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K.T. Koshekov[1], **M.R. Zhomart**[1]
[1]Civil Aviation Academy, Almaty, Kazakhstan

E-mail: mustafazhomart@gmail.com

BEYOND SPEED THRESHOLDS: ENERGY MANAGEMENT DEGRADATION LEADING TO FAST ON APPROACH

Abstract. *Unstable approaches remain one of the most persistent safety risks in commercial aviation and are strongly associated with long landing and runway excursion events. While conventional safety monitoring practices primarily rely on threshold-based exceedance detection within stabilized approach criteria, considerably less attention has been given to the underlying energy management processes that precede such outcomes. This study presents an empirical analysis of Quick Access Recorder (QAR) data collected over a twelve-month operational period from a mixed fleet of Boeing 737 NG and MAX aircraft. Flights were classified into nominal and risk subsets, and systematic differences in key approach energy management parameters were examined across multiple altitude bands during the approach phase using a variability-oriented analytical framework. The results demonstrate that Fast on Approach should not be interpreted as an isolated speed exceedance, but rather as a progressive degradation of approach energy management developing well before stabilized approach criteria are formally violated. Fast on Approach was consistently associated with sustained speed deviations, increased thrust modulation, elevated pitch variability, and a higher likelihood of excess energy being carried into the landing phase. An association between Fast on Approach and long landing outcomes was observed, supporting the interpretation of excess approach speed as an intermediate undesired aircraft state linking early energy management deviations to adverse runway outcomes. The study proposes a risk-based, variability-oriented perspective on approach energy management that complements traditional threshold-based monitoring logic. The findings have direct implications for flight data monitoring systems, pilot training programs, and proactive safety management practices aimed at early identification of approach energy management degradation.*

Keywords: *unstable approach, energy management, fast on approach, long landing, flight data monitoring, threat and error management, runway excursion risk.*

Introduction.

The approach and landing phases remain the most safety-critical segments of commercial flight operations. Despite continuous advances in aircraft systems, procedural standardization, and the widespread adoption of stabilized approach concepts, unstable approaches persist in normal line operations and continue to represent a significant contributor to long landing and runway excursion events [1].

In operational practice and within flight data monitoring (FDM) systems, approach stability is typically assessed through compliance with predefined threshold-based criteria evaluated at stabilized approach criteria, most commonly at 1,000 ft above airport elevation. While this logic enables clear and unambiguous event classification, it provides limited insight into the processes that precede formal stabilization violations. As a consequence, analytical focus is often placed on the detection of unstable approaches rather than on the earlier development of energy management degradation during the approach [2].

One of the most frequently observed manifestations of an unstable approach is excess approach speed during the final segment, commonly referred to as Fast on Approach. In most existing studies and operational monitoring frameworks, Fast on Approach is treated as a discrete threshold exceedance occurring within a defined altitude window. However, excess speed rarely develops in isolation. It is typically accompanied by increased thrust modulation, elevated pitch variability, vertical speed instability, and reduced coordination of longitudinal control, collectively indicating a broader degradation of approach energy management.

Accident investigations and flight data–based studies consistently demonstrate a strong association between excess approach speed and long landing outcomes. Elevated threshold crossing speeds increase flare distance, displace touchdown points beyond the intended touchdown zone, and reduce available safety margins for deceleration. Nevertheless, much of the existing literature remains focused on isolated parameter exceedances or aggregated event statistics, offering limited insight into the temporal evolution and interaction of energy management parameters throughout the approach [3].

From a human factors perspective, the Threat and Error Management (TEM) framework provides a structured basis for examining how operational threats, crew errors, and undesired aircraft states interact during flight operations. Within this framework, unstable approaches are understood not as isolated procedural failures, but as the outcome of accumulated threats and insufficiently managed deviations. Despite its conceptual strength, TEM has predominantly been applied qualitatively, and its quantitative integration with high-resolution QAR and FDM data-particularly in the context of approach energy management-remains limited.

As a result, a methodological gap persists between threshold-based monitoring logic, conceptual human factors models, and data-driven analyses capable of capturing the process-oriented nature of approach energy management degradation. In particular, the role of Fast on Approach as an intermediate undesired aircraft state linking early energy management deviations to adverse landing outcomes has not been sufficiently quantified using large-scale operational data.

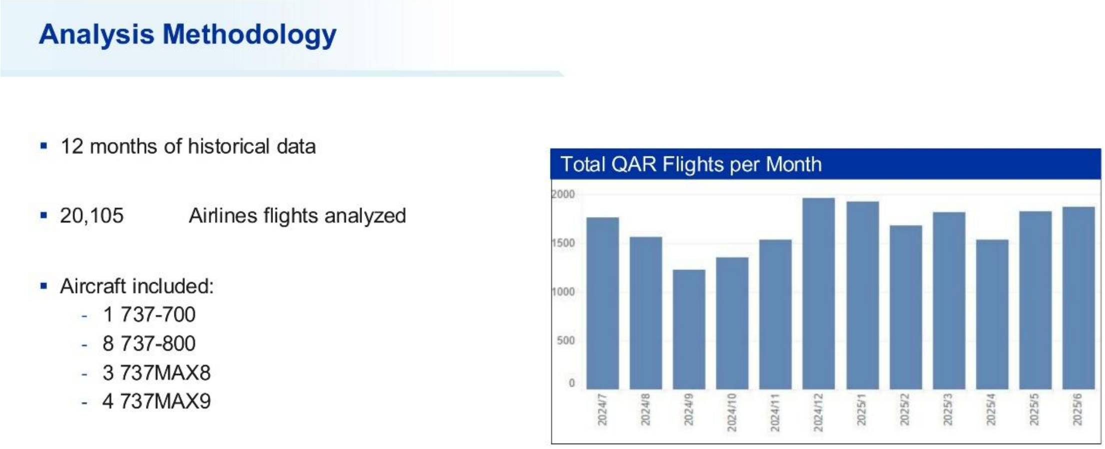
This study addresses this gap through an empirical analysis of Quick Access Recorder (QAR) data collected during normal line operations of a mixed fleet of Boeing 737 NG and MAX aircraft. In contrast to traditional threshold-based assessments, the analysis examines the evolution of approach energy management across multiple altitude bands, enabling characterization of instability development well before stabilized approach criteria are formally violated [4].

The objective of this study is to quantitatively analyze approach energy management degradation and assess its role in the development of Fast on Approach and subsequent long landing events. A variability-oriented, risk-based analytical perspective is proposed that complements conventional threshold-based monitoring logic and is consistent with interpretation within the Threat and Error Management framework.

The findings are intended to support practical applications in flight data monitoring systems, pilot training programs, and proactive safety management practices, while also providing a foundation for future research focused on the early identification of approach stability degradation processes [4].

Materials and research methods.

The study was based on Quick Access Recorder (QAR) data collected during normal line operations of a mixed fleet of Boeing 737 NG and MAX aircraft over a twelve-month period. The initial dataset comprised 20,105 commercial flights. Simulator sessions, test and ferry flights, as well as records with incomplete or corrupted parameter sets, were excluded from the analysis.



Analysis Methodology

- 12 months of historical data
- 20,105 Airlines flights analyzed
- Aircraft included:
  - 1 737-700
  - 8 737-800
  - 3 737MAX8
  - 4 737MAX9

Figure 1 – Total QAR flights per month

The analyzed flight segment was defined as the interval from 3,000 ft above airport elevation (AFE) to runway touchdown. Only flights with continuous and valid recordings of the required parameters throughout this segment were retained to ensure data consistency and comparability.

Flights were classified into nominal and risk subsets using criteria commonly applied in flight data monitoring systems. Fast on Approach was defined as a sustained exceedance of the selected approach speed by more than 10 kt for at least three seconds between 1,000 and 0 ft AFE. The selected thresholds are consistent with standard operational monitoring practices [5], [6].

Long landing was defined as main landing gear touchdown occurring beyond the first 3,000 ft of the runway or beyond one third of the available landing distance, whichever occurred first. Threshold-based criteria were used exclusively for subset classification; subsequent analyses focused on the continuous behavior of energy management parameters rather than on discrete exceedance events.

Approach energy management was evaluated using parameters directly associated with longitudinal energy control: airspeed deviation from the selected approach speed, thrust modulation, pitch angle, and vertical speed. Parameter behavior was examined across multiple discrete altitude bands between 3,000 and 0 ft AFE, allowing the progressive development of energy management degradation to be assessed prior to stabilized approach gate violations.

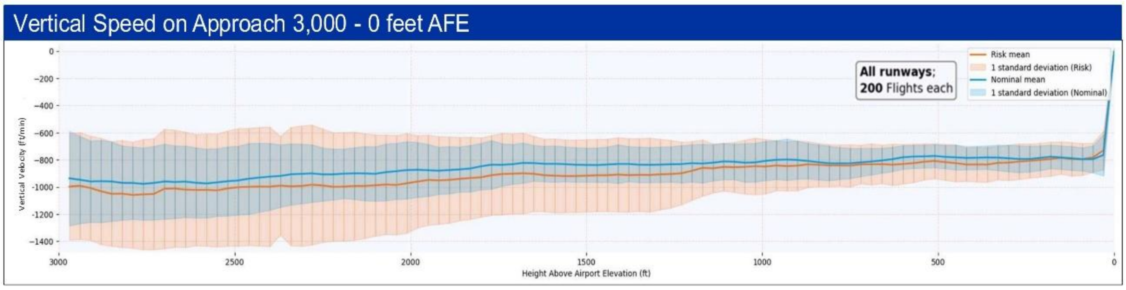


Figure 2 – Vertical speed on approach

Lateral path deviations were reviewed during preliminary analyses but did not exhibit systematic differences between nominal and risk subsets and were therefore excluded from the primary analysis. Manual and automated approaches were not analyzed separately, as the focus of the study was on the evolution of aircraft energy state rather than control authority allocation.

To provide a quantitative summary of the observed variability patterns, an aggregated descriptive indicator of approach energy management variability-the Approach Energy Variability Score (AEVS)-was introduced. For each altitude band h, the indicator was defined as:

$$\mathrm{AEV}S(h)=\frac{1}{N}\sum_{i=1}^{N}\frac{\sigma Risk\ (X_i(h))}{\sigma Nom\ (X_i(h))} \tag{1}$$

where h - a discrete altitude band above airport elevation (AFE), consistent with the altitude segmentation used in the analysis;

$X_i(h)$ - an energy-management-related parameter evaluated within altitude band h;

$\sigma Risk\ (X_i(h))$ и $\sigma Nom\ \left(X_i(h)\right)$ - the standard deviations of parameter X_i for the risk and nominal subsets, respectively;

N- the number of parameters included in the aggregation;

Four parameters were included (N = 4): vertical speed, airspeed deviation from the selected approach speed, pitch angle, and thrust lever angle. These parameters were selected based on their direct relevance to longitudinal energy management and their consistent variability differences between nominal and risk flights across all analyzed altitude bands. The AEVS was used solely as a descriptive aggregation of relative variability patterns and does not represent a normalized metric, statistical estimator, or risk score.

Standard deviation was used solely as a descriptive measure of variability, consistent with the graphical presentation of ±1 standard deviation envelopes. All parameters were assigned equal weights to avoid subjective prioritization. The AEVS was introduced as an aggregated descriptive indicator and was not intended to function as a predictive or causal model.

To illustrate the practical application of the AEVS metric, consider an example for a single altitude band (e.g., 1000–500 ft AFE).

For this altitude band, the standard deviations of the selected parameters were computed separately for the nominal and risk subsets: Airspeed deviation: $\sigma Risk = 6.0\ kt$; $\sigma Nom = 4.2\ kt.$; Vertical speed: $\sigma Risk = 180\frac{ft}{min}, \sigma Nom = 125\frac{ft}{min}$; Pitch angle: $\sigma Risk = 1.8, \sigma Risk = 1.3$; Thrust lever angle: $\sigma Risk = 7.0\%, \sigma Nom = 5.1\%$;

$$\mathrm{AEV}S\ (h)=\frac{1}{4}\left(\frac{6.0}{4.2}+\frac{180}{125}+\frac{1.8}{1.3}+\frac{7.0}{5.1}\right) = 1.405 \tag{2}$$

The resulting value AEVS=1.405 indicates that the variability of energy-management-related parameters in the risk subset exceeds that of nominal approaches by approximately 40.5%.

This elevated variability reflects reduced stability of energy control and supports the interpretation of this altitude segment as exhibiting degraded energy management.

To support a deeper interpretation of the observed approach energy management deviations, a Root Cause Analysis (RCA) methodology integrated with the Threat and Error Management (TEM) framework was applied. Within this approach, Fast on Approach was treated as an intermediate undesired aircraft state resulting from the cumulative effect of operational threats and compensatory crew actions [7]. The analysis was based on a comparative examination of key energy management parameters - airspeed, thrust, pitch, and vertical speed - across consecutive altitude bands, enabling the identification of a process-oriented degradation of energy management preceding formal violations of stabilized approach criteria.

RCA was applied as a descriptive, system-level interpretative tool and was not intended to establish individual crew culpability or strict causal relationships. The aggregated variability indicator (AEVS) was used as a quantitative support for the RCA, enabling observed parameter-level variability patterns to be interpreted in a structured and process-oriented manner across altitude bands.

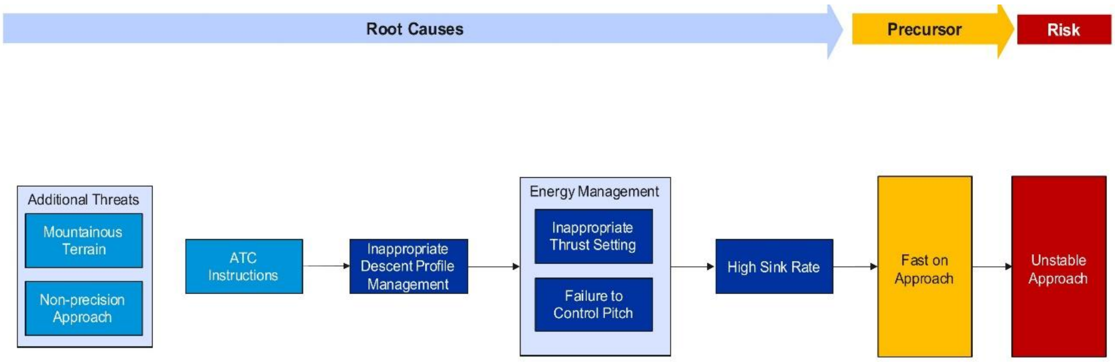


Figure 3 – Root Cause Analysis

Results and their discussion.

Figure 5 illustrates thrust lever angle (TLA) behavior during the final approach segment between 1,000 and 100 ft AFE for the nominal and risk subsets. The risk subset exhibits substantially greater variability in thrust lever angle across the entire analyzed altitude range when compared with nominal approaches. This variability is characterized by frequent and pronounced deviations toward lower thrust settings.

In the risk subset, a large proportion of approaches operated at or near idle thrust between approximately 2,000 and 750 ft AFE. These near-idle thrust conditions were observed consistently across multiple altitude bands and were not confined to a narrow vertical segment. In contrast, the nominal subset demonstrates a more stable thrust setting profile, with reduced variability and tighter clustering of thrust lever angle values, particularly below approximately 1,400 ft AFE.

Airport-level drilldown analyses as shown in figure 4, confirms that the observed thrust variability patterns in the risk subset are not attributable to a single airport, runway configuration, or local operational procedure. Similar thrust modulation characteristics were observed across different aerodromes, indicating that the identified behavior represents a generalized feature of Fast on Approach flights rather than a location-specific effect.

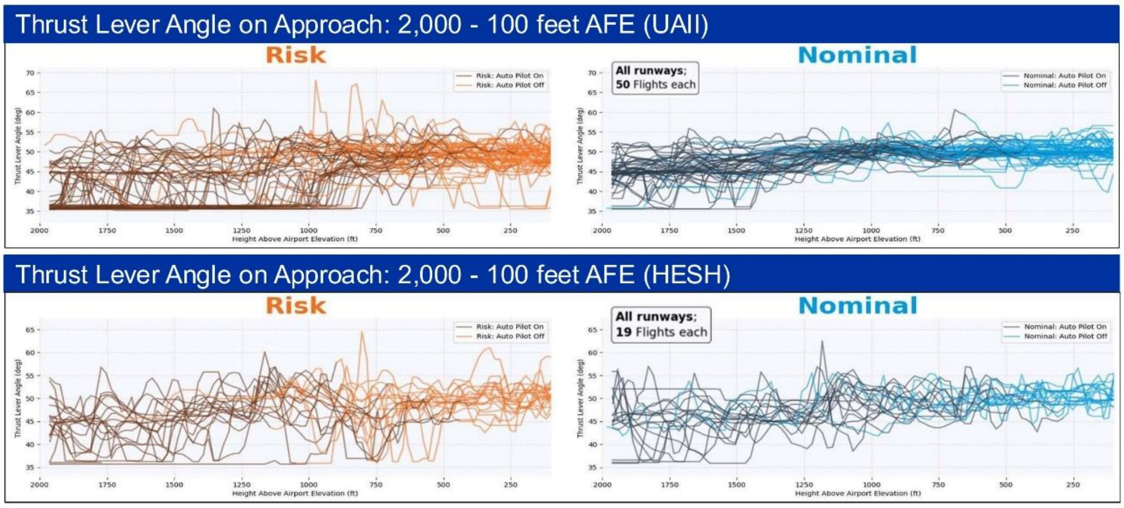


Figure 4 – Airport-level drilldown

Overall, the results indicate that Fast on Approach events are associated with increased thrust modulation and reduced thrust stability during the final approach phase when compared with nominal operations [8].

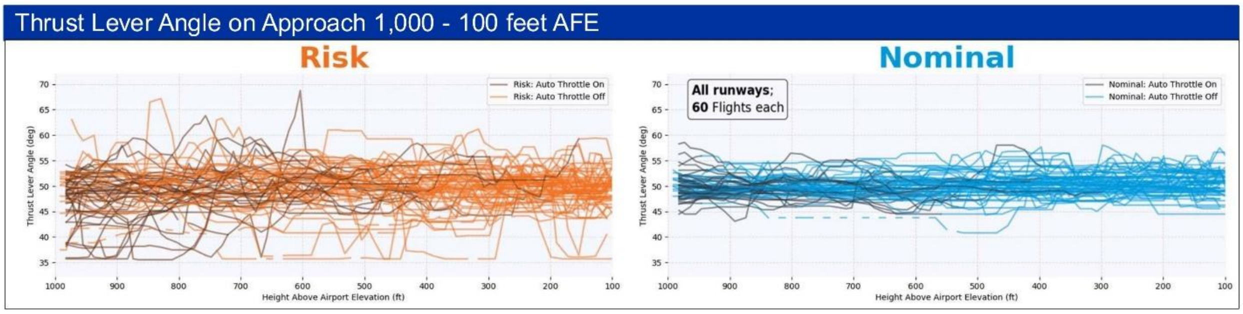


Figure 5 – Thrust lever angle

Figure 6 presents pitch angle behavior as a function of altitude between 1,000 and 100 ft AFE for nominal and risk approaches. The risk subset demonstrates consistently larger pitch angle variability across the analyzed altitude range when compared with the nominal subset. This elevated variability is observed throughout the final approach segment and does not converge toward nominal levels at lower altitudes.

While the mean pitch angle remains relatively constant with decreasing altitude in both subsets, the risk subset exhibits a systematically lower mean pitch angle. On average, the mean pitch angle in the risk subset is approximately 0.8 degrees lower than in nominal approaches across the analyzed altitude range.

The combination of increased pitch variability and reduced mean pitch angle indicates that pitch control during Fast on Approach events is characterized by sustained corrective activity rather than stable tracking of a consistent pitch attitude. These characteristics persist below the company-specific stabilization height of 500 ft AFE, suggesting that pitch control differences between nominal and risk approaches extend into the late stages of the approach.

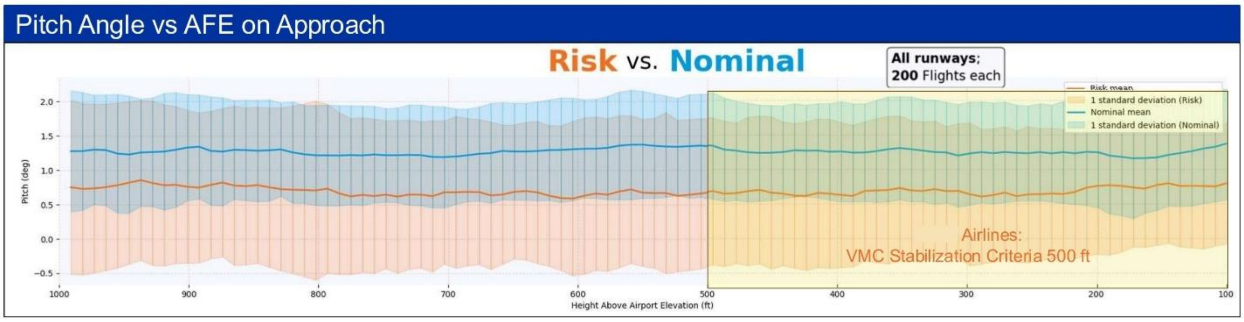


Figure 6 – Pitch angle

Figure 7 summarizes cases in which approach speed selection in Fast on Approach flights may have been influenced by incorrect application of wind additive. The analysis compares recorded meteorological conditions, runway heading, reference speed (VREF), applied wind additive, and the resulting target approach speed setting.

Within the risk subset, 99 flights exhibited approach speed settings inconsistent with the wind additive calculated from the reported steady headwind and gust components. In these cases, the selected target speed exceeded the theoretical approach speed derived from standard wind correction logic. The resulting speed error ranged from +3 to +6 kt above the recommended target speed.

In approximately 11% of Fast on Approach events, the MCP-selected speed was increased beyond the recommended value based on the prevailing wind conditions. These increases were observed despite relatively modest headwind or gust components, suggesting that the elevated approach speed could not be fully explained by environmental wind effects alone.

The observed discrepancies occurred across a range of runway headings and wind directions and were not confined to a specific runway orientation or meteorological pattern. In several cases, the applied wind additive exceeded the value derived from half the steady headwind component plus the full gust increment, as described in standard flight crew training guidance.

Overall, the results indicate that a subset of Fast on Approach events is associated with approach speed settings exceeding those justified by reported wind conditions, highlighting potential inconsistencies in wind additive application during approach speed selection.

METAR Wind*	RWY (True) HDG	VREF / VSEL / additive (kts)	Theoretical Approach Speed	Theoretical Wind Additive (kts)	Target Speed error (kts)	AT OFF height (feet)	Component Headwind / Gust
10005G13MPS	236 (+5)	143 / 153 / 10	148	5	+5	175	0 / 0
22005MPS	150 (+9)	147 / 156 / 9	152	5	+4	938	5 / 0
07007MPS	303 (+8)	145 / 155 / 10	150	5	+5	551	0 / 0
10012KT	096 (-0.4)	144 / 155 / 11	150	6	+5	993	12 / 0
03004MPS 360V060	106 (+6)	141 / 150 / 9	147	6	+3	537	1 / 0
34014KT	043 (+4)	145 / 156 / 11	150	5	+6	977	5 / 0

Figure 7 – Approach speed selection

Figure 8 presents the distribution of Fast on Approach events as a function of ambient temperature deviation from the International Standard Atmosphere (ISA) at the destination airport. The results are grouped into discrete ISA deviation bands, ranging from significantly colder-than-ISA conditions to extreme positive temperature deviations.

The occurrence rate of Fast on Approach events remains relatively stable across negative and near-ISA temperature deviations, with comparable proportions observed for ISA deviations below −10°C, between −9°C and 0°C, and between +1°C and +10°C. In contrast, a marked increase in Fast on Approach occurrence is observed at higher positive ISA deviations.

Flights operating with ISA deviations between +11°C and +25°C exhibit a noticeably higher proportion of Fast on Approach events when compared with near-ISA conditions. The highest occurrence rate is observed for ISA deviations exceeding +25°C, where the proportion of Fast on Approach events is approximately twice that observed under standard or colder-than-standard atmospheric conditions.

These results indicate that elevated ambient temperatures at the destination are associated with a higher likelihood of Fast on Approach events. The distribution also reflects the operational environment of the studied operator, which predominantly operates in colder temperature regimes when compared with the broader benchmarking population, resulting in a smaller absolute number of flights in extreme positive ISA deviation categories.

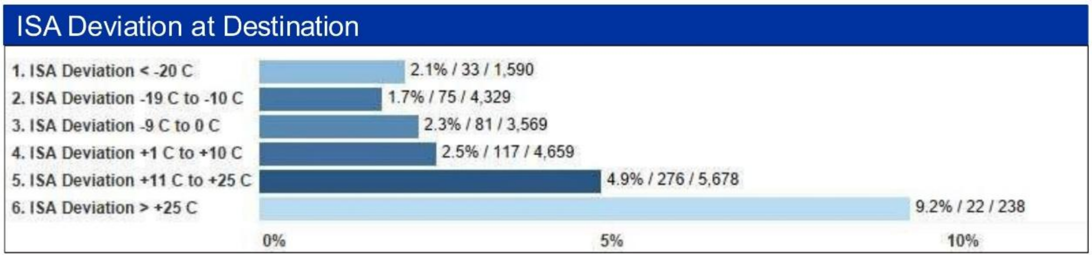


Figure 8 – ISA deviation

Figure 9 presents bank angle behavior and lateral track geometry for approaches to runway 10 at UAI I as an example, comparing nominal and risk subsets. The upper panels show bank angle as a function of altitude between 1,000 and 100 ft AFE, while the lower panels provide a plan-view representation of approach tracks for both subsets.

The risk subset exhibits a higher average bank angle throughout the analyzed approach segment when compared with nominal operations. This difference persists across multiple altitude bands and remains evident below 500 ft AFE. In addition to a higher mean bank angle, the risk subset demonstrates increased variability, indicating more frequent and larger lateral control inputs during the final approach phase.

Plan-view analysis of approach tracks reveals systematic differences in lateral path geometry. Flights in the risk subset inbound to runway 10 show a greater proportion of shorter final approach segments compared with nominal flights. These shorter finals are characterized by later alignment with the runway centerline and increased lateral maneuvering prior to stabilization.

In contrast, nominal flights generally exhibit longer, more stabilized final approach paths, with reduced lateral corrections and lower bank angle variability during the descent [9]. The consistency between the bank angle profiles and the observed lateral track geometries suggests that the increased bank angle activity in the risk subset is associated with differences in approach routing and final approach geometry rather than isolated control anomalies [10].

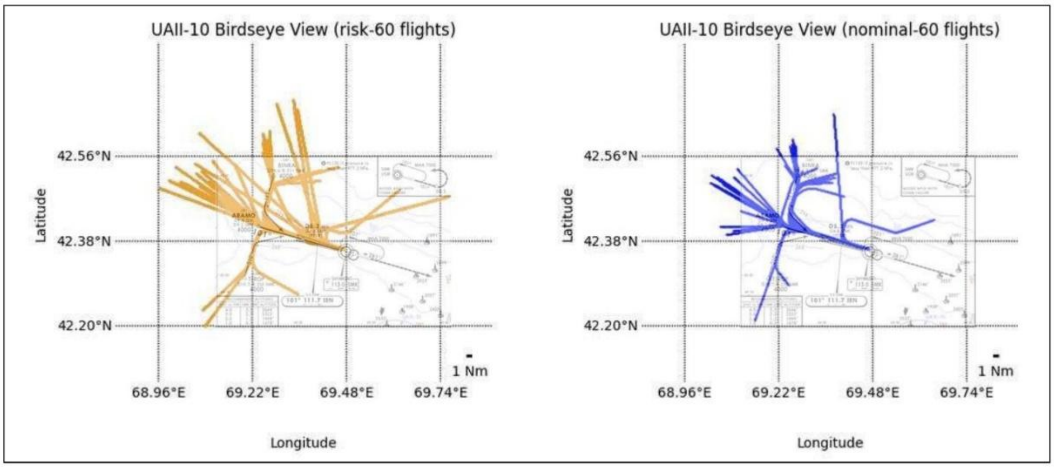


Figure 9 – ATC routing and lateral path characteristics

Figure 10 summarizes landing phase outcomes associated with Fast on Approach events. The distribution of VREF deviation at touchdown shows a clear shift toward higher touchdown speeds in the risk subset when compared with nominal flights. Fast on Approach flights exhibit a broader distribution of touchdown speed deviations, with a larger proportion of landings occurring at elevated speeds.

The probability of a high-speed touchdown is substantially increased following a Fast on Approach event. Fast on Approach flights were approximately 4.7 times more likely to be followed by a high touchdown speed compared with nominal approaches [11], [12].

Touchdown distance distributions also differ between the two subsets. The risk subset exhibits a wider distribution of touchdown distances, with a higher proportion of landings occurring in the long landing range. Approximately 10% of Fast on Approach flights were followed by a long landing event.

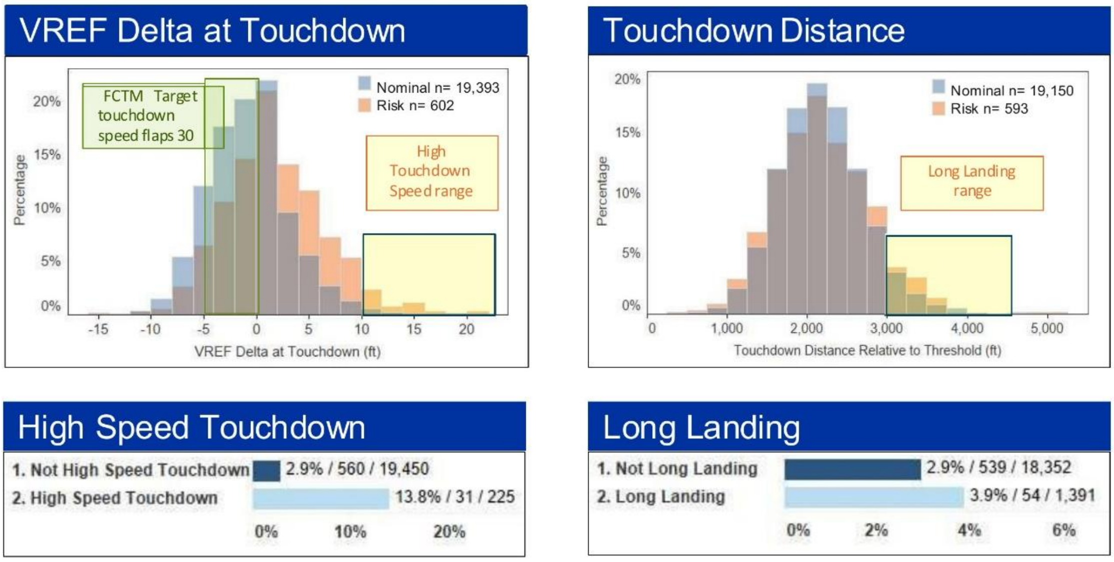


Figure 10 – Landing phase outcomes

The landing phase outcomes further support the interpretation of Fast on Approach as a transitional energy state with measurable downstream consequences. Elevated approach speeds were frequently carried into the flare and touchdown, resulting in a significantly increased likelihood of high touchdown speed and long landing events.

These findings indicate that, once excess energy persists beyond the stabilized approach gate, subsequent corrective actions may be insufficient to fully recover an optimal energy state prior to touchdown. As a result, Fast on Approach represents not only an approach phase deviation, but a condition that can propagate into the landing phase and increase runway safety risk.

Previous studies have shown that improper use or over-reliance on automation may lead to degraded energy management and reduced pilot situational awareness during approach, contributing to unstable approach development and adverse landing outcomes [13]. The impact of automation on approach energy management represents an important factor in interpreting the observed variability patterns. While automated flight control systems, including autopilot and autothrottle, are designed to enhance stability and reduce pilot workload, their effectiveness depends on appropriate mode selection and timely pilot intervention. The increased variability in thrust, pitch, and speed observed in the risk subset suggests that suboptimal interaction between the pilot and automation-such as delayed mode transitions, inappropriate speed management modes, or late disengagement-may contribute to the accumulation of excess energy. In this context, the proposed AEVS metric may serve as an indirect indicator of degraded pilot–automation interaction, reflecting increased corrective inputs and reduced stability of energy control. These findings highlight the importance of training focused on energy management awareness and proper use of automation, as well as the potential integration of variability-based indicators with automation mode data within flight data monitoring systems. Within the analyzed dataset, flights conducted in autoland mode were observed to remain within typical operational parameter ranges. No systematic increase in variability associated specifically with autoland operations was identified.

The analysis of AEVS across altitude bands demonstrates a clear increasing trend as the aircraft descends. While variability differences between nominal and risk subsets remain relatively small at higher altitudes (3000–2000 ft AFE), a pronounced divergence emerges below approximately 1500 ft AFE.

This trend indicates that energy management degradation develops progressively during the approach and becomes more pronounced closer to the runway. The continuous increase in AEVS supports the interpretation of Fast on Approach not as an isolated exceedance event, but as the result of accumulated variability in key control parameters.

Limitations and Future Research

Despite the robustness of the dataset and the consistency of the observed patterns, several methodological and data-related limitations should be acknowledged. The proposed AEVS formulation, based on the ratio of standard deviations between risk and nominal subsets, is inherently sensitive to the variability structure of the nominal baseline. In particular, low values of σNom may amplify the ratio and affect the stability of the indicator. Therefore, AEVS should be interpreted as a relative comparative measure rather than an absolute metric of instability.

The definition of the nominal subset plays a critical role in the computation of AEVS. In this study, nominal flights were identified using threshold-based criteria, which may introduce selection bias and lead to an "idealized" baseline with reduced variability. As a result, differences in nominal subset composition across datasets or operators may affect the comparability and robustness of AEVS values.

In addition, the AEVS aggregates multiple parameters using equal weighting and does not explicitly account for correlations or interactions between variables such as speed, thrust, and pitch. The use of standard deviation as a variability measure also assumes stationarity within altitude bands and does not capture temporal dependencies or non-linear dynamics of the approach phase. Consequently, the metric may not fully represent the multidimensional and dynamic nature of energy management.

Furthermore, the analysis is based on Quick Access Recorder (QAR) data, which are subject to limitations in sampling frequency, signal resolution, and potential measurement noise. These factors may influence the estimation of variability, particularly for rapidly changing parameters such as thrust and vertical speed. Additionally, the study is limited to a single operator and a specific aircraft family (Boeing 737 NG and MAX), which may affect the generalizability of the findings [14].

Future research should focus on validating the proposed approach across different operators and aircraft types, as well as improving the mathematical formulation of variability metrics. In particular, alternative normalization methods, multivariate analysis techniques, and time-dependent models should be explored. Further work is also required to integrate environmental and operational factors and to assess the practical implementation of variability-based indicators within flight data monitoring systems and pilot training programs [15].

An additional methodological consideration relates to the sensitivity of the results to the selection of parameters included in the AEVS formulation. In the present study, four parameters-airspeed deviation, thrust lever angle, pitch angle, and vertical speed-were selected based on their direct relevance to longitudinal energy management and their consistent variability differences between nominal and risk subsets. However, the choice of parameters may influence the resulting AEVS values and the interpretation of variability patterns. In particular, different parameters may exhibit varying sensitivity to operational conditions, measurement noise, or pilot–automation interaction, which may lead to disproportionate contributions to the aggregated indicator. Furthermore, the inclusion or exclusion of additional parameters, such as lateral path deviations or configuration changes, could alter the observed variability structure. Therefore, the results should be interpreted with consideration of the selected parameter set, and future research should explore the sensitivity of the AEVS metric to alternative parameter combinations and weighting strategies.

Conclusion.

This study provides a quantitative, data-driven characterization of approach energy management degradation associated with Fast on Approach events using high-resolution operational flight data. The results demonstrate that increased variability in key control parameters-particularly thrust, pitch, and speed-emerges progressively across altitude and becomes significantly more pronounced below approximately 1500 ft AFE.

Fast on Approach flights were shown to carry sustained excess energy into the final approach segment, resulting in a substantially increased likelihood of high touchdown speed and long landing outcomes. The analysis further identified contributing operational factors, including inconsistencies in wind additive application, elevated ambient temperatures, and shortened final approach geometries, which collectively influence energy dissipation capability prior to touchdown.

Interpreted within the Threat and Error Management framework, these findings support the characterization of Fast on Approach as an intermediate undesired aircraft state arising from cumulative variability in energy management rather than a single parameter exceedance. The proposed variability-based analytical approach provides a complementary perspective to traditional threshold-based monitoring and enables earlier identification of instability development. These results have direct implications for flight data monitoring, pilot training, and proactive safety management aimed at preventing the propagation of excess energy into the landing phase and reducing runway excursion risk.

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ЖЫЛДАМДЫҚ ШЕКТЕРІНЕН ТЫС: FAST ON APPROACH ӘКЕЛЕТІН ЭНЕРГИЯНЫ БАСҚАРУДЫҢ ДЕГРАДАЦИЯСЫ

Аңдатпа. *Тұрақтандырылмаған қонуға кірісулер коммерциялық авиациядағы ең тұрақты қауіп факторларының бірі болып қала береді және ұзын қону мен ұшу-қону жолағынан шығып кету оқиғаларымен тығыз байланысты. Қауіпсіздікті бақылаудың дәстүрлі тәсілдері негізінен тұрақтандырылған қону гейттері шеңберіндегі параметрлердің шекті мәндерден асуын анықтауға сүйенгенімен, мұндай нәтижелерге дейін қалыптасатын энергияны басқару үдерістеріне айтарлықтай аз көңіл бөлінеді. Бұл зерттеуде Boeing 737 NG және MAX әуе кемелерінің аралас паркі бойынша он екі айлық пайдалану кезеңінде жиналған Quick Access Recorder (QAR) деректеріне негізделген эмпирикалық талдау ұсынылады. Ұшулар номинал және тәуекел топтарына бөлініп, қонуға кірісу фазасы барысында бірнеше биіктік интервалдарында энергияны басқарудың негізгі параметрлеріндегі жүйелі айырмашылықтар вариабельділікке негізделген аналитикалық тәсіл арқылы зерттелді. Нәтижелер Fast on Approach жағдайын оқшауланған жылдамдықтың асуы ретінде емес, тұрақтандырылған қону критерийлері ресми түрде бұзылғанға дейін әлдеқайда ерте дамитын энергияны басқарудың біртіндеп деградациясы ретінде қарастыру қажет екенін көрсетеді. Fast on Approach жағдайы жылдамдықтың ұзақ сақталатын ауытқуларымен, тарту күшінің жоғары модуляциясымен, тангаж вариабельділігінің артуымен және артық энергияның қону фазасына өту ықтималдығының жоғарылауымен тұрақты түрде байланысты болды. Fast on Approach пен ұзын қону оқиғалары арасындағы анықталған байланыс қонуға кірісу кезіндегі артық жылдамдықты энергияны басқарудағы ерте ауытқулар мен қолайсыз қону нәтижелерін байланыстыратын аралық жағымсыз әуе кемесі күйі ретінде түсіндіруге мүмкіндік береді. Зерттеу қонуға кірісу кезіндегі энергияны басқаруға тәуекелге және вариабельділікке негізделген көзқарасты ұсынады, ол дәстүрлі шекті мониторинг логикасын толықтырады. Алынған нәтижелер ұшу деректерін мониторингтеу жүйелері, ұшқыштарды даярлау бағдарламалары және қонуға кірісу кезіндегі энергияны басқару деградациясын ерте анықтауға бағытталған проактивті қауіпсіздік басқару тәжірибелері үшін тікелей практикалық маңызға ие.*

Түйін сөздер*: тұрақтандырылмаған қонуға кіру, энергияны басқару, fast on approach, ұзын қону, ұшу деректерін мониторингілеу, қауіптер мен қателіктерді басқару, ұшу-қону жолағынан шығып кету қаупі.*

ЗА ПРЕДЕЛАМИ СКОРОСТНЫХ ПОРОГОВ: ДЕГРАДАЦИЯ УПРАВЛЕНИЯ ЭНЕРГИЕЙ, ПРИВОДЯЩАЯ К FAST ON APPROACH

Аннотация. *Нестабилизированные заходы на посадку остаются одним из наиболее устойчивых факторов риска в коммерческой авиации и тесно связаны с событиями длинной посадки и выкатывания за пределы взлётно-посадочной полосы. В то время как традиционные практики мониторинга безопасности в основном опираются на выявление* *превышений пороговых значений в рамках стабилизационных гейтов, значительно меньше внимания уделяется базовым процессам управления энергией, предшествующим таким исходам. В настоящем исследовании представлен эмпирический анализ данных быстрого доступа к бортовым самописцам (Quick Access Recorder, QAR), собранных за двенадцатимесячный период эксплуатации смешанного парка воздушных судов Boeing 737 NG и MAX. Полёты были классифицированы на номинальные и рискованные подвыборки, после чего были исследованы систематические различия в ключевых параметрах управления энергией на этапе захода на посадку в нескольких высотных интервалах с использованием вариабельностно-ориентированного аналитического подхода. Результаты показывают, что состояние Fast on Approach следует рассматривать не как изолированное превышение скорости, а как прогрессивную деградацию управления энергией на заходе, развивающуюся задолго до формального нарушения критериев стабилизированного захода. Состояние Fast on Approach устойчиво ассоциировалось с длительными отклонениями скорости, повышенной модуляцией тяги, увеличенной вариабельностью тангажа и более высокой вероятностью переноса избыточной энергии в фазу посадки. Выявленная связь между Fast on Approach и событиями длинной посадки подтверждает интерпретацию избыточной скорости на заходе как промежуточного нежелательного состояния воздушного судна, связывающего ранние отклонения управления энергией с неблагоприятными посадочными исходами. В работе предлагается риск-ориентированный, вариабельностно-ориентированный взгляд на управление энергией на заходе на посадку, дополняющий традиционную пороговую логику мониторинга. Полученные результаты имеют прямое практическое значение для систем мониторинга полётных данных, программ подготовки лётного состава и проактивных практик управления безопасностью полётов, направленных на раннее выявление деградации управления энергией на заходе.*

Ключевые слова: *нестабилизированный заход на посадку, управление энергией, fast on a pproach, длинная посадка, мониторинг полётных данных, управление угрозами и ошибками, риск выкатывания за пределы ВПП.*

Сведение об авторах

Кошеков Кайрат Темирбекович	д. т. н., проректор по научной деятельности, АО «Академия гражданской авиации», г.Алматы, Қазақстан, E-mail: kkoshekov@mail.ru
Жомарт Мустафа Русланулы	студент третьего курса докторантуры PhD, АО «Академия Гражданской Авиации», г. Алматы, Казахстан, E-mail: mustafazhomart@gmail.com

Авторлар туралы мәлімет

Кошеков Кайрат Темирбекович	т.ғ.д., «Азаматтық авиация академиясы» АҚ-ның Ғылыми қызметтер жөніндегі проректоры, Алматы қ., Қазақстан, E-mail: kkoshekov@mail.ru
Жомарт Мустафа Русланулы	PhD докторантураның үшінші курс студенті, Ғылыми зерттеулер және құзыреттер орталығының басшысы,, Алматы қ., Қазақстан, E-mail: mustafazhomart@gmail.com

Information about the authors

Koshekov Kairat	Doctor of Engineering Sciences, Vice-Rector for Research, JSC Civil Aviation Academy, Kazakhstan, E-mail: kkoshekov@mail.ru
Zhomart Mustafa	third-year PhD student, Head of the Center for Scientific Research and Competencies, Academy of Civil Aviation JSC, Almaty, Kazakhstan, E-mail: mustafazhomart@gmail.com