INTERNATIONAL CIVIL AVIATION ORGANIZATION

THE SECOND MEETING OF THE APANPIRG AERODROMES OPERATIONS AND PLANNING – WORKING GROUP (AOP/WG/2)

Yogyakarta, Indonesia, 3 – 5 June 2014

Agenda Item 4: Provision of AOP in the Asia/Pacific Region

STUDIES AND APPROVAL OF ENGINEERED MATERIAL ARRESTING SYSTEM

(Presented by China)

SUMMARY

China Academy of Civil Aviation Science and Technology, Beijing, 100028

Abstract: Engineered Material Arresting System (EMAS) is a bed of engineered materials built at the end of a runway to stop an aircraft overrun during its takeoff or landing. The key techniques in this system can be categorized into material fabrication and system design. The material fabrication refers to the fabrication of foamed concretes that can meet the requirements on the mechanical properties and durability; the system design refers to the calculation of stopping distance and simulation modeling for the evaluation of landing gear reliability and crew safety. In this article, we present a study of EMAS in terms of materials characteristics, simulation modeling and safety evaluation. For this study, both bench test and prototype test were designed and conducted. According to relevant laws and regulations, the Civil Aviation Administration of China (CAAC) established an industry sub-committee for the review and approval of newly developed EMAS. As a result, LANZU-1, which is an EMAS with completely independent intellectual property rights, has been developed.

Keywords: Engineered Material Arresting System; material performance; bench test; prototype test; approval

1. BACKGROUND

1.1 Severe consequences of aircraft overruns have been reported previously. On 22 Dec 2009, American Airlines 737 landed in Kingston International Airport, Jamaica, during a rainstorm, and was unable to stop on the runway. As a result, 40 passengers were injured, 3 of which were severe. On 22 May 2010, another Boeing 737 overran and slid into a valley during its landing in Mangalore, India, resulting in 159 deaths. According to data provided by The International Civil Aviation Organization (ICAO), from 1998 to 2007, the frequency of overrun accidents was on the top of aviation accident/potential accident cause list, with 42 accidents per year. In China, overrun is also one of the main potential accident causes. According to CAAC website, from 2005 to 2008, 15 out of 52 severe potential accident causes in China were overrun accidents, which took the first place.

1.2 Due to the potential consequences of aircraft overruns, Federal Aviation Administration (FAA) has initiated the studies and developments of Engineered Material Arresting System (EMAS), which is located in the safety area at the end of a runway. The energy absorbing capability of these materials (such as foamed concretes) will predictably crush under the weight of an aircraft so that the aircraft can be stopped within a preferred distance. In this way, the structural damage to the aircrafts can be minimized without any significant passenger discomfort and catastrophes such as crashing into dangerous regions including cliff, valley and water bodies can be avoided.

1.3 This system has been widely applied in various airports in USA and other countries, including China. With several overrun prevention records, this system is believed to be an effective way to improve the safety margin of airports. As a result of relevant research in the past decades, US have developed a series of EMAS-related systems, in terms of material fabrication, numerical simulation of kinetics and development of simulation software, etc.

	
a. EMAS located at the end of runway	b. EMAS crushed by aircraft

Figure 1. Introduction on EMAS

2. DEVELOPMENT OF EMAS IN CHINA

The key techniques in the arresting system can be categorized into material fabrication and system design. The material fabrication refers to the fabrication of foamed concretes that can meet the requirements on the mechanical properties and durability; the system design refers to the computation of stopping distance and simulation modeling for the evaluation of landing gear reliability and crew safety.

2.1 Characteristics of materials

2.1.1 In spite of its wide applications in the construction industry, the foamed concrete is still considered as a novel candidate in the aircraft arresting system. As a result, the collapse mechanism and mechanical behavior of the foamed concrete crushed by aircraft wheels have been intensively studied.

2.1.2 The arresting material is required to have reasonable and predictable arresting capability, which is believed to be a result of appropriate strength and deformation characteristic. As shown in Figure 2, as a unique composite material, the foamed concrete shows distinctive mechanical properties, as compared to conventional metal or composite materials. Due to its micro-structure, this material shows obvious local deformations due to external forces applied. With penetration mechanics tester and microscope, we conducted an investigation of the collapse mechanism and mechanical behavior of the foamed concrete under pressure in the meso-scale to obtain the unique constitutive relations for this material. In addition, characterization and measurement methods in engineering mechanics for quantitative reflection of energy absorption by material collapse were also investigated to obtain various parameters in the arresting process, including basic mechanical properties and energy absorption capability at transient and steady states, as well as their sensitivity to loading rate and temperature.

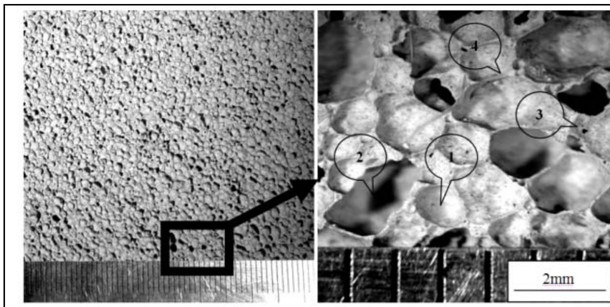	
a. Micro-structure of the sample	b. Penetration test

Figure 2. Experiments for basic mechanical properties of EMAS materials

2.1.3 With improvements on the current apparatus for mechanical property test, we conducted a study on the basic mechanical properties of the arresting materials by using unique apparatus and experimental methods. This study included experiments for the compressive and shear performance of the standard sample, as well as penetration test. Based on that, the collapse mechanism and key mechanical parameters were obtained, and the database for stress-strain curves of different materials was established. In this way, this study serves as a fundamental research for the development of kinetic simulation models.

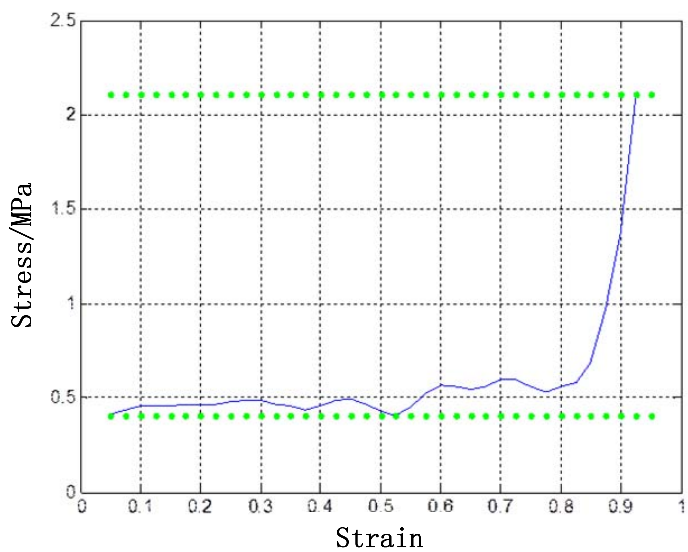

Figure 3. Stress-strain curves of arresting materials

2.1.4 Additionally, we conducted weather ability tests on the arresting materials, including accelerated aging, investigation of their resistance to fuel, hydraulic fluid, lubricant and de-icing fluid, water absorption capability and combustibility.

2.2 EMAS simulation models

The taxiing of aircrafts on the arresting system was investigated and simulation models for aircraft kinetics, landing gear mechanics, wheel/arresting material interface have been developed for this process, as well as safety assessments. Basically, simulation model can never be realized unless the analysis of arresting material's decelerating effect on the aircraft was achieved. The load on the aircraft is related to various parameters such as characteristics of landing gear, mass and structure of aircraft, characteristics of aircraft wheel, arresting bed geometry and taxiing speed of aircraft.

2.2.1 Aircraft kinetic model

In the interaction between the arresting system and aircraft, the arresting effect on the aircraft is dynamically related to its kinetics. The aircraft kinetics can be described by a series of equations including rigid body kinetic equation and structural elasticity kinetic equation. Besides, aerodynamic model for moment of lifting, dragging and pitch forces and engine propulsion model should be developed for the prediction of aircraft motion and the effect of propulsion on the arresting system respectively. In the actual design of arresting systems, it is nearly impossible to take all the kinetic parameters into consideration. Instead, a simplified aerodynamics model based on characteristics of the arresting system and different aircraft types was developed. For instance, a 6-DOF (degree of freedom) aerodynamics model for aircraft with rigid body reported didn't include its motion along the lateral direction.

In conclusion, an aerodynamics model that is simplified while suitable for the design of arresting system is essential for the study of EMAS. This model shall include the description of dynamics in the aircraft taxiing. As part of the fundamental study for arresting system, this aerodynamics model established a link between arresting force by the system and gravity, aerodynamic forces, engine propulsion in the taxiing process. As a result, the prediction of velocity attenuation and load of the aircraft in the system can be realized by this.

2.2.2 Interaction between aircraft wheels and the arresting materials

The arresting effect of EMAS on the aircraft is realized by the relative motion between the aircraft wheels and arresting material. As a result, the core of EMAS design is the mechanics between the aircraft wheels and arresting material.

I. The interface between the aircraft wheels and arresting material: the mechanical interaction between the wheel and arresting material is a result of the contact between them and the magnitude of contact force is partially determined by the size of contact area. The size of contact area is related to various factors such as configuration of loaded wheel, moving direction and configuration of arresting materials. The key part in this project is the measurement of rolling depth based on the deformation of loaded wheel and characteristics of arresting material.

II. The force on the interface: theoretically, the arresting force can be calculated based on the mechanical properties of the arresting material and the interface between aircraft wheels and arresting material. However, the taxiing speed also plays a key role in the practical case. The difference in the speed results in different compression ratios. As a result, the compression ratios at different locations have to be calculated based on the taxiing speed of aircraft. According to the mechanical properties of the arresting materials at different compression ratios, the arresting forces applied on different parts of the wheel can be calculated. As shown in Figure 4, the overall force applied can be calculated by combination of arresting forces at different locations of the wheel.

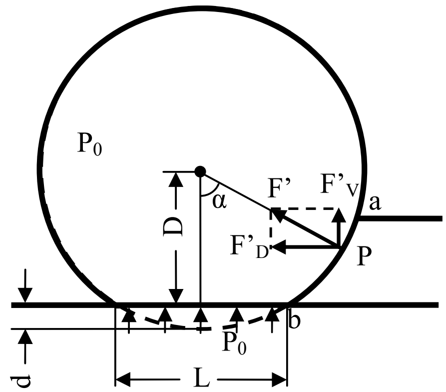

Figure 4. Rolling of arresting materials by the aircraft wheel

III. Effect of material thickness: With a radius smaller than the thickness of arresting material, the moving wheel rolls downward; with a radius larger than the thickness, the destruction of the part above the wheel axis was done by wheel pushing forward. As a result, the simulation models for the calculation of arresting forces are different in the two cases. For this reason, the effect of material thickness shall be taken into consideration so that an optimized design for arresting system that is universally suitable can be realized.

2.2.3 Dynamic characteristics of the landing gears

Directly related to the rolling depth, the dynamic characteristics of landing gear, especially the strut, play a key role in the arresting process.

Filled with air-oleo, the strut in the landing gear is responsible for the absorption of kinetic energy in the landing process so that the force applied on the aircraft is minimized. In the mechanical point of view, the strut is an analogue to a spring damper. As shown in Figure 5, vertical motion was observed on the wheel due to the force applied by the arresting system. As a result, the air-oleo was compressed by the inner cylinder of the gear, resulting in changes in its volume and pressure. This change in turn worked on the aircraft to alter its motions in both vertical and horizontal directions. For different aircrafts, the rigidity and damping are different; for the same aircraft, the rigidity and damping of the nose gear are different from those of the main gear.

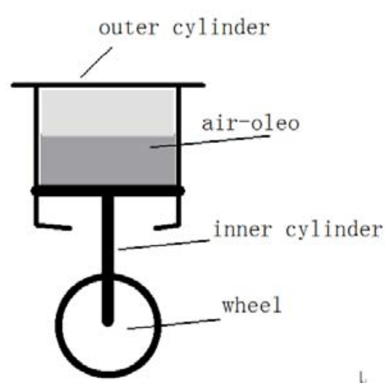

Figure 5. Schematic of landing gear strut

The differential equations describing the dynamic characteristics of the landing gear strut can be used for the study of kinetic relation between the wheel and inner cylinder. This kinetic relation is a determining factor for the rolling depth, thus affecting the magnitude and direction of the arresting force. Meanwhile, magnitude of the force applied by the air-oleo on the outer cylinder of the gear and aircraft can be obtained. Together with aerodynamic force, propulsion by the engine and gravity, this applied force determines the motion of aircraft, thus the motion of landing gear. As a result, a group of differential equations describing the dynamic characteristics of the aircraft and landing gear respectively is established to determine their kinetic relation.

2.2.4 Safety assessment of the aircraft and crew

In the arresting process, the safety of the aircraft and crew is of the highest priority. The key factors in this decelerating process include the load applied on the landing gear along the moving direction and the deceleration which should not exceed the limit of the aircraft structure and human being.

I. Aircraft safety: The safety assessment of aircrafts will be straightforward if the loading limits are provided. Nevertheless, these data are usually confidential, thus not available for the EMAS design. Fortunately, the airworthiness standard is open to public and it is confirmed that all of the commercial aircrafts can satisfy this requirement. As a result, the calculation of loading limits for different aircrafts can be realized based on the airworthiness standards.

   According to *China Civil Aviation Regulations, Section 25* and airport planning manual provided by the aircraft manufacturers, the forces along the moving and vertical directions on the aircraft landing gear were analyzed and calculated for the development of safety assessments for aircraft. Therefore, a clear understanding of the airworthiness standards in terms of the relevant regulations and appropriate selection of safety assessment for arresting system have become the key factors in the aircraft safety assessment.

II. Crew safety: Based on a series of studies on the deceleration limit for human beings conducted by researchers in the aeromedicine field, the safety assessment for the crew can be achieved by comparing the actual deceleration of the aircraft in the arresting process with the limit for human beings.

2.3 Bench tests and prototype tests

Both bench test and prototype test are the key parts in the study of EMAS. The bench test focuses on the mechanical modeling, while the prototype test is an essential step for the verification and approval of the EMAS.

2.3.1 Bench test

This investigation includes single-wheel loading and dragging experiment on the platform. As shown in Figure 6 below, the apparatus for the bench test consists of fixed frame, basket, movable platform, sensor and components for wheel clamping. The frame was fixed to the ground. The basket was confined within the frame by bearing and tracks but free in the vertical direction. In addition, the load can be altered by addition and removal of weights and the wheel can be installed beneath the basket with the help of wheel clamping components. Supported by rollers that are fixed to the ground, the movable platform is free in the horizontal direction. The arresting materials were installed in the slots.

Figure 6. The apparatus for single-wheel load experiment

With this set-up, the effects of wheel size, tire pressure, load, aircraft motion and mechanical properties of the arresting materials can be investigated. In addition, this set-up served as an effective way for the wheel-EMAS mechanical modeling. According to Figure 7, the results on arresting force applied on the wheel from the bench test (dots) are in consistent with calculation based on the simulation model (curves). Additionally, the consistence was repeatable in various situations, indicating that the developed simulation model for the wheel-EMAS is an effective one.

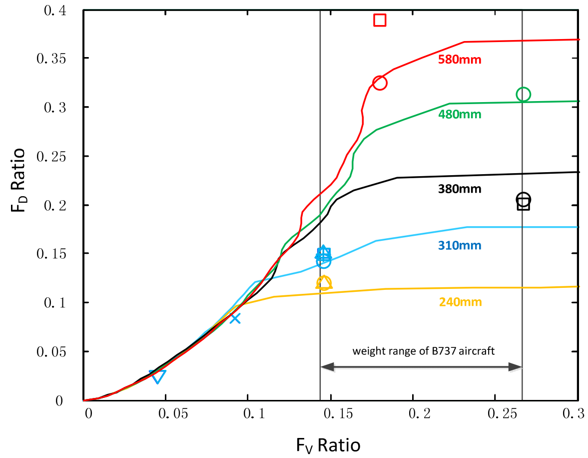

Figure 7. Results from the simulation model and datum dots from bench test

2.3.2 Prototype test

As the final and determining verification of the whole system design, prototype test involves actual civil aircrafts and runway in the airport. In this way, the applications of products with completely independent intellectual property rights can be promoted and the official capability of EMAS approval can be established.

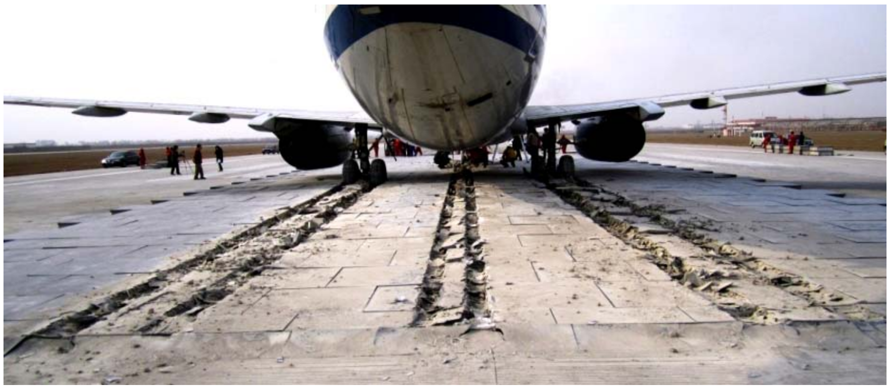

Figure 8. Prototype test

The aircraft used in the prototype test was a model widely accepted and the runway is the second runway in Binhai International airport, Tianjin. 4 out of the total 6 experiments were full-size experiments while the other two were reduced-size ones. Parameters investigated included the speed and acceleration of the aircraft, the forces along vertical and moving directions of the landing gears, loads applied on passengers in different parts of the cabin, the stopping distance, etc. According to Figure 9 and 10, the measurement results were in consistent with the simulation results.

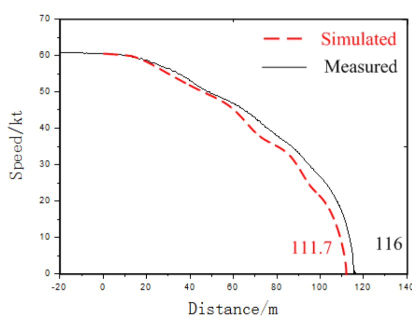

Figure 9. Variation of speed in the experiment

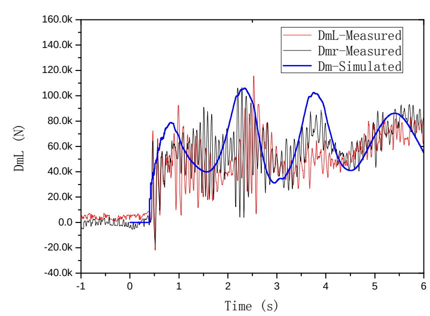

Figure 10. Resistance experienced by the main landing gear

In the last experiment, the investigation on adaptability of arresting bed to the high-speed impact induced by aircraft wake and the consistence of unit head cover with the system have been achieved. The success of this experiment indicated that application of EMAS in China may be realized in a short time.

3. APPROVAL OF EMAS

3.1 As the maturity of EMAS increased, applications of this system for industrial applications have been received and processed, as shown in Table 1.

Since the EMAS is one of the key safety facilities in the airport, CAAC has established a working party responsible for the review and approval of EMAS and released *the outline for EMAS approval process*. Based on that, the review of developed EMAS by relevant experts and professionals has been realized. The review includes various aspects including material performance, systematic principle, modeling, design and process for bench and prototype tests, production capability of the manufacturer and the QA system.

Steps	Date of completion	Result
Establishment of working party	26/04/2011	Completed
Outline draft for approval process	04/05/2011	Completed
Presentation by relevant institutions and release of completed Outline	05/05/2011	Approved
Approval of outline for approval process	09/05/2011	Approved
Review of EMAS design, the experimental design for material performance test and bench tests	13/07/2011	Approved
Bench test witnessed by the working party	21/10/2011	Completed
Material performance test witnessed by the working party	21/10/2011	Completed
Review of results from bench test and design for prototype test	08/11/2011	Approved
Prototype test witnessed by the working party	29/03/2012	Completed
Review of production capability and QA system	28/04/2012	Approved
Review of results from material performance test	13/06/2012	Approved
Review of results from prototype test and systematic design for specific programs	13/06/2012	Approved
Conclusion	12/07/2012	Completed

Table 1. The process of application approval

4. CONCLUSION

4.1 Due to the limitations in the topography, location and size of airports in China, especially those in the central and western part, the requirements of safety area size at the end of runways have not been completely satisfied, leaving severe safety risks. With the efforts in the development of EMAS, our institution made a considerable contribution to the design and fabrication of arresting system for aircrafts. More importantly, we provide a solution to the aircraft overrun, thus enhancing the overall safety of civil aviation system.

4.2 The development of arresting system at the end of runway involves various factors including arresting material, the main body of aircraft, landing gear, wheels and safety assessment. In this study, mechanics of materials, mechanics of wheel, aerodynamics, landing gear design, aviation safety and aeromedicine have also been involved, while the core part is the mechanical relation between the wheel and arresting material. The key parts of this project are the study of mechanical performance of arresting materials and interaction between these materials and aircraft wheels. In addition, all of the simulation models and algorithms involved should be verified by tests.

4.3 In this project, the development of foamed concretes, material performance test, development of system design and establishment of large-scale production have been achieved, as well as the approval process. As a result, LANZU-1, which is an EMAS product with completely independent intellectual property rights, has been developed and approved by CAAC.

5. ACTION BY THE MEETING

5.1 The meeting is invited to note the information contained in this paper.

…………………………….