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Compensating Provisions

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Introduction

- Purpose of Compensating Provisions
- Review of Compensating Provisions categories, with:
  - Examples
  - Discussion of some subtleties
- Selection of Compensating Provisions

Reminder: Design Assessment Rule

- JAR 29.917(b) & .547(b) require a Design Assessment
- This must identify *the means* to minimise the likelihood of failures that will prevent safe flight and landing
  - i.e. catastrophic & hazardous failures
- The term ‘Compensating Provisions’ is introduced in the advisory material

The Purpose of Compensating Provisions

- AC-29.917A describes the purpose of Compensating Provisions (CPs) as:
  - **To minimise the likelihood of hazardous and catastrophic failures**
- The AC also states that CPs can be used to:
  - **Circumvent or mitigate the effect of failures**
- CPs are the JAR 29.917(b)/.547(b) *'means'*
- CPs are to be appropriately substantiated
- Applicant should obtain early concurrence from the certifying authority for the CPs

Compensating Provision Categories

1. Design features
2. A high level of integrity
3. Fatigue tolerance evaluation
4. Flight limitations
5. Emergency procedures
6. Inspections / checks
7. Preventative maintenance action
8. Special assembly procedures / functional tests
9. Other safety devices / health monitoring

Specific examples follow

Note: there is overlap between some categories

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Design Features & A High Level of Integrity

- Design Features
  - Safety factors / Part-derating criteria
  - Redundancy
    - Duplicate load paths, oil pipes, mechanisms etc
  - ‘Fail safe’ design
  - Human centred design
- A High Level of Integrity
  - A design that results in a probability of failure that is as low as technically feasible & economically justifiable when considering the severity of that failure
  - Critical parts where appropriate

Fatigue Tolerance Evaluation

- Fatigue related catastrophic failure modes:
  – A JAR 29.571 Fatigue Evaluation is already required
  – However to use as a CP the applicant should demonstrate fatigue margin to give allowance for variability & minimise likelihood of failures
- Fatigue related hazardous failure modes:
  – A JAR 29.571 Fatigue Evaluation approach demonstrating margin should be used as a CP if technically feasible & economically justifiable

Flight Limitations & Emergency Procedures

- Flight Limitations
  - Placed on those conditions that:
    - Increase the risk of failure
    - Reduce the probability of a safe outcome after a failure
- Emergency Procedures
  - Flight Manual instructions:
    - Confirmatory checks
    - Emergency flight ‘limitations’
    - Crew actions
    - Land immediately / As Soon as Possible / As Soon as Practical

Inspections / Checks

- Inspections or checks that would detect:
  - The failure mode or
  - Evidence of conditions that could cause it
  - These may be:
    - Pre-flight ‘walk around’ checks
    - Out of phase maintenance inspections
    - Phased inspections (A, B, C Checks etc)
    - Component overhaul inspections
  - Techniques include:
    - Visual (specific [inc oil levels], zonal, boroscoping etc)
    - Physical (measurements, pull tests, RTB etc)
    - Non Destructive (FP, MP, EC, UT, Radiographic etc)
    - Magnetic chip detectors / SOAP *(health monitoring ?)*
    - BITE

Preventative Maintenance Action

- To minimise the likelihood of failure:
  - Replacement actions
    - Following inspections or at a TBO or life limit
  - Verification of serviceability of items with a dormant failure mode *(inspection?)*
  - Periodic:
    - Overhaul
    - Adjustment
      - e.g. pitch link orientation changes
    - Lubrication

Assembly Procedures / Functional Tests

- Special Assembly Procedures
  - To avoid safety critical assembly errors
    - Implies that components are vulnerable to maintenance error
    - Case for Human Centred Design in future?
- Functional Tests
  - To detect safety critical assembly errors

Other Safety Devices / Health Monitoring

- Other Safety Devices
  - Devices that can mitigate the effects of a failure:
    - Emergency lubrication system
    - Extreme example (!): drag chutes / inflatable fins to counter loss of TR drive at high speeds
- Health Monitoring
  - Means by which selected incipient failure or degradation can be determined

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Health Monitoring Options: 1

- Oil System (Note: minimal capability against cracks):
  - Oil temperature & pressure indications
  - Oil level indicators / warnings
  - Electronic chip detectors *(MCDs - inspection?)*
  - Quantitative debris monitoring
  - Oil analysis (real time / SOAP)
  - Filter bypass indication
- Physical movement:
  - Shaft misalignment
  - Rotor Track and Balance *(inspection?)*
  - Rotation (e.g loss of TR drive)
- Bearing temperature
- Acoustic (i.e. microphone monitoring)

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Health Monitoring Options: 2

- Vibration Health Monitoring:
  - Applicable to a wide range of components
  - Vibration sources:
    - Rotating hardware generally (imbalance & misalignment)
    - Shafts:
      - Cracks, wear & joint looseness
    - Gears:
      - Gear eccentricity
      - Gear tooth defects (fatigue cracks, pits etc)
      - *Normal meshing (filtered out!)*
    - Bearings (pitting, cracking, spalling etc)
    - Accessories
  - Capability against fatigue failures (unlike oil HM)

Impetus for VHM Development

- Airworthiness Requirements Board panel 1984
- UK Air Accidents Investigation Branch recommendations:
    - Spiral bevel gear failure (1986 – fatal hull loss)
    - Uncontained engine failure (1987 - hull loss)
    - Drive failure leading to fire (1988 – hull loss)
    - Combiner gear failure (1988 – hull loss)
    - Drive shaft bearing failure (1989)
    - Drive shaft coupling failure (1990)
- An operator's study in 1989 predicted:
    - VHM would have been able to prevent 50% of airworthiness related accidents
    - Avoiding 17 accidents (7 fatal) over 1.8 million flying hours

Experience with VHM

- Routine Royal Australian Navy VHM sampling (carry-out equipment) 1977 on
- Westland 30 developed with VHM in mid 1980s
- UK CAA trial permanently installed systems 1987-90
- UK CAA seeded defect testing (S-61 & AS332L)
- VHM systems entered service 1991
- Over two million flight hours
- Over 400 systems in service
- EHOC/AECMA/AIA data Nov 2002:
  - 93% of HUMS in civil service with European operators

Operational VHM Fleet

Operator	Total	North Sea & AHUMS	IHUMS	EuroHUMS	EuroARMS
CHC Scotia / Denmark/Ireland	45	6 x S61N, 10 x AS332L, 1 x S76A+	10 x AS365, 5 x S76A+, 7 x AS332L, 3 x S76C	3 x AS332L2	
British International Ltd	9	7 x S61N	2 x AS365N2		
Bristow Helicopters	62		32 x AS332L, 6 x S61N, 17 x S76A, 6 x Bell 212, 1 x Bell 214		
Brunei Shell	3		3 x S61N		
CHC Helikopter Service	25	7 x S61N	1 x AS332L 3 x AS332L1 3 x AS365N2 1 x B214ST	6 x AS332L2 3 x AS332L	1 x AS332L2
Norsk Helikopter	7		3 x AS332L 1 x AS332L1 1 x S76C+		2 x AS332L2
Schreiner Northsea	9	3 x S61N 6 x S76B (AHUMS)			
CHC Australia	6		3 x AS332L1 2 x S76A++	1 x AS332L1	
EHOC Total	**166**	**40**	**110**	**13**	**3**
Malaysian Helicopters	3			3 x AS332 L1	
SSFC (Vietnam)	2				2 x AS332L2
Cougar	3			3 x AS332 L1	
CHC South Africa	2	2 x S61			
Non EHOC Civil Total	**10**	**2**	**0**	**6**	**2**
Military	149	99 x Bell 412 (AHUMS)		32 x AS332L1 (RSAF) 17 x AS332L2 (RNLAF)	1 x AS332L2 (French Army)
Military Total	**149**	**99**	**0**	**49**	**1**
Grand Total	**325**	**141**	**110**	**68**	**6**

Data source: EHOC/AIA/AECMA as of Nov 2000.
Excludes Goodrich system on Rega A109Ks & GenHUMS on 47 RAF Chinooks and 66 RN/RAF Merlins).
Since then 2000 IHUMS, EuroHUMS and EuroARMS have made further sales.
Sikorsky have announced that all S-92As are to be fitted with IMD-HUMS (also in trial with USN).
GenHUMS has been selected for AB139 and BA609.

VHM Performance 1

- A 1997 UK CAA study - VHM warned for:
  - 69% of the failure types
  - 60% of the potentially catastrophic failure cases
  - 80% is a reasonable target with improvements
- Sikorsky study in 1997:
  - MGB false removals rate was < 1 per 147,000 flying hours
- UK CAA and EHOC/AECMA/AIA studies suggest:
  - One third of detailed VHM investigations confirmed defects (one per 6,000 hours)
- SINTEF 'Helicopter Safety 2' study in 1999:
  - health monitoring '…was probably the most significant isolated safety improvement of the last decade'.
- AAIB/N has concluded that health monitoring:
  - '…is capable of being an important tool in accident prevention'.

VHM Performance 2
UK 2000-2001

2000 – 17 warnings resulting in major maintenance action

1 x Engine
2 x Engine-MGB Coupling
3 x MGB
2 x Aircraft Accessories
2 x TR Drive Shafts
1 x TGB/IGB
5 x Tail Rotor
1 x Airframe Structure

2001 – 22 warnings resulting in major maintenance action

6 x Engine
3 x Engine-MGB Coupling
4 x MGB
3 x Aircraft Accessories
1 x TR Drive Shafts
0 x TGB/IGB
5 x Tail Rotor
0 x Airframe Structure

CP Selection: 1

- AC-29.917A(e)(2) states that CPs:
  - 'May be selected from one or more of those listed'.
- Use of complimentary CPs is possible.
- AC-29.917A(e)(2) states that CPs are not necessarily limited to those listed:
  - There is thus allowance for other CPs to become technically feasible & economically justifiable in the future

CP Selection: 2

- They *must* be selected to meet the JAR 29.917(b) & .547(b) requirements *to minimise*
- Potential CPs can therefore only be eliminated if they are:
  - Not technically feasible *or*
  - Not economically justifiable
- All options must be considered

CP Selection: 2

- The onus should be on the applicant to show their CP strategy, i.e:
  - What they have included
  - What they have rejected as not technically feasible or economically justifiable
- Dialogue with the applicant is likely
- The transmission specialist will need to be familiar with the latest developments in CPs

Conclusions

- There is a wide range of Compensation Provisions available
- The Design Assessment is:
  - A powerful requirement
  - But one that must be carefully applied
- Questions?