Australian Government
Australian Transport Safety Bureau

Safe Transport

RESEARCH REPORT

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Released in accordance with s.25 of the *Transport Safety Investigation Act 2003* (Cth).

ISBN1 877071 57 9 March 2004

This report was produced by the Australian Transport Safety Bureau (ATSB), PO Box 967, Civic Square ACT 2608.

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EXECUTIVE SUMMARY

Cannabis is a commonly used recreational drug, which has widespread effects within the body. Smoking is the most common form of administration. The adverse effects of cannabis on behaviour, cognitive function and psychomotor performance are dose-dependent and related to task difficulty. Complex tasks such as driving or flying are particularly sensitive to the performance impairing effects of cannabis. Chronic cannabis use is associated with a number of adverse health effects, and there is evidence suggesting the development of tolerance to chronic use as well as a well-defined withdrawal syndrome. There is also evidence that the residual effects of cannabis can last up to 24 hours. Significantly, the modern dose of cannabis is much more potent than in the past, when the majority of the research was conducted. As such, the reported adverse health effects may well be conservative. Although only a limited number of studies have examined the effects of cannabis on pilot performance, the results overall have been consistent. Flying skills deteriorate, and the number of minor and major errors committed by the pilot increase, while at the same time the pilot is often unaware of any performance problems. Cannabis use in a pilot is therefore a significant flight safety hazard.

INTRODUCTION

After alcohol and tobacco, and excluding caffeine, cannabis is the third most popular recreational drug (15). Taken predominantly for its euphoric effect, cannabis has widespread effects within the body. Most body systems are affected to some degree by cannabis.

The use of marijuana in the young adult population has been increasing in recent years. It is logical to assume, therefore, that some pilots will be at least social users of cannabis. The purpose of this review is to examine the literature concerning the effects of cannabis on pilot performance and flying skills. To do that, this review will first examine the nature of cannabis, and its acute and chronic effects on the health of the user. Then, the limited literature on pilot performance under the influence of cannabis will be discussed at length.

Prevalence of cannabis use

Cannabis is an illicit drug, widely used in many developed countries. The prevalence of cannabis consumption has grown throughout the 1990s (2,13). According to some reports, it has been tried by many young adults in the USA, Europe and Australia (6,18,19,23,38,46). In Australia, marijuana has reportedly been tried by approximately half the population in the 14 to 19 year age group (38). Marijuana is the most widely used illicit drug in the USA (19,23). In a UK study, 60 per cent of university students surveyed reported having used cannabis at least once (46). Another study found that 30 per cent of 90 hospital doctors surveyed were current cannabis users (6).

Cannabis can be used in several ways. The most common way of using cannabis is by smoking the dried leaves of the cannabis plant in cigarette form or with a pipe. This method is preferred by the majority of users (10). In some cases tobacco is added to assist with burning. Cannabis is also sometimes taken orally in baked form (e.g., biscuits) or less commonly extracted by infusion and drunk in liquid form. However, the smoked form is far more effective in delivering the desired effects.

Marijuana is generally smoked in cigarette form (known as a 'joint' or 'reefer') while the stronger hashish is generally smoked using a water-cooled pipe (2,7,18). The smoke from marijuana contains all the mutagenic and carcinogenic compounds found in tobacco, as well as all the other constituents such as carbon monoxide, but with the exception of nicotine (2).

Cannabis is a controversial drug, in that debate continues over its illegal nature and whether or not it should be legalised. This has become more problematic in recent years with the emergence of cannabis as a potential therapeutic agent for some medical problems (such as multiple sclerosis). Significantly, the issue of the long-term health effects of cannabis use remains unresolved. Much of the scientific debate has become entangled with the wider social question of whether its use should remain illegal or not.

The pharmacology of cannabis

Cannabis comes from the Cannabis Sativa plant (2,7,15,18). Different parts of the plant are used to make different forms of cannabis. Cannabis is a general term for the many different preparations of the drug. Marijuana comes from the dried flowering tops and leaves of the plant. Hashish comes from dried cannabis resin and compressed leaves, and is sometimes used to make hashish oil.

Cannabis contains over 400 chemical compounds, including over 60 pharmacologically active constituents known as cannabinoids (2,7,15). The most potent and psychoactive of these is Δ^9–tetrahydrocannabinol (Δ^9–THC). The THC content of cannabis varies with the form in which it is prepared. Marijuana has a THC content in the range of 0.5 per cent to 5 per cent, while hashish can have a THC content of up to 20 per cent (18). In Australia, the content of THC varies between 0.6 per cent and 13 per cent, with an average of 1 per cent to 3 per cent (38). Hashish oil may contain THC at concentrations of up to 50 per cent (18).

A typical marijuana joint will contain approximately 1 g of cannabis, with the proportion of THC delivered to the body being anywhere between 20 per cent and 70 per cent (18). It is estimated that 2 to 3 mg of THC will produce the typical cannabis 'high' (18).

Over the last several decades, advances in cultivation technology have resulted in more potent forms of cannabis becoming available. This is illustrated by a comparison of the THC content of a marijuana joint from the 1960s with a modern-day marijuana joint. In the 1960s, the average marijuana cigarette contained approximately 10 mg of THC. The modern joint contains approximately 150 mg of THC, or if laced with hashish oil this may increase to 300 mg (2). The modern cannabis user is therefore exposed to a dose of THC many times greater than their 1960s counterparts.

Cannabinoids act on a specific class of cell-based receptor in humans. These receptors are widely distributed in the brain, and tend to be predominantly located in regions of the brain that are concerned with cognitive processes, memory, pain perception and psychomotor coordination (18).

The function of these receptors in humans remains largely unknown. They respond to an endogenous ligand (a naturally-occurring substance) known as anandamide, named after the Sanskrit word ananda, meaning 'bliss' (2). Anandamide is much less potent than Δ^9-THC and its duration of action is shorter. Since its discovery, anandamide has been found to be one of a number of similar compounds that occur naturally in the human body. The recent identification of these cannabinoid receptors and anandamides may help to further our understanding of the role of cannabinoids in human brain function.

Approximately 50 per cent of the THC in a marijuana joint enters the lungs via mainstream smoke. Almost all of this is rapidly absorbed into the pulmonary blood stream and enters the brain within minutes (2,38). The effects of marijuana are perceptible after only a few seconds and are fully apparent in minutes (2,38).

Oral marijuana results in significant delays in the onset of effects (1/2 to 1 hour), with peak effects not being seen until 2 to 3 hours after ingestion (2,10). Taken orally, marijuana is still active up to 12 hours, due to ongoing absorption from the gut (2,10,29).

Cannabinoids accumulate in fatty tissues, reaching peak concentration within 4 to 5 days. After that, the THC is gradually released back into other body areas, including the brain. For this reason, blood Δ^9-THC levels do not correlate well with intoxication (38).

Cannabinoids are metabolised in the liver over 1 to 2 days (38), this process resulting in the formation of over 20 different metabolites (2). Some of these are psychoactive, and all have long half-lives. One of the major metabolites is <11-hydroxyTHC, which may be more potent than Δ^9-THC. The metabolites are excreted in urine (25%) and from the gut (65%). Metabolites in the gut are reabsorbed, which prolongs their actions in the body.

Eventually, Δ^9-THC is broken down into an inactive metabolite, 11-nor- Δ^9-THC-9-carboxylic acid (THC-COOH). This substance is then excreted from the body over a period of days to weeks (38). Detection of THC-COOH in the blood only indicates prior use of marijuana, within the previous few weeks (38).

The elimination of marijuana can be slow. A single dose of THC may take up to 30 days to fully eliminate from the body. Plasma concentrations of Δ^9-THC are generally negligible within 3 to 4 hours after smoking. However, Δ^9-THC may be found in urine for at least 48 to 72 hours after oral administration (47). The tissue half-life of THC is approximately 7 days. With repeated use, however, cannabinoids can accumulate in high levels in the body and continue to reach the brain (2).

Health effects of cannabis

There is a significant amount of epidemiological and scientific evidence concerning the health effects of cannabis. The majority of this evidence indicates that cannabis use is associated with acute and chronic adverse health effects.

The point needs to be made that much of the early research into the effects of cannabis on the health of the user was done in the 1960s and 1970s, when the THC content of the drug was much lower than is the case now. As such, much of this early research has become superseded by more modern research into the health effects of cannabis with higher THC content. This is significant, since the effects of cannabis are dose-related, and the modern dose of THC is much higher than some decades ago (2,18).

Acute effects of cannabis

Cannabis produces a wide variety of effects in all parts of the body and most body systems. It thus shares some properties of alcohol and other drug classes such as tranquillisers and opiates. The acute toxicity of cannabis is low – no cases of death directly due to acute cannabis exposure have been reported in the literature (2,18).

Behavioural effects

Marijuana produces a sense of relaxation and euphoria: the so-called “high” well known to users. The euphoriant high can be produced with a THC dose as low as 2.5 mg (2). The high gives the user a feeling of intoxication, with decreased anxiety and increased sociability (if the drug is taken in friendly surroundings). The enhancement of pleasure, the sense of euphoria and the level of sedation associated with the marijuana high seem to depend on the expectations and personality of the user, the dose of the drug and the environment in which the drug is taken (2,15). The high lasts approximately 2 hours or more, depending on the drug dose (2). The high may be a function of increased cerebral blood flow to those areas of the brain associated with arousal and emotion (33).

Some adverse behavioural and mood effects have been noted in some users. These include severe anxiety reactions and panic attacks, as well as paranoia and psychosis (2,15). Acute panic reaction has been described as the most frequent adverse effect of cannabis (15). These effects are dose-related and appear to be more common in naive users or those who are psychologically vulnerable (2,15). Hallucinations may even occur with large doses of cannabis.

Perceptual alterations are a feature of acute cannabis use. Users report intensification of sensory experiences (e.g., colours, music, tastes, and smells), and heightened emotions (2,15,18). There is also a degree of time distortion (so-called temporal disintegration), in that time appears to move much slower under the influence of cannabis (2,12,15,35,45). Marijuana also produces a dose-dependent linear increase in pain threshold (16).

Physiological effects

Marijuana exerts a number of physiological effects on several body systems. For example, increased appetite has been reported, with some studies showing an increase in subjective ratings of hunger after marijuana exposure (10,14). Significant increases in heart rate have also been consistently demonstrated after acute marijuana use (2,14,18,21,23,32,45). Postural hypotension has been reported, with some users feeling faint upon standing (2,18). There is also widespread peripheral vasodilatation, with reddening of the conjunctivae a characteristic sign of cannabis use (2,32,45). Marijuana can affect the function of the eyes in a dose-dependent manner. Large doses of THC appear to impair normal eye movements (3).

Psychomotor performance and cognitive effects

The effects of cannabis on cognitive function and psychomotor performance are dose-related (2,4,18,23,32). However, they are often manifest with doses as low as 5 to 10 mg THC, even in regular users. Various studies have shown that acute exposure to marijuana impairs attention and learning, increases reaction time and causes difficulty in concentration (5,12,21,31,45).

Reduction in motor skills has also been described (2,15,18,23,32,36,41). These include reductions in physical strength, impaired balance, coordination and steadiness (15,36). A study by Manno et al demonstrated impaired motor performance on pursuit-type tests following administration of Δ^9-THC (32). Similar marijuana-induced performance decrements on tracking tasks have been found by others (41).

Acutely, marijuana impairs the ability to perform complex tasks requiring attention and mental coordination (2,12,15,18,21,23,30,31,42). Heishman et al (23) found that marijuana produced a dose-dependent impairment of cognitive function and psychomotor performance. Indeed, the authors noted that complex tasks requiring rapid responses and discriminations are particularly sensitive to the effects of marijuana (23). Many studies in the previous 10 to 15 years have demonstrated that marijuana produces significant impairment of driving performance (8,38,43).

In an attempt to equate alcohol intoxication with marijuana, Heishman et al (22) found that the subjective and performance effects produced by smoking marijuana closely resembled those produced by ingestion of a low dose of alcohol (0.6 g/kg). This approximates to the consumption of five standard drinks by an 83kg person.

A consistent finding with marijuana use is that it significantly affects memory. Marijuana-induced disruption to the normal functions of memory, especially short-term memory, have been well described by several researchers (1,2,5,11,12,15,18,20,21,23,27,29,35,44,45). Short-term memory, or working memory as it is also called, is extremely important in everyday activities. Working memory involves the temporary storage of information derived from sensory systems, long-term memory stores, and motor programmes to enable the completion of cognitive tasks that require conscious thought, reasoning, and divided or focused attention (27,28). Working memory has been described as a limited capacity work space (27,28). Marijuana's detrimental effect on working memory function contributes to the overall impairment of psychomotor performance associated with the acute use of cannabis.

Chronic effects of cannabis

Chronic cannabis use is associated with a number of adverse health effects. Bronchitis and emphysema are associated with chronic smoking of marijuana, in much the same way as chronic tobacco smoking (2,18). Smoking a marijuana cigarette results in a higher amount of tar being ingested and a higher level of carboxyhaemoglobin in the user's blood, due to deeper inhalation and the absence of filters on the marijuana cigarettes (2).

Chronic airways disease and bronchogenic carcinoma are potential risks with chronic marijuana smoking. Also, there is an observed increased risk of rare forms of mouth and throat cancer in young, chronic cannabis users (2,18).

Chronic cannabis use has been shown to interfere with the normal function of the immune system, and has also been associated with a number of reproductive risks (2,15,18).

The ‘amotivational syndrome’ has become synonymous with chronic cannabis use (26). This syndrome is described as personality deterioration, with apathy, loss of energy and lack of drive or motivation to work (15,26). However, some authors believe that this syndrome more truly represents ongoing intoxication in frequent cannabis users (26). Others have suggested that it could simply represent the type of person who becomes a chronic cannabis user (15). However, there remains ongoing debate in the scientific and clinical literature on the issue of the validity of this syndrome.

Heavy cannabis users are at risk of developing a psychotic episode, and schizophrenics who use cannabis risk the aggravation of their symptoms (such as hallucinations and delusions). Large doses of Δ^9-THC produce confusion, amnesia, delusions, hallucinations, anxiety and agitation (18). A Swedish study indicated that chronic cannabis use may precipitate schizophrenia in vulnerable individuals (18). However, this point remains controversial with no reliable data one way or another. The balance of evidence is, however, that cannabis use can exacerbate the symptoms of schizophrenia (17,26).

It has been suggested that subtle cognitive impairment could develop in chronic users over several years (18). Solowij et al examined cognitive functioning in a group of nine long-term cannabis users. Their findings suggested that long-term cannabis use may impair the efficient processing of information (42).

Tolerance and dependence

Tolerance to the effects of cannabis develops with chronic use (2,15,18). Indeed, chronic users may consume amounts that would be effectively toxic to inexperienced or naïve users (15). Tolerance to the heart rate-elevating effects of cannabis has been seen in daily marijuana users (39).

It was initially believed that cannabis did not produce dependence in the user and was not associated with a withdrawal syndrome after discontinuation of use. However, since the 1970s this view has been challenged. Daily users of cannabis are at increased risk of developing dependence. In the US, there are reports that cannabis dependence is among the most common forms of illicit drug dependence (18). There is a 10 per cent risk that someone who uses cannabis will develop a dependence on it (18,26). The dependence syndrome is similar to that for alcohol, and is characterised by an inability to stop using cannabis or to control its use (2,18).

Many studies have been performed that confirm that cannabis is associated with a well-defined withdrawal syndrome (2,18,26). According to Johns (26), the cannabis withdrawal syndrome has now been unequivocally demonstrated. Sudden cessation of cannabis use in chronic heavy users results in symptoms of withdrawal, including irritability, restlessness, anxiety insomnia and decreased appetite (2,15). This is similar to the abstinence syndrome seen with hypnotic drug withdrawal (2,15).

Residual effects of cannabis

In their review of the relevant literature, Pope et al found that there is evidence of a residual drug effect on attention, psychomotor tasks and short-term memory during the 12 to 24 hour period following cannabis use (40). This effect may occur after just a single dose of cannabis. The residual drug effects of cannabis appear to consistently involve impairment of performance on tests of focused attention, visual and verbal memory, and visuomotor functions (40). It has also been demonstrated that marijuana can adversely affect human performance of complex cognitive tasks for up to 24 hours after smoking marijuana (21). It has been further suggested that the extent of cannabis effects post-exposure may well depend on the complexity of the task being performed (47).

The problem of marijuana in aviation

On March 30, 1983, a Gates Learjet 25 was approaching its destination at Newark Airport, USA. The arrival was flown at a speed in excess of the 250 kts maximum allowed for flight below 10,000 ft. They were instructed not to descend below 2,000 ft until on final approach. Despite this, the turn to final was made at 1 mile from the runway at an altitude of approximately 700 ft. A 50 descent was flown at a vertical speed of approximately 1000 feet per minute. The aircraft bounced on landing, banked to the right then struck the ground in a right-wing low attitude and was destroyed. Both pilots were killed. No mechanical faults or failures were identified with the aircraft. Toxicological examination of the pilots revealed that both had used or been exposed to marijuana. Impairment of both pilots due to drugs was listed as a contributing factor in the cause of this accident, with the pilot being found to have smoked marijuana in the 24 hours prior to the crash (37,47).

Flying an aircraft is a complex task requiring a high level of cognitive function and psychomotor performance. Marijuana has been shown in many studies to impair the performance of complex tasks, and was felt to be a major contributory factor in the accident detailed above. Other studies have also reported cases of aviation accidents in which marijuana was found in the pilot (9,48). In 1973, an FAA report revealed that in a 2-year period, some 500 out of 1,000,000 applicants for a medical certificate admitted to previous marijuana use (29). The implications of marijuana use in pilots and the consequent potential for reduced flight safety are clearly important issues.

The aerospace medicine literature consists of only a small number of studies that have examined the role of marijuana in impairing pilot performance. Lewis et al found that marijuana and altitude can produce cumulative effects on some cognitive tasks. Work output and speed of response were reduced at altitudes of 8,000 ft and 12,000 ft as the dose of Δ^9-THC increased. The authors felt that this finding had clear implications for flight safety (30).

Meacham et al (34) examined the performance of 6 pilots who were also classed as infrequent marijuana users. After being trained to fly a specific flight sequence using an instrument flight simulator, the pilots were all given either a controlled dose of marijuana or a matched marijuana placebo. Each pilot flew the instrument sequence under both marijuana and placebo conditions. The results of this experiment showed that each pilot suffered a significant deterioration in flying performance during the 30 minute period after taking marijuana, but not after taking placebo.

The marijuana-associated decrease in flight performance involved an increase in major errors (such as navigational errors, major altitude deviations, stalling and loss of control events). Minor errors were also significantly more common with marijuana, and these involved altitude deviations greater than 100 ft, heading errors more than 300. The authors felt that marijuana intoxication was incompatible with safe aircraft operation.

Janowsky et al reported anecdotal information that social marijuana use among pilots they surveyed was not uncommon, and that some pilots admitted having flown while frankly intoxicated by marijuana (24,25).

Janowsky et al (24,25) performed a more detailed version of Meacham's earlier study, using a similar instrument flight sequence on an identical instrument flight simulator. 10 pilots, all experienced social marijuana smokers, participated in their study. 7 were professional pilots, and 3 were private pilots. All were trained on the specific flight sequence on the simulator, before completing 2 tests (1 with a controlled marijuana dose and the other with a placebo).

The results of this experiment confirmed the earlier work by Meacham. Marijuana caused gross impairment of flying skills and performance, reflected in a greater number of both major and minor errors. The acute effects of marijuana were seen to persist for 2 to 6 hours after administration.

Marijuana caused alterations in concentration, and in some cases complete loss of orientation. Attending behaviour also changed in some pilots, with them paying attention to only one variable to the absolute exclusion of all others. Temporal distortion, a known consequence of acute marijuana exposure, was also noted, with some pilots no longer being able to tell how long they had been flying for. This occurred despite the presence of a stopwatch and written instructions for the flight sequence.

There is a difference between the acute effects of marijuana on pilot performance and flight safety, as seen above, and the carry-over or hang-over effects following cannabis use in pilots. To that end, Yesavage et al examined whether Δ^9-THC has a persistent effect on flying skills and performance (47). In their study, 10 pilots who were also marijuana users were trained on a flight simulator-based landing task for 8 hours. They then smoked a marijuana cigarette with a standard Δ^9-THC content (19 mg), equivalent to a "social dose." Their performance on the simulator landing task was then assessed up to 24 hours after smoking the marijuana.

The results of this experiment indicated that there were significant effects on pilot performance 24 hours after smoking a single marijuana cigarette. Overall, the pilots demonstrated much more difficulty in aligning with and landing on the runway after Δ^9-THC exposure. There were increases in the number and size of aileron changes, the size of elevator changes and the degree of vertical and lateral deviation from the required flightpath during the approach to land. At 24 hours post-marijuana, the lateral deviation on approach to land was almost twice that of the pre-marijuana test. There was also a significant increase in the distance from the centre of the runway on touchdown. Indeed, one pilot 24 hours after smoking the marijuana landed off the runway entirely. More worrying, perhaps, was their finding that the pilots were not aware of any impairment of their flying performance at 24 hours after marijuana use.

Leirer et al examined the inter-relationship between marijuana, age and difficulty of the task on pilot performance (27). They found that there was a cumulative adverse effect of age, marijuana and task difficulty on pilot performance. Older pilots performed less well than younger pilots, bad weather resulted in lower pilot performance, and impaired performance occurred immediately after exposure to marijuana. In this group of pilots, a carry-over effect of marijuana was not found at 24 hours post-exposure.

They also found that in terms of marijuana effects on pilot performance, there was no association between marijuana and a specific flight task or manoeuvre. Impairment in pilot performance seemed to randomly fluctuate across time. Flying an aircraft has been described as a resource-limited simultaneous attention and performance task (27). It is highly dependent on the capacity of working memory. Accordingly, performance at the flying task may be limited by either the speed of working memory or its capacity to process information presented to the pilot during the flying task (27). On the basis of their research findings, they concluded that recreational marijuana users may not necessarily have any performance difficulties with complex human-machine interactions such as flying. However, if other performance-reducing factors are added (such as bad weather or other flying-related difficulties) then they may find that their performance becomes significantly impaired, due to the cumulative effects of these factors overloading cognitive function and working memory (27).

Carry-over effects of marijuana on pilot performance have been shown to occur at up to 24 hours post-exposure. Two studies by the same group of researchers found contradictory evidence of a 24-hour carry-over effect – one study demonstrated a carry-over effect at 24 hours which was not found in a subsequent study. This same research group then conducted a third study, using a flight simulator and a difficult flying task, to examine the issue of a 24-hour carry-over effect of a single, low-to-moderate social dose of marijuana.

The results of their study confirmed that there is indeed a significant carry-over effect of marijuana on pilot performance up to 24 hours post-exposure. Only 1 pilot reported awareness of any drug effects at the 24-hour mark (28). These findings led them to the conclusion that the combination of impaired performance and lack of subjective awareness of any performance decrement is a dangerous condition in pilots. They emphasise the point that marijuana users operating complex human-machine systems such as aircraft cannot rely on their own judgement as to whether they are fully able to perform the required tasks.

On the basis of the available evidence, it would appear that impairment of performance and skills is at a maximum during the first 4 hours after taking marijuana, and although performance improves after this period there is still some residual impairment over the subsequent 24 hours. The combination of this impaired performance at 24 hours and some other performance-reducing factors such as increased task difficulty can result in significant impairment of performance in pilots.

CONCLUSION

Cannabis is a commonly used recreational drug. While it is usually taken for its mood altering properties, a number of adverse effects have been documented with acute use. The effects of cannabis are dose-dependent. Chronic use puts the user at risk of a number of adverse health effects. There is considerable evidence that cannabis, like alcohol and other drugs such as tranquillisers, can lead to the development of tolerance and dependence. Similarly, there is also evidence that sudden cessation following a period of chronic use is associated with a withdrawal syndrome.

There is also evidence that residual effects of cannabis can persist for up to 24 hours. These effects include persisting difficulty with psychomotor tasks and interference with cognitive function (especially memory). These adverse residual effects will clearly cause problems for anyone attempting to drive a car or train, fly an aircraft or navigate a ship during this period.

While the literature concerning the effects of cannabis on pilot performance is limited in number, the conclusions drawn by the researchers are consistent. Cannabis causes impaired performance of complex tasks such as flying an aircraft. Flying skills deteriorate, and the number of minor and major errors committed by the pilot increase, while at the same time the pilot is often unaware of any performance problems. Clearly then, acute cannabis intoxication is incompatible with the safe operation of an aircraft.

The question as to when it is safe to operate an aircraft after a dose of cannabis is a more difficult one to answer. On the basis of the scientific research reviewed here, it would appear that a pilot should not fly an aircraft in the 24 hours following even a single social dose of cannabis. This is a consequence of the known carry-over effects of cannabis on pilot performance after 24 hours.

The psychomotor and performance-reducing effects of cannabis are dose-dependent and appear to be related to task difficulty. The more difficult the task required of the pilot, the more likely that carry-over effects of cannabis will result in impaired performance of the flying task. Thus, a pilot may cope well with a routine flight in the 24 hours after a cannabis dose, provided nothing goes wrong. However, in-flight problems such as engine failure or deteriorating weather conditions may overload the cognitive capacity of the pilot to a detrimental extent. Thus, the combination of recent cannabis use and other performance-reducing factors such as increased task difficulty can lead to serious impairment of pilot performance and a significant reduction in flight safety.

The exact duration of the cannabis carry-over effect and its interaction with other physiological stressors (altitude, fatigue etc) are largely unknown. While carry-over effects have been observed at 24 hours, the adoption of a 24 hour time limit between cannabis use and flying may well be insufficient. Some pilots may exhibit carry-over effects of cannabis more than 24 hours after a dose, depending on the circumstances and the level of task difficulty. An appropriate "cannabis-to-throttle" time remains to be determined, either scientifically or administratively (leaving aside the wider social and regulatory question of whether such a rule is acceptable or not).

In summary, therefore, and on the basis of the currently available evidence, cannabis use in a pilot should be considered a significant and unpredictable flight safety hazard, which can result in impaired pilot performance.

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