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STEEPER APPROACHES

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Abstract

It is becoming increasing difficult to increase airport capacity due to infrastructure and operational constraints. Research of new technologies and operational practices suggests that by including variables such as approach angle and approach speed in the design process, noise and capacity constraints may be alleviated.

The paper considers the implications of re-optimising Conventional Take-off and Landing (CTOL) aircraft for approaches up to 6° with field length of secondary importance. The associated cost penalties of such operations are reduced compared to that of pure Short Take Off and Landing (STOL) operations. As such, steeper approaches should appear more attractive to potential operators.

The theoretical results are related to practical operations by considering the modification of existing aircraft for steeper approaches. For some aircraft, lower landing weights will enable the approach speed to be reduced whilst maintaining acceptable vertical descent rates. In this way the economics may be controlled by developing variants of existing aircraft and increasing production runs. The resulting lower noise levels may allow Stage 3 aircraft to become Stage 3½ without limiting payload.

Introduction

World air travel continues to grow at around 5 percent per year. This constitutes a doubling in air travel in approximately 15 years. One of the main bottlenecks in the air transport system is associated with that of airport capacity. Increasingly airport capacity is becoming constrained by physical capacity and environmental constraints such as noise, air and water quality, and more recently third party safety. It is likely that stricter environmental constraints will be introduced, some of which may actually favour the capping of airport capacity. Many airports around the world already employ stricter noise rules than are required for aircraft airworthiness purposes.

In order to increase physical runway capacity, a greater number of movements by larger aircraft will have to be accommodated, despite these increasingly severe environmental problems. The public will only tolerate such expansion if the industry is seen to be doing everything economically possible to each make aircraft movement as neighbourly as possible. Stricter noise standards for aircraft certification may only be part of the solution. As airlines continue to upgrade their fleets from Stage 2 to Stage 3, opponents want to see the introduction of stricter rules, such as a new Stage 3½. Many Stage 3 aircraft would have difficulty meeting the new standards. These aircraft may then be devalued, leaving a tremendous financial burden for airlines which has caused great concern. Further, in order to meet stricter noise rules, aircraft weight may be increased resulting in increased fuel burn which leads to higher operating costs and engine emissions. The recent Aircraft Noise Design Effects Study (ANDES) argues that, whereas the previous 20dB reduction in noise was achieved at a cost of an additional one percent on operating cost, on fuel used and on emissions produced, the next 3dB noise reduction may cost five times as much[1].

For larger aircraft with significant airframe noise during the approach phase, it may be necessary also to change the approach and take-off flight profiles.

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In the past engine noise was the significant contributor to aircraft noise. The trend to higher bypass ratio engines to improve fuel efficiency also reduced noise, mainly due to the slower jet-velocity of the bypass air flow. Improvements in aircraft performance, especially for twin engined aircraft have lead to increased climb rates during the take-off phase, increasing the distance between the noise source and communities on the ground. During the approach phase, however, the aircraft is operating at low power settings and the airframe noise becomes increasingly important, especially for large aircraft due to their faster approach speeds. This situation is then amplified by fact that conventional aircraft at most of the world's airport descend at angle of 3°. This leads to a relatively long period of time where the aircraft is close to the ground and results in a large noise 'foot-print' for this phase of flight.

Changing the approach profile to reduce aircraft noise has been suggested in the past, but in the main these attempts have been unsuccessful. In the early 1970's, Short Take Off and Landing (STOL) was considered as a way of supplementing airport capacity using short runways[2,3,4]. In order to meet the landing field length requirements these aircraft has slower approach speeds. This enabled the aircraft to fly much steeper approach than the conventional 3°. Currently, these aircraft have only found favour in niche markets due to increased costs, associated with the short field length requirements.

At around the same time, investigations were also carried out on two-segment approaches with conventional aircraft, but these were not adopted, partly due to difficulties in making the transition from 6° to 3° and the pilots' dislike of high descent rates[5]. Also in these cases the noise near the threshold was not improved. These studies showed that all of the concepts appeared to be too extreme to gain acceptance.

Faced with increasing complaints as air traffic growth continues, airports are beginning to reconsider alternatives to the conventional 3° approach. The approach angle may be increased to around 4° with conventional aircraft currently in service. This would increase the height on approach at any single point by a third and possibly reduce the engine thrust setting during the approach. Indeed, many airports already use approaches between 3° and 4° for obstacle clearance reasons. Recently, Minneapolis St. Paul announced it planned to introduce 4° approaches to reduce noise[6].

Approaches above 4° will require a reduction in approach speed in order to maintain acceptable descent rates. It is likely that the maximum descent rate will limited by the air crews and also by the aircraft Ground Proximity Warning System (GPWS). The airlines do not want to incur retraining costs for air crews flying steeper approaches. As some airports already operate between 3° and 4°, the training may be minimal and simply involve the use of ground based simulators to provide experience of steeper approaches. The second, more limiting factor, is the wide use of the GPWS. These systems are used by virtually all airlines to reduce the risk of collision with the ground and work by monitoring the aircraft's height above ground and also the rate of descent towards the ground. If the approach angle is increased substantially above 3° at the same approach speed, the aircraft's rate of descent will increase and could trigger a GPWS alarm. Current systems may allow approaches to increase up to 4° whilst maintaining current approach speeds. Above 4°, changes to the GPWS would be required. This may be costly and unwanted by airlines, many of which have recently introduced enhanced systems with the introduction of terrain mapping. Alternatively, the GPWS may be disabled during the approach phase. This, however, may lead to a significant reduction in safety levels if it is considered that GPWS increases safety.

Approaches greater than 4° may be achievable with smaller aircraft with approach speeds and hence descent rates lower than that of the larger aircraft types. Further increases in approach angle may then be achieved by reducing the maximum landing weight of the aircraft and increasing lift on approach. The first option may be possible with changes to the payload/range characteristics of the aircraft resulting in an operating cost penalty. By reducing the take-off and landing weight, the BAe 146 is making 5½° approaches to London City Airport and the Fokker 100 has also demonstrated this capability. The take-off weight was reduced to meet take-off requirements for the 1,200m long runway and enables the aircraft to make the approaches at descent rates of around 1,100ft/min. The second option may be possible with improved flaps and/or increased wing area to increased maximum lift during approach at the same landing weight. This will increase the structural weight of the aircraft and require an increase in the maximum take-off of the aircraft unless payload/range is sacrificed with major redesign implications for the whole airframe.

The steeper approach concept will bring benefits in terms of noise, safety and capacity. The noise contours on the ground should shrink due to the greater distances from the ground and lower power settings. Displacing the landing runway threshold to increase the height of the aircraft above the ground will further reduce approach noise levels. These benefits will be reduced if the lower approach speeds, increases duration of the overflight. This may increase the integrated noise energy on the ground more than other factors reduce it.

Safety of third parties and passengers should be increased because the greater height will give greater margin over obstacles and a greater probability of reaching the threshold following an airworthiness problem. If lower approach speeds are used to existing runways, there will be additional safety benefits associated with a lower percentage of operations at critical runway lengths.

Incremental Change

By gradually increasing the approach angle to reduce noise and capacity constraints, the economic penalties incurred may be minimised. Initially, conventional aircraft may be operated on approaches of 4.0° to reduce noise. Further benefits would then be obtained by reducing the approach speed of aircraft for approaches greater than 4.0°. The slower approach may be achieved by reducing the landing weight of the aircraft or increasing the amount of lift produced during approach through changes to the airframe. These options will now be investigated to determine the potential benefits and the economic penalties involved.

The descent rate on approach is dependent on both the approach angle and the approach speed. Analysing the approach speeds of current civil transport aircraft shows that the Boeing 747-400 has the highest approach speed of current civil transport aircraft at 153knots[7]. Assuming an increase in approach angle to 4° is allowable without modification of the GPWS, the descent rate increases to 1,083ft/min. Piloting techniques are feasible at such values as this figure compares favourably with descent rates of around 1,100ft/min flown at London City Airport.

On level ground, the approach noise certification point is 2,000m from the threshold and assumes that the glide slope originates from a point 300m beyond the threshold, resulting in a total distance 2,300m from touchdown to the certification point.

Taking the Boeing 757 as an example of a modern Stage 3 aircraft with an approach speed of 132knots, and using the maximum descent rate calculated above gives a maximum approach angle of around 4.5°. Increasing the approach angle from 3° to 4.5° will increase the height at the certification point from 120m to 180m. In order to determine the associated reduction in thrust for the steeper approach, a detailed aircraft design program was produced. Validation was achieved by comparing program results with quoted performance figures for the Boeing 757 aircraft. The changes in airframe noise levels for the aircraft are estimated using the NASA Aircraft Noise Prediction Program (ANOPP)[8]. The noise model requires detailed geometrical information of the aircraft to predict airframe noise levels. This data is provided by the aircraft design program. Detailed engine information is necessary to predict engine noise. This is provided by a theoretical engine cycle program, supported by data from current engines. Table 1 shows the results for Boeing 757 aircraft operating 3°, 3.5°, 4° and 4.5° approaches.

Approach Angle (°)	Height at Cert. Point (m)	Approach Thrust (kN)	Thrust Setting (%)
3.0	120	55.154	15.5
3.5	140	46.290	12.97
4.0	160	36.441	10.2
4.5	180	27.577	7.7

Table 1: Approach Thrust Levels

The results show the expected a decrease in thrust with increasing approach angle. The low thrust setting of 7.7 percent for the 4.5° approach may seem very low when considering engine spool up times for emergency approach climb requirements, but modern high bypass turbofan engines are often able to reach full power from thrust levels as low as 5 percent in eight seconds.

Approach Angle (°)	Airframe Noise (dBA)	Engine Noise (dBA)	Total Noise (dBA)
3.0	66.78	112.84	112.88
3.5	65.44	110.73	110.77
4.0	64.28	108.91	108.96
4.5	63.25	107.37	107.43

Table 2: Approach Point Noise Results

Table 2 shows the A-weighted noise levels for each major noise generating component. The airframe noise is seen to decrease at approximately 2.25dBA/degree. This decrease it entirely due to the increase in height at the certification point. The airframe noise is a product of several key airframe components. Of these the trailing edge and leading edge high lift devices are the dominant noise generating components. This is of importance, since any attempt to reduce approach speed with more powerful high lift devices is likely to increase total airframe noise. Although, this would have little effect on the total noise produced for this aircraft, the use of higher bypass ratio engines on future aircraft suggests airframe noise could the become dominant component of noise generation.

Engine noise is seen to decrease at approximately 3.0dBA/degree. The decrease is more pronounced than for airframe noise due to the added reduction in thrust with increasing approach angle.

Initially it has been shown that reductions in total noise levels may be achieved for small increases in approach angle. However, the requirement to maintain descent rates at or below 1,100ft/min limits the basic Boeing 757 to a maximum approach angle of around 4.5°. To increase the approach angle further, either the maximum lift achievable must be increased or the maximum landing weight must be reduced. The first of these two options requires either more powerful high lift devices or an increase in wing area; both requiring major changes to the airframe. The second option is to reduce the aircraft maximum landing weight. This may be achieved by altering the payload/range characteristics of the aircraft.

These options will now be analysed. First the payload/range characteristics will be altered to enable the aircraft to operate on 5° approaches. Secondly the Boeing 757 design point will be used to design two aircraft for 5° and 5.5° approaches respectively. The resulting aircraft will be analysed in terms of both performance and economics. Initial estimates will be made of aircraft noise levels.

Reduced Take-off Weight Option (5°)

To enable the aircraft to operate on 5° approaches with a maximum descent rate of 1,100ft/min, the approach speed must be reduced from 132 to 124knots. Assuming, for simplicity, that the ratio of maximum landing weight to maximum take-off weight renames the same. This requires a maximum take-off weight of 88,411kg, a reduction of approximately 11%. Checking the original aircraft characteristics shows that this will lead to a maximum landing weight below the maximum zero fuel weight, which is not sensible. Thus the maximum zero fuel weight and hence maximum payload must be reduced, together with a reduction in range flown.

Data for the Boeing 757-200 'Lite' is shown in Table 3. Maximum payload is reduced by 4208kg. The aircraft, however, is still able to operate with a typical payload (186 passengers and baggage) over 1334nm compared with 2820nm for the standard aircraft. The complete payload/range diagram is shown in Figure 1 for comparison with that of the original aircraft.

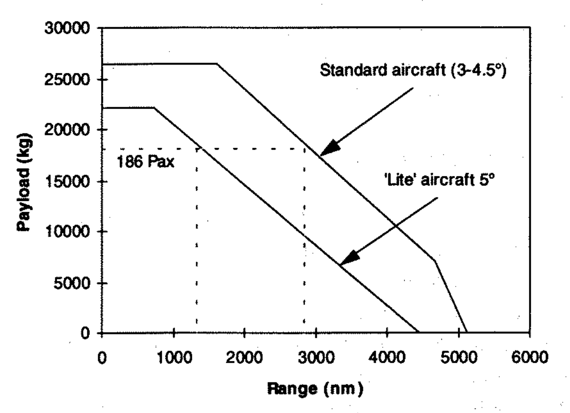

Figure 1: Payload/range diagram for reduced weight aircraft

Aircraft direct operating cost per air seat mile(DOC/ASM) is estimated using the method developed by the Association of European Airlines[9]. The results show a 10 percent increase in DOC/ASM, due to the significant reduction in range for the lighter aircraft. These results, however, assume the same aircraft cost as the standard model. If such a variant was offered, it is likely that the extended production runs would reduce aircraft cost and hence DOC/ASM.

Analysing the approach performance shows that thrust has been significantly reduced by a combination of a lighter aircraft and a steeper approach angle. The 4 percent thrust setting suggests that full thrust may not be achieved in the eight seconds required for baulked landing requirements. However, the aircraft will exceed baulked climb criteria with only 40 percent thrust available, which should be possible within eight seconds.

First estimates of aircraft noise are given for the whole aircraft, together with airframe and engine noise components. The airframe noise level is calculated from the individual airframe components. Of these components, leading edge and trailing edge noise was seen to be the dominant component. Thus if more powerful high devices are used, the airframe noise will increase. However, since airframe noise levels in this case are well below engine noise levels, more powerful high lift devices are unlikely to increase overall noise levels significantly. For larger aircraft with significant airframe noise, high lift device noise levels may become more critical.

New Design Option (5° and 5.5°)

Reducing the aircraft take-off weight further for approaches greater than 5° will severely limit payload and range for this aircraft. Reducing payload is undesirable as this will tend to reduce the passengers carried of each air transport movement and hence decrease airport capacity.

	Standard 757-200	757-200 Lite	5° Design	5.5° Design
Geometry:				
Wing Area (m^2)	185.25	185.25	210.18	271.77
Wing Aspect Ratio (-)	7.81	7.81	6.70	6.35
Engine Thrust (kN)	178.4	178.4	177.00	191.50
Mass:				
Operating empty mass (kg)*	56928	56928	55774	60433
Max zero fuel mass (kg)*	83278	79070	82124	86783
Max take-off mass (kg)*	100307	88411	100312	107083
Performance:				
Take-off Field length (m)*	1662	1048	1814	1434
Landing field Length (m)*	1439	1197	1197	1040
Cruise lift to Drag ratio (-)*	15.86	15.60	15.06	14.86
Thrust/weight ratio (-)	0.363	0.411	0.360	0.365
Wing Loading (kg/m^2)	541.47	477.25	477.27	394.01
Range (186 passengers) (nm)	2820	1334	2820	2820
Fuel Consumption*	3264	3109	3413	3686
Approach Characteristics:				
Approach Angle (°)	3	5	5	5.5
Approach Speed (knots)	132	124	124	113
Approach T/W (-)*	0.054	0.016	0.030	0.024
Thrust (kN)*	52.854	14.257	29.287	25.252
Thrust Setting (%)*	14.81%	4.00%	8.27%	6.59%
Economics:				
Purchase cost ($mil)*	49.90	49.90	49.16	53.16
Direct operating cost (Cents/ASM)*	6.57	7.24	6.57	6.95
A-weighted Approach Noise:				
Airframe (dBA)*	66.78	60.72	60.66	58.21
Engine (dBA)*	112.84	106.18	106.72	106.11
Total Noise Level (dBA)*	112.88	106.23	106.76	106.14

Table3: Aircraft design data for standard and modified aircraft
(* Data estimated for standard Boeing 757-200 using common aircraft design program)

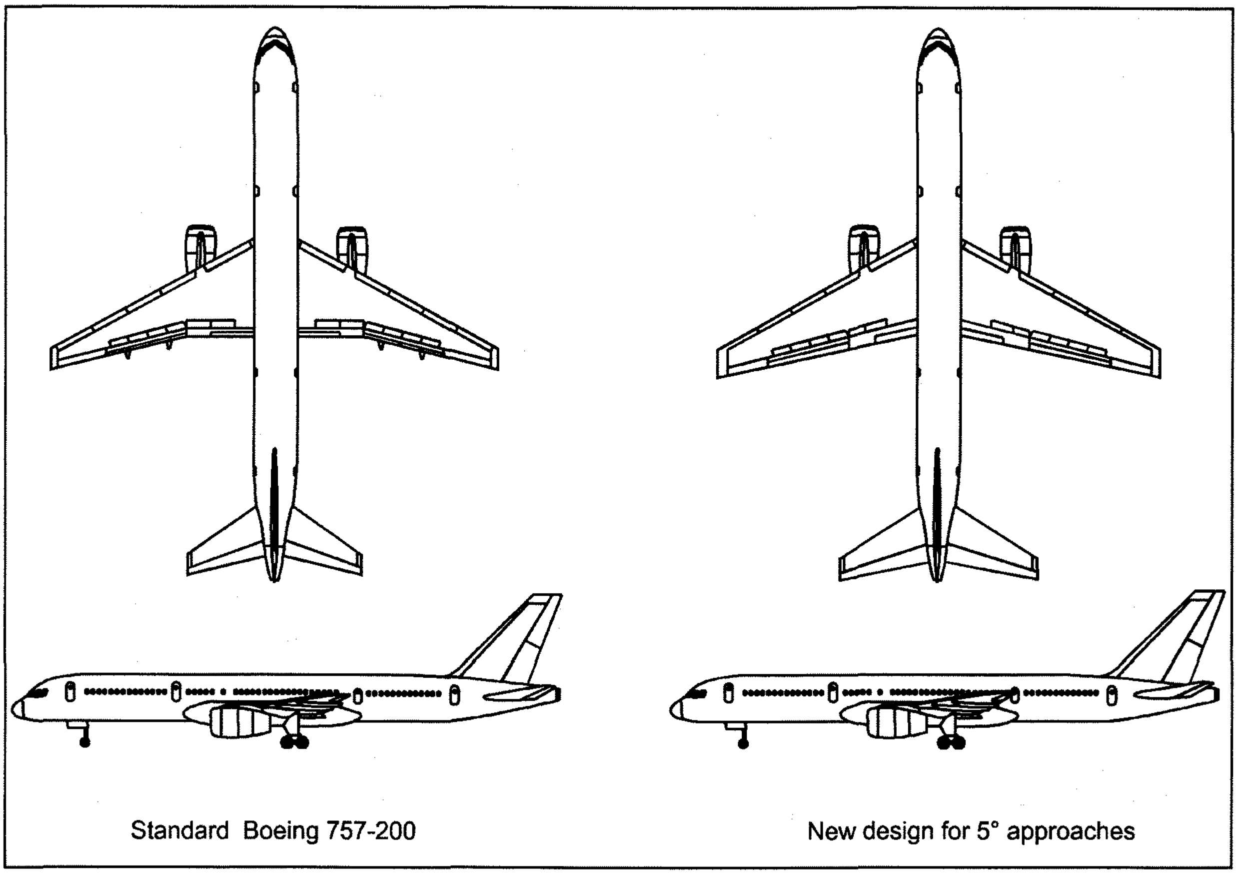

Figure 2: General arrangement drawings for Standard 757-200 and New Design for 5° approaches

The alternative option is to increase the maximum lift produced, either with more powerful high lift devices or by increasing wing area. This will necessitate major changes to the airframe. For this reason, two aircraft were designed for 5° and 5.5° approaches respectively using the same Boeing 757 design point and fuselage. Analysing aircraft of this size suggests a maximum lift coefficient of around 2.85. It was felt that only a small increase over this value was possible with a more powerful and complex flap system. Thus is was decided to retain the same maximum lift coefficient and then increase the wing area to achieve the desired approach speed. The aspect ratio of the new wing was chosen for minimum DOC/ASM.

For the 5 degree aircraft, an approach speed of 124knots, dictated a wing loading of 477kg/m². This is 12 percent lower than for the original aircraft. This would be expected to increase aircraft empty weight, but a reduction in aspect ratio to 6.70 and slight decrease in engine thrust, results in a drop in empty weight of 1154kg. Cruise performance deteriorates increasing fuel consumption by 4.5 percent. The total effect increases the maximum take-off weight by 4kg. Thrust levels decrease on approach, resulting in a 6.12dBA reduction in total noise levels at the approach noise measurement point. However, the slower approach speed will increase the flyover time and may result in a smaller decrease in time integrated noise levels. The economic analysis shows that there is no increase in DOC/ASM. This is due to the reduction in empty weight reducing aircraft cost offset by the increase in fuel cost.

The 5.5° aircraft requires an approach speed of 113knots, which dictates a wing loading of 394kg/m², a reduction of 27 percent. The wing aspect ratio for minimum DOC/ASM decreases to 6.35. The larger wing increases cruise drag more severely than the previous design, requiring an increase in engine thrust to 191.5kN. This helps to reduce take-off field length to 1434m. Landing field length is further reduced to 1040m, offering the potential for operations to runways with displaced thresholds to further increase flyover height at the approach point. Airframe noise levels are reduced considerably as a result of the slower approach speed and total noise levels reduce slightly to give the lowest levels of all the designs. The economic analysis shows that there is an 5.8 percent penalty due to the increases in empty weight and fuel consumption. In contrast, total noise levels are lower than that for the two previous options.

Finally, a general arrangement drawing for the Standard Boeing 757-200 and the new design for 5° approaches is shown in Figure 2. Although the wing area is increased, the lower aspect ratio results in a similar wing span.

Conclusions

Aircraft performance analysis indicates that with conventional aircraft, approaches up to 4° are possible without changes to the aircraft. Further increases in approach angle are achievable by reducing aircraft weight. This increases the direct operating costs of the aircraft, although this may be partially offset through extended production runs if the aircraft has a wider market. Engine spool up times do not appear to limit thrust settings on approach for these aircraft, thus thrust levels may be reduced to obtain maximum noise reduction benefits.

Further reductions in flyover noise levels may be possible by displacing the landing runway threshold. The results show that, in the case of the reduced weight Boeing 757, landing distances may be reduced to less than 1,200m.

It is too early to determine if the estimated reductions in noise levels will enable existing Stage 3 aircraft to meet future noise regulations. Further work will involve developing the noise model to generate time integrated noise levels, i.e. Effective Perceived Noise Levels (EPNL) and ultimately complete contours for the take-off and landing phase.

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