Quantitative grading of store separation trajectories

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Outline

- Background and requirements for store separation analyses
- Acceptance criteria for store separation & jettison
- Approaches for assessing separation dynamics
- Development of quantitative separation criteria
- Implementation of separation grading algorithm
- Applications
- Conclusions

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Background and requirements for store separation analyses

Comprehensive aero/mechanical compatibility evaluation must be done when integrating stores onto aircraft

- MIL-HDBK-244A Guide to aircraft/stores compatibility 1990
- MIL-HDBK-1763 Aircraft-stores compatibility 1998

Why? Ensure that:

- All aircraft/store combinations have acceptable aerodynamic, structural, dynamic characteristics
  - under all flight and ground conditions.
- Ensure safety & minimise risk of functional failure

Aspects include:

- Carriage loads
- Aeroelastic (flutter) compatibility
- **Store separation safety**
- Performance & handling

Hawk picture copyright Frans Dely

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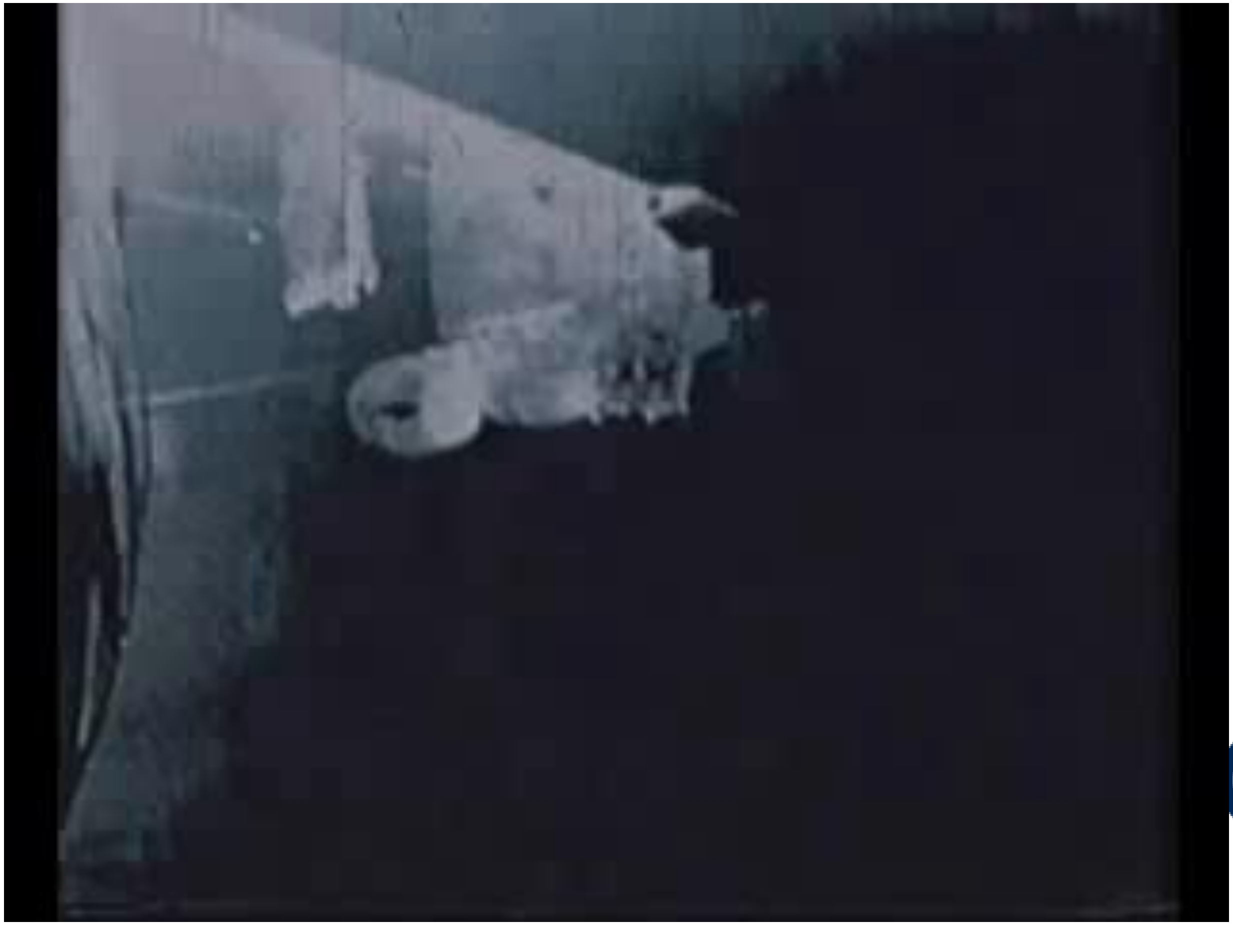
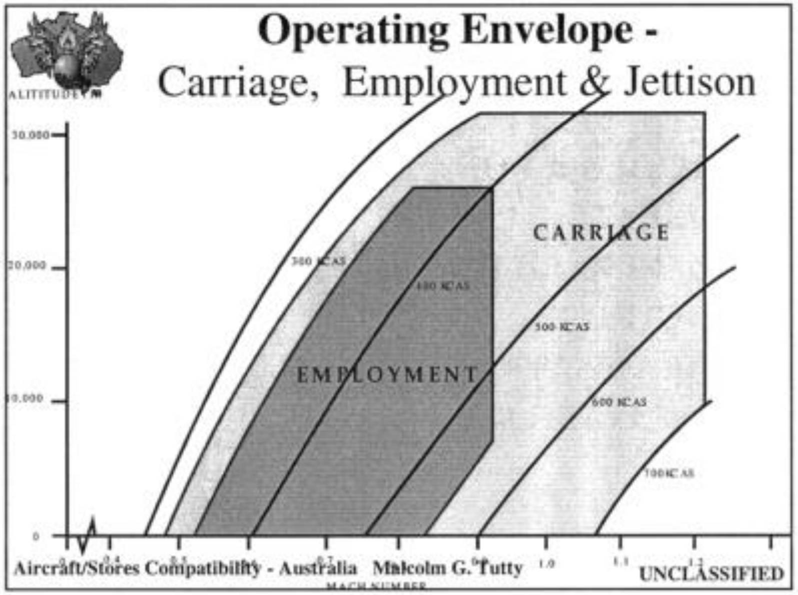
Background and requirements for store separation analyses

- Why are store separation analyses required?
  - Based on painful experience: stores that are individually stable can behave VERY differently in aircraft flowfield



Background and requirements for store separation analyses

- Requirement for store separation analyses - MIL-HDBK-244A § 5.1.1.2.3.1(g) ; MIL-HDBK 1763: 271.4
  - Verify that stores can be released safety over full employment & jettison envelopes
    - Includes all perturbations of:
      - store mass and physical properties
      - ejector rack performance
      - aircraft release flight conditions
      - stations on aircraft
      - neighbouring stores
      - Etc.
  - Results in a very large analysis matrix!



From: Tutty, M.G., “Aircraft/Stores Compatibility - The Australian Perspective”, 1998

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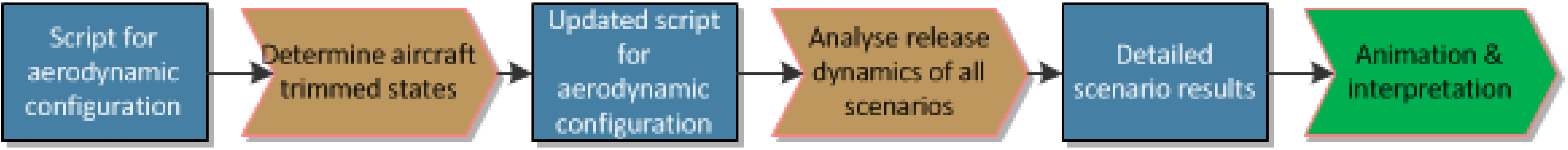
Acceptance criteria for store separation & jettison

- Typical process flow for store separation analyses



  – Often automated to run multitude of separation scenarios

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Acceptance criteria for store separation & jettison

MIL-HDBK-1763 discriminates between two classes of store separation with differing acceptance criteria:

Employment

(store operated in its normal mode to accomplish operational objective)

- Positive movement away from aircraft
- No part of store penetrates interference boundary of aircraft

  6 inch (152 mm) encapsulation
- Portions of store inside boundary prohibited further encroachment. Once outside no part of the store may re-enter.
- In vicinity of aircraft empennage, encapsulation boundary is expanded to ten (10) feet minimum.

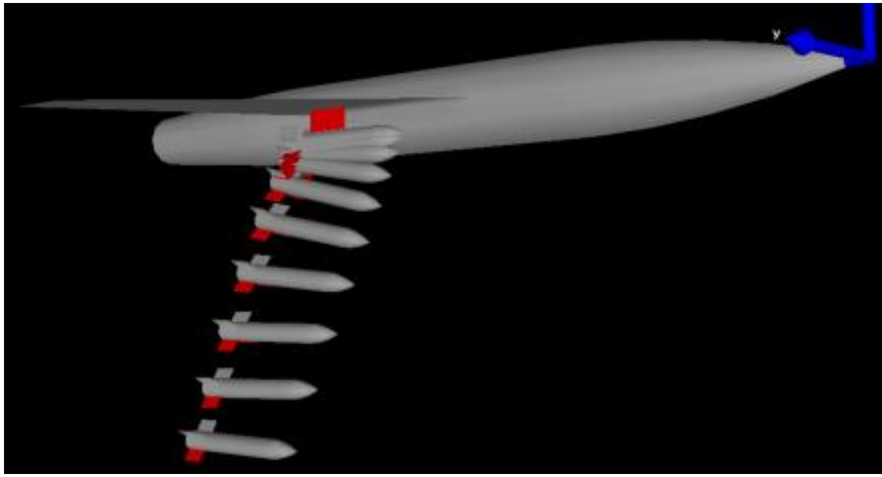
Jettison

(simply separate the stores from aircraft for safety or performance reasons)

- Must be safe, not necessarily satisfactory
- For non-emergency jettison store-to-aircraft contact is unacceptable.
- For emergency, minor store-to-store or store-to-aircraft contact may be acceptable.
- Store may break up, but should not threaten aircraft

Approaches for assessing separation dynamics

- Traditional approach: qualitative assessment of animations & graphs
  - Objections:
    - inconsistent & subjective
    - Analysts easily overwhelmed by volume of results from automated tools
- Need for automated tool to grade separation trajectories quantitatively to criteria traced to regulatory requirements
- Example: BAE CRASH 3D (Akroyd 1998)
  - Determines closest approach point between aircraft & store
  - Focuses solely on separation distance between store & aircraft
  - Criterion for positive movement away from aircraft not evaluated
  - No graduation in criteria



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Development of quantitative separation criteria

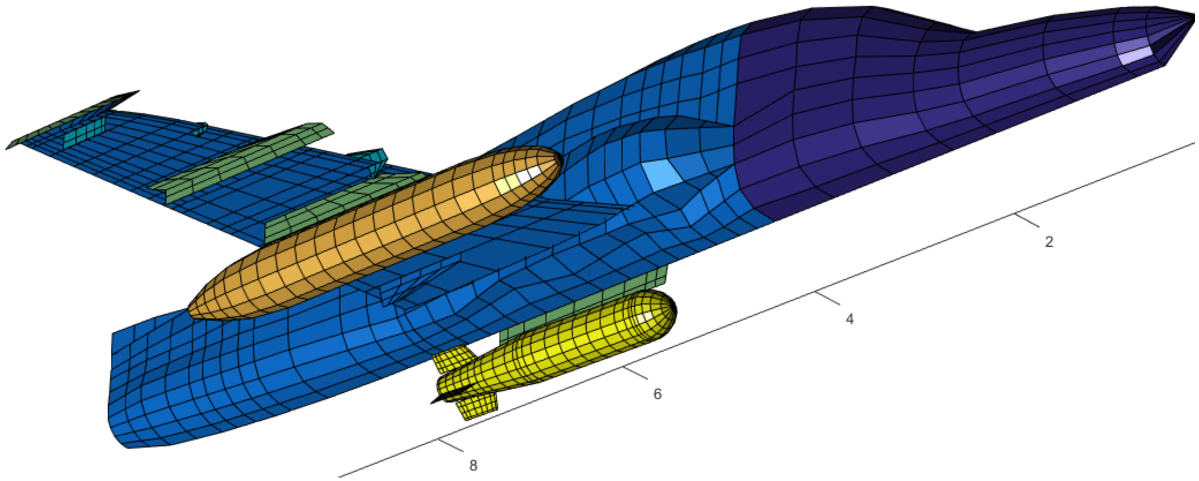
- No recent papers on topic
  - Schoch (1969(& Covert (1971) present criteria to assess separation acceptability based on initial velocities & accelerations after ejection
    - Analytical criteria supported by available test data
    - Used to judge entire separation trajectory
    - No longer used as entire trajectory can easily be computed nowadays
- Set of separation rating codes proposed based on experience
  - Applicable for ejector released stores; a different scale is required for rail released stores using similar philosophy
  - Need for automated tool to grade separation trajectories quantitatively to criteria traced to regulatory requirements
- Rating codes supported by quantitative analytical criteria
  - Correlates with regulations
  - Developed & refined iteratively over time

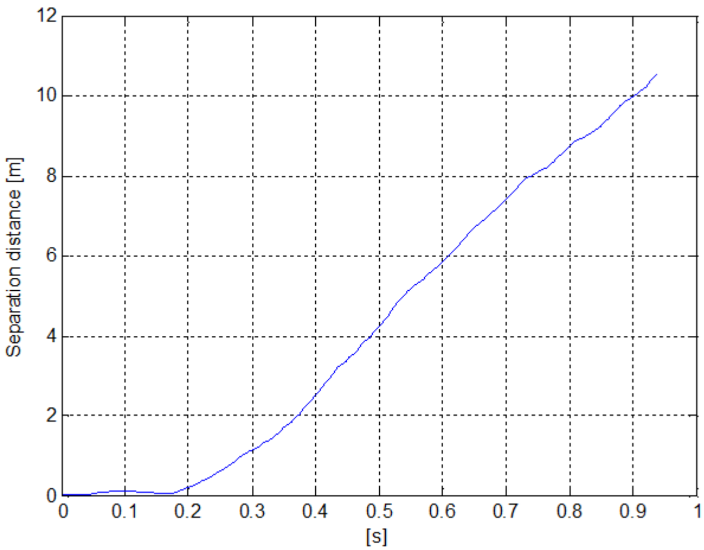
Code	Definition
0	Store strikes some part of the aircraft
1	Store misses the aircraft marginally
2	Store moves towards the aircraft
3	Store "hovers" near the aircraft
4	Store separates cleanly from the aircraft

Code	Absolute Separation Distance	Separation Velocity	Separation Velocity Relative to Ejection Velocity
0	< 0		
1	< 0.020 after 0.07 s < store radius after 0.25 s	< 0 before 0.06 s	
2		< 0	
3			< 0.3 Veject after 0.07 s
4			

Implementation of quantitative separation criteria

- Separation grading implemented as separate function in CSIR's automated store separation code, MRCS
- As ARUV panel code model usually created for store separation projects, used panelling of the aircraft and the store to define the geometries to calculate miss distances
  - Algorithm slices aircraft & store trajectories into 5 ms intervals
  - At each time interval calculate the distance of all store panel corners from all aircraft panel corners
  - Shortest distance at each time interval is miss distance for that interval





Implementation of quantitative separation criteria

Employment envelope

- Release codes 3 & 4 acceptable.
- Controllable limitations may be specified to obtain codes of ≥ 3 over wider envelope

Jettison envelope

- Release codes ≥ 1 acceptable
- Contact with the aircraft only acceptable during emergency jettison if relative velocities are very low
- Controllable limitations may be specified to widen envelope

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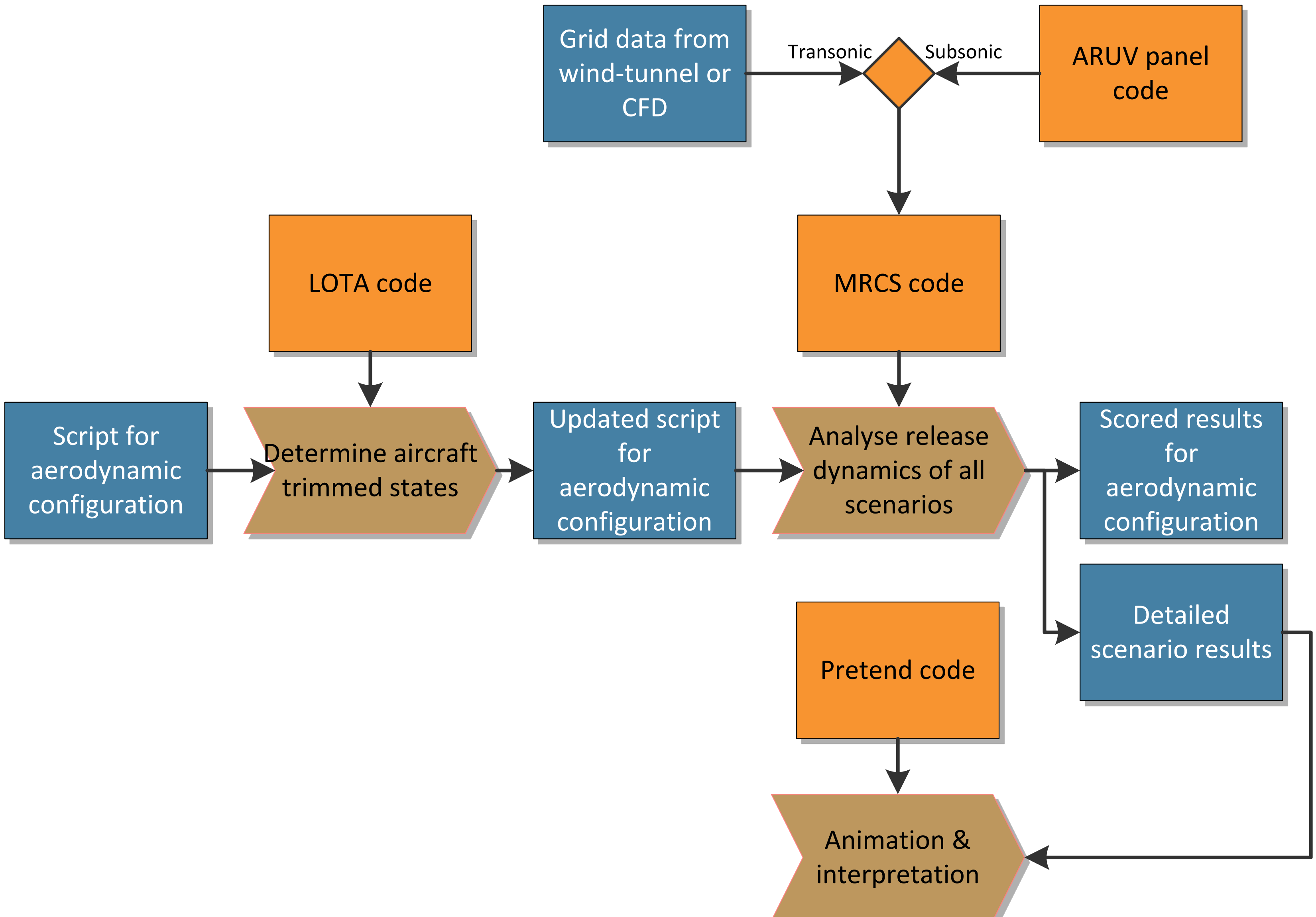
Application of grading in automated separation analyses



Application of grading in automated separation analyses

- Example: emergency jettison analysis of CSIR's Inundu electronics pod from BAE Hawk Mk.120
  - Inundu is airborne pod capable of mimicking radar emissions of threat aircraft/missiles and radar jamming
    - Being developed for aggressor training & electronics test and evaluation
  - Integrated on centreline station with & without drop tanks
  - Pod can accommodate different modular payloads – variable CG & mass (±5% mass variation)
  - Pod is self-powered using Ram-Air Turbine (causes asymmetric aerodynamic properties)
- Goal: determine widest permissible emergency jettison envelope
- Cost constraint: use panel code hence only subsonic jettison envelope considered

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Application of grading in automated separation analyses

- Separation analysis script
  - Excel file with rows specifying each release scenario
  - Even jettison analysis has hundreds of scenario combinations
  - Use Modern Design of Experiments (MDOE) to optimise scenario combinations
  - Aircraft manual used to determine angles of attack

Envelope point	Mach No.	Alt	Nz	Ejector force setting	Flight Path Angle	Bank Angle	Roll rate	Store Mass	Store cg-x	Aircraft Mass
		(ft)	(x 1g)	(%)	(deg)	(deg)	(deg/s)	(kg)	(m)	(kg)

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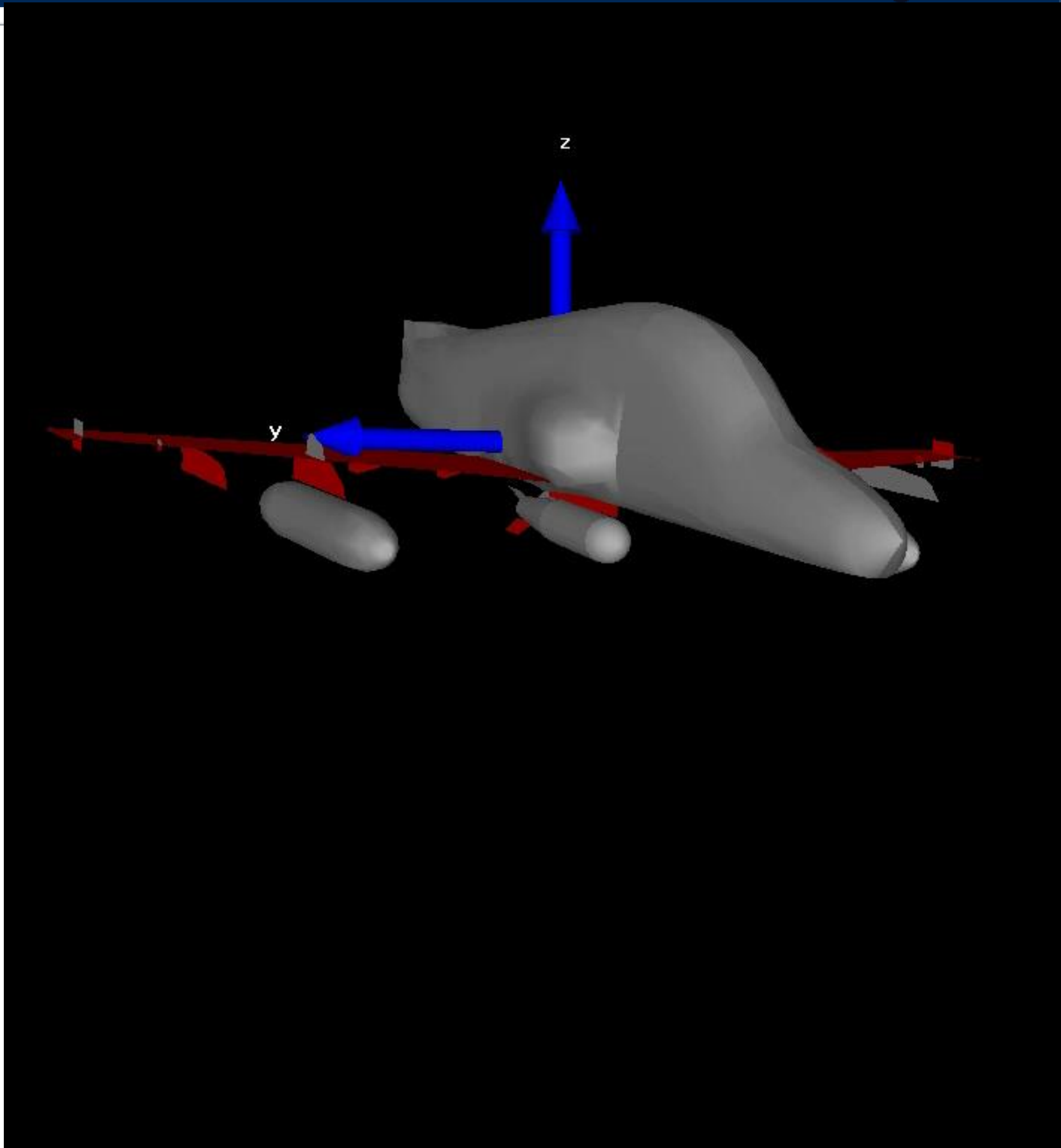
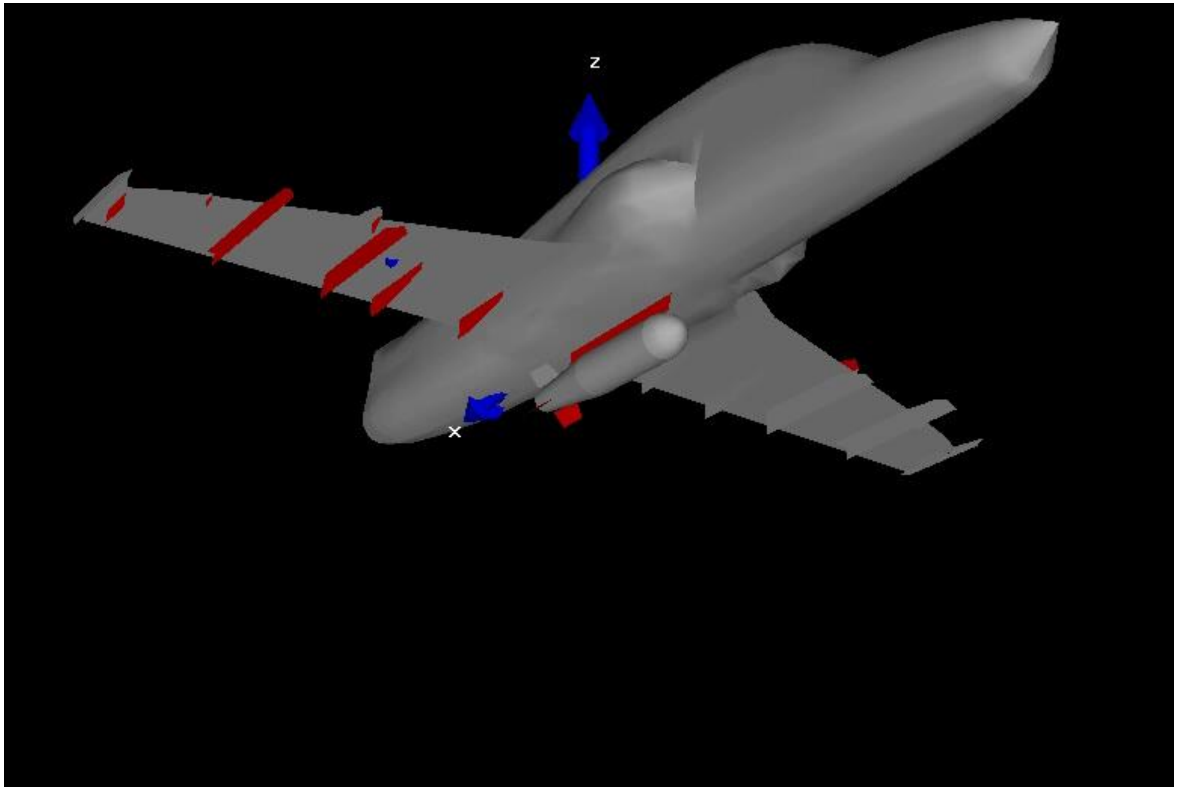
Application of grading in automated separation analyses

- Result examples
  - Nominal Code 4: biased T55-T37 ERU: Mach 0.665, sea-level, Nz = 1.5g, ERU = maximum, flight path = -10deg, bank angle = -10deg, roll rate = 10deg/s, store mass = minimum, store CG = front limit, aircraft 80% fuel



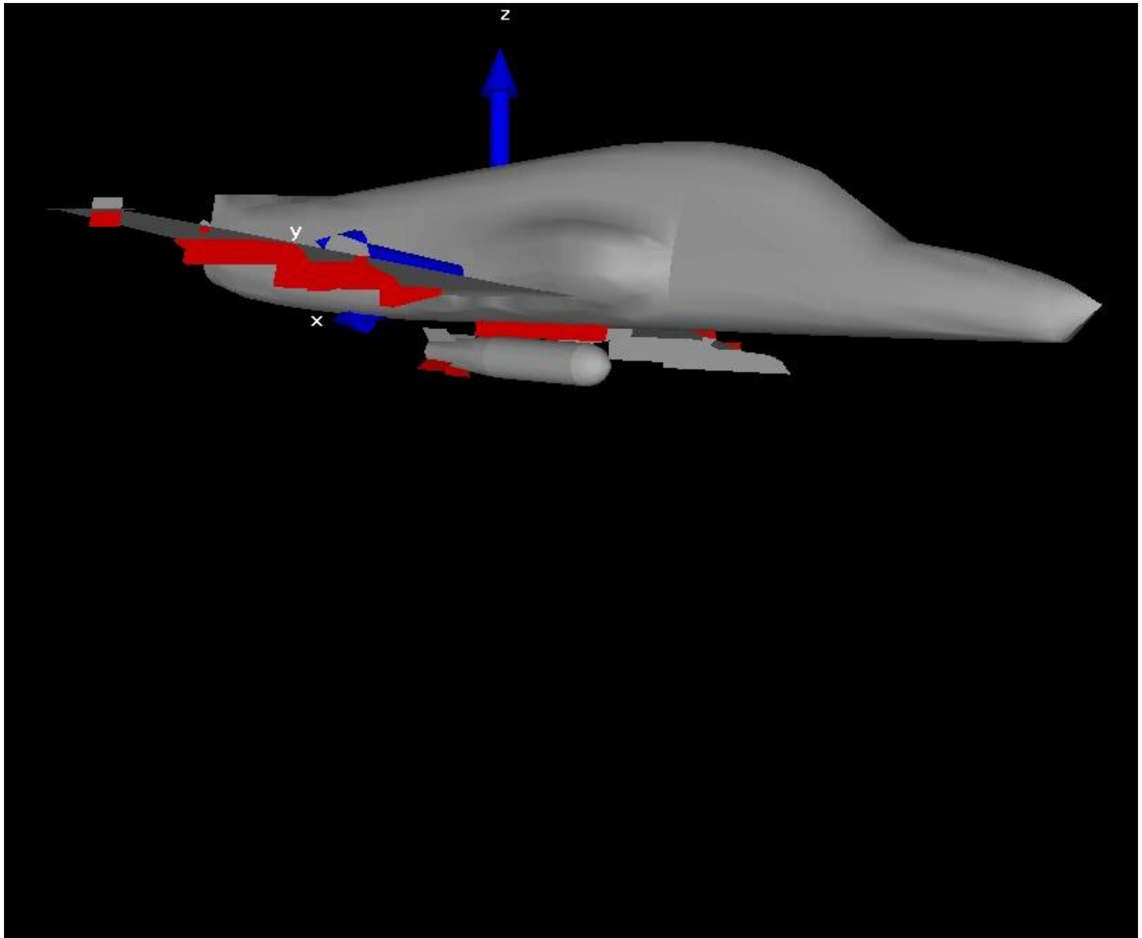
Application of grading in automated separation analyses

- Improvement due to biased ejector configuration
  - Original: Code 0: dual T37-T37 ejector throttles, Mach 0.665, sea-level, Nz = 0.5g, ERU = minimum, flight path = -10deg, bank angle = -10deg, roll rate = 10deg/s, store mass = minimum, store CG = front limit, aircraft 80% fuel



Application of grading in automated separation analyses

- Improvement due to biased ejector configuration
  - Improved: Code 2: T55-T37 ejector throttles, Mach 0.665, sea-level, Nz = 0.5g, ERU = minimum, flight path = -10deg, bank angle = -10deg, roll rate = 10deg/s, store mass = minimum, store CG = front limit, aircraft 80% fuel



Conclusions

- Development of automated, quantitative store separation trajectory grading algorithm described
  - Automation reduces time to analyse “aerodynamic” configuration from 1 month to 2 – 3 hours
  - Facilitates robust investigation of all perturbations required by regulations – increases safety
  - Reduces subjectivity due to manual interpretation of results
  - Clear criteria, agreed upon by all stakeholders facilitates common understanding of results
- Application to jettison analysis of electronics pod described
  - Found pod could not be acceptably jettisoned with ejector release unit (ERU) configured with dual T37 throttles. A biased ERU setup with T55 front & T37 rear throttles provided the largest acceptable jettison envelope
- Quantitative store separation trajectory grading algorithm has been applied with great success to multiple store integration projects at CSIR

Thank you