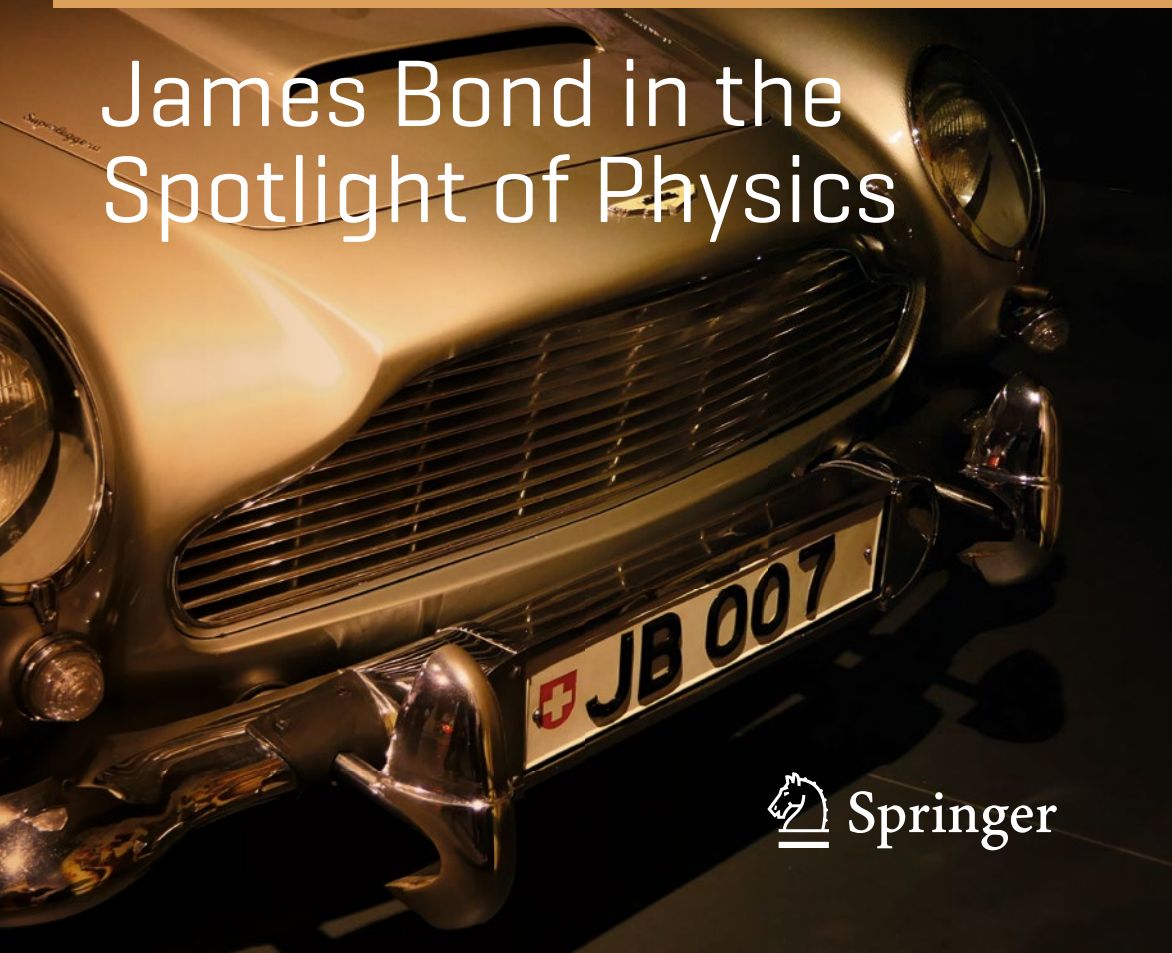
Metin Tolan · Joachim Stolze

Shaken, Not Stirred!

James Bond in the Spotlight of Physics



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Metin Tolan
Fakultät Physik
TU Dortmund
Dortmund, Nordrhein-Westfalen, Germany

Joachim Stolze
Fakultät Physik
TU Dortmund
Dortmund, Nordrhein-Westfalen, Germany

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A Quantum of Physics

Bond: *"Vodka-Martini!"*
Bartender: *"Shaken or stirred?"*
Bond: *"Do I look like I give a damn?"*
(Quote from the 21st Bond movie *Casino Royale*)

Introduction

James Bond is celebrating an anniversary. The 25th film *No Time to Die* finally makes him the most successful character in film history. When Ian Fleming published the first James Bond novel entitled *Casino Royale* in 1953, he had no idea just what kind of a character he had created. The British secret agent James Bond, whom Ian Fleming named after an ornithologist from Philadelphia, is one of the best-known film characters ever.[1] He has the habit of introducing himself with the words *"The name is Bond, James Bond"* and he enjoys a worldwide popularity that could hardly be increased. The double-O number stands for the license to kill, or as his superior M once put it,[2] in the very first Bond movie *Dr. No*:

If you carry a double-O number it means you're licensed to kill—not get killed

[1] Ian Fleming actually owned the book *Birds of the West Indies* by ornithologist James Bond (1900–1989). In the 20th Bond film *Die Another Day* it is alluded to directly: 007 says to the Bond girl Jinx: *"Oh, I'm just here for the birds—ornithologist."*

[2] M was played in the first eleven James Bond films by Bernhard Lee. In the 17th film *Golden Eye* M became female and was impersonated by Judi Dench, who died in the 23rd film *Skyfall* and has been replaced by Ralph Fiennes ever since.

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Figure 1.1 For many, Sean Connery is still the most popular actor of the secret agent 007

There's no better way to put it. So far, however, it has not been clarified whether it is a coincidence that his secret number "007" coincides with Russia's international dialing code.

James Bond is regarded as the epitome of the elegant Brit who eats Beluga caviar in the most beautiful places in the world, likes to drink Dom Pérignon or Château Lafite Rothschild from 1953, and never lets a beautiful woman pass by unattended (Figure 1.1). He survives unbelievable dangers, is always impossibly fit, has nerves like wire ropes, and flaunts a fabulous general knowledge.

But what does this all-purpose heartthrob have to do with physics? Actually, one should ask the exact opposite question: Does anyone seriously believe that James Bond would still live without knowledge of physics? When 007 pursues villains at breakneck speeds or flees spectacularly from his enemies, he naturally has to follow the laws of physics like everyone else, even if the scene in question seems unrealistic. In order to exploit these laws of physics for his own purposes, he should, of course, master them. So after reading this book everyone will agree with the statement that James Bond simply has to have a profound knowledge of physics, otherwise 007 would not be among the living anymore. And not only that. More than once it has been shown that he is also able to do superhuman things in mental arithmetic. Who else can solve coupled nonlinear differential equations[3] in a few seconds while sitting on a motorcycle, as Bond—as we will see—demonstrates in the opening sequence of *GoldenEye*?

According to Ian Fleming, James Bond has blue eyes and black hair. To everyone's surprise he is a child of the Ruhr area in Germany, because he was

[3] Experts know what that is. Non-experts can be reassured: even experts have great respect for coupled nonlinear differential equations.

born on November 11th 1920 in Wattenscheid as the son of the Scottish engineer Andrew Bond from Glencoe and a Swiss mountaineer, Monique Delacroix from Vaud. During the first five years of his life he inhaled the air of the Ruhr area and spoke better German than English, as can be seen from the "official" Bond biography.[4] He is slim, a good sportsman, excellent pistol shooter, boxer, knife thrower, and strong smoker of the brand "Morlands". The secret agent is armed with a knife on his left forearm and a Walther PPK 7.65 millimeter pistol, which was replaced by a more modern Walther P99 in 1997. Since 2012 he has used a Walther PPK/S, 9 millimeters short. James Bond is also in the enviable position of always weighing exactly 76 kilograms at a height of 1.83 meters, no matter how old he is or which actor he is portrayed by. He has a perfect body mass index[5] of 22.7. The performers have always adapted pretty closely to these ideal values. During the shooting of the film *Casino Royale* in 2006, Daniel Craig almost had the optimal dimensions with a weight of 78 kilograms and a height of 1.82 meters. James Bond will therefore always weigh 76 kilograms in all calculations in this book. This information is used when the top agent, for example, flies through the air or when he is accelerated and the force acting on him can be determined using the formula *force = mass times acceleration.* Distances or the size of objects are each indicated in "James Bond units", compared with his body size of 1.83 meters and scaled accordingly. This often makes it possible to estimate the relevant figures quite accurately. For example, we can determine the distance of the teaspoon to M's saucer, which 007 attracts with his fantastic magnetic watch in the movie *Live and Let Die*.

Other numerical values for individual scenes in James Bond films are also well known. The data for Jaws from the films *The Spy Who Loved Me* and *Moonraker* can be determined from the corresponding values of the actor Richard Kiel: 144 kilograms at a height of 2.20 meters.[6] With this information the fall of James Bond and Jaws from an airplane at the beginning of the film *Moonraker can* be analyzed in detail.

Some data are, however, less conspicuous than for example the imposing stature of Jaws. In *GoldenEye,* James Bond and a pilotless plane crash off a cliff. Here the height of this cliff is of decisive importance. The beginning of

[4] To be read in: *James Bond—the Authorized Biography of 007,* by John Pearson from 1973.

[5] The body mass index (BMI) is calculated according to the formula body weight in kilograms divided by body height in meters squared. A BMI between 20 and 25 is optimal. A BMI under 20 means underweight for men, over 25 the zone of overweight begins.

[6] In contrast to the precise values for James Bond, however, the data here fluctuate somewhat. Some sources speak of only 140 kilograms, and for the body size of Jaws one finds values between 2.14 and 2.38 meters.

this scene was actually shot real, so this cliff really exists, and it has a height of 2651 meters. It is clear that this figure is extremely important for James Bond, who jumps after the plane and catches it in the air. If a calculation shows, for example, that he can only enter the plane after a drop of 5000 meters, then this is certainly interesting—but unfortunately would not have helped him. In the discussion of the scenes in this book, we therefore use all available information, such as the height of cliffs or buildings, the weights of actors and equipment, or the dimensions of space stations and missiles, as far as they are known.[7]

But if important information is not known at all, then something must be done that the average citizen would not dare to reconcile with the image of a precisely analyzing physicist: one must estimate! For example, to calculate whether Jill Masterson really died of her gold plating, we need her weight. However, it is clear that information about the weight of a lady like the actress Shirley Eaton, who played Jill Masterson in *Goldfinger* in 1964, cannot be found anywhere. Therefore, her weight must be estimated as realistically as possible. From her height and general appearance it follows that she is certainly heavier than 45 kilograms and lighter than 65 kilograms. So a value of 55 kilograms seems to be quite realistic, even if it is not quite exact. This value can then be used to calculate that the lady must have died of her gold coating after about six hours. The same fate, by the way, also befalls the unfortunate Strawberry Fields in *Quantum of Solace*. After an hour of love-making with the top agent, she lies dead in her hotel room, completely covered in crude oil.

So far there are 25 official films in which 007 has to endure the most diverse adventures.[8] The series began in 1962 with the film *Dr. No*, which was followed on a yearly basis by the films *From Russia with Love*, *Goldfinger*, and *Thunderball. Goldfinger* is probably the most popular James Bond film ever, and it has created some myths that are still believed today. In 1967 *You Only Live Twice* reached the cinemas, in which the Scot Sean Connery appeared as James Bond for the last time. It took another two years for 007 to return to the big screen with *On Her Majesty's Secret Service*, this time played by the Australian actor George Lazenby. But this movie wasn't as successful as its predecessors, and in 1971 Sean Connery was once again persuaded to imper-

[7] Here *Das große James Bond Buch* by Siegfried Tesche (Militzke-Verlag Leipzig 2006, in German) with over 600 pages is an almost inexhaustible source of information (see www.siegfriedtesche.de). Books by the German Bond expert Danny Morgenstern, like *James Bond für Besserwisser—Der Tiefe Einblick in die Welt des Geheimagenten 007,* published by Damokles-Verlag 2014, are highly recommended. On the Internet, Klaus Gericke's www.jamesbondfilme.de is the best German source on the topic of 007.

[8] This refers to films by the production company EON, which holds the licenses to film all of Ian Fleming's books. Films like *Never Say Never Again* from the year 1983 or the slapstick version of *Casino Royale* from the year 1967 are therefore not among the official films.

sonate the top agent in *Diamonds Are Forever.*[9] However, he didn't want to be committed to this character as an actor and finally stopped slipping into the role of 007. James Bond was then played in seven adventures by Englishman Roger Moore. *Live and Let Die* came to the cinemas in 1973, *The Man with the Golden Gun* in 1974, *The Spy Who Loved Me* in 1977, *Moonraker* in 1979, *For Your Eyes Only* in 1981, and *Octopussy* in 1983. Finally, Moore played the agent on a secret mission once again in 1985, in *A View to a Kill*, already slightly out of shape and only fitting Fleming's ideal measurements with some effort. In 1987, *The Living Daylights* was then the premiere of the Welshman Timothy Dalton in the leading role, followed by the film *License to Kill* two years later.[10] This followed by a long break of six years in which a new 007 was found with the Irish actor Pierce Brosnan. The very first film *GoldenEye* in 1995 was a bang, which also took into account the new world political situation after the collapse of the Eastern bloc. Now James Bond was regularly seen on the big screen again: 1997 in *Tomorrow Never Dies* and 1999 in *The World Is Not Enough*, the last film in which Desmond Llewelyn plays the legendary inventor Q, who develops the technical gimmicks for James Bond that often enable him to survive in hopeless situations.[11] At the same time, however, John Cleese is already being trained as his successor and appears in the following film *Die Another Day* from 2002 in the Q role. It took another four years—until autumn 2006—when *Casino Royale* reached the cinemas. The Bond-series was restarted by first explaining how Bond became a double-O agent. Of course, a fresh new actor was needed for this task and was found in the Englishman Daniel Craig, who also played the role in the following four movies. *Quantum of Solace* followed in 2008 as an immediate sequel to *Casino Royale*. These two films show a Bond that first has to deserve his status as a double-O agent and thus does not yet receive all the technical gimmicks of his predecessors from MI6. So these films are playing before *Dr. No,* the very first film. Q does not appear because the British secret service provides top equipment only to a top agent. Bond hasn't had his martinis shaken yet either. In short: 007 is not yet the smart daredevil we all love. He is, however, a tough fist fighter who rushes from one spectacular action scene to the next and even forgets to eat up the Bond girl in *Quantum of Solace*! But not only that, the physics also falls well short in these movies. Spectacular action scenes usually don't include so much spectacular physics. When two cars collide at high

[9] Rumor has it that Sean Connery was "persuaded" with money.

[10] The two films with Timothy Dalton finished at the box office among the worst of all the films in the Bond series.

[11] Desmond Llewelyn died in a car accident in 1999 at the age of 85.

speed, the result is a pile of scrap metal—a physicist can't say much more about it. In 2012 *Skyfall* came to the cinemas for the 50th film anniversary of the James Bond series. 007 was here again, the old one, and with Ben Whishaw there was also a new Q. However, this was—adapted to today's times—a very young computer nerd, whose cyber abilities the new Bond needs more than the small gadgets of earlier times. *Skyfall* became the most successful Bond film of all time, with 1.1 billion dollars collected worldwide at the box office alone.[12] In 2015, the 24th film in the series, *Spectre,* was released in cinemas and continued its success seamlessly. And at last, Bond lets his vodka martinis get shaken again, not stirred. In the 25th Bond strip *No Time to Die*, the blonde Englishman is then the top agent 007 for the fifth time.

In all his adventures so far, James Bond has ordered a vodka martini 28 times, visited 38 countries, and been told 33 times that he will die. There were 60 bond girls, 31 of them brunettes, 25 blondes, and 4 redheads. A total of 16 times we can hear women whispering *"Oh, James!"* and he has sex exactly 84 times, 19 times in hotel rooms, 2 times in a London apartment, 15 times at her place, once at someone else's, 4 times on the train, 2 times in a barn, 2 times in the woods, 2 times in a nomad tent, 2 times in hospital, 2 times in an airplane, 2 times in a seaplane, once in a submarine, once in a car, once in a shower, once in a motorized iceberg, once in a space shuttle, and 26 times in, on, or under the water.[13]

At least as meticulously as these facts, the chapters of this book will physically analyze concrete scenes from the James Bond films and evaluate them as quantitatively and in as much detail as possible. All James Bond films also derive their appeal from the fact that the viewer repeatedly asks himself the question: *"Could this perhaps work somehow after all?"* when watching spectacular stunts or technical tricks. That's why we're not trying to explain how unrealistic one or the other scene is, but we're always trying to give conditions under which the scenes could actually be realized, because James Bond is not a science fiction character. However, it should come as no surprise that these conditions are sometimes somewhat unusual.

James Bond is only as good as his opponent. The villain Hugo Drax builds a large station in space and pursues a diabolical plan: he wants to destroy mankind with the help of satellites, which contain deadly poison from orchids, and repopulate the earth with flawless people selected by him. A plan that challenges a more detailed analysis. But the best James Bond opponent is

[12] The top three bond films by box-office takings (inflation-adjusted, as of January 2019) are *Skyfall, Thunderball*, and *Goldfinger*.

[13] These figures are based on a very careful analysis of all relevant scenes from the first 24 films.

undoubtedly Auric Goldfinger from the film of the same name. Everybody knows him, everybody knows that Goldfinger wants to break into Fort Knox, the American gold depot, and everybody knows that a so-called "atomic device" is supposed to help him, but James Bond defuses it only "007" seconds—as the time bomb counter indicates—before the detonation. But has anyone really understood in detail what Goldfinger calls his crime, the operation Grand Slam? This book will finally uncover secrets like these and even answer the question to end all questions: Why must 007's favourite drink, the vodka martini, always be shaken and not stirred?

Since the readers of this book certainly have different physics backgrounds, the sections are always divided into three parts. First, the James Bond scene is explained in detail. Afterwards the physics behind this scene is explained, avoiding complicated formulas as far as possible. At the end of each paragraph there is a section "Details for know-it-alls", where you can find out more about the relevant physics behind the given scenes and the calculations performed.

As an excellent introduction to this book, we recommend watching the two films *Goldfinger* and *Moonraker.* Firstly, you can't enjoy these classics often enough and secondly, in this book we examine all the important details from these films. But the new movies with Daniel Craig are also well worth it, so a cinema evening with *Casino Royale*, *Quantum of Solace, Skyfall*, and *Spectre* as preparation would also be useful. Anyway, this book is most fun if you look at the corresponding scene from the James Bond movie before each chapter. Then you will be optimally prepared to understand the analyses. However, this is not a must: all scenes are usually so well known that most have seen them before. In addition, at the beginning of each chapter we describe the relevant excerpts in detail, so that you will always be able to imagine the situation.

Basic Course Mechanics

In order to explain Bond's daring adventures we will often need *classical mechanics*. It is based on three axioms which Isaac Newton set out in 1687 in his pioneering work *"Philosophiae Naturalis Principia Mathematica"*. With the help of these three laws, all mechanical processes, be they jumps from great heights, breathtaking chases in the air, or the launch of a rocket, can be described. They are:

(1) A body moves in a straight line and at a constant speed when no force is applied to it.

(2) The rate of change of the momentum of a body is equal to the force acting on it. The momentum is given by the product of mass and speed.
(3) When two bodies interact with each other, the force exerted by the first on the second is equal to the force exerted by the second on the first, or "action = reaction" for short.

All three axioms are obviously needed to describe the adventures of 007. Using only these three relatively simple laws, all mechanical processes in nature can be understood, as long as speeds are not too high. Only when bodies move approximately at the speed of light do Newton's axioms lose their validity, and then they must be replaced by the laws of Albert Einstein's *Special Theory of Relativity,* which he found in 1905. But this will not be needed with James Bond. Although he often moves fast, compared to the 300,000 kilometers per second of the speed of light he is not soooo fast!

Newton's first axiom is also called the law of inertia, because once a body has a certain velocity, it will maintain it as long as no force is applied. Newton's second axiom, which is sometimes confusingly also referred to as the law of inertia, is often found in a special variant, because in many cases the mass of a body does not change during its motion. Then this axiom can simply be written as:

(2′) force = mass • acceleration, where the dot indicates multiplication.

In order to calculate the force acting on a body, one only has to know its mass and the rate of change of its speed. The latter is the definition of the term "acceleration" in physics. James Bond weighs 76 kilograms. Strictly speaking, we should say that his mass is 76 kilograms. His weight, the force exerted on him by gravity, is then equal to his mass m = 76 kg multiplied by the acceleration due to gravity g = 9.81 m/s^2, i.e., 76 kg • 9.81 m/s^2 = 745.5 newtons. However, as the acceleration of gravity is constant, there is no need to distinguish between the mass and the weight of a body. That's how we'll handle things throughout this book. Moreover, the value of the acceleration due to gravity is so close to the value of ten that we will often simply set g = 10 m/s^2 without incurring any major error in our calculations.

The unit of measurement of the force is the "newton". 1 newton is the force needed to increase the speed of a mass of 1 kilogram by 1 meter per second every second. This is a rather unwieldy statement. Forces are therefore best compared with the weight force that a corresponding mass would exert. If, for example, one asks whether 4000 newtons is a large force, then it simply follows from Newton's 2nd axiom and g = 10 m/s^2 that this value corresponds to

the weight force of a mass of 400 kilograms. So if James Bond's arm were to be loaded with this force, it would be as if 400 kilos or eight sacks of potatoes of 50 kilos each were hung on his arm. His arm would thus be loaded by a rather large force, as the comparison with the weight force clearly shows.

The three Newtonian axioms are laws of nature, as the physicist would put it. They therefore apply universally and everywhere, at any time and in any context. Even a James Bond can't ignore them. We'll see exactly what that means for him now.

2

The Daniel Craig Bond Movies

> The way in which the new name of the new Bond actor was leaked to the press even before today's official presentation is from the point of view of a real secret agent an embarrassing catastrophe: Mummy chatted. No torture, no coercion, no, Mum was just proud of her son, the new James Bond. Or to use his words to say, "Mommy wasn't shaken. She was just stirred!"
>
> (On 15 October 2005, Normen Odenthal, anchorman for the German TV night magazine, announced the name of the new Bond actor.)

Daniel Craig has now impersonated the famous secret agent five times. With him, the James Bond series was relaunched in 2006, as the film *Casino Royale was* intended to explain how Bond became what he is today: a cold-blooded double-O agent with the license to kill (Figure 2.1). The film also strongly oriented itself on the first Bond novel with the same title published by Ian Fleming in 1953. In contrast to all other Fleming books, this material had not yet been filmed. But since there are now more films than novels about our hero, the relationship with his creator is no longer so strong.[1] The following three Craig Bond films therefore follow their own stories, among which *Quantum of Solace* stands out. With a length of 106 minutes, it is not only the shortest, but also immediately continues the story of its predecessor. In the films *Skyfall* and *Spectre* that follow, there are also repeated references to these first two Craig Bonds, so that an overarching action is created.

[1] Ian Fleming wrote 12 novels and 9 short stories about James Bond. With 25 films it is therefore clear that novels can no longer be the basis of the film stories.

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Figure 2.1 James Bond was played in the last five films by Daniel Craig. Here he follows the bomber Mollaka in the movie Casino Royale

The Physical Burdens of a Secret Agent

At the beginning of the movie *Casino Royale*, James Bond faces a new challenge. After the inconspicuous tailing of the bomber Mollaka fails, he has to risk his neck to face the fugitive criminal in Madagascar.[2] The chase leads the two opponents to a large construction site and into the embassy of the fictitious country Nambutu, where 007 can finally catch up with the fugitive. The only problem: James Bond has to do without all the accessories of his agent existence this time and pursue his opponent on foot. This turns out to be not so easy, because Mollaka succeeds with spectacular jumps and acrobatic tricks in increasing his lead over his pursuer. The question soon arises: Are these death-defying moves even physically possible? Would the human body be able to endure the stresses and strains that occur?

A large part of the chase takes place on the very busy construction site. However, to get to the scaffolding first, James Bond chooses the path via the boom of a mobile crane (see Figure 2.2). He runs up in an upright stance and at the end jumps to the railing of the scaffolding. Based on the number of floors of the building and the average floor height to be assumed, the height of the crane boom can be estimated at around 16 meters. The angle of attack of the boom is not so easy to determine. Here it must be taken into account that scenes are often distorted in perspective. In order to nevertheless deter-

[2] By the way, Mollaka was played by Sébastien Foucan, the founder of "Freerunning", a variant of the more famous "Parkour", with more aesthetic and acrobatic elements.

Figure 2.2 James Bond can reach a construction site by walking up the boom of a truck-mounted crane. In the picture are shown the height *h* and length *l* of the boom as well as the parallel *H* and perpendicular, or normal, *N* force-components of Bond's *weight force* F_G. The angle of attack of the boom is $\alpha \approx 40°$

mine the angle with sufficient accuracy, one chooses a setting in which the camera is positioned almost perpendicular to the running direction of James Bond. This makes it possible to determine the angle of attack as about 40 degrees. Now it is easy to calculate that 007 has to cover a distance of 25 meters. However, there is another way to determine the running distance. James Bond takes twelve seconds to walk up the crane and makes about 3.5 steps per second with a span of about 60 centimeters. A short calculation also gives a length of 25 meters for the crane boom. The coefficient of static friction between the shoes of our top agent and the surface of the crane now becomes an interesting subject for physical consideration. This describes the strength of the mechanical adhesion between his shoes and the surface.[3] In general, adhesion on an inclined plane depends on the coefficient of static friction and the angle of attack. The steeper the angle, the greater the coefficient of static friction must be. This is illustrated in Figure 2.3.

The minimum static friction coefficient required to run on the slope can therefore be easily calculated. It turns out that this must fall in the range of numerical values close to those of car tires on asphalt. The secret agent's shoes, which were certainly developed by Q's department, naturally fulfilled this necessary condition and would have enabled him to pursue Mollaka via the

[3] The minimum static friction coefficient required is obtained from the quotient of the parallel and perpendicular, or normal components of the weight force, as shown in Figure 2.1.

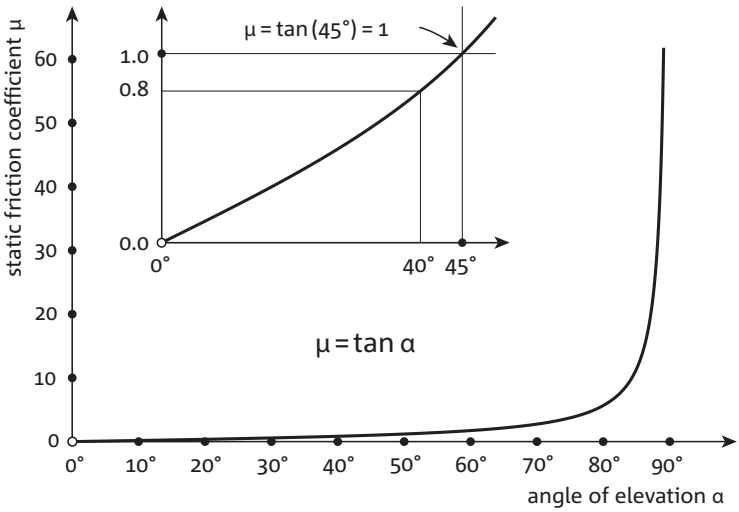

Figure 2.3 Minimum static friction coefficient μ as a function of the angle of elevation α of the crane boom. The inset shows just the angle range up to 45 degrees. For angles close to 90 degrees (i.e., a vertical wall) the coefficient of static friction increases to infinity. Most static friction coefficients lie between 0 and 1, so that inclines of a maximum of 45 degrees can be climbed upright. Typical values are: wood on stone 0.7; leather on metal 0.4; skis on snow 0.2, and car tires on asphalt 0.8

crane's boom without further problems. James Bond's analytical understanding, however, goes far beyond these rather simple calculations. He quickly realizes that the workers on the construction site have glued three sheets of commercially available roofing felt to the surface of the boom, probably for maintenance reasons. This bitumen-soaked paperboard, mixed with coarse-grained sand, is normally used as a moisture barrier in roof trusses. Due to its composition, the coefficient of static friction increases significantly and makes running on the crane a rather simple exercise for a top agent. In the film scene this roofing felt to increase the static friction on the surface of the crane boom is clearly visible.

In the next scene, first Mollaka and shortly afterwards James Bond climb up a vertical double T-beam of almost three meters in length with breathtaking speed and ease.[4] At first, this kind of locomotion might seem difficult, if not impossible, to carry out. One tends to believe that other ways of overcoming the obstacle would be more realistic. James Bond, on the other hand, is apparently immediately aware that this climbing variant is merely a special case of running on an inclined plane, which he has already mastered perfectly—as just seen.

[4] A T-beam is a steel beam that has the shape of the letter T in its profile. In the film you can see a double T-beam; it has the shape of a tilted H.