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Explosive Booster Selection Criteria for Insensitive Munitions Applications

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BAE SYSTEMS Land Systems Munitions




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Presentation Outline

- Introduction
- Explosive formulations
- Qualification
- Selection Criteria
  - Performance and fitness for purpose
  - Hazard and insensitive munitions compatibility
  - Gun launch survivability
  - Processability
  - Environmental survivability and ageing
- Insensitive Munitions and Hazard Division 1.6
- Summary and Acknowledgements

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Introduction (1)

- Scope

- Presentation describes the UK and Land Systems rationale and methodology for the assessment and selection of candidate pressed booster explosives
  - Part of a systems approach to meeting IM requirements

- Examples given of assessment trials

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Introduction (2)

- Boosters play essential role in explosive-filled ordnance
  - Safe and reliable functioning
  - Propagation and magnification of detonation wave from initiator to main charge

For IM applications boosters must fulfil a number of exacting and apparently conflicting requirements

  - Shock sensitive enough for reliable take-over
  - Reduced vulnerability towards hazardous thermal and shock induced stimuli (STANAG 4439)
  - Consistent performance under in-service conditions
  - Survivability throughout the munition's lifecycle
- Necessitates preservation of physical integrity, thermal stability and resistance to ageing
- High-g environment considerations during launch and retardation

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Explosive Formulations (1)

- Booster explosives to be addressed are pressed formulations
  - Initially produced as granulated moulding powders
  - Then fabricated into pellets by compaction process
- The energetic filler may take many forms and may be a mixture of two or more components
  - Examples: RDX, HMX, HNS, TATB
- Binder present to:
  - Improve physical integrity and resilience
  - Phlegmatise and protect the energetic filler
  - Act as granulating agent
- Binder levels can be in the range 1 to 8% m/m but more typically around 5% m/m
- Binders can take many forms:
  - Examples: hydrocarbon waxes, thermoplastic elastomers (TPEs), fluoropolymers

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Explosive Formulations (2)

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Ingredients	Booster Explosive Formulations						
	Debrix 18AS	HNS II /Binder	PBXN-5	RF-68-01	RF-68-02	ROWANEX 3600	ROWANEX 3601
RDX (%)	95			35	35	35	35
HMX (%)			95				
HNS (%)		96					
TATB (%)				60	60	60	60
Binder (%)	5	4	5	5	5	5	5
Binder Type	Wax	FP* (KelF 800)	FP* (Viton)	FP* (Hostaflon)	FP* (Fluon PTFE)	TPE (XBS 6005)	FP* (Viton)

* Fluoropolymer

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Qualification and IMAP Assessment

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- In the UK booster explosives are characterised and qualified to STANAG 4170 as a means of assessing their safety and suitability for introduction into service
- Qualification programme establishes a set of baseline data for evaluating any changes occurring throughout the booster's service life
- A typical qualification test programme includes:
  - Small scale hazard properties
  - Chemical and thermal stability
  - Mechanical properties
  - Shock sensitiveness
  - Charge scale explosiveness (tube tests)
  - Ageing characteristics (accelerated)
- The Insensitive Munitions Assessment Panel (IMAP) begins to review available data on munition components, such as boosters, at early stage in a project's life
  - To assess IM compatibility of proposed design options
  - Down-selection of energetic materials
  - Predicting the IM signature of munition
- Much of data used for selection is derived from material qualification programmes

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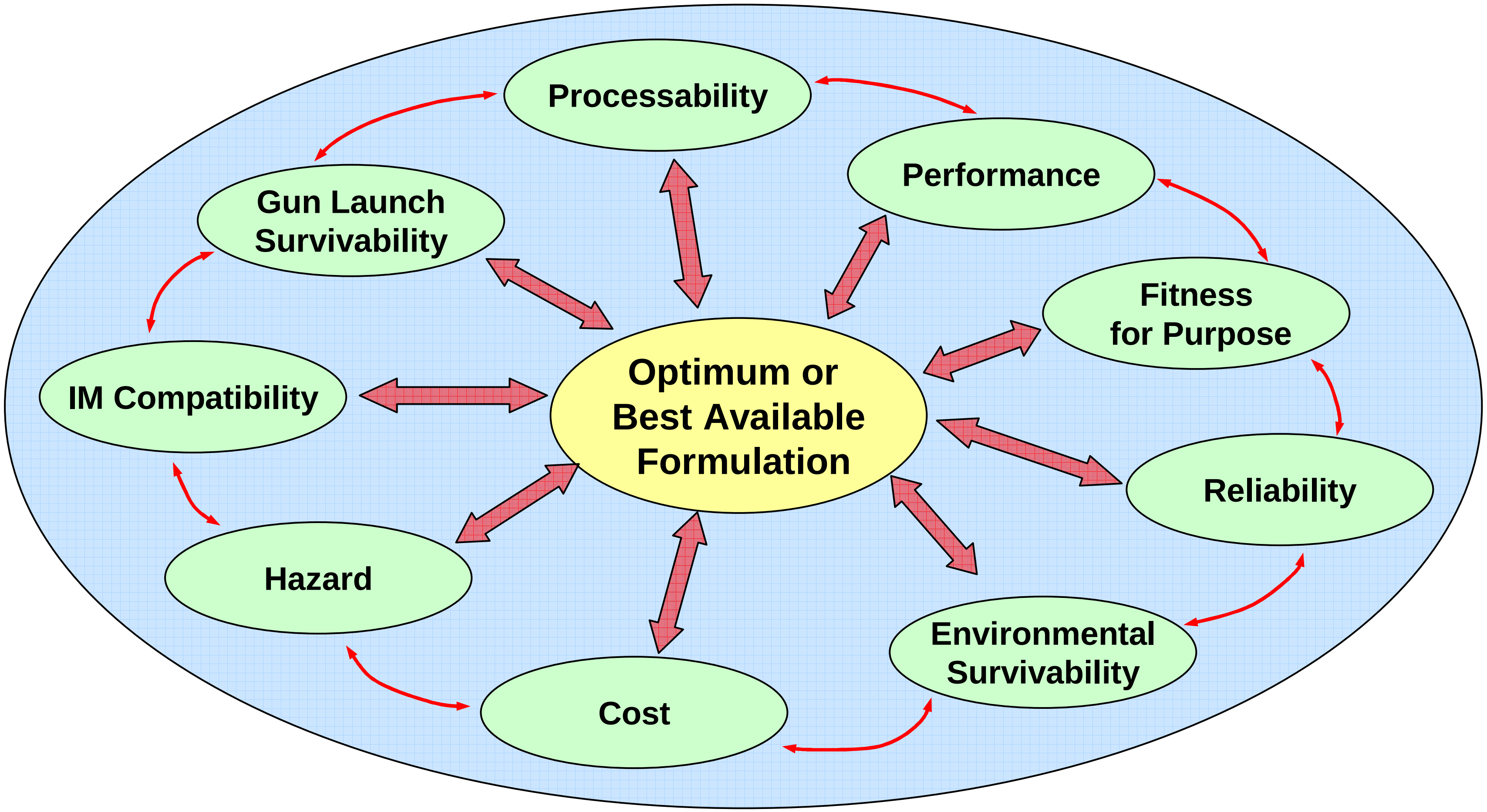
Selection Criteria Interactions and Trade-offs



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Selection Criteria

- Performance and fitness for purpose
- Hazard and insensitive munition compatibility
- Gun launch survivability
- Processability
- Environmental survivability and ageing

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Performance and Fitness for Purpose

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Performance

- Safety critical application
- Essential performance attributes
  - Ability to take-over from initiator or stemming
  - Transmit detonation efficiently to main charge
- An appropriate trade-off has to be struck
  - Between critical diameter and response to hazardous stimuli
- Relatively small critical diameter:
  - Higher shock sensitiveness, but
  - Smaller size booster and easier to protect in IM system
- Relatively large critical diameter:
  - Intrinsically less hazardous, but
  - Booster may be too large to include in desired fuzing configuration, and
  - Presents larger target and mitigation difficulties
- An indication of relative shock sensitivities of booster explosives can be gained from gap test results
  - UK large Scale Gap Test (EMTAP 22)
  - Based on NOL LSGT

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Large Scale Gap Test Results

EMTAP 22 Procedure

Results expressed as the pressure Pg just inside the attenuator at the attenuator/acceptor interface resulting in 50% probability of detonation of the acceptor

LSGT Results	Booster Explosives				
	RF-68-01	RF-68-02	HNS II/Binder	ROWANEX 3600	ROWANEX 3601
50% Gap (mm)	55.7	57.5	59.5	47.9	59.3
50% Pressure (GPa)	1.6	1.5	1.40	2.2	1.40
Density (gcm^{-3})	1.837	1.836	1.578	1.755	1.740

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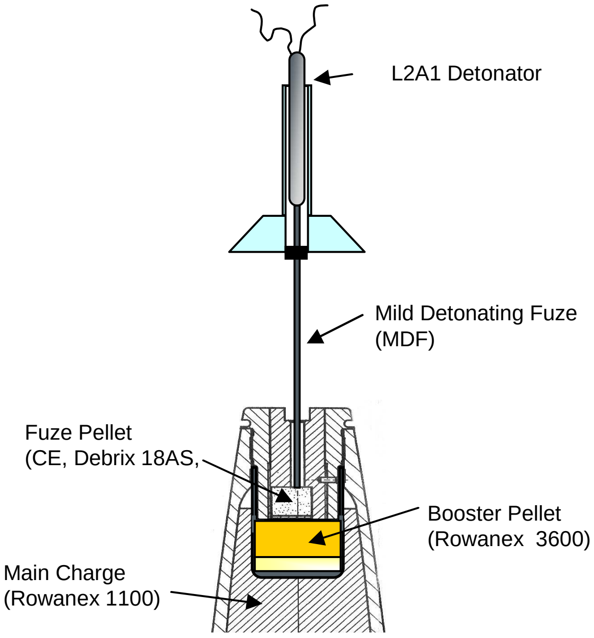
Fitness for Purpose (1)

- Greater confidence in take-over can be achieved by conducting a series of trials on representative hardware under worst case conditions
- A recent Land Systems artillery projectile development programme involved assessment of initiation of the ROWANEX 3600 booster from a range of in-service fuzes
- Trials utilized front end sections of shell containing ROWANEX 1100 main charge explosive and equipped with booster cavities and ROWANEX 3600 pellets
- Output from the ROWANEX 1100 main charge was recorded with steel witness plates located under the hardware
- Fuze pellets initiated by length of MDF connected to an L2A1 detonator



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Fitness for Purpose (2)

- Take-over tests conducted with fuze set-ups representative of
  - CX23 (4.5” shell) with Debrix 18AS pellet
  - L106 (155mm shell) with tetryl pellet

- Both fuze types were found to fully initiate the ROWANEX 3600 pellet and ROWANEX 1100 main charge as demonstrated by penetration of the steel witness plates

- To represent worst case conditions and simulate the worst possible combination of factors thee static firings were conducted to investigate correct take-over of a ROWANEX 3601 booster onto ROWANEX 1100 main charge with
  - 105mm hardware
  - L116 fuze (lower output than L106)
  - Firing conducted at -46℃
  - Air and clutter gap of 32mm between booster and main charge
  - Lowest density booster pellets likely to occur in production

- All firngs provided evidence of correct detonation by penetration of the steel witness plates

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Hazard and Insensitive Munitions Compatibility

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EMTAP Tube Tests (1)

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- EMTAP tube tests are used to evaluate relative explosiveness of candidate boosters
- Responses give clear indication of propensity of explosive to undergo deflagration to detonation transition (DDT)
- Conclusions can be drawn on suitability of boosters for IM applications
- There are three variants of the test
    - Internal Ignition (EMTAP 35)
    - Fast Heating (EMTAP 41)
    - Electrically heated (EMPTAP 42)
- Degree of fragmentation of the tube and proportion of recovered explosive are used to assess the degree of reaction

Reaction Category	Reaction Description	Observation
0	No Reaction	No mass loss
0/1	Burning /Decomposition	No disruption of test Vehicle
1	Pressure burst due to burning/decomposition	Test vehicle ruptured but one fragment approximates to original mass
2	Deflagration	2 to 9 test vehicle body fragments
3	Explosion	10 to 100 test vehicle body fragments
4	Detonation	> 100 test vehicle body fragments showing evidence of detonation

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EMTAP Tube Tests (2)

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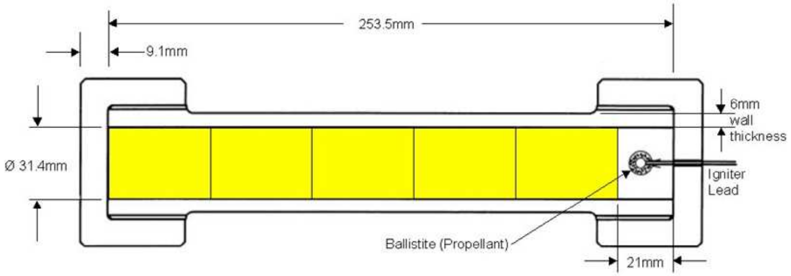
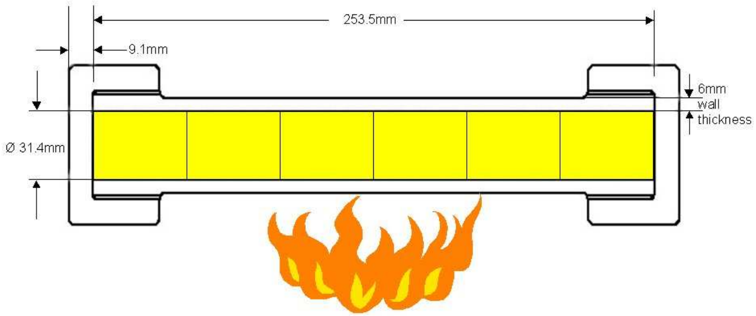
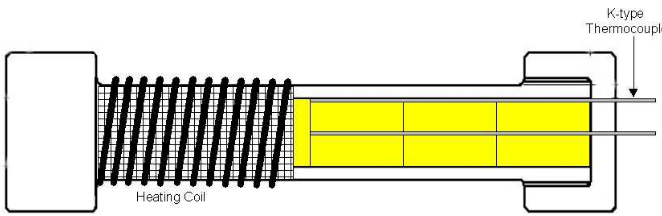
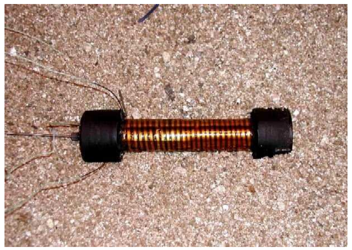


EMTAP Test No 35 Tube Test Internal Ignition



EMTAP Test No 41 Tube Test Fast Heating





EMTAP Test No 42 Tube Test Electrically Heated (Heating rates 3°,4°,5°, 7.5°, 10°C/min)

All tests use the same basic vehicle: steel tube with screw on steel end caps

The central tube is designed to fail before the end caps

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Booster Explosiveness Assessment: Internal Ignition Tube Test EMTAP 35

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Booster Composition	Reaction Category	Average Number of Fragments
ROWANEX 3601	5 off Cat 1 5 off Cat 2	1.4
HNS II / Binder	7 off Cat 2 3 off Cat 3	6
Debrix 18AS	10 off Cat 3	23
Tetryl	1 off Cat 1 3 off Cat 3 6 off Cat 4	200

Conclusions

- Response of conventional boosters Debrix 18AS and tetryl much more violent than the candidate IM boosters in terms of fragmentation
- Burning/deflagration response of ROWANEX 3601 more benign than deflagration/explosion response of HNS II / Binder

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Booster Explosiveness Assessment: Fast Heating Tube Test EMTAP 41 (1)

Booster Composition	Reaction Category	Average Number of Fragments	Average Time to Reaction (s)
ROWANEX 3601	4 off Cat 1 6 off Cat 2	2	136
HNS II / Binder	9 off Cat 3 1 off cat 2	52	243
ROWANEX 3600	8 off Cat 1 2 off Cat 2	1.4	143
RF-68-01	6 off Cat 1 4 off Cat 2	1.4	163
RF-68-02	10 off Cat 2	1.4	167
Debrix 18AS	7 offCat 1 1 off Cat 2 2 off Cat 4		

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Booster Explosiveness Assessment: Fast Heating Tube Test EMTAP 41 (2)

- Conclusions
- Responses of all the TATB-based booster formulations relatively low order
- Responses of HNS composition significantly more violent casting doubts on its suitability for IM applications
- The average time to to reaction for HNS II / Binder is over 100 seconds longer than for ROWANEX 3601
- Can be explained by the higher thermal stability of the HNS (T of I 328℃ versus 220 ℃)
- Thermal stability of ROWANEX 3601 limited by RDX component
- Gradual thermal decomposition of booster formulation at lower temperature appears preferable in terms of explosiveness to rapid decomposition *en masse* at higher temperature

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Booster Explosiveness Assessment: Electrically Heated Tube Test EMTAP 42

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Booster Composition	Reaction Category	Average Number of Fragments
ROWANEX 3601	5 off Cat 2	8
HNS II / Binder	5 off Cat 3	12

Conclusion

- Response of HNS II / Binder formulation generally higher order than that of ROWANEX 3601 producing explosions rather than deflagrations in each case

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Effect of Booster on IM Response

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- A series of fuel fire trials (STANAG 4240) on 4.5” IA Naval projectiles show influence choice of booster explosive has on response
- 4.5” IA non-IM round filled with RDX/TNT gave high order response with severe disruption of case
- 4.5” IAIM round filled with ROWANEX 1100 equipped with a ROWANEX 3600 booster burnt out in situ after ejecting nose plug
- Non ideal intermediate configuration with ROWANEX 1100 main charge and a conventional Debrix 18AS booster produced deflagration with shell splitting open from nose end
- Comparison indicates benefits of consistent approach to explosives selection

RDX/TNT 60/40 Fill with Debrix 18AS Booster

ROWANEX 1100 and ROWANEX 3600 Booster

ROWANEX 1100 Fill with Debrix 18AS Booster

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Gun Launch Survivability

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High-g Launch Survivability Assessment (1)

- For gun-launched applications there is a need to ascertain how boosters will react to high-g environments under representative conditions
- Evaluation of new explosives in large calibre shell involves high degree of risk
- At Land Systems new candidate explosives for boosters and main fill are first evaluated in gun firing trials on 30mm Aden ammunition
  - Relatively inexpensive
  - Damage restricted to localised area if unexpected event
  - Gun barrel generally expendable
  - Projectiles can be recovered easily
- Recovery trials conducted on Aden rounds filled with ROWANEX 3600 and ROWANEX 3601
  - Nominal acceleration of 60,000g
  - Extremes of temperature: -46℃ and +63 ℃
  - High speed photographs of shell immediately after leaving barrel and just before recovery
  - All rounds radiographed before and after firing
  - Selected rounds sectioned
- No evidence of damage or reaction of filling encountered in recovered rounds
- Confidence raised in outcome of full scale trials on 4.5”, 105mm and 155mm projectiles

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High-g Launch Survivability Assessment (2)

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30mm Aden Barrel

Sectioned 30mm Aden Round after Recovery

High Speed Camera 1

High Speed Camera 2

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Processability

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Processability (1)

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- Mass production of explosive items in high volume, such as artillery shell boosters, demands high degree of processability through all stages of pellet pressing operation
  - Flow of moulding powder from hopper into automated rotary press
  - Compaction to form pellet
  - Rapid ejection

- Composition processing requirements
  - Flow without clogging
  - Consistent consolidation
  - Uniform density
  - High degree of physical robustness

- Granulation of moulding powder is critical and influences
  - Pourability, bulk density and pressing characteristics

- ROWANEX 3601 has undergone comprehensive range of pellet producibility trials
- Relationship between pellet density and dimensions and pressing conditions established

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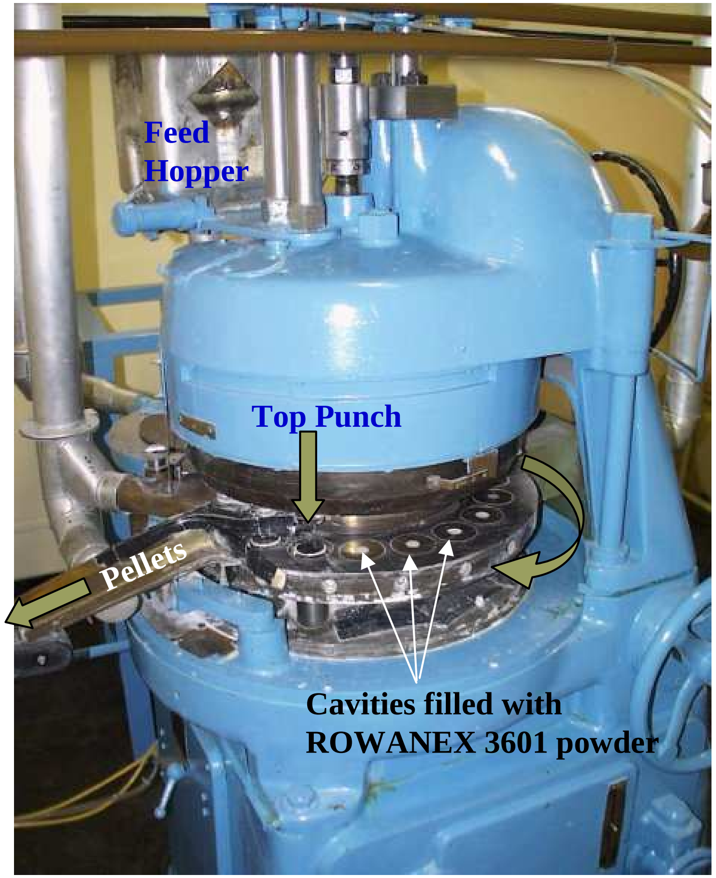
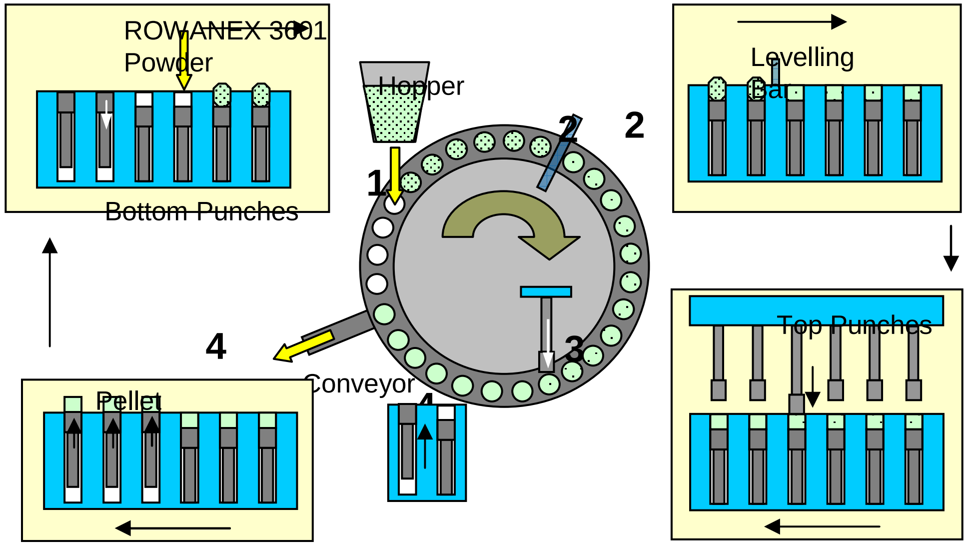
Processability (2)

Automated rotary pressing of ROWANEX 3601 booster pellets





1. ROWANEX 3601powder enters cavity created by the lowering bottom punch
2. ROWANEX 3601powder inside the cavity is then spread level
3. ROWANEX 3601powder is pressed by the top punch pressing down onto the cavity
4. Pellet is ejected from the cavity by the rising bottom punch

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Environmental Survivability and Ageing

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Environmental Survivability

- Trials on 4.5” IA IM rounds filled with ROWANEX 1100 main charge and ROWANEX 3601 booster
  - Reliability of functioning demonstrated after three year DOSG sequential programme
    - -18^{o}C to + 49^{o}C, logistic vibration, restrained cargo shock, Multiple freefall, horizontal impact, C1 and B2 diurnal cycling (3 year life), 2.1/1.5/1.0m drop tests.
  - Five rounds fitted with L106 fuzes
  - Fired at temperatures of -18℃ and +49 ℃
  - All rounds observed to function full order
- Similar trials on seven 4.5” IA IM rounds fitted with NC23 fuzes (same output as L116 fuze)
  - Reliability of functioning demonstrated after ten year DOSG sequential programme (extension of above trial)
  - Rounds fired at -18℃ and +49 ℃
  - All rounds observed to function full order

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Accelerated Ageing Trial on ROWANEX 3601 (1)

- Undertaken as part of ROWANEX 3601 Qualification programme

- Six months duration at constant 60℃

- ROWANEX 3601 assessed in the form of both powder and pellets (25.4mm right cylinders)

- Parameters monitored
  - Sensitiveness (impact and friction)
  - Thermal stability (VS and DSC)
  - Physical properties (mass, density, compression)

- In approximate terms the accelerated ageing equates to 8 years storage at 20℃

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Accelerated Ageing Trial on ROWANEX 3601(2)

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Test	Sample	0 month	3 months at 60°C	6 months at 60°C
Sensitiveness to Impact (F of I)	Powder	90	80	80
Mallet Friction (Steel on Steel)	Powder	0%	0%	0%
Vacuum Stability (cm^3 / gram)	Powder	0.10	0.09	0.07
DSC (°C) Exotherm Onset Extrapolated Peak	Powder	190.65 206.30	190.03 205.92	188.57 203.85
Average Pellet Mass (g) (average of 20 pellets)	Pellet	23.40	23.36	-
		23.42	-	23.37
Average Pellet Density (g/cm^3) (average of 20 pellets)	Pellet	1.824	1.815	-
		1.823	-	1.816
Average Pellet Shore A Hardness (average of 20 pellets)	Pellet	96	96	97
Average Max. Stress (N/mm^2)	(average of 5 pellets at each temperature)			
at –40°C	Pellet	> 19.73	>19.73	>19.73
at +25°C		9.04	8.96	9.79
at +60°C		6.42	6.71	7.51
Average Deformation (mm)	(average of 5 pellets at each temperature)			
at –40°C	Pellet	1.26	1.17	1.34
at +25°C		1.42	1.34	1.45
at +60°C		1.62	1.52	1.51

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Insensitive Munitions and Hazard Division 1.6

- Disparity exists between the technologies required to give IM compliance and those needed to achieve UN HD 1.6
- UN HD 1.6 is directed at extremely insensitive articles
  - No mass detonation hazard
  - In theory the most appropriate HD for Insensitive Munitions
- However, requirements for HD 1.6 are very prescriptive
  - HD 1.6 article may only contain explosives classed as Extremely Insensitive Detonating Substances (EIDS)
- Substances are judged to meet EIDS criteria if they have passed UN test series 7 and in particular test 7a the EIDS cap test
- In will be immediately apparent that the majority of IMs which contain relatively shock sensitive booster explosives are excluded from HD 1.6 even though the overall system demonstrates negligible probability of accidental initiation or propagation
- The dilemma is highlighted by the absence of any HD 1.6 article candidates
- One solution is to revise UN test series 7 to place more emphasis on demonstration of low explosiveness

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Summary

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- UK and Land Systems rationale and methodology for selection of booster explosives for IM applications explained
- A systems approach with through life considerations important
- Selection criteria reviewed
  - Trade-offs often necessary to achieve the best compromise
- Examples of evaluation trials given
- Attention drawn to the usefulness of charge scale explosiveness (tube) tests to differentiate between formulations
- Disparity between the requirements of Insensitive Munitions and UN Hazard Division 1.6 highlighted

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Questions?

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