B51HB – Reassessment 2023

The reassessment is in three parts.

1 A critical analysis (40%)

2 Part 1 – Applied Mechanics (30%)

3 Part 2 – Fire and Explosions (30%)

Your completed assessment will consist of 3 files that you will upload to Canvas on three separate links. Please use the naming convention

Student number_Critical Analysis.pptx

Student number_Part1.pdf

Student number_Part2.pdf

Note it is against university regulations to plagiarise / collude / not reference material taken from a third party.

NO submissions emailed directly to any of the academic staff will be marked., It has to be submitted to Canvas.

A declaration of authorship should be included in each part of your submission.

Deadline for Submission – Friday 4th August, 2023 – 11:59 AM BST.

B51 HB3: Failure and Accident Analysis

Reassessment 2023

Critical Analysis Assignment: Disasters, accidents and failures

This project-based assignment accounts for **40%** of the marks for the resit and is therefore expected to be a substantial piece of work. You should devote around 20 hours over the period between issue and hand-in. Also note that your work should not merely be a scrap-book, or collection of facts, but that you should be engaging in some critical analysis. It is very rare that an acceptable project can be put together from a single case study. You need to be making a specific argument based on your reading about engineering accidents and disasters.

This part of the resit is an **essay** (in the form of an annotated and voiced-over presentation), to be submitted via Canvas.

Essay (voiced-over presentation, lasting approximately 20 minutes)

For the topic chosen discuss, using examples, how engineers learn to improve designs on the basis of past experience. Analyse critically the steps that have been taken to investigate each of the examples and to publicise the outcome of the investigation, and draw conclusions on how the design, manufacture, operation and development of engineering artefacts have been influenced over the course of time by experience of accidents, incidents and disasters.

Justify your choice of topic (a topic being a particular issue, a particular cause or a particular type of accident/incident or, more likely, a combination of these) in terms of what you expect to be able to demonstrate, using the following guidelines.

- **Avoid single-example topics as you will find it very difficult to say anything new about them and, in most cases, there will have been an enquiry.**
- **Avoid topics where there has been a lot of attention but no agreed cause as this is likely to lead you into a morass of conspiracy theories.**
- **Avoid merely collecting information or relaying the opinions of others; this is an M-level course, so you are expected to form some opinions of your own and to analyse published information critically.**
- **Make sure that you have sufficient published information to support your argument; for example, it will not be possible to provide an appropriate level of critical analysis with only one reference, or even with multiple references all tracing back to the same source (e.g. a public enquiry).**

Use the medium(powerpoint) as it is intended and do not attempt to produce a written essay. This usually means limiting the amount of text in your slides and relying on making your point verbally. Presentations where the slides are simply read out to the audience will not attract a good presentation mark. Generally speaking, you should aim for about one slide per minute. You may use the notes area of the presentations to bring to the attention of the marker any information (such as references) that cannot conveniently be placed directly onto the slides.

B51 HB3: Failure and Accident Analysis

Reassessment 2023

This assignment relates to Part 1 of the course and accounts for **30%** of the marks for the resit and is therefore expected to be a substantial piece of work. You should devote around 15 hours over the period between issue and hand-in.

You must attempt BOTH questions. The points scores indicate the weighting of the parts in making up the 30 marks.

QUESTION 1

1(a) Compare and contrast the use high strength aluminium alloys and titanium alloys for airframes. Your answer should include a description of precipitation hardening and its implications for airframe design and manufacture and an explanation of the role of alloying and processing on the properties of titanium alloys. You should consider both strength and toughness.

Your answer should be around 350 words and you ***must*** use your own words.

[15 points]

1(b) The root cause of an air crash has been traced to a fatigue crack which grew from a stress concentration in a difficult-to-inspect area of the wing centre section forging. As part of the investigation, it has become necessary to examine the operator's approach to fatigue control. At the time of the crash, the aircraft had accrued around 50,000 hours of flight, spread over a total of 5000 flights. The stress range can be subdivided into two blocks, one at 300MPa, which occurs on average twice per flight, and one at 150MPa, which occurs on average ten times per flying hour.

The minimum detectable crack depth in the forging has been estimated to be about 0.5mm and the values of the Paris constants C and m (for fatigue crack propagation) are 5×10^{-10} and 2.3 in MPa and m units irrespective of the type of aluminium alloy. For each of the stress ranges determine the number of cycles for the crack to grow from the minimum detectable size to the critical size. To determine the critical crack size, you may take Y=1 and assume plane strain conditions at a stress of half of the applied stress range. You may take the fracture toughness to be between 40 and 80MPa$\sqrt{m}$.

Form an opinion on the adequacy of the maintenance schedule, which calls for an inspection of the forging every 500 flights.

[15 points]

1(c) A section of Arctic pipeline leading to a loading terminal has ruptured with the release of a large amount of crude oil into the ocean. The pipeline (designed to operate at 20MPa) is of 1m external diameter with a wall-thickness of 40mm, and can be considered to be a thin-walled cylinder so that the hoop stress (maximum principal stress) is constant across the wall thickness: $\sigma_h = \frac{pD}{2t}$

Examination of the ruptured pipe has indicated that, prior to failure, it contained an axial defect of length 200mm and depth 20mm in its inner wall, assumed to have been introduced during seam-welding of the pipe sections in the factory of the pipe supplier. There is no evidence that the defect has grown in service. The operators maintain that their field test would find any critical defect and that the pipe supplier was wholly at fault. The exact pipe specification is not known.

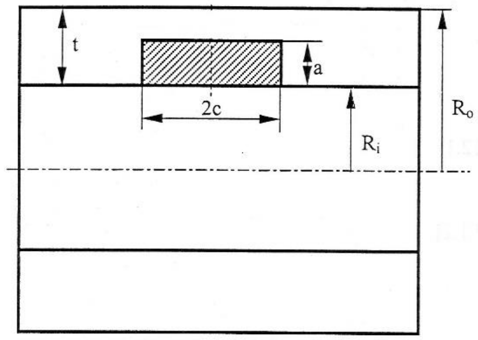
Using the information in the data sheet supplied, determine K_r and $S_r \left(= p/p_c \right)$ for the defect. You should express each in terms of the fracture toughness and flow stress (mean between yield stress and UTS), respectively, i.e. $K_r = \frac{number}{K_{Ic}}$ and $S_r = \frac{number}{\sigma_f}$

Form an opinion on whether the operator has been supplied with an appropriate quality of steel (notwithstanding the defect). To do this, you will need to obtain yield stress and UTS values for a range of pipeline steels, which you can assume do not vary with temperature. You will also need to find values of fracture toughness at 15°C and -15°C. Using this data, plot the defect conditions on the failure envelope provided on the worksheet for the hydrotest condition of 1.5 × operating pressure at 15°C and for the operating pressure at the estimated temperature at the time of the rupture (-15°C).

[20 points]

Data sheet for Q1(c)

Plastic collapse pressure: for a cylinder with internal axial defect



$$p_c = \frac{\sigma_f \alpha\eta}{\left(1-\frac{1}{2}\eta\right)M_g} + \frac{\sigma_f\left(1-\frac{1}{2}\eta\right)}{\left(1-\frac{1}{2}\eta\right)+\alpha\eta}\ln\left(\frac{\left(1+\frac{1}{2}\eta\right)}{\left(1-\frac{1}{2}\eta\right)+\alpha\eta}\right)$$

where: $M_g = \sqrt{1+1.05\frac{\alpha\eta}{\varphi^2\left(1-\frac{1}{2}\eta\right)}}$

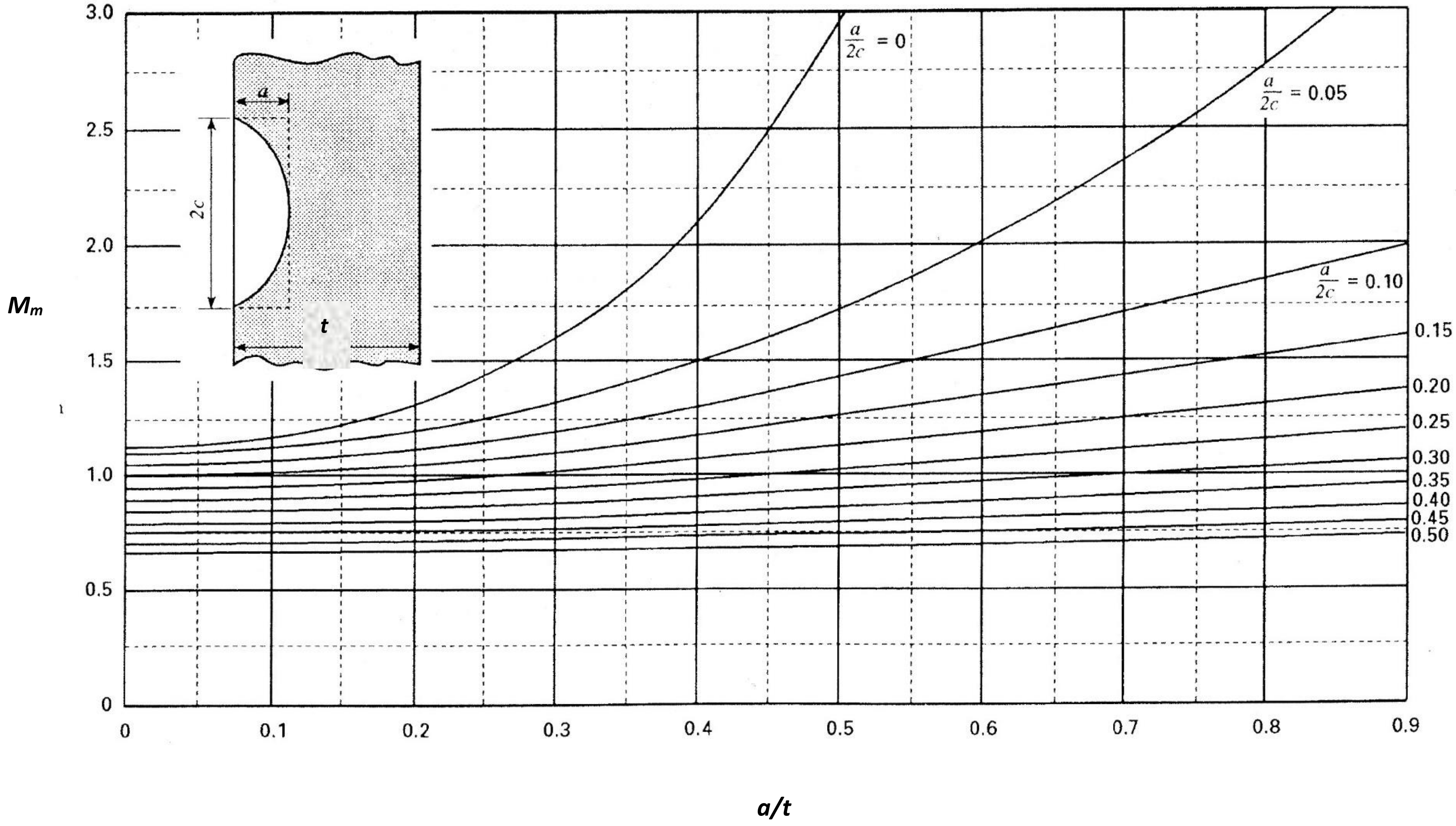
$$\alpha = \frac{a}{t} \qquad \eta = \frac{2t}{R_i+R_o} \qquad \varphi = \frac{a}{c}$$

Stress intensity factor: for thin cylinder with internal axial defect under pressure:

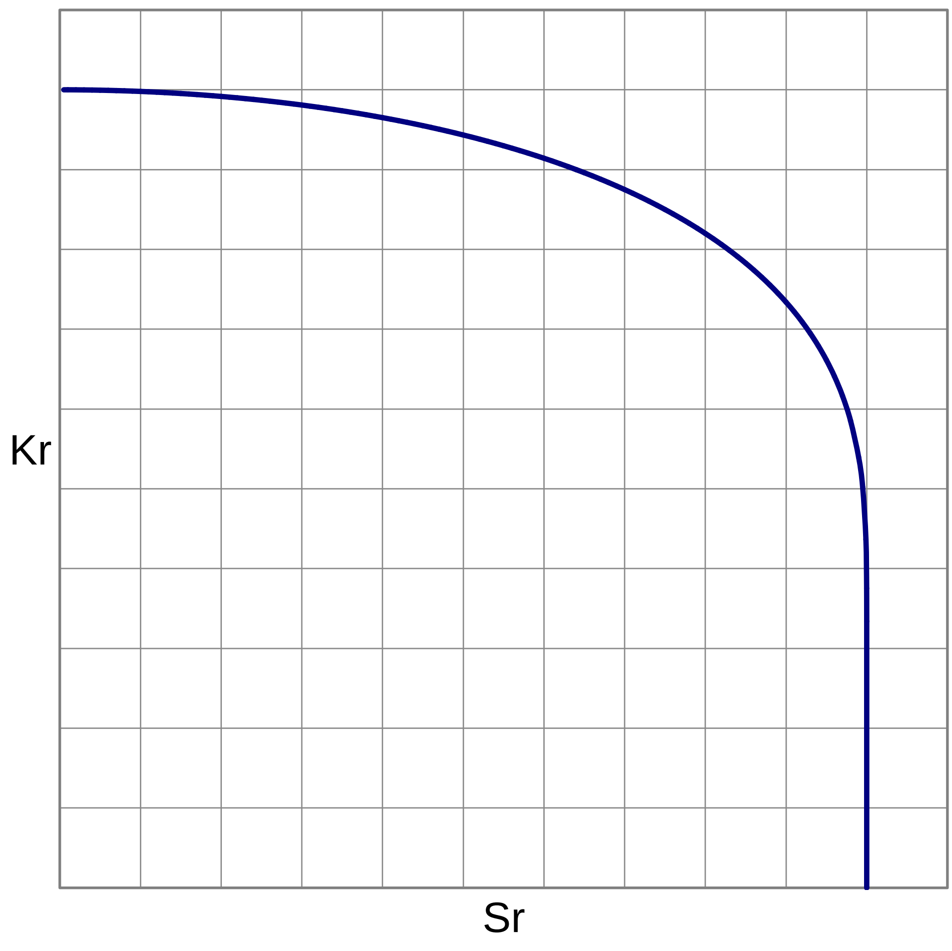
$$K_I = (Y\sigma)\sqrt{\pi a} \quad \text{where}\,(Y\sigma) = M\left[P_m M_m\right], \quad M = \frac{1-\frac{a}{M_T t}}{1-\frac{a}{t}}, \quad M_T = \sqrt{1+3.2\frac{c^2}{t\left(R_o+R_i\right)}}$$

and the parameter M_m is given in the chart on the following page.

Data sheet for Q1(c) (contd.)



Worksheet for Q1(c)



QUESTION 2

Figure (2a) shows a simplified sectional diagram of the field joint for a rocket motor. The tang and clevis are the profiles of the top and bottom of two of the large-diameter cylinders which are joined together at the launch site to make the rocket tube. If propellant leaks from the right-hand side (inside the cylinder) to the left-hand side (outside the cylinder) during launch, the rocket may explode. The key sealing elements and their failure modes and statistically independent probabilities are:

- the zinc chromate putty which, if poorly applied, can erode under the heat from the burning propellant, with a probability of P_{Pe}
- the O-rings, which can fail:

  either due to lack of resilience, with a probability of P_{Ores}

  or by erosion due to hot gases once the putty and any upstream O-ring has eroded, with a probability of P_{Oe}

  or by misalignment during assembly, with a probability of P_{Omis}, or with a probability of P_{OLCmis} once leak-checked (only applies to the primary O-ring)
- the leak-check port can be inadvertently left open with a probability of P_{LC}

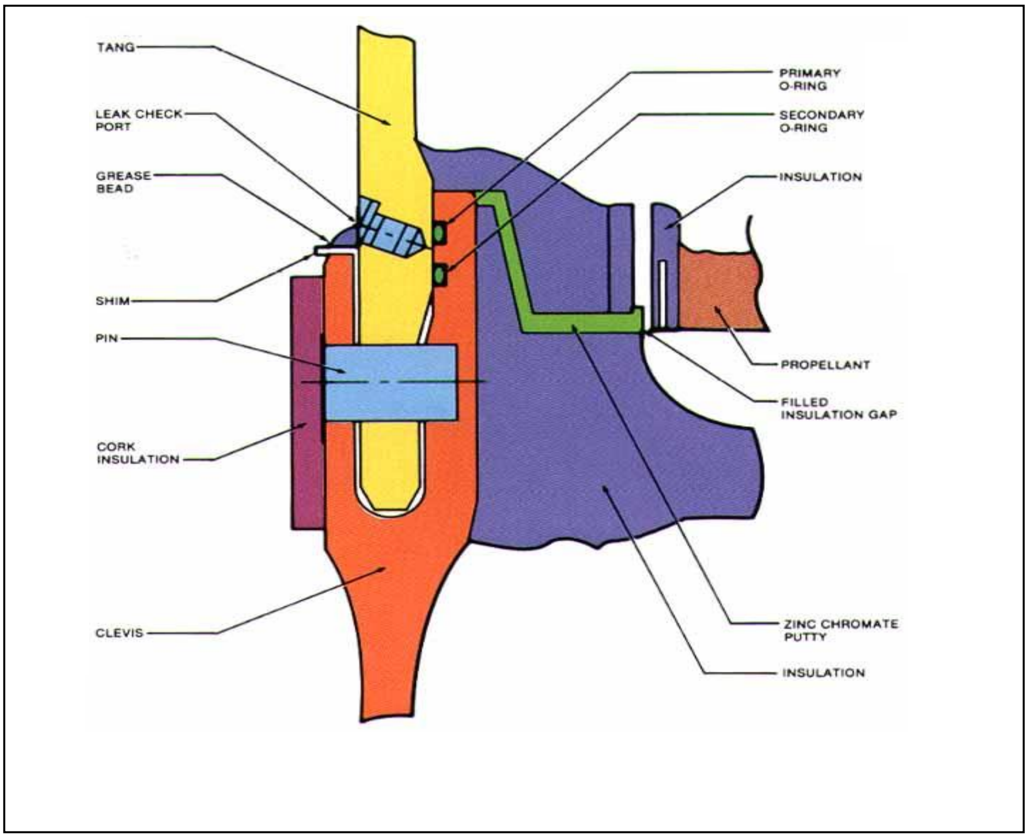
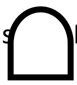


Figure (2a): Schematic diagram of rocket motor propellant containment

(2a) Figure (2b) shows a fault tree for the design where  is  ND gate and is an OR gate

Construct a reliability diagram for the design, inserting the relevant reliabilities (without actual values).

[5 points]

(2b) A recent explosion during launch of an unmanned vehicle has brought into sharp focus the role of O-ring resilience and alignment of the field joint. Choose a value of P_{Ores} that gives an acceptable (in your view) overall system reliability at a launch temperature of 20°C for the design which uses a leak-check port. ***You will not be penalised for your judgement in making the choice, but you must make your own choice and state this clearly.***

Discuss *quantitatively* the effect of launch temperature on the probability of failure for the designs with and without the leak-check port. You can make the conservative assumption that P_{Ores} increases by a factor of 10 for every 10C° reduction of the launch temperature down to zero, where the resilience is known to be unacceptable. Use fixed values for the remaining failure probabilities according to the table below:

Element	P_{Pe}	P_{Oe}	P_{Omis}	P_{OLCmis}	P_{LC}
Failure probability	0.01	0.08	0.015	0.0007	0.008

[25 points]

(2c) Imagine that you are the head engineer representing a company which supplies rocket motors to a commercial organisation which, in turn, is contracted to a state space administration. A manned mission to Mars, carrying civilian volunteers, is waiting for launch and is equipped with two of your motors. You have already cleared the risk as acceptable for launch at 10°C using the reliability model in Part (b). Weather forecasters say that the temperature is unlikely to rise above 5°C before the launch window closes for 6 months, so you are being pressed very hard to clear the risk as being acceptable.

With reference to the Royal Academy of Engineering's Ethical Principles, prepare a briefing for your company's press office. You ***must*** make a decision (for which you will bear the full responsibility) and you should explain your decision in terms that it can be understood by the general public. Your answer should be around 500 words long. Note that marks will be awarded for a clear line of argument referring to each of the four principles, leading to a conclusion which justifies your decision.

[20 points]

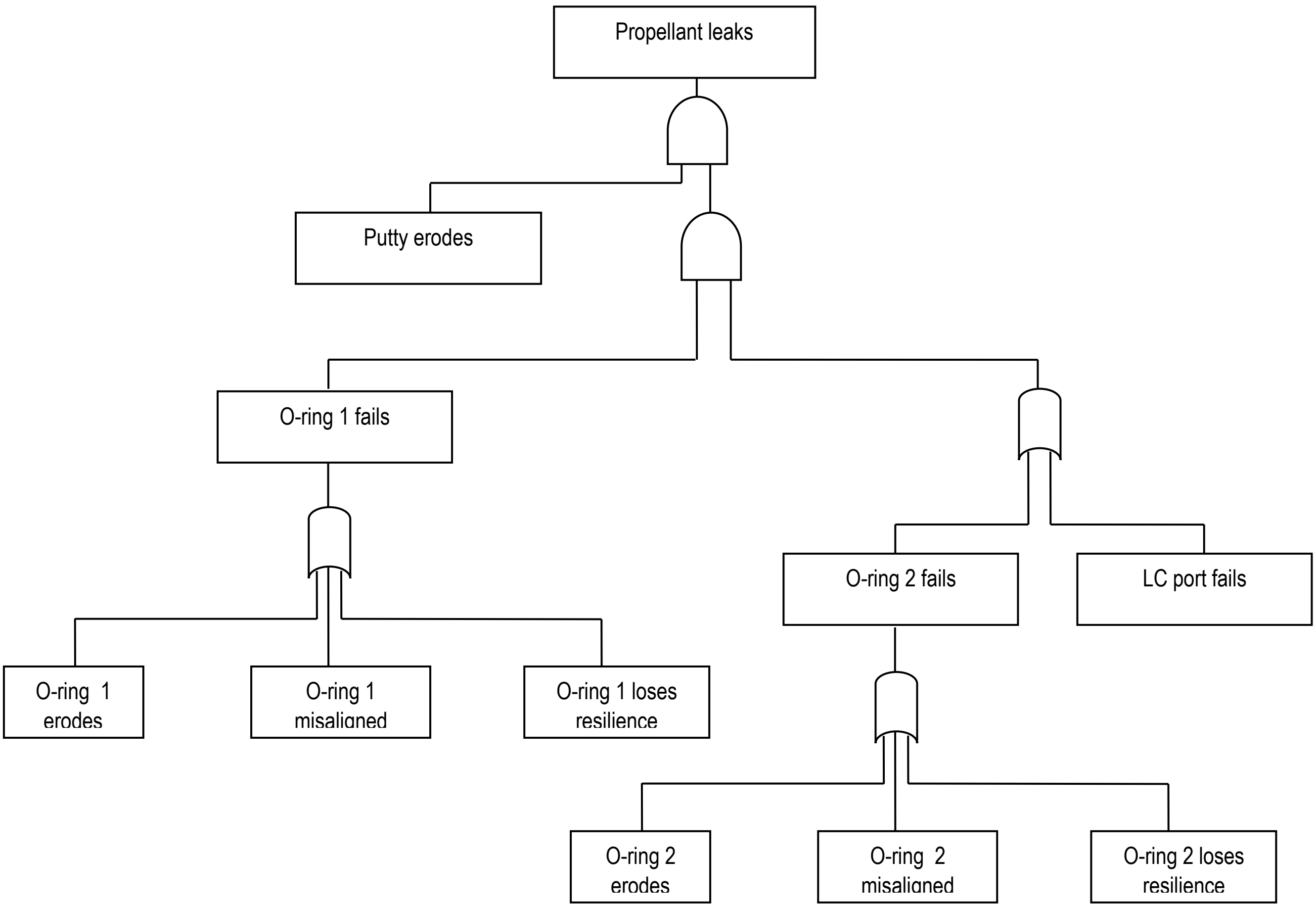


Figure (2b): Fault tree for rocket motor propellant containment

B51 HB3: Failure and Accident Analysis

Reassessment 2023

This assignment relates to Part 2 of the course and accounts for **30%** of the marks for the resit.

You must attempt BOTH questions. The point scores indicate the weighting of the parts in making up the 30 marks.

Q1 – 15 points

Q2 – 25 points

Question 1

a) It is proposed to design a smoke control system using a mechanical extract system. If the design fire has a heat release of

$$\dot{Q} = 500\,kW$$

and the enclosure has a height of 4.5 metres see Figure Q1,

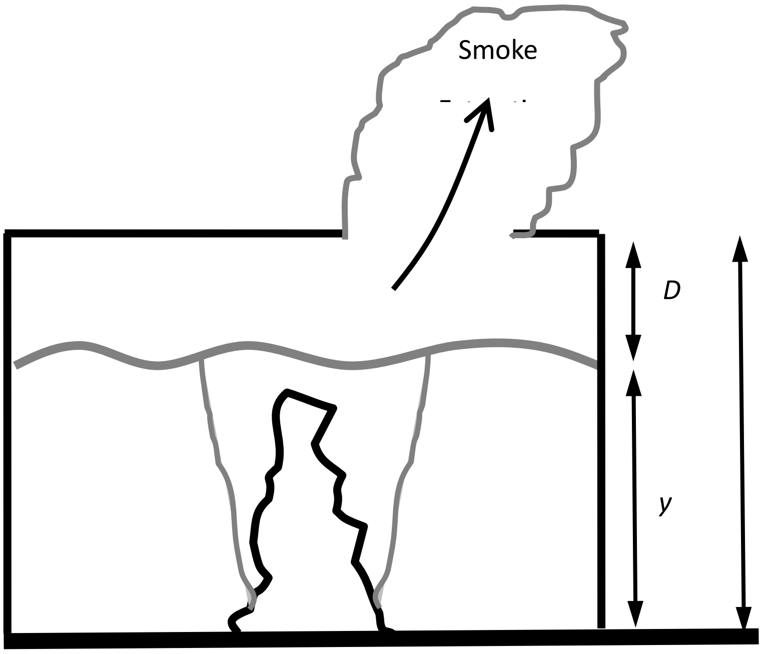


Figure Q1

calculate an appropriate smoke extraction rate. Show all your calculations to justify your design.

Take the ambient air density as 1.22 kg/m^3, ambient temperature (T_{amb}) as 290K and the specific heat capacity at constant pressure, c_P as 1.04 kJ/kg K.

[15 points]

Question 2

It is proposed to build chemical plant processing butane. Part of the processing plant consists of two high-pressure storage vessels with a capacity of several tonnes as shown below in Figure Q2.

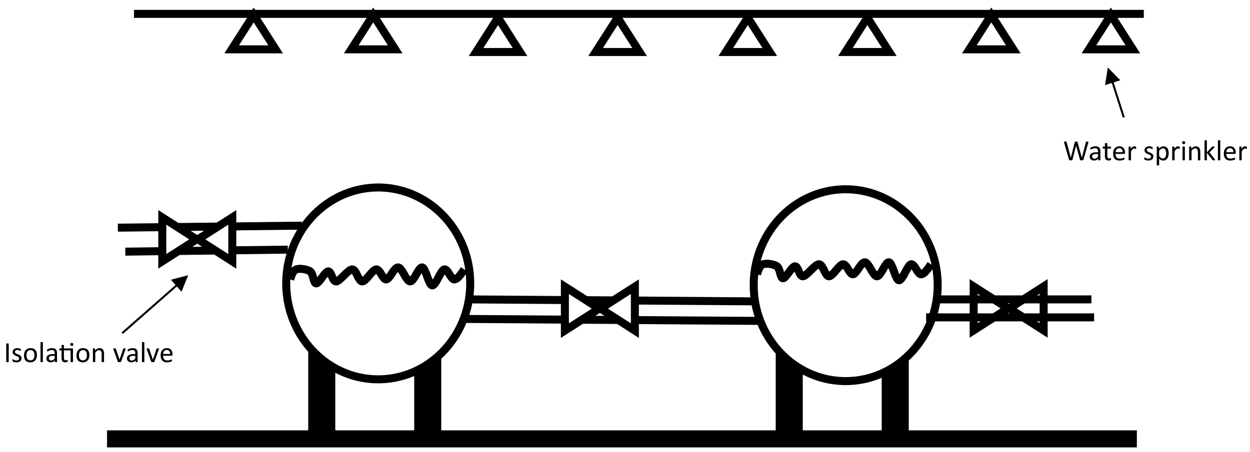


Figure Q2

a) State three credible hazardous events associated with this equipment?

[2 points each]

b) Describe the concept of escalation in the context of the above scenario. How might consequence analysis be used to reduce the possibility of escalation?

[6 points]

c) It is proposed to use a water sprinkler system linked to a fire detection system to extinguish any fire that might occur, see Figure Q2. Is this a good strategy for fire protection? Give reasons for your answers.

[7 points]

d) Name 3 alternative fire protection/ prevention strategies.

[2 points each]