

## Solution to Italian Job Dilemma

### **The Situation:**

This problem concerns a system of moments in equilibrium; if that is not the case, it makes no sense and no solution is possible. Unfortunately, being essentially a comedy film, there are several inconsistencies which require some rather rash assumptions to explain them away in order to create equilibrium. The good thing is that these inconsistencies give rise to some possible solutions.

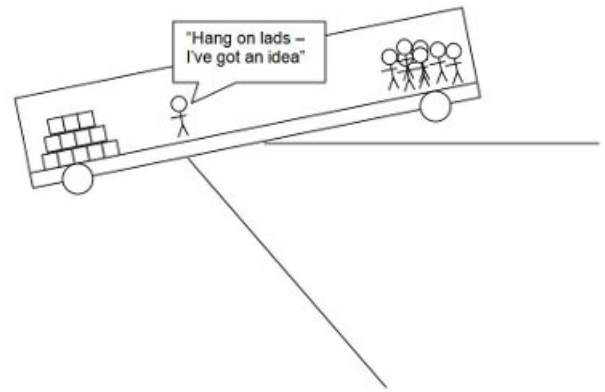
Let us deal first with the **clockwise moments** as seen in the diagram.

There are three forces contributing to the total clockwise moment: the weight of the men, the weight of the engine and the weight of that portion of the bus which is on that side of the fulcrum.

First inconsistency – how many men are on the bus? The diagram shows 7; this is certainly wrong. The film shows a bus with a driver and two men putting a ramp out for the minis to drive up; three minis enter, each with 2 men in it; the bus stops to pick up 6 men from the dormobile.  $3+6+6 = 15$

Second inconsistency – there are seven men in the dormobile as it leaves Turin but only six get out of it on the mountain.

Third inconsistency - try as I may, I cannot count more than 12 men at the front end of the bus, the driver is probably a thirteenth, behind the partition, but one man must have jumped off or been thrown clear when the bus swerved. (In reality, I know that the man at the back, ushering the minis onto the bus was, in fact, the director, Peter Collinson, because no one else was brave or foolhardy enough to do it. He obviously returned to the director's seat but you cannot assume that in the context of this problem!)



### **Assumptions:**

- 1) Bus would be of uniform density throughout its length if the fuel tank and engine were not present.
- 2) There are 13 men at the front of the bus + Charlie Croker above the fulcrum.
- 3) Men are assumed to have average mass of 65 kilos – Bennie Hill and Fred Emney are certainly not there and the rest are pretty slim.

**Clockwise Moments continued:**

13 men are at an average distance, measured as 3.4 cm. on diagram – at a scale of 1:180, that represents 6.12m. Total mass of men, except Charlie at fulcrum and the missing man, would be  $13 \times 65 = 845\text{kg}$ .

Weight of men =  $845 \times 9.8 = 8280\text{N}$

Angle to horizontal =  $12.5^\circ$  so –

Clockwise moment due to component of weight of men =  $8280 \times \cos 12.5^\circ \times 6.12 \approx 49500\text{ Nm}$ .

To this could be added the turning moment of the engine, assumed to be 350kg and about 2/3 of the weight of the bus, assumed to be 3.5 tonnes (excluding fuel and engine).

Distance from fulcrum of engine =  $(0.67 \times 11) - 0.5 = 6.87\text{m}$

Clockwise moment of engine =  $350 \times 9.8 \times \cos 12.5^\circ \times 6.87 \approx 23000\text{ Nm}$

Weight of bus portion acts at a distance of  $0.5 \times 0.67 \times 11 = 3.69\text{ m}$

Clockwise moment of bus portion =  $0.67 \times 3500 \times 9.8 \times \cos 12.5^\circ \times 3.69 \approx 83000\text{Nm}$

Total Clockwise moment  $\approx 49\,500 + 23\,000 + 83\,000$   
 $\approx 155\,500\text{ Nm}$

For the problem to make sense, that must be approximately equal to the sum of the anticlockwise turning moments, assumed to be due to the weight of the gold bars, the weight of the fuel tank and the weight of the bus portion overhanging the cliff.

**Anticlockwise Moments:**

If fuel has density  $0.85\text{ kg dm}^{-3}$ , weight of remaining fuel is  $300 \times 0.85 \times 9.8 = 2500\text{N}$ . If tank is at a distance of 1.00m from back, it is  $(0.33 \times 11) - 1 = 2.63\text{ m}$  from fulcrum, anticlockwise turning moment due to fuel =

$2500 \times \cos 12.5^\circ \times 2.63 \approx 6400\text{Nm}$

Anticlockwise moment from portion of bus over cliff acts at distance  $0.5 \times 0.33 \times 11\text{ m} = 1.82\text{m}$

Anticlockwise moment from bus =  $0.33 \times 9.8 \times 3500 \times \cos 12.5^\circ \times 1.82 \approx 20000\text{Nm}$

$155\,500 - (20\,000 + 6400) \approx 129\,000\text{ Nm}$

4) The bus is known to be a Harrington Legionnaire of length 11m. The length in the diagram is 6cm so the scale is about 1:180.

5) “g” =  $9.8\text{ N kg}^{-1}$ .

6) Fuel tank is assumed to be on average 1.00m from rear of bus. And there is some 300 litres left in it at this stage.

7) Engine is assumed to have mass 350kg and to be sited 0.50m from the front.

8) Using the diagram, 1/3 of the length of the bus (2cm on diagram) is assumed to be overhanging the cliff and 2/3 is over terra firma.

129 000 Nm must be due to the weight of the gold.

Gold bars are sited at an average distance measured as 1.3 cm. on diagram. At a scale of 1:180, this represents 2.34m. They look closer to the edge than that in the film, so I will work on a figure of 2.70m

If "W" = weight of gold,  $W \times \cos 12.5^\circ \times 2.70 = 129000 \text{ Nm}$ .

$W = 48\,937 \text{ N}$

Mass of gold =  $48\,937 / 9.8 \approx 5000 \text{ kg}$

5.0 tonnes of gold. Is that realistic?

We are told that there is 0.50 tonne of gold.

However, that is not enough to look impressive in a film. The stack looks more like something in excess of 300 bars. If the gold bars are 12.5 kg (400 troy oz.) each, that would make at least 3.75 tonnes so 5.0 tonnes is just about feasible. (In an audio commentary, available on some DVD versions of the film, Matthew Field discussed aspects of the film with producer Michael Deeley. Mr. Field had clearly done his research and commented that it looked like a lot more than half a tonne of gold to him; Mr. Deeley dismissively replied that it looked like half a tonne to him.)

9) "g" =  $9.8 \text{ N kg}^{-1}$ .

10) Fuel tank is assumed to be on average 1.00m from rear of bus.

11) Engine is assumed to have mass 350kg and to be sited 0.50m from the front.

12) Using the diagram, 1/3 of the length of the bus (2cm on diagram) is assumed to be overhanging the cliff and 2/3 is over terra firma.

### **The Solution:**

Does Charlie's idea work?

If you burn off all the fuel, you reduce the anticlockwise moment by about 6400 Nm

If Charlie advances to the gold, he increases the anticlockwise moment by about  $65 \times 9.8 \times \cos 12.5^\circ \times 2.70 \approx 1700 \text{ Nm}$

Hence, it *would* work but it would take too long and the rest of the gang shout him down, both because of the time aspect and because it sounds mad to them – how will they get away with no fuel?

Mr. Bridger (Noel Coward) has, at no stage, trusted Charlie Croker (Michael Caine). (Well, who would?) Throughout the robbery and escape attempt, Mr. Bridger has had one of the gang reporting back everything the gang has done. This gang member was in the dormobile as it left Turin but, just outside the city, he complained of travel sickness and insisted on being let out. (They did not take much persuading – more gold for them!) He walked to a nearby farmhouse where Mr. Bridger had arranged for him to pick up an Austin Healey 3000. This trusted aide sped off in pursuit of his colleagues and arrived just as Charlie had finished explaining his idea for burning off the fuel. Outside the bus, With a mass of 1,157 kg, attaching the Austin Healey by tow rope to the back of the bus would give plenty of turning moment, even without using its engine to pull. If only life were so simple – who keeps a tow rope in a sports car?

What the trusted aide does do is to find the final member of the gang outside the bus with a sprained ankle. He roughly splints the ankle with magazines from the car and bits of clothing.

The two men the pick up pieces of limestone rock and hand them to the driver to pile in the front of the bus. On average, the rocks they pick up have mass 2.0 kg. The able bodied can bring one rock to take to the bus per minute and the temporarily disabled man one rock every two minutes. After 12 minutes, they have piled 18 rocks at the front of the bus some 6.0 m from the fulcrum.

Clockwise turning motion due to weight of rocks =  $18 \times 2.0 \times 9.8 \times \cos 12.5^\circ \times 6.0$   
= 2066 Nm

If Charlie advances to the gold, he increases the anticlockwise moment by about  $65 \times 9.8 \times \cos 12.5^\circ \times 2.70 \approx 1700 \text{ Nm}$

Hence, after twelve minutes, Charlie feels confident about crawling forward and sliding the gold bars backwards.

Another ten minutes on and all the bars had been slid backwards and the gang had safely disembarked.

The gang then desperately tried to pull the bus back manually but they only succeeded in tipping the bus up so that the rocks rolled to the front and the bus fell down the cliff. They stood there before their pile of gold, most unimpressed by Mr. Bridger's trusted aide's kind offer to drive the bars away, ten at a time, when the Mafia arrived and relieved them of their problem altogether.

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(No relation to any famous scientist!)