Strengthening Brazilian Air Power by Mitigating Phantom Air Traffic Congestion

1st Lt Bruno Garcia Franciscone
Brazilian Air Force
Brig Gen Pedro Arthur Linhares Lima
Brazilian Air Force, Reserve

Introduction

Full development of civilian aviation is the cornerstone to strengthen a nation's airpower and ensure its airspace sovereignty,[1] as it constitutes a reserve force that can be readily mobilized in a wartime environment.[2] To this end, in 1990, Brazil created the Brazilian Airspace Control System (Sistema de Controle do Espaço Aéreo Brasileiro, SISCEAB) to provide communications and radar infrastructure in support of airspace control. The Brazilian air defense and air traffic control model encompasses the integration of SISCEAB and the Brazilian Air Defense System (Sistema de Defesa Aéreo Brasileiro, SISDABRA).[3] This integrated model contributes to Brazilian Air Force's air surveillance priority strategic objective, part of its overall National Defense Strategy, as it provides aircraft with a solid infrastructure of communications and radars to ensure efficient operations during military actions. Additionally, it allows for rapid interaction between air defense and air traffic control agencies to identify aircraft jeopardizing airspace safety or acting unlawfully. Having all these systems working in tandem help support advancement of Brazilian Air Power.[4]

According to Fangni Zhang and Daniel Graham, this kind of integrated development, besides strengthening a nation's Air Power, boosts tourism, improves supply chain efficiency, fosters trade, and generates well-known advantageous side order effects in metropolitan areas where efficient air services are also available (with increased employment rates being one of these advantages).[5]

Furthermore, Brazil has a National Civil Aviation Policy (Política Nacional de Aviação Civil, PNAC) that provides a roadmap for its development.[6] This policy was created due to the ever-increasing demand for transport services, and calls for, amongst several of its objectives, a civilian aviation development strategy that includes human resources training and introduction of new technologies, methods, and air traffic management processes to improve efficiency of civilian aviation operations without jeopardizing security.

The efficacy of civilian aviation operations depends on the continuity of air traffic flow, as interruptions result in undesirable inefficiencies. However, while most obvious causes of these interruptions are due to adverse weather conditions, non-viable runways for landings or take-offs, limited airspace, or airport capacity, among others, not all causes of these interruptions are readily evident.

Initially, the detection of air traffic congestion due to non-evident causes was based on early automobile traffic studies. Authors Martin Treiber and Arne Kesting categorize this phenomenon as phantom traffic congestion, caused by the interruption of motorized vehicle flow due to inefficient vehicle speed management.[7] This study found, that while the cause of this type of congestion mainly goes unnoticed by motorists on the ground, a helicopter pilot flying over a highway, observing the flow of these vehicles, would be able to notice.

Analogously, the occurrence of this type of congestion in air traffic flow becomes evident as well. Depending on the number of aircraft in flight, there is an optimal speed that maximizes traffic flow. However, interruptions occur if aircraft employ speeds that are different from this optimum, which can then be remedied by changing their trajectory, when possible, or by placing them in a holding pattern. However, when holding patterns are in place, airplanes fly in closed circuits while waiting to continue their flight, as they cannot stop in the air in the same way as motor vehicles can stop on the ground.

Ranking of Airports — 2018

(Landing + Departures + Crossings + TGL)

			Annual Variation 2017/2018
1º	Guarulhos, SP	299.961	▲ 10.59%
2º	Congonhas, SP	228.866	▲ 2.18%
3º	Brasília, DF	164.485	▲ 3.77%
4º	Santos Dumont, RJ	114.740	▼ -0.35%
5º	Galeao, RJ	116.717	▼ -8.16%
6º	Campinas, SP	111.472	▼ -1.15%
7º	Confins, BH	102.134	▲ 1.53%
8º	Campo de Marte, SP	87.044	▲ 5.37%
9º	Porto Alegre, RS	85.963	▲ 3.10%
10º	Salvador, BA	83.558	▲ 2.27%

Figure 1. Ranking of Airports — 2018

Source: 2018 Statistical Yearbook, Air Navigation Management Center

The article presents the findings of a study conducted, based on accelerated-time simulations, that analyzed the occurrence of phantom traffic jams using approach data from actual aircraft flight plans for Guarulhos International Airport (GRU) on a typical day of operations (GRU airport is located west of the São Paulo Air Terminal). This airport was chosen because it is the hub of international aviation in the region, and the busiest airport in Brazil, as shown in Figure 1. The results show inefficiencies in aircraft flow departing and arriving to and from this airport, and how they impact both Brazil's national and international air traffic networks. They also show that there's a significant environmental impact caused by the increased emission of polluting gases into the atmosphere and increased noise levels, caused by aircraft in unnecessary holding patterns and constant trajectory changes at low altitudes.

According to this study, aircraft on approach patterns to GRU airport, after starting their descent, follow different traffic flows from across Brazil and the world, merging into a single stream for their landing sequence. However, even if capabilities were not exceeded, there were phantom traffic jams generated for no apparent reason to controllers and pilots, based on inefficient aircraft speed management. These findings are in accordance with the findings of Claus Gwiggner and Sakae Nagaoka, in which forecastable congestions occur when the average aircraft demand exceeds airspace or airport capacity due to peak hours or weather conditions; unnecessarily exacerbated by ground delays, when not managed properly.[8]

Human Factors and Air Traffic Control and Management Decision Support Systems

Approach center controllers work in a very dynamic environment, and are responsible for maintaining a fast, safe, and orderly flow of aircraft. These professionals deal with many aircraft arriving and departing from airports in restricted airspace, arranging them in safely spaced inbound and outbound streams.

Since the 1950s, airspace was segmented according to air traffic controller workload, to properly manage the ever-increasing volume of air traffic. This introduced a level of complexity that required the coordination of controllers across adjacent airspace segments.[9] As there were still no automated decision-making tools providing global situational awareness, nor a central body that managed the flow of aircraft and airspace structure, controllers relied on empirical techniques to determine aircraft sequencing and separation patterns. This sometimes led to inefficiencies, as aircraft speed management must be properly synchronized to ensure efficient air traffic flows and avoid, as much as possible, changing trajectories and holding patterns.[10] For this to occur appropriately, it is essential for air traffic controllers to properly instruct aircraft on optimal speed maintenance, and for pilots to comply accordingly.

As aircraft density in a given volume of airspace grows and traffic control complexity soars, the demand for air traffic controllers explodes, and maintaining an appropriate level of performance without excessive pilot interactions and waste of energy becomes imperative.[11] However, to accomplish this requires experienced controllers with a high level of adaptability, something which is hard to teach. Thus, in addition to air traffic controllers, decision support systems become fundamental for the successful management of air traffic flow.[12]

The Arrival Management System (AMAN) is a decision support system widely used by several air navigation service providers worldwide. Arrival Management is the established term for organizing aircraft approaching a given airport in continuous and efficient flows for landing.[13] While this system was not originally designed for decision-making by air traffic controllers, nor as a tool for alerting and resolving air traffic conflicts, this system allows air traffic controllers to establish proper aircraft order to ensure an efficient approach sequence in a given airport, according to defined sequencing criteria and preferred arrival schedules, as seen in Figure 2.[14]

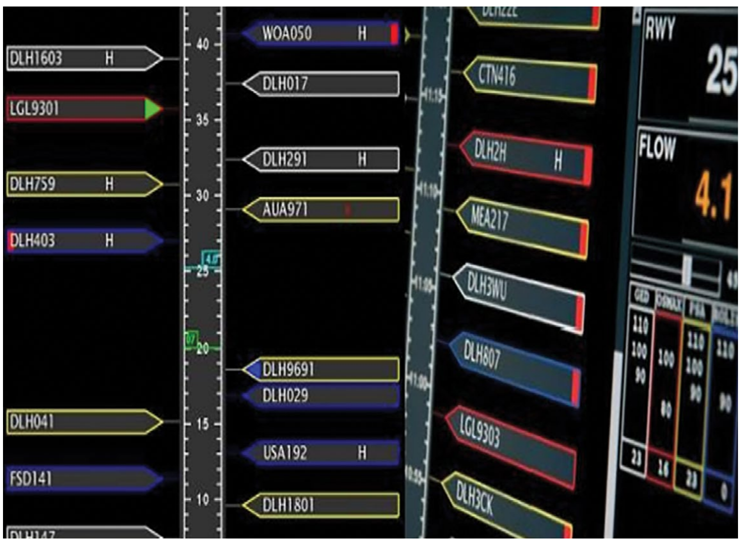

Figure 2. Arrival Manager (AMAN)

Source: made available by the Airspace Control Department (DECEA), on Aug. 1, 2019

AMAN has been gradually implemented in Brazil and in those air traffic control agencies where it has been implemented, there has been a considerable improvement in the efficiency of aircraft approach flows, as reflected by the reduction of flight delays. However, there is room for improvement. AMAN performs calculations based on pre-fixed values for aircraft speeds and does not consider factors such as airline operating preferences and altitude winds.[15] Additionally, the system does not recognize routes outside established standard routes, which prevents it from correctly defining the optimum sequencing of aircraft during adverse weather conditions.[16] The system also presents the same problem when aircraft are allowed to shorten their flight trajectories.

The São Paulo air terminal does not yet have AMAN implemented in its leading airports, including Guarulhos airport. However, there are plans for its implementation in the coming years.

Relationship Between Human Factors and Efficiency in Air Traffic Control

The appearance of chaos in the dynamics and activities inherent to air traffic controllers was observed in a case study that sought to observe the impact of human factors on the efficiency of air traffic approach flows by at Guangzhou Approach Control, responsible for controlling aircraft departing from and arriving at Baiyun International Airport, one of China's three busiest airports.[17]

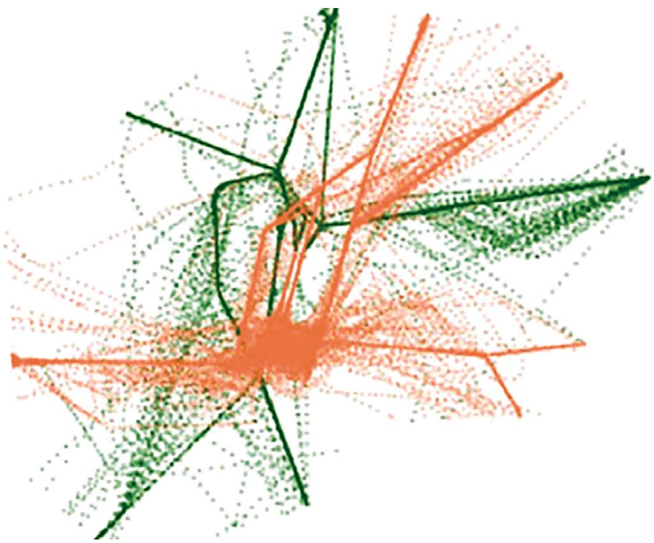

Figure 3. Data of arrival (orange) and departure (green) trajectories in Guangzhou Terminal

Source: Author, adapted from YANG

This empirical study analyzed air traffic approach flows, taking into account several air traffic control variables (flow, density, among others), as indicated in orange in Figure 3, to understand the dynamics of airspace based on a multilevel network. It had the aid of analytical metrics of data from synchronized trajectories and communications data from three specific days of operation.[18] This appearance of chaos emerged in both semi-stable and congested flow stages.

Therefore, automation tools of the future must be intelligent and customizable enough to account for human factors and the different phases of air traffic flow.[19]

Observing complete phases on a single route proved challenging due to the sparse and random distributions of aircraft flows. Thus, all data was analyzed jointly, to include approach routes with the highest traffic volume.[20] As expected, when the aircraft density on the routes increased, operations restrictions led to a lower flow due to a slower average aircraft speed, as seen in Figure 4.[21]

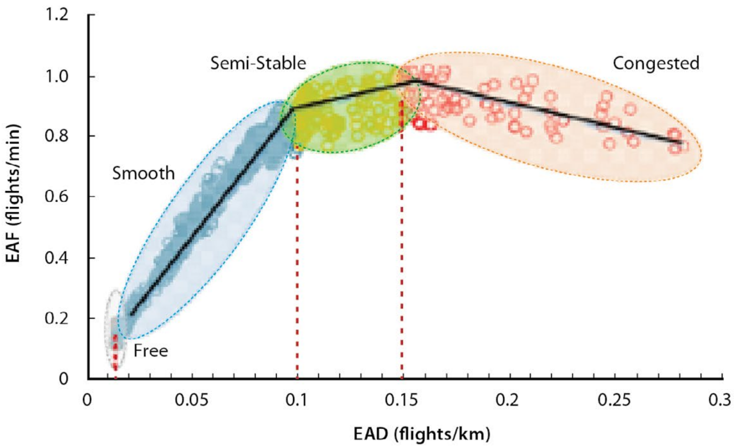

Figure 4. Flow phases

Source: Author, adapted from YANG

Aircraft trajectories were observed, during the three days of the study, using snapshots of the images from the air traffic controllers' surveillance screens. Four phases (free phase, smooth phase, semi-stable phase, and congested phase) were defined based on the dynamics of the air traffic flows in the selected routes. Afterwards, human interactions during each of these phases were analyzed.[22]

Intuitively, an increase in the volume of traffic should result in a higher probability of aircraft being on conflicting trajectories, which would consequently generate a more significant workload for air traffic controllers. However, the study demonstrated that the simplified air flow control strategies used by Guangzhou Approach Control ensured flow efficiency was maintained during the smooth phase, despite an increase in air flow conflicts from the free phase. Additionally, due to these simplified air flow control strategies, the workload for air traffic controllers did not change.[23]

This was even better evidenced in the more congested traffic phases, during which controllers define specific points in the approach path to change an aircraft's flight trajectory or place in a hold pattern, in addition to having increased interactions with pilots depending on traffic conflicts. The study found that the standardized simplified air flow control strategies reduced the workload considerably.[24]

However, as air traffic volume grew and reached the congestion phase, controllers were significantly influenced by their emotions. Without tools to better handle this increased volume, they prioritized safety over efficiency. As a result, air traffic controllers applied excessive speed reductions to ensure separations greater than needed, in addition to increased requests for pilots to change trajectories and maintain in-flight holding patterns.[25]

This study demonstrated the influence of human factors in the emergence of traffic congestion at times of peak demand and highlights how it could be mitigated through decision support systems, such as AMAN.

Data Analysis of Guarulhos Airport (GRU) Case Study

Using an accelerated time simulator called Total Airspace and Airport Modeler (TAAM), this article presents the results of a study conducted on aircraft on approach to GRU airport, regarding the relationship between aircraft speed management and air traffic flow efficiency.

Three simulation scenarios were generated using the actual flight plans of 309 flights destined for this airport on a high traffic demand day. These scenarios assumed favorable weather conditions and considered only in-flight holding patterns (versus any changes in aircraft trajectories) as input, with fuel consumption (in tons) and in-flight waiting times as the output. Changes in aircraft trajectories were not considered since the overarching São Paulo terminal has many arrival and departure routes from several airports, thus any trajectory deviations would significantly impact air traffic flows at these other airports as well.

The first simulation was based on available aircraft performance reference data, and assigned an ideal speed for each aircraft, based on their performance specifications and flight phase. Additionally, the simulator was configured to maintain the minimum required separation of five nautical miles between aircraft.

In the second simulation, high speeds were assigned to the aircraft, for as long as possible, provided that the minimum separation of five nautical miles between them was maintained. Furthermore, speed was restricted to the 250 knots per hour below 10,000’, as per international standards.

Finally, the third simulation was modeled after observed air traffic controllers’ behavior during high demand periods, without the aid of decision support tools, by setting slightly larger separations between aircraft on final approach, varying randomly between 6 and 8 nautical miles. As a result, broader than ideal separations were allocated between aircraft, simulating restrictive human factor behavior in high-demand scenarios. Data can be observed in Figure 5.

	Parameters 1 (Optimal Speed)	**Parameters 2 (High speed)**	**Parameters 3 (Low speed)**
Waiting time	5 hours and 43 minutes	10 hours and 47 minutes	33 hours
Consumption	137 tons	123 tons	174 tons

Figure 5. Outputs obtained in the accelerated-time simulations in TAAM

Source: Author

The outputs generated by the three simulations demonstrated that maintaining speeds below the ideal resulted in longer flight times and more in-flight holding patterns, as expected. Counterintuitively, maintaining high speeds for as long as possible (second simulation) did not result in shorter flight times.

Furthermore, the results indicate that in high-demand scenarios, aircraft that employ high approach speeds need to accelerate more sharply when closer to landing, to ensure their speeds decrease sufficiently to maintain the five nautical mile separation minimum from the aircraft just in from of them, creating a continuous third order effect. Since aircraft cannot stop entirely in the air, they initiate in-flight holding patterns. Thus, phantom traffic congestion is generated, just like road traffic, without a seemingly apparent reason, for pilots and air traffic controllers, as shown in Figure 6.

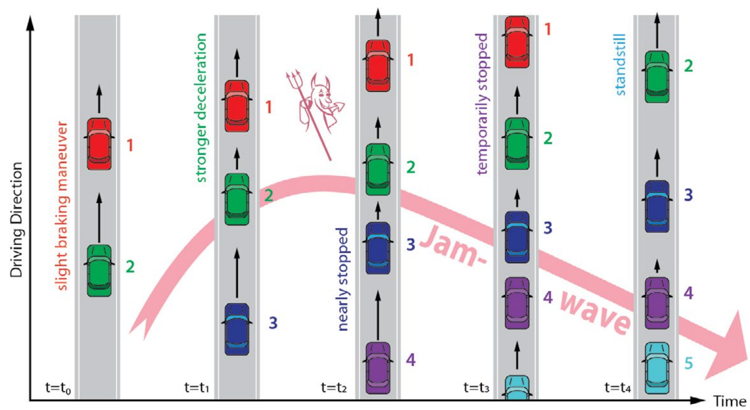

Figure 6. Dynamics of generating a phantom traffic jam

Source: Author, adapted from TREIBER and KESTING

Of note, TAAM considers only the aircraft's flight time in the calculation of fuel consumption without consideration for their speed. Therefore, as expected, the shortest fuel consumption from all three simulations was achieved in the second simulation, in which aircraft maintained the highest allowable speed.

In addition to the simulations, electronic questionnaires were sent to air traffic controllers at the São Paulo terminal. The questions were crafted to obtain insight into how air traffic controllers manage the speed of aircraft under their control, and what techniques they use to maintain the minimum safety separations between aircraft. Additionally, questionnaires were sent to airline pilots who frequently operate at GRU airport to understand, based on their answers, how they manage their aircraft speed, and how they perceive the effectiveness of interventions carried out by air traffic controllers.

Based on the answers provided, most pilots and air traffic controllers considered that using high speeds implied shorter flight times. Moreover, most air traffic controllers, like most pilots, considered changing aircraft trajectory to be the best technique to get them lined up efficiently for landing. However, it should be noted that the structure of the São Paulo terminal does not favor the use of trajectory changes, due to the vast number of airports in proximity, and accompanying high volume arrival and departure traffic.

Some pilots answered that they often change the speed set by the air traffic controller without authorization. They stated they do this when, with the help of their onboard Traffic Collision Avoidance System, which's primary purpose is collision avoidance and generation of traffic alerts (versus efficient landing sequencing), when either the aircraft ahead is at an excessive distance, or to overtake other aircraft versus following the sequencing instructed by an air traffic controller.

To a lesser extent, some air traffic controllers and pilots considered speed management as the best technique to sequence aircraft for landing. This may be due to the absence of a decision support system, such as AMAN, even though few pointed out the need to implement decision support tools as an essential factor to reduce congestion. Specifically, with regards to pilots, this may be related to a lack of confidence that air traffic controllers can efficiently manage aircraft speed.

Both air traffic controllers and pilots pointed out that the lack of coordination between airspace control centers adjacent to São Paulo terminal airspace and São Paulo approach control can cause traffic flow inefficiencies and phantom congestion. The may be due to the control center maintaining aircraft speed above or below the optimal speed because they are unaware of real-time conditions at the terminal.

Most air traffic controllers identified separation by distance as the most used separation method to sequence aircraft for landing, with others mentioning separation by time. It should be noted, however, that the separation by distance methodology does not take into account wind changes at altitude, nor mandated aircraft speed decreases as they descend; in which aircraft ahead in the approach sequence eventually initiate speed reductions before those that follow them. Thus, allocated distances often reduce as aircraft descend, which in turn can trigger phantom traffic congestion.

Although there are rules for the separation of aircraft by distance in environments where surveillance systems are employed, such as those used by São Paulo Air Terminal controllers, there are no equivalent rules for applying separation of aircraft by time. Moreover, there are no established separation techniques manuals for controllers, who mainly rely on personal experiences acquired throughout their careers.

On the other hand, in the United Kingdom, the separation of aircraft by time methodology is used, based on Heathrow Airport's Time-Based Separation concept.[26] Using time-based separation, the distances between aircraft on final approach are reduced, thus maintaining appropriate flight times between aircraft even during strong headwinds. As a result, the efficiency of air traffic flow management has improved considerably.[27] In 2018, Heathrow Airport implemented an enhanced version of the Time-Based Separation concept using additional separation tools, which gained an average of 2.6 extra landings per hour with headwind greater than 20 knots.[28]

Conclusions

This study demonstrates that the inadequate management of speed by both pilots and air traffic controllers, due to flawed perceptions of reality, lack of decision support tools, and absence of well-established aircraft separation techniques, are the most likely causes of phantom traffic jams, as initially identified for automobile traffic flows. This lack of awareness can generate inefficiencies in the flow of air traffic that can be avoided with establishment of proper separation techniques, training, and implementation of decision support tools.

Therefore, it's within the realm of possibility to optimize the efficiency of aircraft approach sequencing, especially at airports with a large volume of traffic, such as in the case of Guarulhos. This efficiency can then permeate throughout the entire Brazilian domestic and most international airspace networks; and would serve to meet PNAC's strategic objectives, strengthen Brazilian civil aviation, and consequently, Brazilian Air Power as a whole. ❑

Notes

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First Lieutenant Bruno Garcia Franciscone
Brazilian Air Force

Specialist in Air Traffic Control. Graduated from the Brazilian Center for Aeronautical Instruction and Adaptation, Master's degree in Aerospace Sciences from the University of the Air Force, Air Traffic Controller, Instructor and Supervisor for the Approach Control of São Paulo. Currently, Advisor of the Airspace and Air Traffic Services section, Coordination and Control Division, Operations Department of the Airspace Control Department (DECEA).

Brig Gen Pedro Arthur Linhares Lima
Brazilian Air Force, Reserve

Graduate from the Brazilian Air Force Academy, with Specialization in Information Technology from the Universidade Católica do Rio de Janeiro, Master's degree in Computer Science at the USAF Institute of Technology, Ph.D. in Production Engineering from the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE) from Federal University of Rio de Janeiro (UFRJ), MBA in Policy and Strategy from the COPPEAD Institute of Administration, Federal University of Rio de Janeiro. He was Chief of the Aeronautics Computer Center in São José dos Campos, Deputy Director of Information Technology Systems and Infrastructure, Deputy Director of Information Technology Projects, Chief Advisor for Information Technology Governance, and Director of Information Technology of the Air Force. Currently serves as researcher and Professor at the Post-Graduate Program in Aerospace Sciences, Brazilian Air Force University, UNIFA.