ANALYSING THE EFFECTS OF RIGID AND FLEXIBLE AIRCRAFT DYNAMICS ON THE EJECTION OF A LARGE STORE

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Aeronautical Systems Competency

Defence, Peace, Safety and Security (DPSS)

CSIR

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Objectives

- Present the process followed at CSIR to evaluate the integration of the Katleho PGM with the BAE Hawk Mk120
  - Emphasis on ejection dynamics
- Share some of the experience and lessons learned with the project

Outline

- Background to Hawk / Katleho project
- Requirements for integration evaluation
- Previous work in ejection dynamics
- The *AnalyseEjection* program
- Application to the Hawk/Katleho release
- Evaluation of effect of flexible & rigid aircraft dynamics on store release
- Closing the loop – comparison with flight tests
- Conclusions

Background to Hawk / Katleho project

- Katleho is a PGM under development by Denel Dynamics
- Hawk selected as platform for carriage & release testing
- Katleho on outboard pylon, Mk82 to balance

Requirements for evaluation of store integration

- Based on painful experience
  - Stores behave VERY differently in aircraft flowfield
- Regulations for military stores carriage and release:
  - MIL-HDBK-244A, 1990, which calls up MIL-HDBK-1763, 1998
- Requires evaluation of safe separation
  - Does not prescribe techniques or tools
  - Encourages use of similarity where justifiable
- Similarity cannot be justified for Katleho

A major factor in store release - ejection

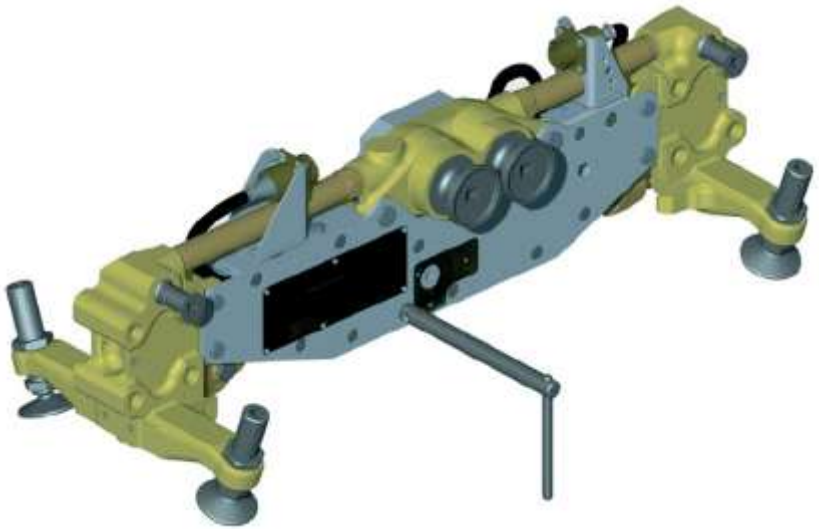


Illustration of the Hawk ERU-119 from the Cobham datasheet

- Pylons fitted with ejectors to propel stores rapidly away from aircraft
- Exert high forces (>30 kN) for short duration
- ERU forces + store weight release causes aircraft “g-jump”
- Period of ERU force is short enough to excite wing vibration modes
- ERU force/time & front/back force balance important for determining store separation rates from aircraft

The big questions

Would ejectors located well ahead of wing, on outboard pylon, accelerating a heavy store, induce significant **flexible response** affecting store release dynamics?

Would **aircraft roll** induced by the ejectors affect the store release dynamics?

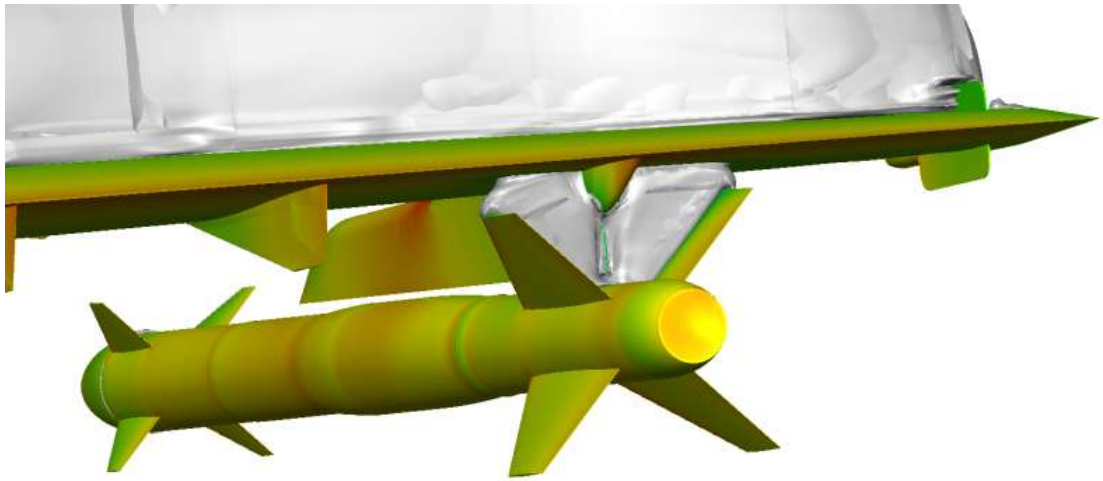
Is it necessary to model **both** rigid roll and flexible responses?

Previous work in flexible release dynamics

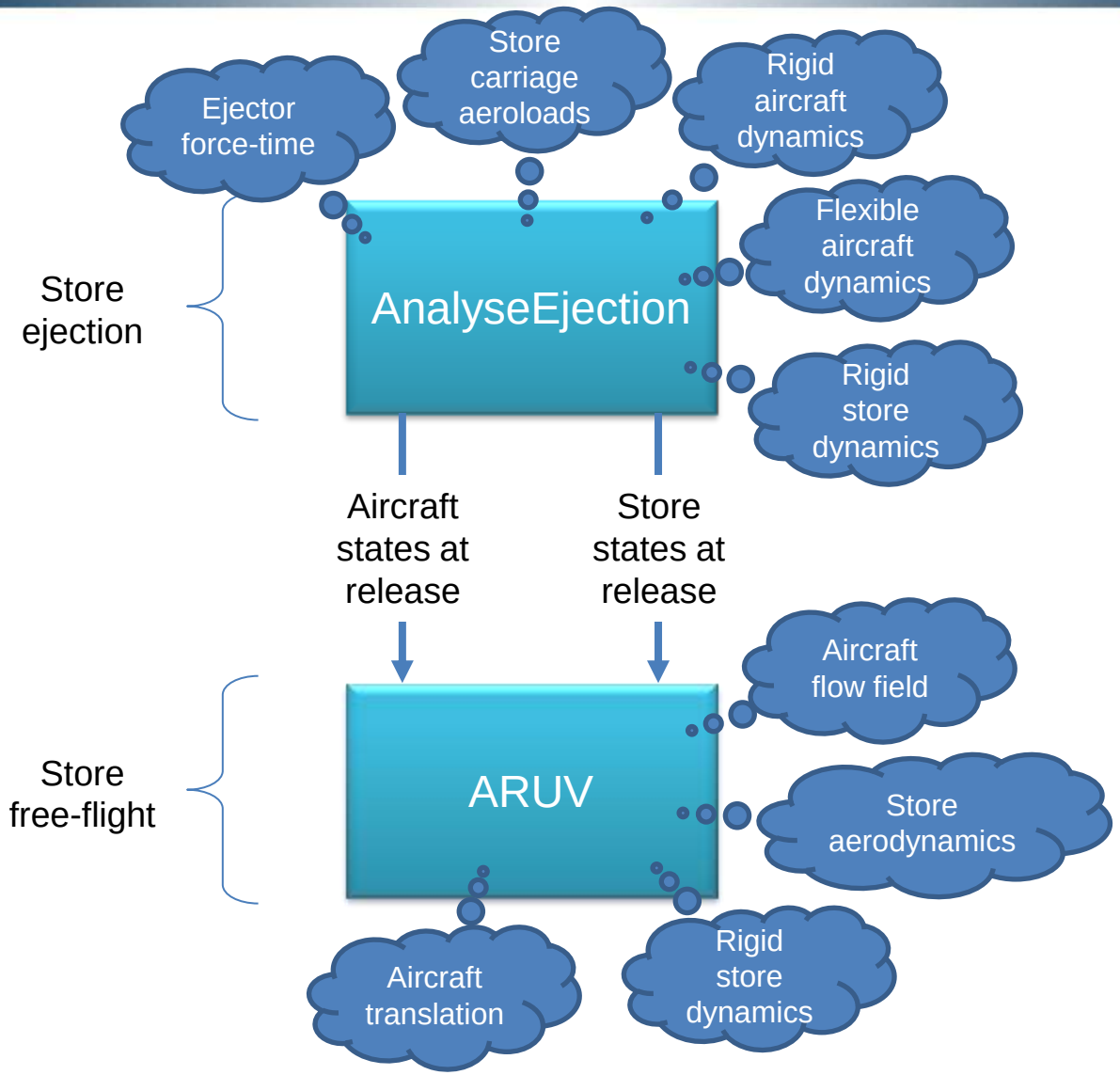
- Analytical
  - Modal analysis
    - Wallenius, H. & Lindberg, A., *Major Improvements In Stores Separation Analysis Using Flexible Aircraft*, ICAS 2010
  - ADAMS software package
    - Hetreed, C., et al, *Safe Separation Analysis of the Internal GBU-32 JDAM from JSF*, MSC. Software VPD Conference, 2006
- Empirical
  - Cenko, A. T., et al, *Use of Statistical Tolls to Improve Modelling and Simulation of Store Separation*, RTO AVT-108, Paper #13, 2004

The AnalyseEjection program

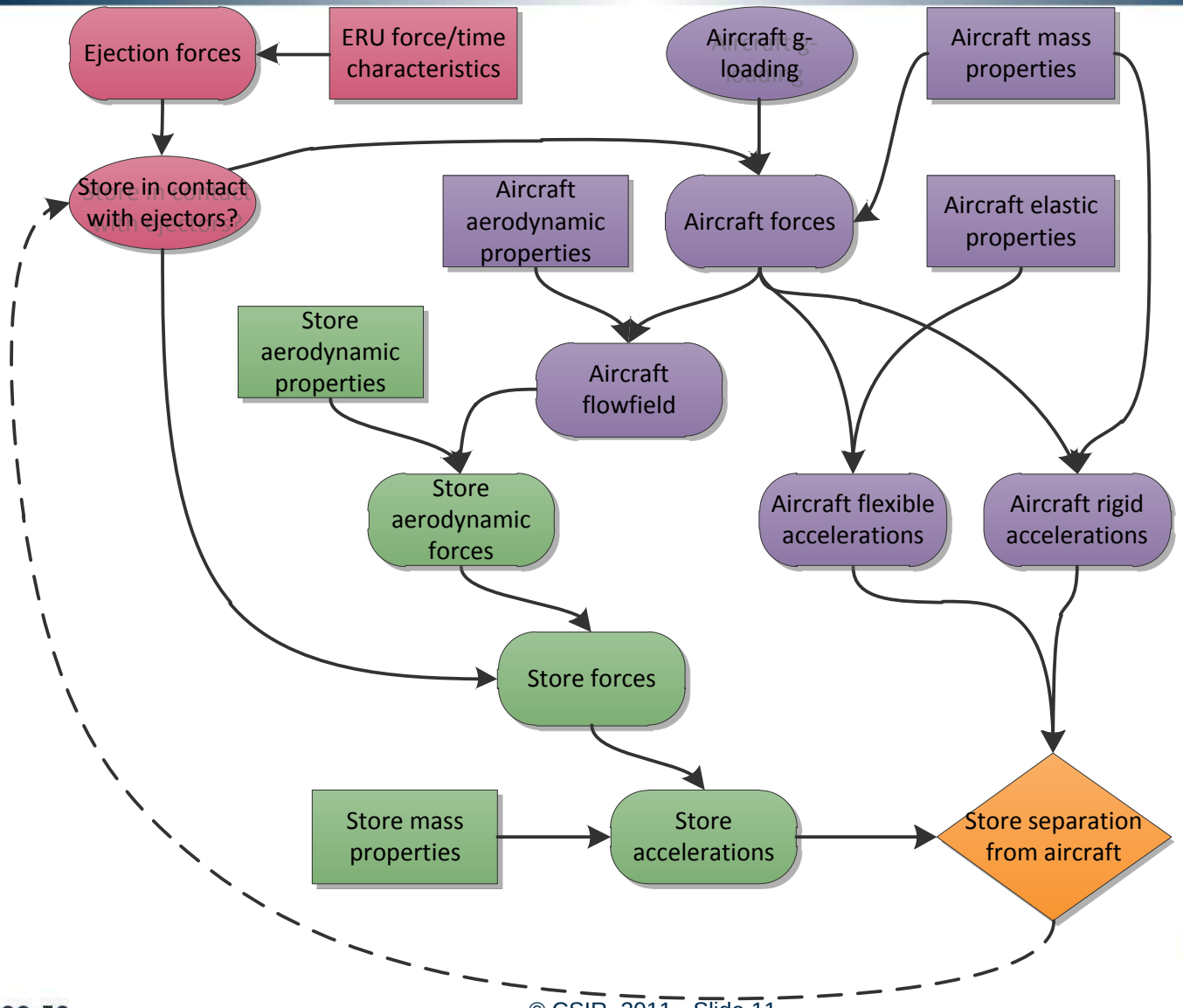
- Panel code *ARUV* usually used for store release analyses
  - But found significant transonic shock waves in carriage position
  - Needed to incorporate CFD results for near-field loads while using *ARUV* for far-field loads
  - *ARUV* limited in modelling ejection dynamics
- *AnalyseEjection* developed as pre-processor to *ARUV*



The AnalyseEjection tool

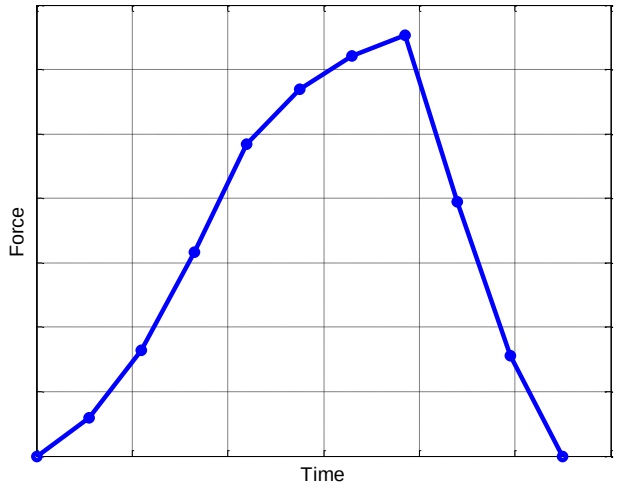


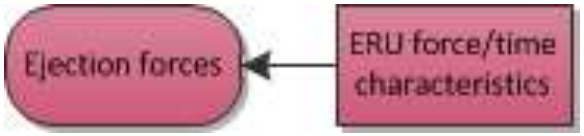
Factors influencing store release dynamics



Application to Hawk/Katleho - ERU forces

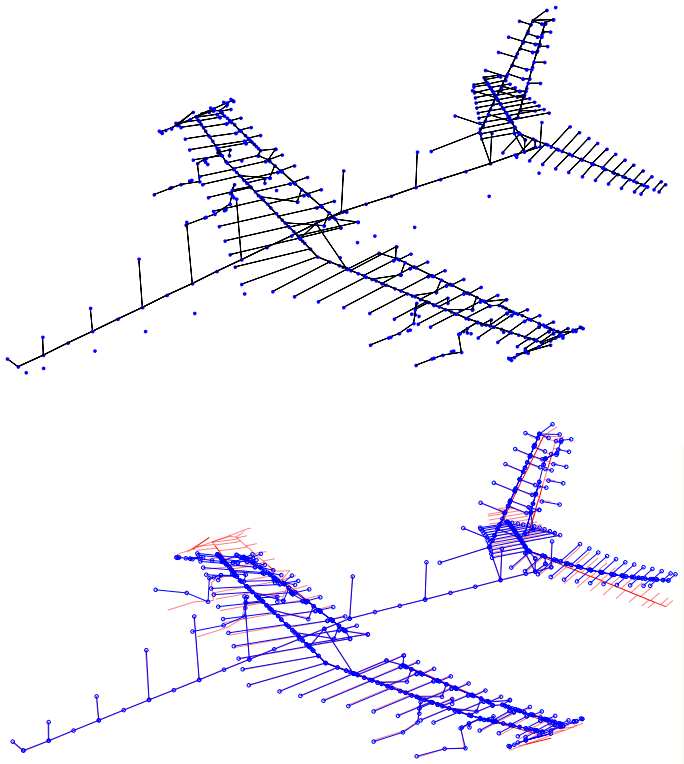
(Picture from Denel Dynamics)

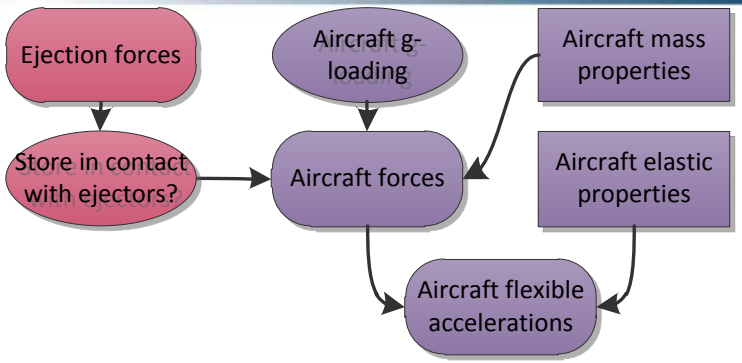




- ERU forces obtained from gantry tests with Hawk pylon performed by Denel Dynamics
- Two tests done – one in 2010 prior to release analysis and one in 2011 afterwards
  - 32% difference in measured forces and impulse
- Noted apparent release of ERU hooks 0.01 s before application of ejector forces
- Variability of Hawk ERU forces a major concern, especially for low altitude releases
  - an investigation has been recommended.

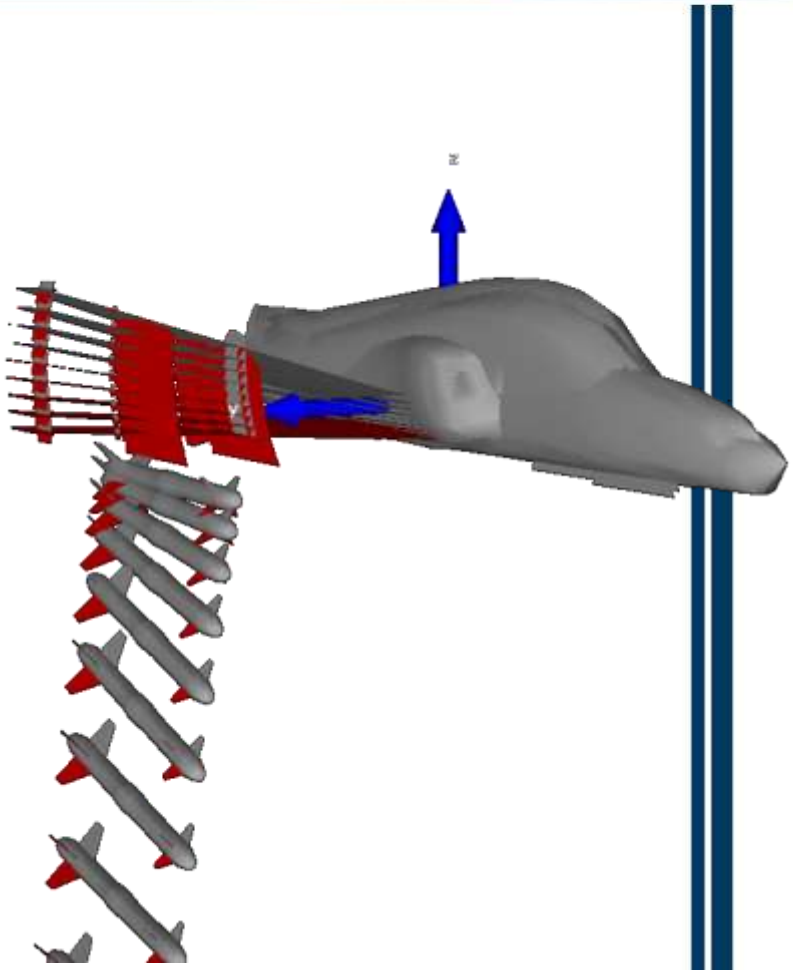
Application to Hawk/Katleho - aircraft flexible accelerations

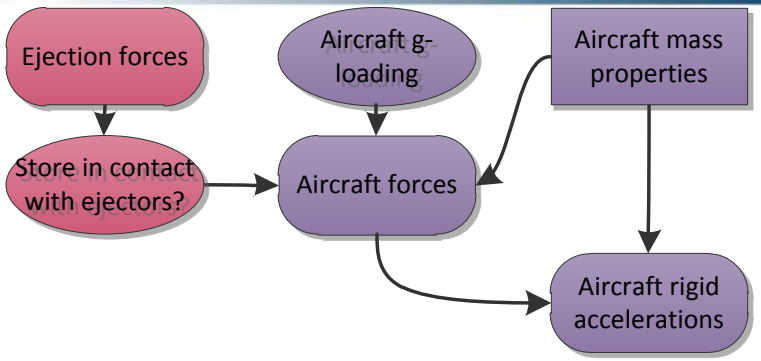




- Modal properties obtained from broomstick finite element model of Hawk Mk-120 supplied by BAE Systems
- Aeroelastic effects not modelled – flutter analysis shows limited change
- Modal data generated for aircraft with pylons & Mk-82 but not Katleho
- 24 flexible modes included in model

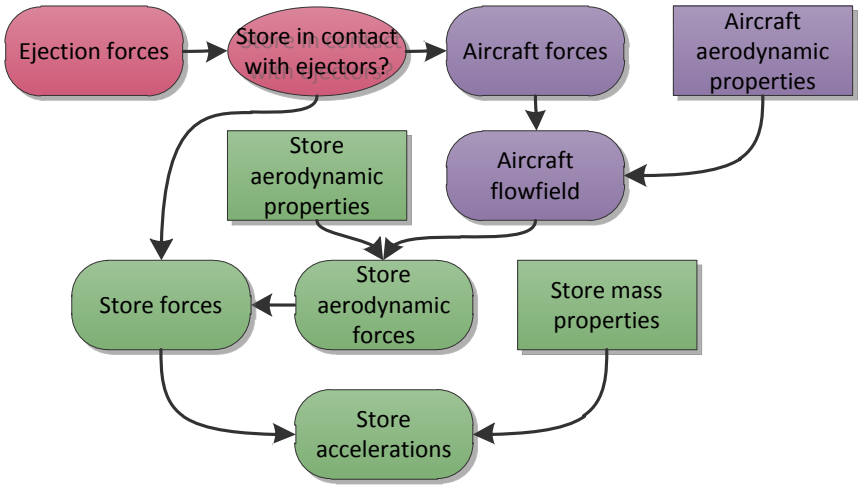
Application to Hawk/Katleho - aircraft rigid accelerations





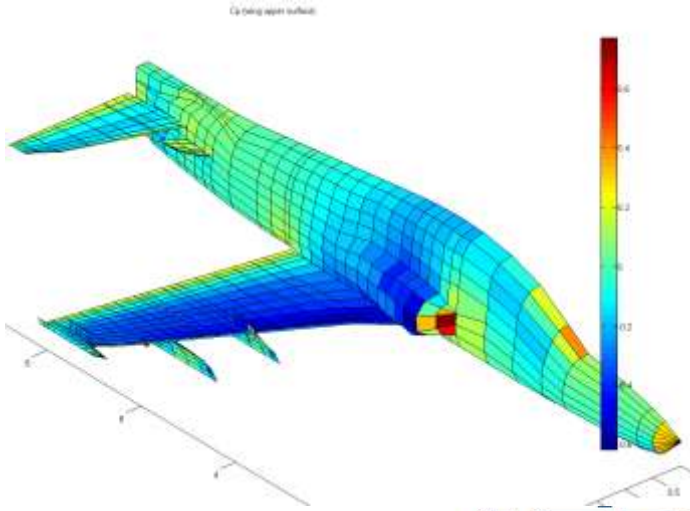
- 2 aircraft rigid body DOF analysed:
  - Normal (Z), roll
  - Constrained motion in other DOF
- Used mass, inertias, CG of aircraft *without* Katleho
- Used trimmed forces of aircraft *with* Katleho
  - Assumes delay in pilot response to g-jump

Application to Hawk/Katleho - store rigid accelerations

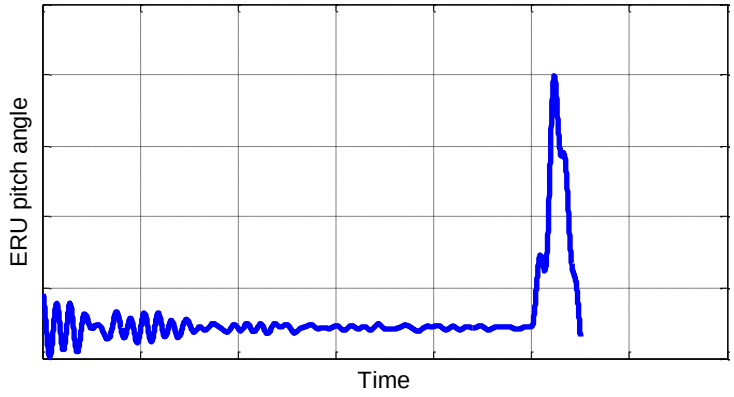


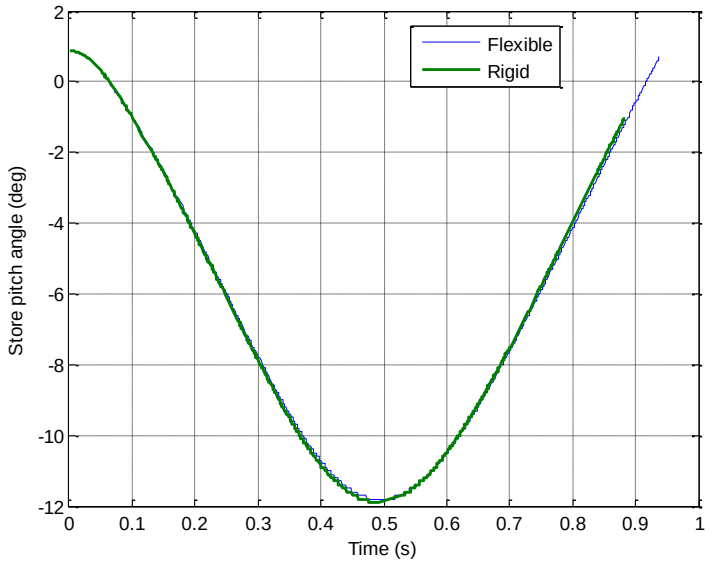
- Note links with aircraft
  - Ejector forces
  - Aircraft perturbation of flowfield
- 6-DOF model for store rigid dynamics

- ARUV panel code for all subsonic aircraft perturbation aerodynamics



Effect of flexible & rigid aircraft dynamics on store release





- Identical cases analysed considering flexible & rigid aircraft structure
- Impact of flexible aircraft structure on store trajectory is insignificant for this configuration

Effect of flexible & rigid aircraft dynamics on store release

- Compared different combinations against “ideal”
- Store pitch rate is critical for store release analyses
- Impact of flexibility is minimal, but ignoring rigid roll introduces 15% error

	Vz (end of ejection) (m/s)	Error (%)	Pitch rate (end of ejection) (°/s)	Error (%)
Flexible structure, free to roll	-3.010	0	-24.27	0
Rigid structure, free to roll	-3.084	2.5	-25.02	3.1
Flexible structure, roll constrained	-3.255	8.1	-28.02	15.5
Rigid structure, roll constrained	-3.255	8.1	-27.84	14.7

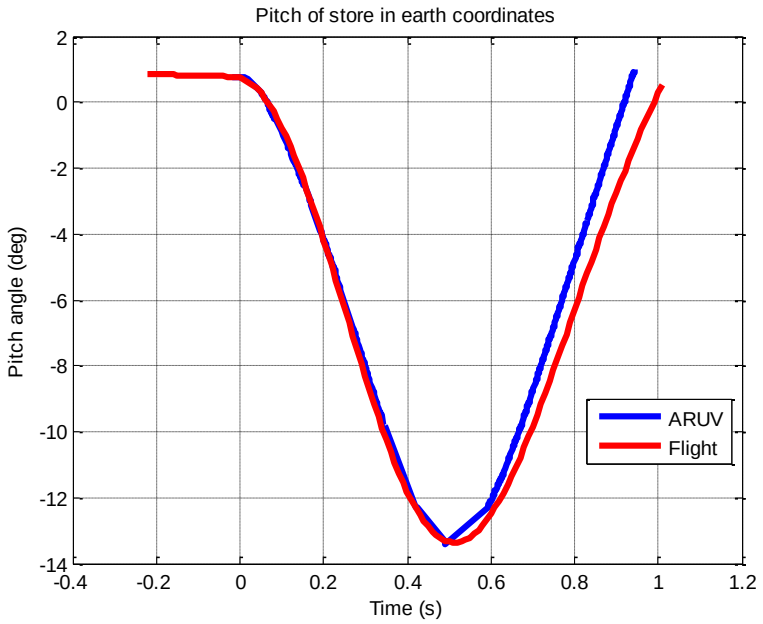
Katleho flight tests

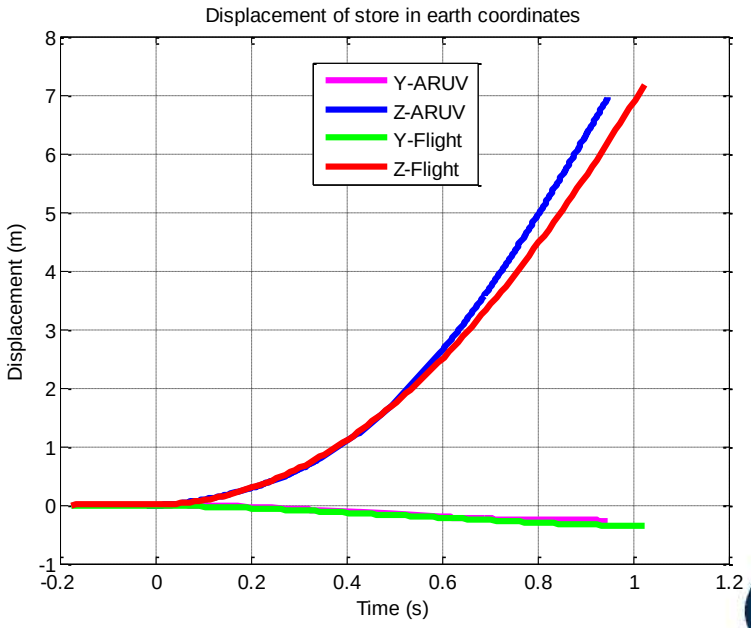
- Two releases of instrumented stores from instrumented aircraft took place in June 2011
  - Ideal opportunity to “close the loop”

(Pictures from release video supplied by SAAF)

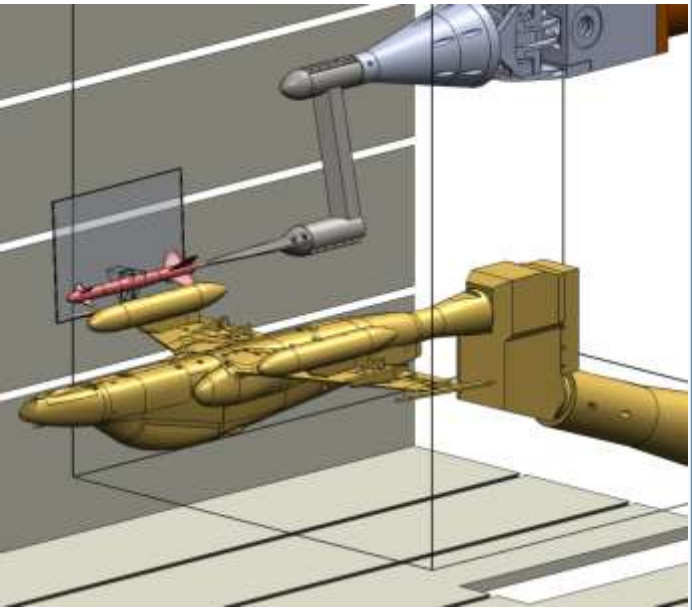
Katleho flight tests

- Numerically, excellent correlation was found
  - Software and process validated
- Inconsistent ejector force/time behaviour is biggest concern
  - Compared with baseline measured at Denel Dynamics, the releases had 37% and 50% LESS impulse
  - For 50% less impulse case, Katleho could hit aircraft if released at low altitude, maximum Mach number case





Conclusions



- Store releases are complex to analyse – many interacting factors
- Analyses are only as good as their inputs
  - Investigation into inconsistent Hawk ERU forces recommended
- Adding roll to aircraft “g-jump” dynamics important for accurate release analyses
- Aircraft flexible response not significant for release of Katleho on Hawk
- Wind-tunnel testing recommended to supply near-field aeroloads for all configuration combinations

Acknowledgements

- Katleho release & carriage project team at DPSS, CSIR without whom there is nothing to present
- Denel Dynamics for Katleho & ERU data, plus Katleho flight test telemetry
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