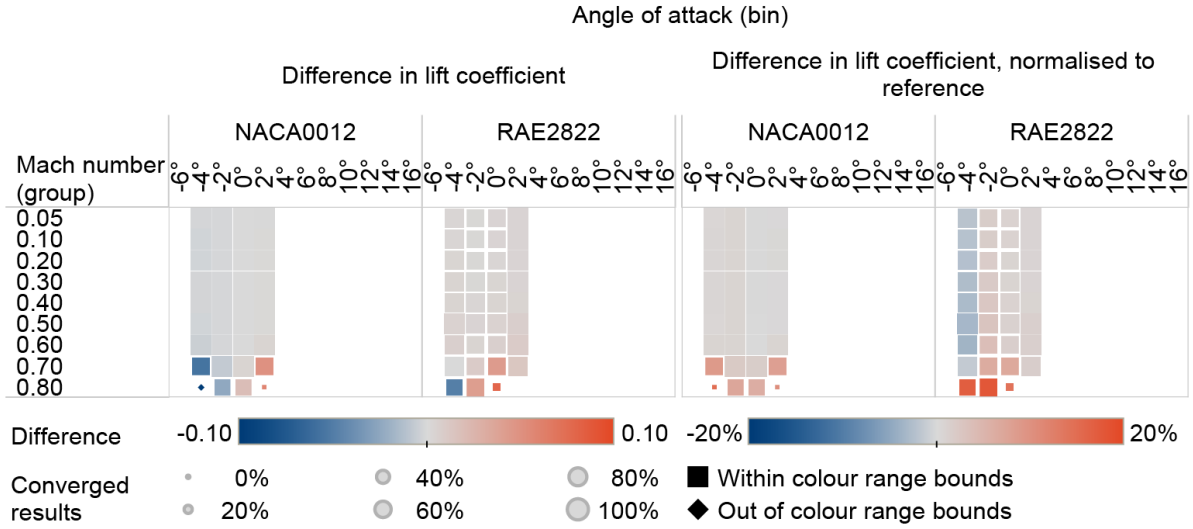
Incompressible flow assumption (XFOIL versus VGK)



- Clear relation with α
- Geometry causes shift in α, rather than substantial differences in magnitudes

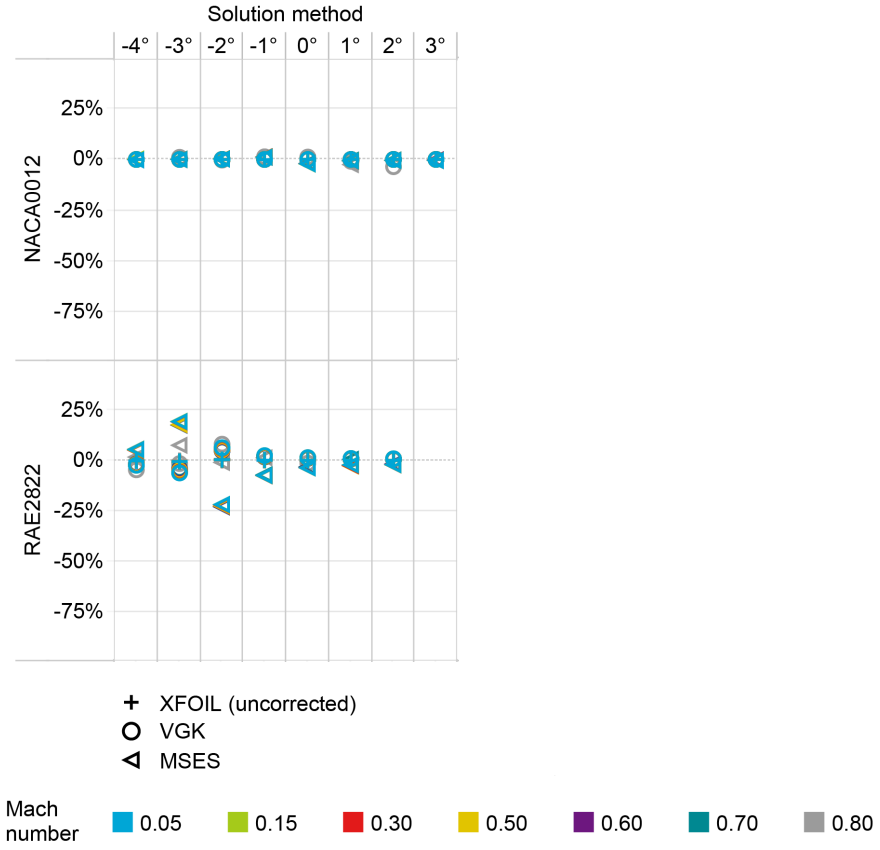
Results: Influence of flow model

Irrotational flow assumption (VGK versus MSES)



- Limited in α due to problems with MSES
- Reduced influence of M_∞
- Caused by differences in shock modelling (strength and location)

Results: Solution method and flow model compared



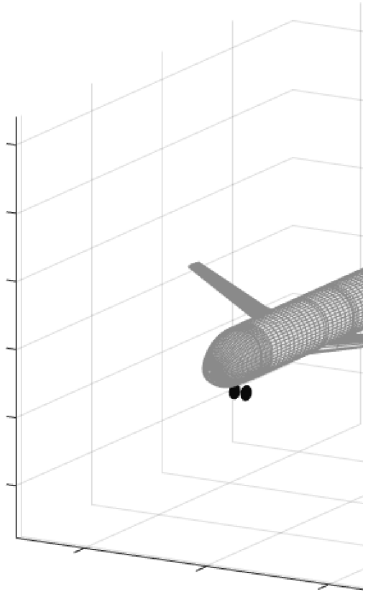
- Little influence of solution method
- Larger influence of flow model, more dependent on α and M_∞
- Impact of incompressible flow □ assumption much larger than irrotational flow ◇ assumption

Uncertainty propagation

How do two-dimensional aerodynamic model uncertainties propagate to three dimensions – at wing- and aircraft-level?

Approach

Qualitative rather than quantitative analysis



Results: wing-level

- Three-dimensional results are consistent with two-dimensional results
  - Variation with α and M_∞
  - Incompressible flow assumption $\gg$ irrotational flow assumption
- Three-dimensional characteristics affect influence of assumption
  - Aspect ratio — Increases influence
  - Sweep — Decreases influence
  - Taper — Increases influence

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Results: aircraft-level

- Highest impact on
  1. Aircraft-level lift and pitching moment derivatives
  2. Horizontal stabiliser mass, up to $\pm 6\%$
  3. Location of neutral point, up to $\pm 5\%$
- True high-level impact (MTOM, OEM, fuel mass) limited to $\approx 1\%$
- High-level impact is lower than band of uncertainty associated to aircraft analysis suite (ADI)
  - No definitive conclusion about the impact of assumptions on conceptual design in general

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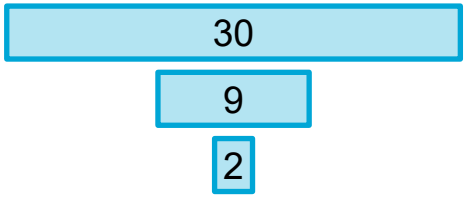
Socio-psychological perspective

How can a (combination of) relevant socio-psychological factors negatively impacting group decision quality be combined in a conceptual model and subsequent tool that helps to understand and mitigate that impact?

Project description

- “Make a contribution to the technology maturation TRL 1-3 to TRL 4-5 for novel aircraft movable concepts that will contribute to […]
  3 to 5% aircraft fuel burn reduction”
- 6 years, 4 major phases
  1. Idea generation
  2. Performance assessment
  3. Down-selection
  4. Further development



Project characteristics

- European public-private partnership
  - 2 industrial partners, 2 research institutes, 1 university
  - 2 involved ‘topic leaders’

- Different roles
- Different (sub)goals
- Different agendas
- Different relationships

} complex project

Problem statement

The quality of screening decisions in the project is negatively impacted by the fact that goal uncertainty exists and is not sufficiently explicated, reduced or otherwise managed

- Results in industrial / business goals trumping project goals
- Hinders transparency and prevents decision quality assessment and improvement

Problem identified is not limited to current project or context

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Theoretical framework

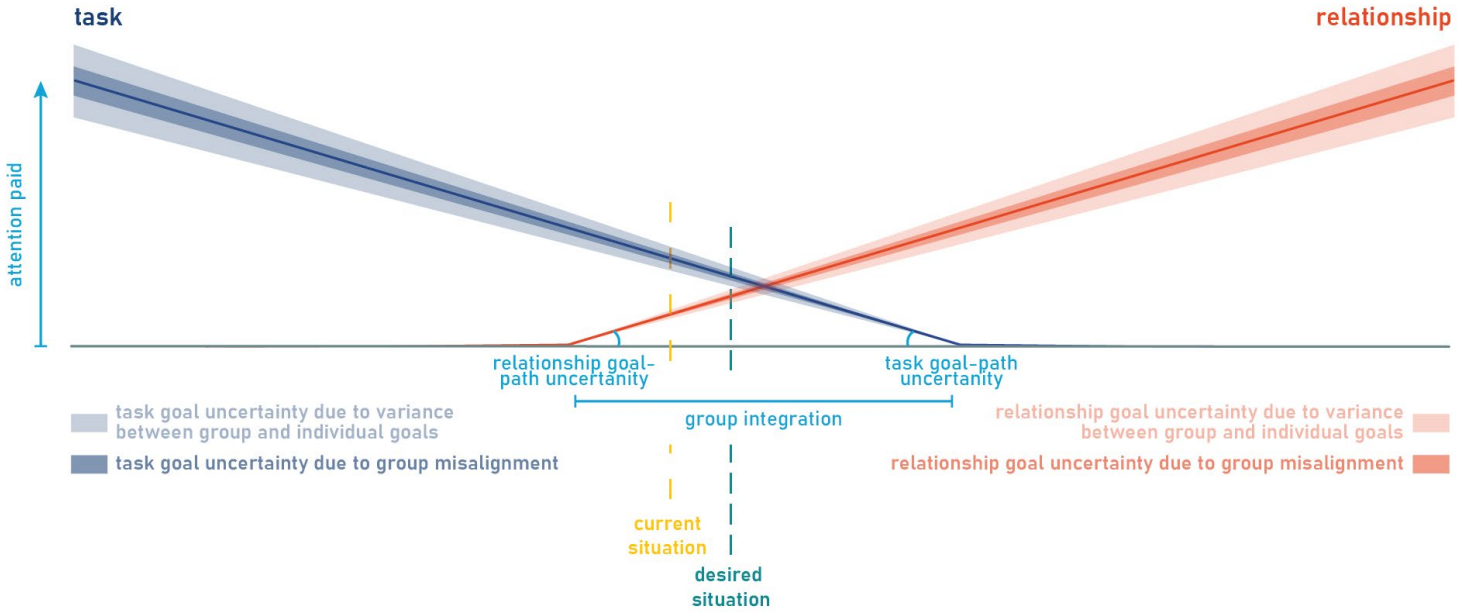
Vigilant interaction theory and *effective intercultural workgroup communication theory*

- Decision quality is improved if decision making is ‘vigilant’ and people show critical thinking
- Decision making processes yield both task and relationship outcomes, which various people value differently
  - ‘West’ versus ‘East’
  - Individualist versus collectivist
  - Independent versus interdependent
- Groups need to achieve balance between task and relationship outcomes

Hirokawa and Rost (1982), Hirokawa and Scheerhorn (1986), Schulz et al. (1995), Sassenberg et al. (2014), Janis (1989), Salazar (2009), Larson Jr. et al. (1998), McLeod (2013), Oetzel (1995, 2005, 2007), Markus & Kitayama (1991), Hofstede (1984), Triandis et al. (1990), Triandis (1995)

TARE-model

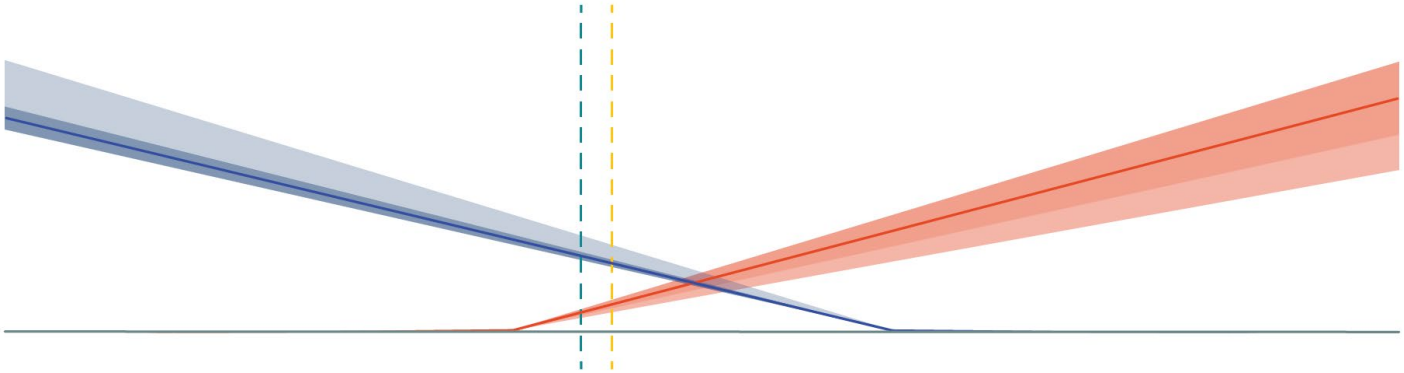
Balancing task and relationship outcomes under various forms of uncertainty



Suggested use of the TARE-model

Possible use in three phases

1. Collection — of participants' perspectives and goals
2. Aggregation — of individual participants' perspectives to a group spread / average
3. Evaluation — with the group, to explicate uncertainties, balance and (mis)alignment



Integrated perspective

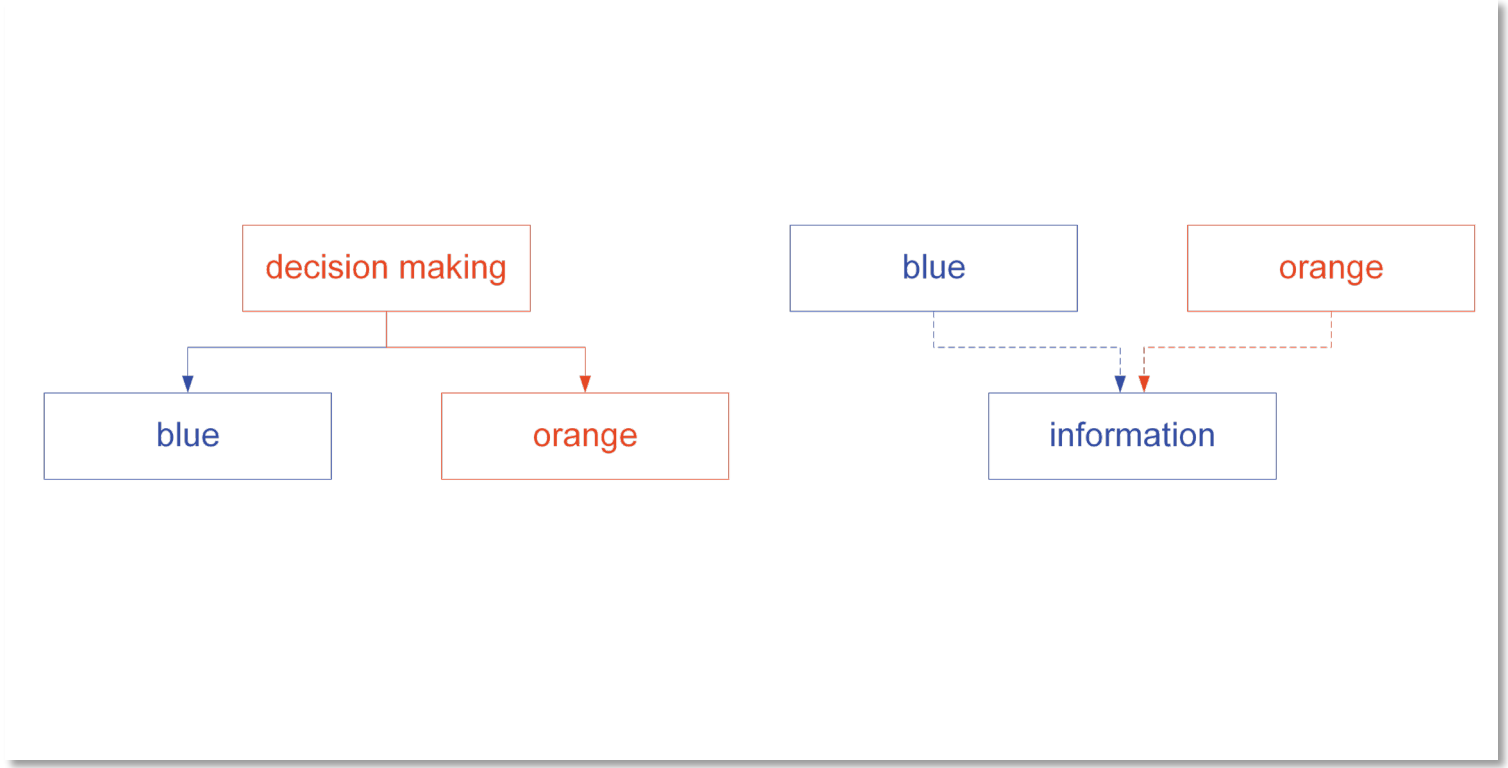
How can technical and socio-psychological perspectives be integrated in order to improve group decision quality under uncertainty in aircraft conceptual design and technology assessment and selection?

A recurring theme

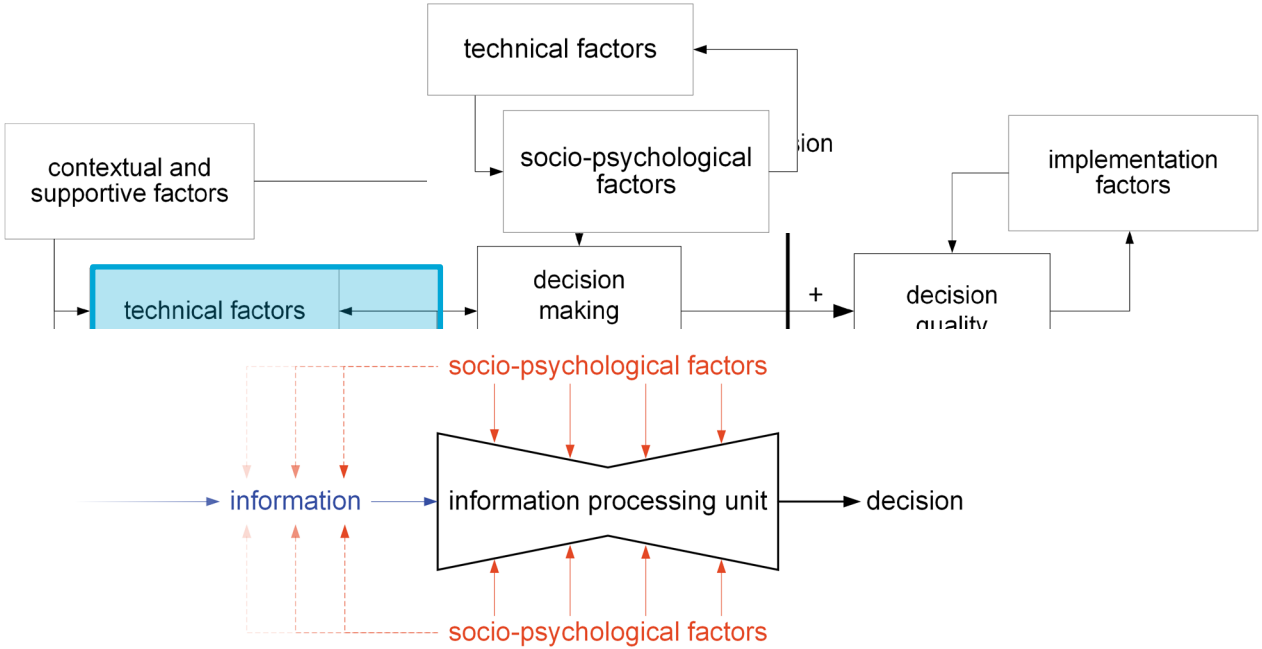
Objectivity	Trust
Technical factors	Socio-psychological factors
Task outcomes	Relationship outcomes

- Instinctively related
- Not identical
  - Possible to completely focus on task
  - Impossible to neglect socio-psychological factors

Blue and orange

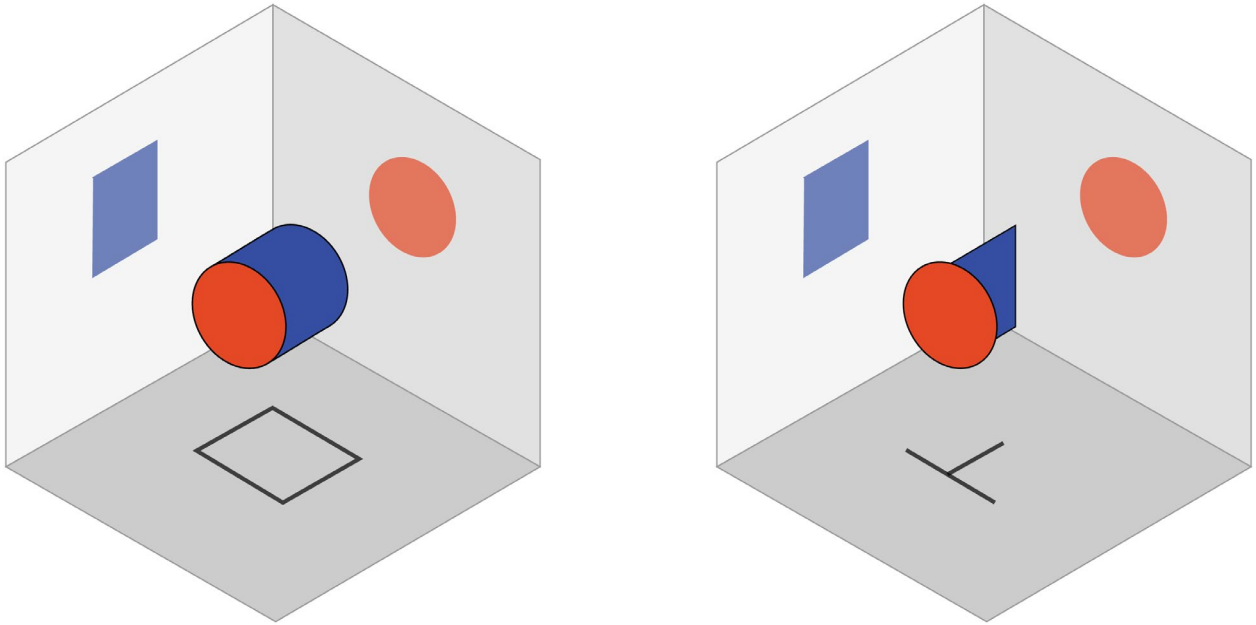


Updated interrelation



‘Blue’ and ‘orange’ are projections

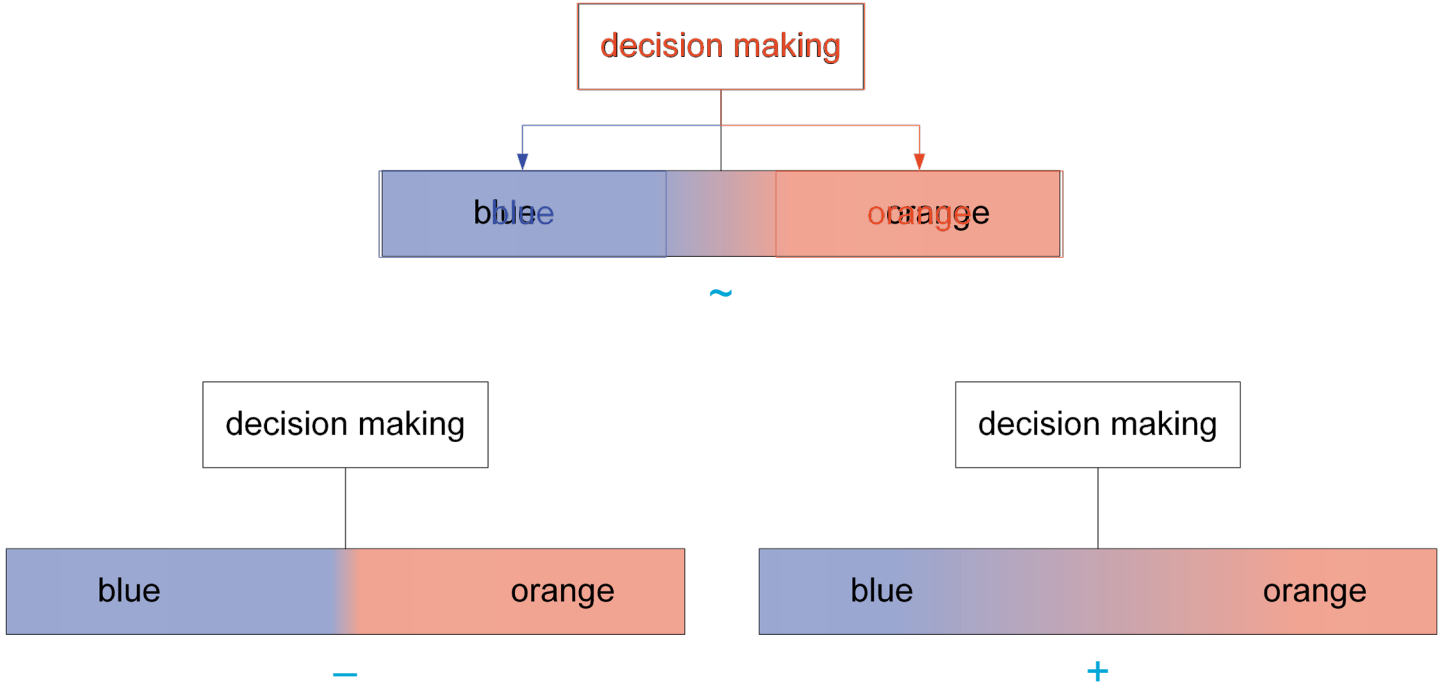
But of which 3D-object?



Based on StareCat

What about uncertainty?

Propose to guide interwovenness of blue and orange



Closing

Conclusions

- Technical and socio-psychological factors contribute to high-quality group decisions
- Model uncertainty can be quantified bottom-up using systematic comparisons, scaling and correction factors – separating flow model and solution method
- The TARE-model aims to explicate uncertainty about project goals, which negatively influences decision quality
- Technical and socio-psychological perspectives are already integrated
  - They can be distinguished, but not taken apart
  - Group decision quality can be improved by recognising this integration

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Implications

- Current trends in computational aerodynamics move towards earlier use of higher-fidelity models
- In the ADI, two very fundamental flow assumptions have no clear impact
- Yet, the ADI has been used for conceptual design successfully
- **Is higher-fidelity conceptual design really the best way forward?**

- In the project studied, not all decisions are based on analytical results
- **Shouldn't we rather spend more attention to socio-psychological factors?**

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Opportunities

In research and in practice

- Validation and testing
  - Schematics of decision making and ‘information processing unit’
  - TARE-model and proposed use
- Further developing a (web-based) TARE-tool
- Analysing the influence of viscous flow models and solution methods
- Developing a meta-model, based on current (and additional) results
- Finding uniform terms for ‘blue’ and ‘orange’ – if possible
- Increasing recognition for the inseparable socio-psychological perspective – especially in technical contexts

Thank you for your attention!

Questions?

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