行政院及所屬機關出國報告
(出國類別:其他)

「增設 28 跑道頭工程材料攔機系統 (EMAS)工程」EMAS 材料廠驗報告

服務機關:交通部民用航空局臺北國際航空站
姓名職稱: 陳組長周駿、吳工務員政憲
派赴國家:美國（紐澤西 ESCO 公司）
出國期間:民國 99 年 6 月 23 日至 6 月 30 日
報告日期:民國 99 年 7 月 16 日

目 錄

摘 要

爲配合松山機場之東北亞等航線將開放大型航機飛航政策，臺北國際航空站經評估奉准採購全球唯一經 FAA 認證、獲美國國家運輸安全委員會以及加拿大運輸安全委員會之推薦、具多次攔截飛機成功實績未曾失敗之 EMAS 材料執行本計畫，以確保飛航安全，並強化改善 28 跑道端安全區。

考量 EMAS 材料之品質攸關整體工程效益，故臺北國際航空站經申請後奉准派員至美國進行廠驗，並按材料案契約及參酌 FAA 諮詢公告 AC150/5220-22A 之規定，檢視 EMAS 材料分析設計、生產、品管、數量及裝運等作業；經查 ESCO 公司之 EMAS 設計方式、材料及製造流程業獲 FAA 認證，該公司並已針對松山機場目前及未來營運機型依據 FAA 相關規定進行分析設計，其結果顯示松山機場 28 跑道端安全區域空間足夠安裝完整之 EMAS 系統，可煞停 70 節速度下，各最大起飛重量及 80%最大降落重量之營運航機，另臺北國際航空站人員亦現場就 EMAS 材料之生產製造過程、品管作業進行瞭解、核對 EMAS 之數量，並與運送案廠商代表共同商討 EMAS 材料裝櫃及貨櫃運送事宜。

本次廠驗 ESCO 公司之各項作業尚符契約規範，惟爲確保飛航安全，依據材料案契約附件一規定，ESCO 公司將於安裝完成後，確認其是否符合 FAA 諮詢公告 AC150/5220-22A 之要求，經確認無誤後，該公司將提出 EMAS 安裝工程驗收證明書，以確保其功能可達 FAA 所訂標準，發揮預期攔機效益。

壹、目的

臺北國際航空站為配合東北亞等航線將開放大型航機飛航政策，又考量松山機場 85%航機由 10 跑道端起降，為確保飛航安全，並強化改善 28 跑道端安全區，經評估奉准採購全球唯一經 FAA 認證、獲美國國家運輸安全委員會以及加拿大運輸安全委員會之推薦、具多次攔截飛機成功實績未曾失敗之 EMAS 材料執行本計畫。

本計畫經費合計新台幣 4 億 3,327 萬 4,000 元，共分為 EMAS 材料案、EMAS 運送案、設計監造案及工程案等 4 項採購，有關 EMAS 材料採購部分已於 99 年 1 月 14 日以 809 萬 2,500 美元決標予美國 ESCO 公司，依據材料案契約第 12 條規定，臺北國際航空站有權進行廠驗，且考量 EMAS 材料之品質攸關整體工程效益，故經申請後奉准派員至美國進行廠驗，以瞭解 EMAS 材料分析設計、生產、品管、數量及裝運作業等情形，確保工程如期如質完成並發揮其效益。

貳、廠驗過程及內容

本次出國廠驗經奉准派員兩名、共計 7 天，惟為配合航機班表，故自 99 年 6 月 23 日夜間出發、99 年 6 月 30 日清晨返抵台灣。

臺北國際航空站人員經 99 年 6 月 24 日與 ESCO 公司人員於該公司會議室集合後開始進行廠驗作業，另為商討 EMAS 材料裝櫃及貨櫃運送事宜，故亦請運送案廠商指派代表共同參與。

本次廠驗項目係依據本採購案契約並參酌 FAA 諮詢公告 AC150/5220-22A（詳見附錄五）內容制定，經臺北國際航空站人員說明廠驗項目後，ESCO 公司出具其 EMAS 之設計方式、材料及製造流程已獲 FAA 認證之證明文件（詳見附錄一），並提出該產品執行計畫書（詳見附錄一），表示該公司針對 EMAS 材料從受顧客委託至安裝完成止，期間包含分析設計、生產製造、裝載、運送等作業皆有一套標準作業流程依循，餘各項廠驗內容說明如后。

一、EMAS 之分析、設計

（一）設計輸入及分析設計方式

鑒於本計畫係為配合東北亞等航線，松山機場開放大型航機飛航政策，故有關 EMAS 系統所需攔阻之機型除需考量松山機場目前營運機型外，亦需包含未來營運航機， ESCO 公司提出設計文件（詳見附錄二）證明其設計皆已依實際狀況通盤考量，並按 FAA 相關規定分析設計，又針對松山機場目前及未來營運機型特性，該公司採以 60psi 強度之材料強度進行計算，以達最佳效益。

EMASMAX

DESIGN REPORT
FOR EMAS AT THE
RUNWAY 10 DEPARTURE END
AT
TAIPEI SONGSHAN AIRPORT
IN
TAIPEI, REPUBLIC OF CHINA

FEBRUARY 24, 2010

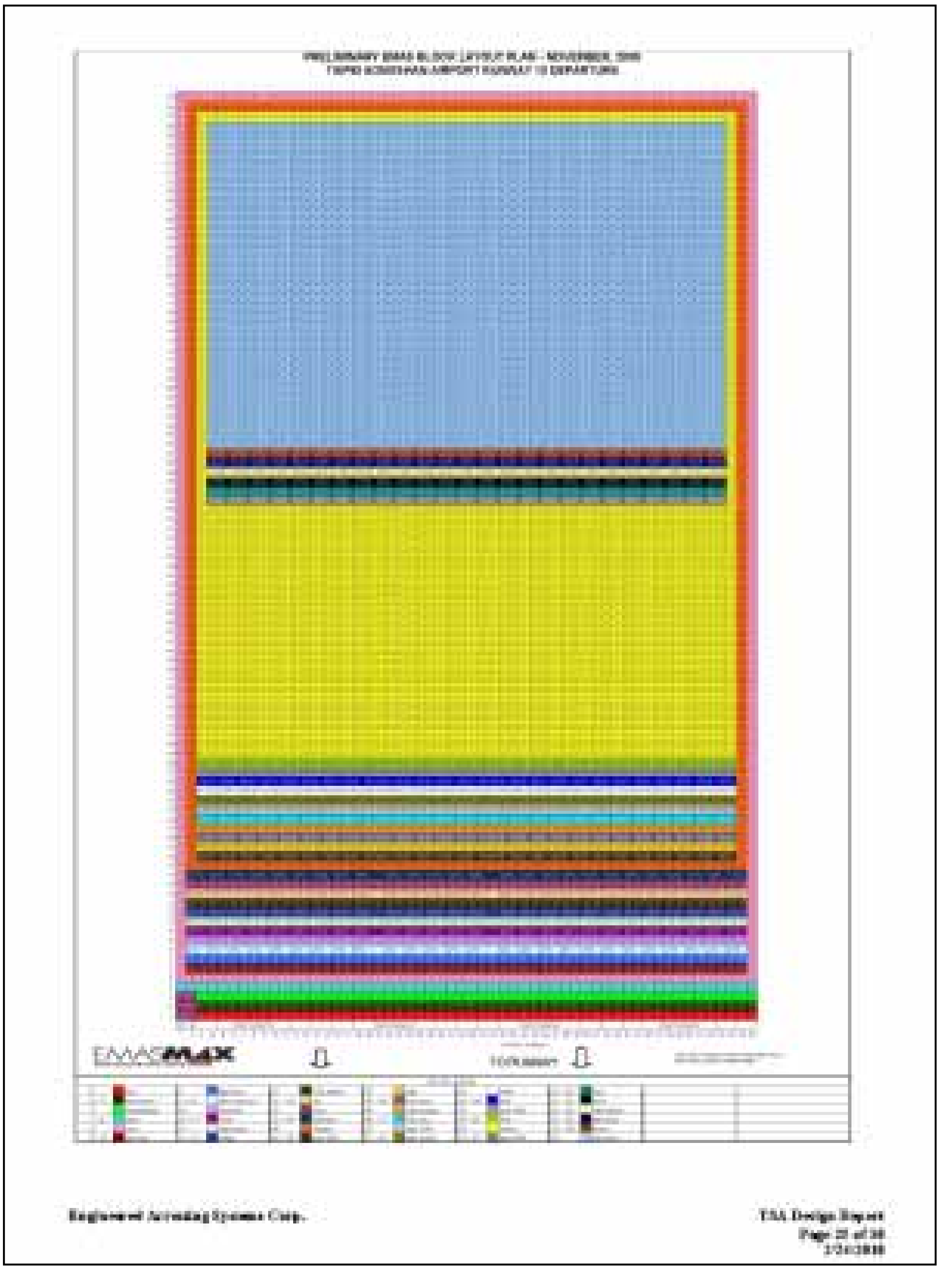
Aircraft	MTOW (lb)	MTOW (kg)	Design Case	Notes
DHC-8-200	36,500	16,560	>70	Using Dash 8-300
ATR72-500	49,000	22,230	>70	Estimated using Dash 8
FK-100	101,000	45,810	>70	Estimated using DC 9
MD-82	149,000	67,590	>75	
MD-90	168,000	76,204	>75	Using MD-82
A320/321	162,000	73,480	>70	Estimated w/ B737-400
B737-800	175,000	79,380	>75	Using B737-400
B757-200	255,000	115,670	>75	
A330-200F	460,000	208,660	**70**	Estimated using B767
B777-200	*765,000*	*347,000*	*65*	*Estimated AC data*
B747-400F	*875,000*	*396,900*	*66*	

Aircraft	80% MLW (lb)	80% MLW (kg)	Design Case	Notes
DHC-8-200	25,400	11,520	>70	Using Dash 8-300
ATR72-500	38,530	17,480	>70	Estimated using Dash 8
FK-100	73,460	33,320	>70	Estimated using DC 9
MD-82	104,000	47,170	>75	
MD-90	113,600	51,530	>75	Using MD-82
A320/321	113,760	51,600	>70	Estimated w/ B737-400
B737-800	117,040	53,090	>75	Using B737-400
B757-200	168,000	76,200	>75	
A330-200F	306,000	138,800	>70	Estimated using B767
B777-200	*368,000*	*166,920*	*>70*	*Estimated AC data*
B747-400F	*524,000*	*237,690*	*>75*	

又有關分析設計方式部分，該公司表示已依循 FAA 諮詢公告 AC150/5220-22A 之規範據以開發新版設計軟體，其設計方式並獲 FAA 認證（詳見附錄一）。

（二）分析設計結果

依據 ESCO 公司所提 EMAS 系統設計報告書表示，其按 FAA 等規定進行分析設計後，松山機場 28 跑道端安全區域空間足夠安裝完整之 EMAS 系統，可煞停 70 節速度下，各最大起飛重量及 80%最大降落重量之營運航機，設計平面圖如下（該平面設計圖已顯示 EMAS 系統各基塊高度及排列方式，詳見附錄二）。



二、EMAS 之生產製造

臺北國際航空站人員現場就 EMAS 材料之生產製造過程進行瞭解，相關說明如下：

●模板組立

該公司所採系統鋼模乃配合 EMAS 基塊尺寸，組裝後內徑長 1.2 公尺、寬 1.2 公尺。

●混凝土拌和及澆置

該公司依據 EMAS 材料所需強度選擇配比拌和混凝土，並控制環境溫度、溼度等變數，完成後再進行澆置。

●脫模及材料檢驗

經澆置達預定強度後，進行脫模，並堆置等待材料檢驗（詳本章第三節內容所述）。


●裁切

經檢驗合格後，方可將 EMAS 基塊依所需尺寸，裁切高度，再以儀器量測尺寸是否無誤，本項作業亦可將 EMAS 基塊表層品質較差部分一併切除。


●表層處理

為避免 EMAS 基塊因自然或人為因素受損，故進行表層處理，並加裝阻尼墊，吸收外力撞擊能量。

●包裝及暫放

EMAS 基塊完成後，仍需進行包裝，上、下 EMAS 基塊間需以緩衝材隔開，且堆置不可過高，以避免底層 EMAS 基塊損壞，最後於各基塊貼上條碼，進行物料管理，對應條碼編號依序暫放於工廠內。

●移至倉庫儲存

經完成之 EMAS 基塊將裝櫃，移至於 ESCO 公司所屬倉庫內暫時儲存。

三、EMAS 之品管作業

（一）抽查品管作業主要試驗項目

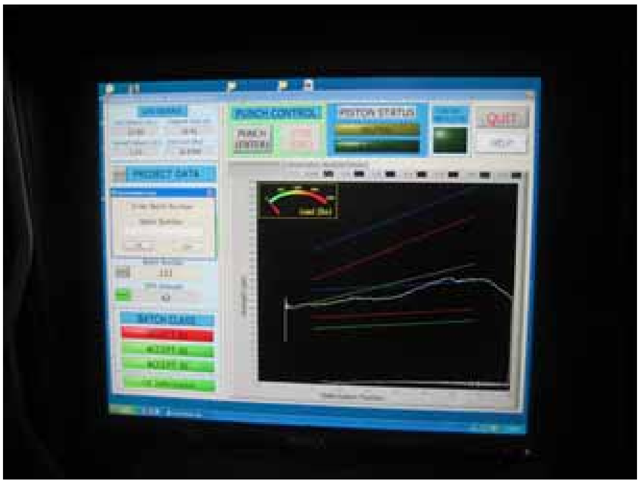
按 FAA 諮詢公告 AC150/5220-22A（詳見附錄五）規定，EMAS 材料合格與否決於該材料強度與變形能否達到標準，此為研判 EMAS 材料能否發揮預期效益之關鍵，ESCO 公司於產品執行計畫書中已將相關試驗列入標準作業流程（詳見附錄一），據此，臺北國際航空站人員特別抽查該項目之品管文書作業並現場進行該試驗。

經查 ESCO 公司為獲得 EMAS 材料強度與變形之數據，已研擬抗壓梯度強度試驗（compressive gradient strength，其乃求取大量變形過程間之應力應變關係，與一般混凝土採抗壓試驗求取微量變形破壞時之抗壓強度不同）藉以模擬航機衝撞 EMAS 材料產生大量變形過程中，該材料強度始終維持穩定，不致過硬或過軟，確保其可成功攔阻航機且又不致傷及機身，並據以驗證產品與設計是否相符，該公司之 EMAS 材料抗壓梯度強度試驗品管作業文件及該試驗專利證明資料詳見附錄三。

依據抗壓梯度強度試驗品管作業文件及該試驗專利證明資料之內容所述，該試驗所採試體為 18 天以上齡期之特殊發泡混凝土，其貫入桿直徑為 7.5 公分，貫入深度至少為厚度之 60%，並針對每批拌和後之材料進行取樣，檢測標準係先試驗第 1 個試體後，若未達標準，則再取第 2 個試體進行試驗，惟若仍未達標準，則需全數廢棄不用。

經查本工程 EMAS 系統設計報告書載明案內 EMAS 材料強度係以 60psi 進行設計（詳見附錄二），據此，臺北國際航空站人員依據前述規定及作業標準，實際抽驗現場試體進行抗壓梯度強度試驗。

本次檢測試體爲 21 天齡期，經儀器試驗後，由本次檢測所得應力應變關係曲線圖（詳見附錄三）顯示，該試體於變形量 10%至 60%間（已屬大量變形），材料強度始終維持介於 60psi 所需對應之上、下規定值範圍內，據此，研判該 EMAS 材料尚符所訂 60psi 要求。



（二）隨機取樣量測 EMAS 基塊

考量材料案契約附件一載明採購之EMAS基塊尺寸規格爲4英呎長、4 英呎寬，高度爲 6 英吋至 26 英吋不等，故臺北國際航空站人員針對該範圍內之 EMAS 基塊隨機取樣量測實際尺寸，經現場取樣 14 英吋高度之 EMAS 基塊，其實際量測數據確實爲 4 英呎長、4 英呎寬、14 英吋高。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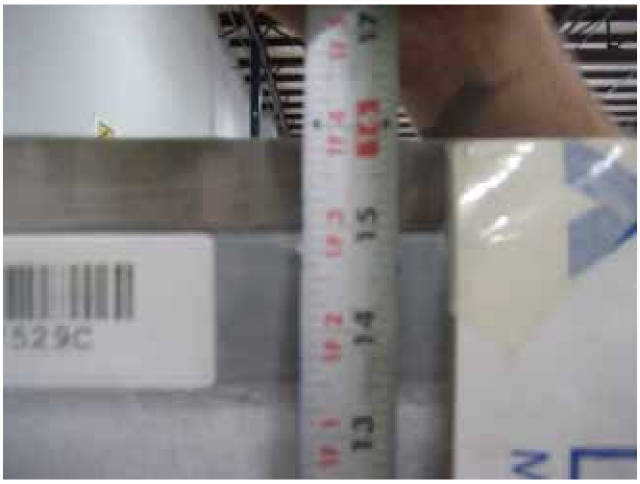
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四、EMAS 之數量核對

ESCO 公司人員表示該公司設有 3 座倉庫，其中 1 座目前堆置臺北國際航空站所採購之 EMAS 材料，復經至該倉庫現場勘查，臺北國際航空站所採購之 EMAS 材料皆已貼上 TAIPEI SONGSHAN AIRPORT（TAIWAN）、Contract # TP-C980010 之標籤，並整齊堆列該公司倉庫。

因材料案契約共採購 5,600 個 EMAS 基塊，且於契約附件一要求 ESCO 公司需提供 1%材料作爲應急用途，故經至現場勘查，其目前已近堆滿整座倉庫，臺北國際航空站人員現場抽點部分尺寸之 EMAS 基塊數量，該抽點部分數量共爲 918 個，又 ESCO 公司表示已製作完成 5,739 個 EMAS 基塊，並提出數量統計表佐證（詳見附錄四）。

另 EMAS 基塊尚需考量物料管理，ESCO 公司已於每一 EMAS 基塊皆貼上各單元之編號，堆疊後再貼上該落之編號（含該落內各單元之編號），藉以進行管理，其方式除可追蹤各 EMAS 基塊原製作過程外，並可確保現場安裝作業之正確性，並加快安裝速度，且未來若需進行緊急修復亦可立即獲知所需準備之 EMAS 基塊各項訊息，以迅速有效修復 EMAS 系統。

五、瞭解裝櫃包裝細節以避免運送途中受損

依照契約規定運送案廠商需提供貨櫃予 ESCO 公司進行裝櫃作業後運抵松山機場，爲商討 EMAS 材料裝櫃及貨櫃運送事宜，故本次廠驗亦請運送案廠商指派代表共同參與。

爲避免運送途中受損，ESCO 公司除已於各 EMAS 基塊表層水平裝設阻尼墊及緩衝材外（詳見前述第貳章第二節內容），未來裝櫃時 EMAS 水平落與垂直落將配合空間相鄰放置，並採氣墊填充 EMAS 基塊與貨櫃間空隙，以減緩運送途中可能產生之碰撞損壞。

又臺北國際航空站已於材料案契約附件一明訂「ESCO 並將提供約相當於上述總數量 1%的預製塊（約 55-60 塊），作爲應急用途，以更換運輸過程中合理損壞的預製塊。這些應急預製塊不另外計費…」，以確保工程能順利如期如質執行，另於運送案契約第 3 條第 4 項規定「本契約費用業已包含保險費，其保額不得少於 EMAS 材料費用計約美金 830 萬元之 1.1 倍且承保範圍至少達 ICC(A)等級。」，藉以進行風險控管，併此敘明。

六、其他議題

針對交通部民用航空局 99 年 6 月 15 日召開本工程之規劃設計報告書審查會議時，部分出席單位提出「1%備料無法應付航機衝撞後之修復」及「建制對應之後續緊急修復採購機制」等建議事項，ESCO 公司人員表示 EMAS 材料需存放於具頂蓋之場所，惟經本次現場討論後，考量臺北國際航空站確實無具頂蓋之空間可供儲存 A330 航機衝出跑道事後修復所需之最少需求的 10%備品，故該公司仍建議維持材料案契約內原定 1%備料之採購，以供發生如九寨溝機場勤務車輛不慎撞損系統修復所需。

另有關「建制對應之後續緊急修復採購機制」1 節，ESCO 公司人員表示，業主未來可選擇向該公司採購 EMAS 材料後，自行修復，或委由該公司（或其協力廠商）進行修復，惟其 EMAS 材料售價乃配合物價調整，現階段尚無法預期未來價格，據此，臺北國際航空站後續之緊急修復採購程序仍將遵照政府採購法相關規定再行辦理。

參、廠驗結論、心得及建議

一、廠驗結論

本次廠驗係按材料案契約並參酌 FAA 諮詢公告 AC150/5220-22A 之規定，檢視 EMAS 之分析設計、生產製造、品質管理等各項作業，並核對已完成之數量，經查 ESCO 公司各項作業尚符契約規定，惟為確保飛航安全，依據材料案契約附件一規定，ESCO 公司將於安裝完成後，確認其是否符合 FAA 諮詢公告 AC150/5220-22A 之規定，經確認無誤後，該公司將提出 EMAS 安裝工程驗收證明書，以確保其功能可達 FAA 所訂標準，發揮預期攔機效益。

二、心得及建議

本次出國廠驗成果豐碩，雖原定廠驗項目主要係瞭解美國 ESCO 公司是否依契約及相關規定執行工作，然於實際出國廠驗後，獲知該公司業已針對 EMAS 材料從受顧客委託至安裝完成止，製作一套標準作業流程依循，其中除包含分析設計、生產製造、裝載、運送等作業外，亦將顧客意見納入；另有關物料管理部分，該公司將各 EMAS 基塊貼上各自專屬的編號，除可藉此追蹤各 EMAS 基塊原製作過程外，亦可確保現場安裝作業之正確性，並加快安裝速度，且未來若需進行緊急修復亦可立即獲知所需準備之 EMAS 基塊各項訊息，以迅速有效修復 EMAS 系統；此外，經實際進行「抗壓梯度強度試驗（compressive gradient strength）」瞭解該試驗過程、內容，及其與研判 EMAS 材料能否發揮預期效益間之關連性，該公司並針對 EMAS 之設計方式、材料及製造流程取得 FAA 認證，藉以確信該公司所供應之 EMAS 材料可符合標準。

因本計畫「增設 28 跑道頭工程材料攔機系統(EMAS)工程」係屬國內首例，有關本計畫執行方式及本次廠驗等相關經驗，建議可提供協助國內其他機場未來裝置 EMAS 時之參考，以提升採購效率、確保飛航安全。

肆、附錄

附錄一- ESCO 公司之 EMAS 之設計方式、材料及製造流程獲 FAA 認證函及該產品執行計畫書

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Airport Safety
and Standards

800 Independence Ave., SW.
Washington, DC 20591

March 8, 2010

To Whom It May Concern:

The Federal Aviation Administration Circular 150/5220-22A, Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns, contains standards for arresting systems installed on U.S. civil airports.

As of the date of this letter, Engineered Arresting Systems Company, Inc. (ESCO) is the only enterprise that has demonstrated and validated a design method, material and manufacturing process meeting the Advisory Circular requirements to the satisfaction of the FAA.

Sincerely,

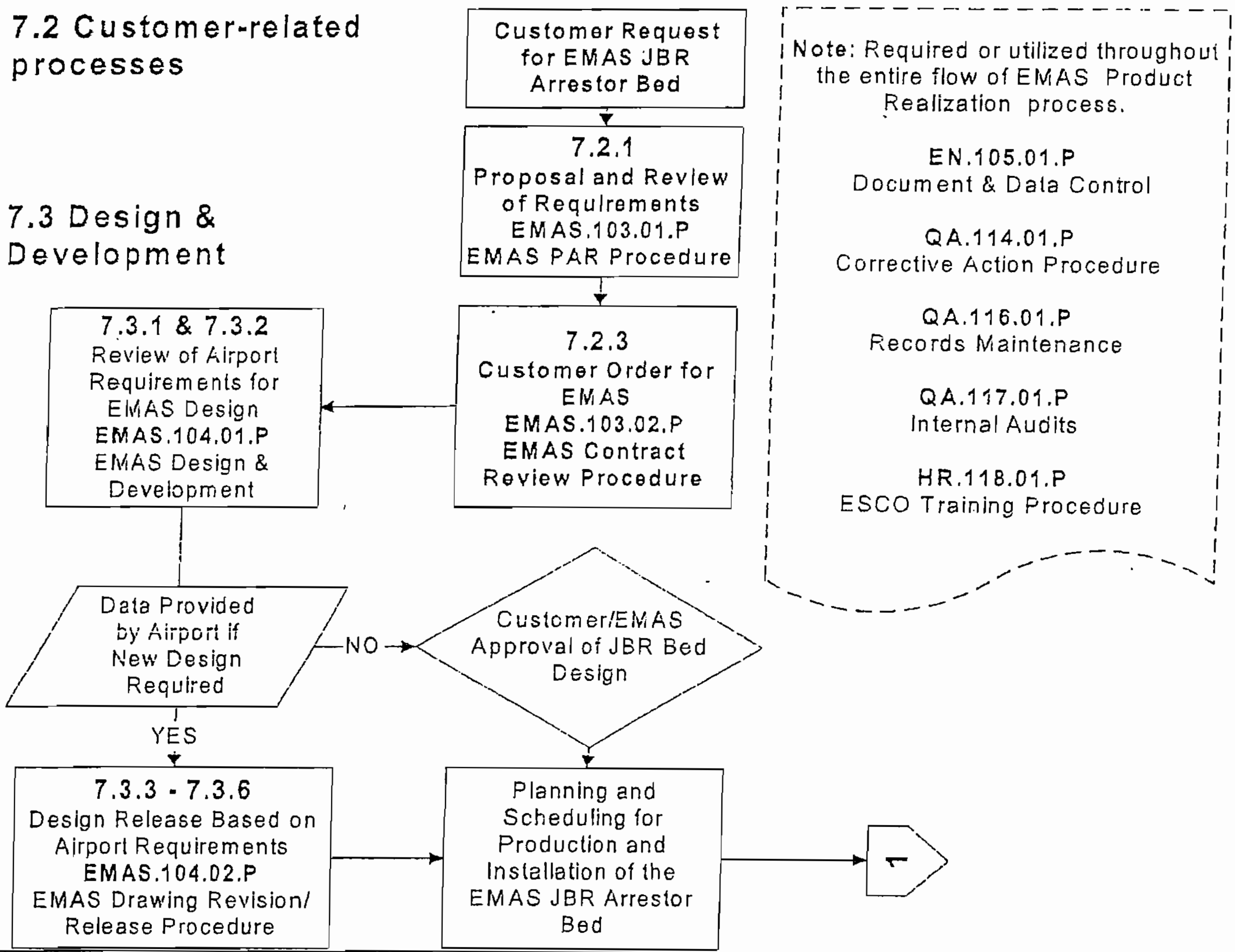
Rick Marinelli

Rick Marinelli, P.E.
Manager, Airport Engineering
Division

Subject:
EMAS PRODUCT REALIZATION FLOWCHART

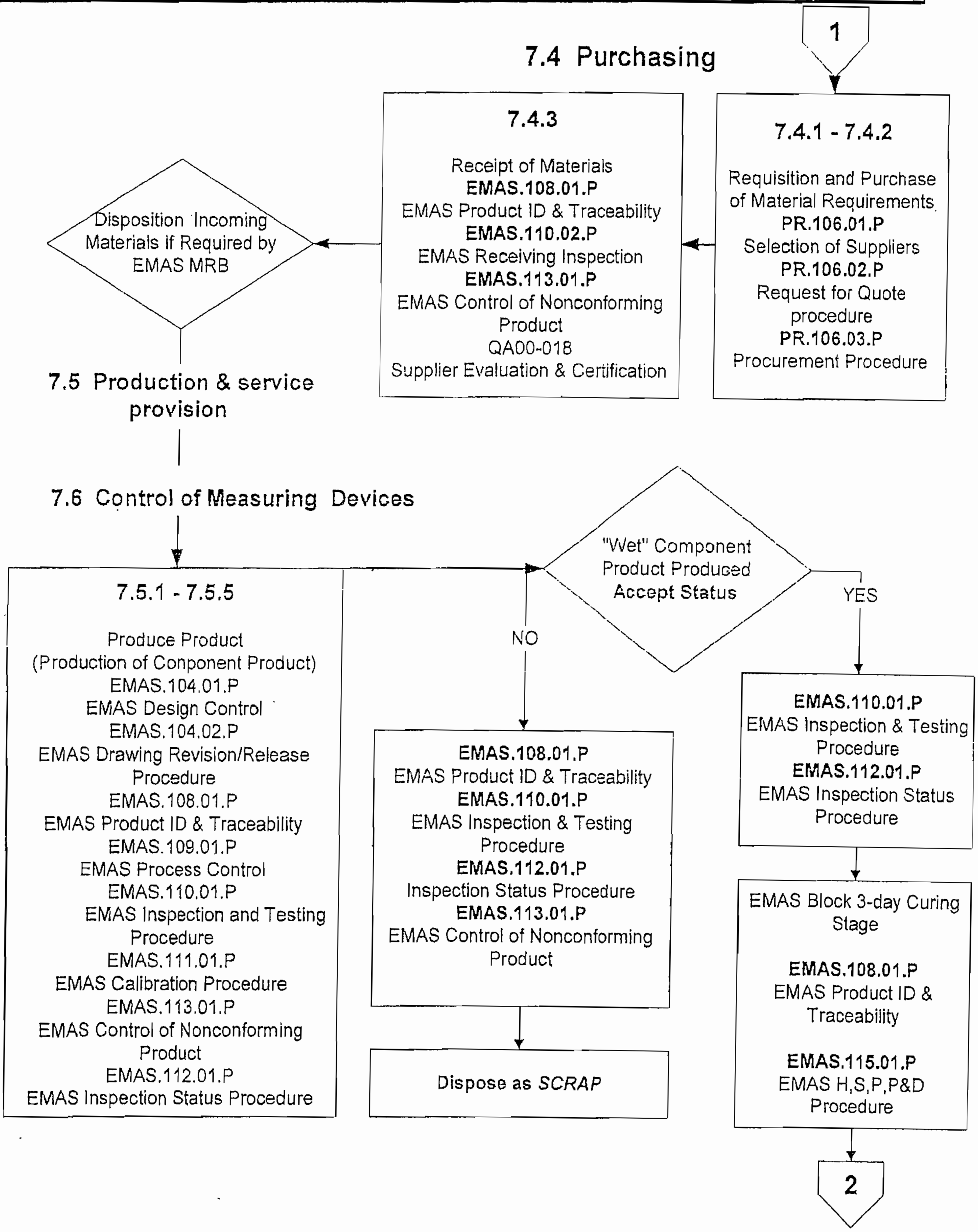
This flowchart demonstrates how a customer order for an EMAS JBR Arrestor Bed is handled from receipt through component product (EMAS JBR blocks) production, shipment, delivery, and installation to realize an EMAS Jet Blast Resistant (JBR) Arrestor Bed (the final product).

EMAS PRODUCT REALIZATION PLAN (Ref. 7.1)

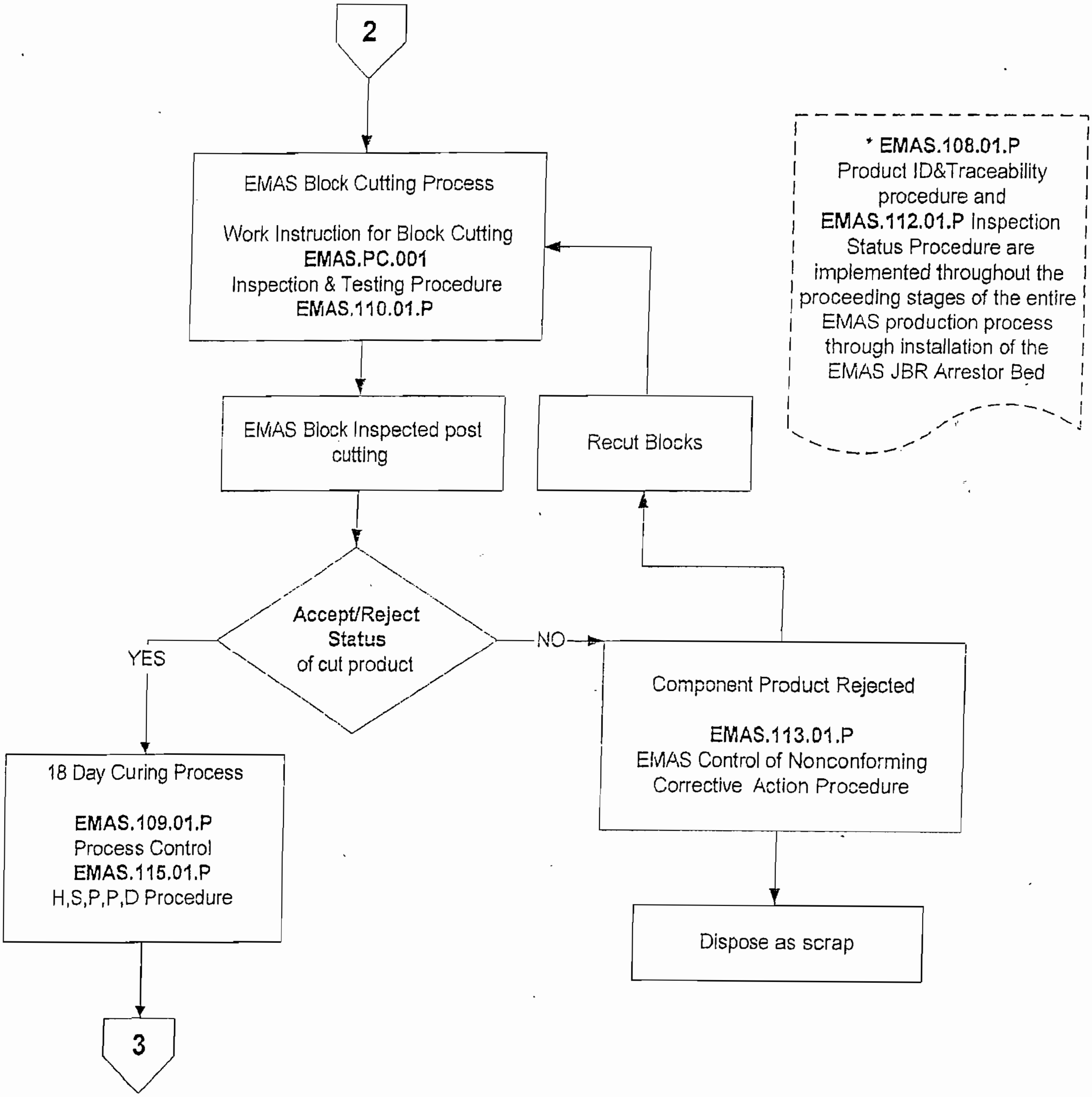


Originator: Geoffrey H. Fowler	Title: EMAS Quality Assurance Manager
Signature:	Date:
Approved by: Geoffrey H. Fowler	Title: EMAS Quality Assurance Manager
Signature:	Date:

Subject:
EMAS PRODUCT REALIZATION FLOWCHART

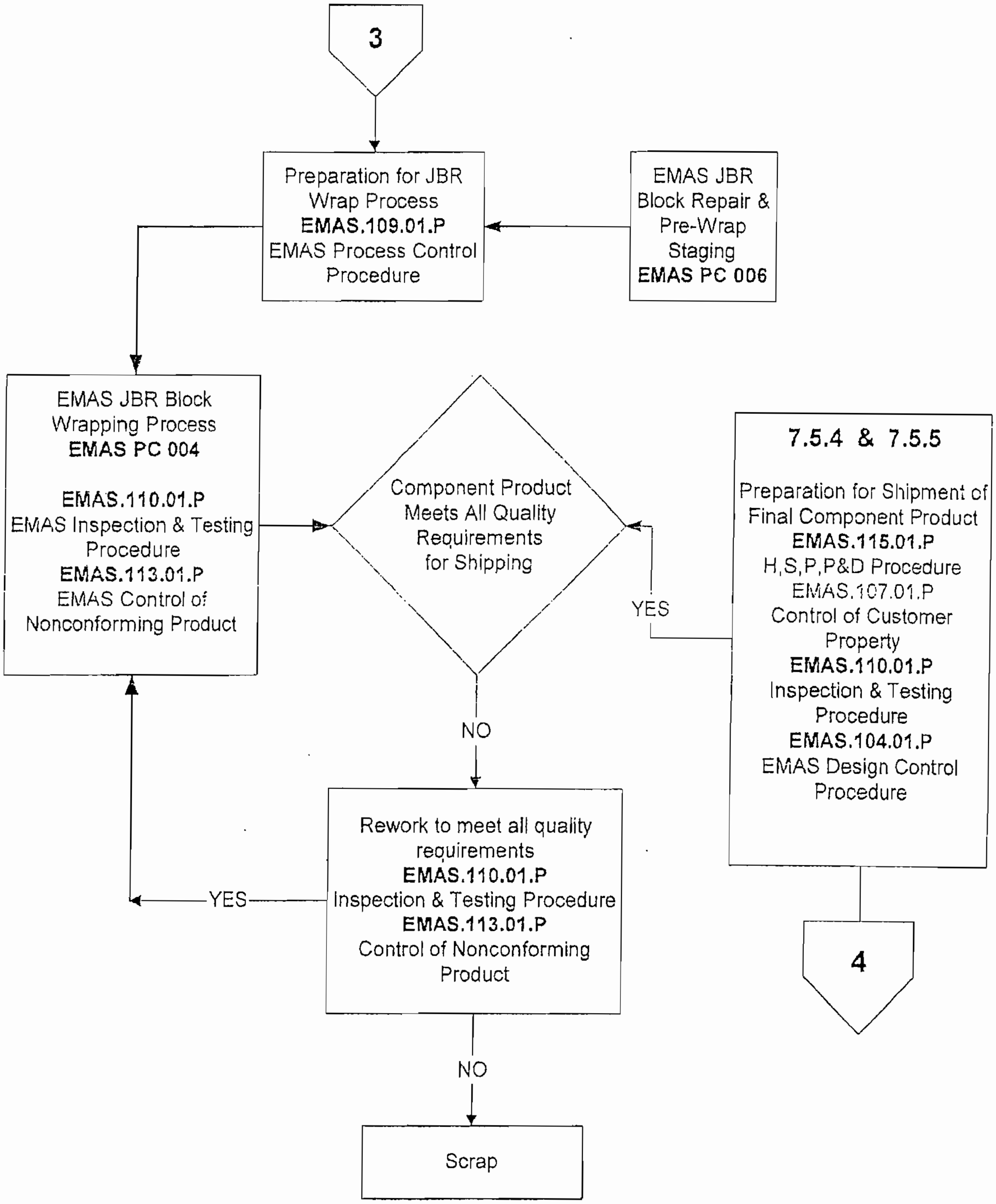


EMAS PRODUCT REALIZATION FLOWCHART



ESCO ENGINEERED ARRESTING SYSTEMS CORP. EMAS Division	*Page No:* 4 of 6	*Procedure No:* EMAS.102.01.FC
	Revision Date: April 27, 2007	*Revision Letter:* K

Subject:
EMAS PRODUCT REALIZATION FLOWCHART



4

Ship Component Product to the Customer for EMAS JBR Arrestor Bed Installation

7.5.1

Installation of the EMAS JBR Arrestor Bed as the Final Product

EMAS FSP XXX
EMAS Field Service Procedures (Installation & Repairs)

EMAS Arrestor Bed Maintenace Manual

EMAS.103.02.P
EMAS Contract Review

EMAS.103.03.P
EMAS Work Authorization Procedure

EMAS.104.01.P
EMAS Design & Development

EMAS.104.02.P
EMAS Drawing Revision/Release Procedure

EMAS.108.01.P
EMAS Product Identification & Traceability

EMAS.110.01.P
EMAS Inspection & Testing Procedure

EMAS.113.01.P
EMAS Control of Nonconforming Product

EMAS Field Service Reports

Customer Satisfaction Surveys (Installation & Repair)
EMAS.103.02.02.FM
EMAS.103.02.03.FM

6.0 REVISION HISTORY

REVISION	REVISION DATE	SUMMARY
A	July 17, 1997	Initial Release
B	September 22, 1997	Corrected spelling error, added scrap box off of nonconforming wet material
C	October 10, 1997	Reformatted footer; added final inspection, accept and nonconforming blocks to flowchart.
D	August 31,1998	Corrected EMAS.114.01.P procedure reference to QA.114.01.P (page 2 of 4)
E	March 13, 2000	Revised header and footer.
F	October 20, 2000	Revised the entire format of the flowchart to include those procedures impacting on product quality as determined by current EMAS processes. This includes the addition of EMAS.104.01.P, EMAS.104.02.P, EMAS.104.03.P, EMAS.103.01.P, EMAS.103.02.P, EMAS.119.01.P, PR.106.01.P, PR.106.02.P, PR.106.03.P, AND PR.106.04.P.
G	December 22, 2000	Added reference to product status indicators where appropriate; revised flowchart explanation and Customer element to reflect the final product produced as the EMAS Arrestor Bed; updated appropriate procedures where required to each element of the flowchart.
H	April 8, 2002	Revised the entire flowchart to reflect the interaction of all EMAS departments in each element of the quality plan; changed the name of the EMAS final product to the EMAS JBR Arrestor Bed in the appropriate elements throughout the flowchart; revised section 5.2 to redefine archive retention.
I	N/A	N/A
J	October 25, 2002	Revised title to better reflect the purpose of the flow chart under the ISO 9000:2000 requirements; Revised installation of the JBR Arrestor Bed to include updated documentation for block inspection criteria, installation, final product acceptance, and customer communication; revised sign-off block to reflect title changes.
K	April 27, 2007	Revised document to better reflect current processes and process flow in the organization.

附錄二-EMAS 系統設計報告書

EMASMAX
Maximizing Runway Safety

DESIGN REPORT
FOR EMAS AT THE
RUNWAY 10 DEPARTURE END
AT
TAIPEI SONGSHAN AIRPORT
IN
TAIPEI, REPUBLIC OF CHINA

FEBRUARY 24, 2010

TABLE OF CONTENTS:

INTRODUCTION / SCOPE OF SERVICE

Taipei Songshan Airport, a major domestic and international air carrier facility with a military presence, is located near the center of Taipei City, Republic of China, and encompasses 182 hectares (500 acres) of land. Of this area, 83 hectares (205 acres) are devoted to civil aviation. The airport serves as the main domestic facility in the country, and is actively expanding its international charter and air carrier components. The airport has two runways: Runways 10/28 are both 2605 meters (8547 feet) long and 60 meters (197 feet) wide. The airport is operated by the Civil Aeronautics Administration (CAA), M.O.T.C. The CAA has proposed installation of an Engineered Material Arresting System (EMAS) arrestor bed as part of a program to improve runway safety. The new bed is proposed at the departure end of Runway 10. The CAA's prime engineer, Calvin Consulting Engineers, is responsible for the overall design of the Runway 10 departure Runway End Safety Area (RESA), with Engineered Arresting Systems Corporation (ESCO) providing consultation and design of the EMAS bed.

The scope of service by ESCO includes:

- Using FAA-approved design methods and information provided by the CAA concerning the mix of aircraft utilizing this runway and other salient variables, ESCO will conduct preliminary modeling to determine the appropriate bed width, length, and other characteristics;

- Discussing the results of the preliminary modeling with the CAA, to learn any concerns the CAA might have about the cost and practical feasibility of installing an EMAS bed consistent with the preliminary modeling results; and

- Taking into account the CAA's comments and constraints, revising the preliminary modeling results to yield a final EMAS bed size and configuration which, if implemented in accordance with ESCO's recommendations, is predicted by FAA-validated methods to be capable of stated arrestment performance.

This report contains the design results from the above steps.

BACKGROUND OF AIRPORT AND EMAS

Zodiac Aerospace's ESCO is the world leader in aircraft arresting systems with over 50 years experience in developing and supplying products to safely decelerate aircraft in overrun emergencies.

ESCO has supplied over 4,000 arresting systems to 67 countries worldwide for protection of military jet fighter aircraft. They have also developed and supplied arresting systems for unique applications such as protection of the space shuttle in the event of a launch abort. ESCO's military systems have accumulated over 125,000 successful arrestments.

In 1994. ESCO joined with the FAA under a Cooperative Research and Development Agreement (CRDA) to bring a similar capability of overrun protection to the commercial aviation community. From 1994 to 1996, the FAA conducted a series of tests with ESCO's Engineered Material Arresting System (EMAS) and, subsequently, approved the system for use at commercial airports throughout the United States.

EMAS consists of a material placed at the end of a runway that will predictably and reliably crush under the weight of an aircraft traveling off the end of the runway. The resistance provided by the crushed material decelerates the aircraft and brings it to a safe stop within the confines of the overrun area.

The first EMAS was a prototype, installed in 1996 at JFK airport on the 22L end of runway 04R, the site of a serious overrun accident of a DC-10 passenger aircraft in 1984 in which the aircraft exited the runway, traversed the available overrun area and came to a stop in the tidal waters of Thurston Basin. On May 8, 1999 a similar overrun occurred but this time the EMAS was in place to safely stop the Saab 340 commuter aircraft before it reached Thurston Basin. The EMAS was also required on May 30, 2003 to safely stop an MD-11 cargo plane that overran runway 22L. On January 22, 2005, a B747 cargo plane was safely stopped by EMAS after overrunning runway 22L at JFK. In July, 2006 a Dassault Falconjet was safely stopped by an EMAS at Greenville Downtown Airport in South Carolina. In July, 2008, a Mexicana Airlines A-320 was safely stopped by an EMAS at O'Hare International Airport in Chicago, Illinois. Most recently, on January 19, 2010, a CRJ-200 that had aborted takeoff was safely stopped by an EMAS at Yeager Airport in Charleston, West Virginia.

EMAS is now part of US airport design standards and is described in FAA Advisory Circular 150/5220-22A "Engineered Material Arresting Systems for Aircraft Overruns" dated 9/30/05. EMAS and Runway Safety Area planning are also guided by FAA Orders 5200.8 and 5200.9. The Advisory Circular and Orders are discussed in further detail in the following paragraphs.

ADVISORY CIRCULAR AC150/5220-22A

FAA Advisory Circular AC150/5220-22A contains the standards for design and installation of an Engineered Material Arresting System (EMAS) in non-standard runway safety areas. It provides the guidelines that an EMAS manufacturer must follow in order to design and produce an FAA-acceptable aircraft arresting system for air carrier aircraft. At the time of its latest revision, an air carrier aircraft was still defined as an aircraft flying scheduled service with 30 or more passengers and weighing typically over 25,000 lbs.

The EMAS as manufactured by ESCO meets all the specified requirements in AC150/5220-22A. These include:

- Use of an FAA validated design method.
- Predicted stopping capability of 70 knots of runway exit speed for design aircraft, or the maximum speed reduction possible within the available safety area, based on FAA-approved predictive modeling.
- Designed to accept ARFF equipment movement and to provide an easy means of ingress and egress in emergency situations.
- Designed for repair-ability within 45 days.
- Use of materials of uniform deformation characteristics to ensure predictable and reliable performance.
- Incorporates an FAA approved material sampling and testing program.

The Advisory Circular requires that the EMAS be designed for 70-knot performance to the "maximum extent possible within the available safety area." The design objective is to get all Category C and higher aircraft to at least 70 knot computer-predicted performance as studies have shown that over 90% of overruns have occurred at runway exit speeds of 70 knots or less. (It is not uncommon, however, for EMAS systems to be designed for less than 70 knots runway exit speed stopping capability, if an individual airport's space constraints will not permit meeting the 70-knot performance.) Design considerations must also be taken to limit major structural damage to the aircraft as well as minimizing injuries to the occupants.

The Advisory Circular also states "The design aircraft is defined as that aircraft using the associated runway that imposes the greatest demand upon the EMAS. To the extent practicable, however, the EMAS design should consider the range of aircraft expected to operate on the runway."

The Runway Safety Area (RSA) Program was established by FAA under FAA Order 5200.8 with the objective that RSAs at all Part 139 airports should conform to the standards contained in the airport design Advisory Circular. Following the national inventorying of RSAs in 2000, "determinations" were made for each runway end RSA. Each RSA was judged to have one of the following four determinations:

1. Meets standards.
2. Does not meet standards but it is practicable to make it meet standard.
3. Does not meet standards, can be improved but will still not meet standard.
4. Does not meet standards and it is not practicable to improve the RSA.

These determinations are subject to revision when new information becomes available. Stand-alone RSA improvement projects can be initiated at any time, but runway construction, expansion or reconstruction work requires that "the project shall also provide for improving the RSA in accordance with the determination".

Had the Runway 10 departure end Runway End Safety Area (RESA) been reviewed under FAA Order 5200.8, it would have been judged to meet the second determination criteria listed above. The goal of these EMAS installations is to fully meet the standard of stopping all Category C and higher aircraft from 70 knots (with a minimum predicted performance of 40 knots.) The guidance also allowed the use of a full performance EMAS to "justify decreasing the dimensions of existing RSA's in connection with runway extension projects".

In a concurrent and parallel effort, the ICAO asked member countries to investigate and report on their Runway End Safety Areas in late 2004. The RESA geometric standards found in Annex 14 of "The International Standards and Recommended Practices for Aerodromes" are derived from and are very similar to the United States standards. Clearly, there is a worldwide concern about safety space at the end of runways. While the CAA is not bound to follow either organization, this project represents the prudent application of aircraft arresting technology, which is sized in the context of guidance from other outside entities.

Recently, the policy guidance has been interpreted to include all types of civil aircraft that weigh over 12,500 pounds and have more than 500 operations per year. This means that air cargo, air charter and even heavy corporate aircraft are now potentially included in every airport-specific fleet mix that establishes the design aircraft which drives the computation of the EMAS bed length.

In addition to complying with the above AC requirements, the EMAS system is sized and sited to minimize or avoid conflict with other components such as approach lights and NAVAIDS, while not interfering with Part 77 surfaces and complying with other airport design standards, such as the AC 150/5300-13 Airport Design Manual. While most of the EMAS design effort focuses on EMAS length, it is important to note that bed width also varies site-to-site. As a minimum, beds must be full depth for the published width of the runway. Because the EMAS blocks are roughly 4 foot by 4 foot cast blocks of varying heights that must be fully supported across their entire base, the presence or absence of an extended centerline crown affects the number of blocks in a row. Additionally, rows of side steps are included in every design to provide a normal eight inch riser (with four foot tread) configuration for passenger egress and ARFF vehicle access.

PRODUCT PERFORMANCE ASSESSMENT & MODELING PROCESS

ESCO utilizes an FAA-validated design method to predict the performance of the EMAS. The basis of our design method is our computer simulation program, which is the only FAA-accepted model available. It involves complex computer analysis of over 100 variables for each operating aircraft. In conducting its modeling, ESCO relies heavily upon the airport client to provide accurate and complete information concerning the range of aircraft that must be considered and the aircraft's characteristics, and also makes reasonable efforts to obtain additional information about relevant aircraft characteristics directly from the manufacturers. However, when less than complete information concerning relevant aircraft characteristics is made available, ESCO may, after discussion with the client airport, eliminate specific aircraft from the analysis or use available data for comparable aircraft for purposes of its modeling.

The EMAS bed configuration is determined only after going through multiple iterations of this computer modeling. EMAS performance, as predicted by FAA-validated methods, is assessed to determine the best product configuration for the client airport's reported mix of aircraft in use.

In general, the main objective of the performance modeling is to obtain the maximum EMAS performance achievable within the limits of the landing gear size/strength of each aircraft and the available length of safety area. Of most importance would be the nose landing gear limitation of each aircraft. These two limitations dictate the maximum performance attainable.

For all EMAS designs, two distinct scenarios are modeled. The "standard", or design case assumes poor braking and no reverse thrust with a 0.25 braking friction coefficient. A second and more typical scenario assumes full braking and full reverse thrust on wet pavement with a 0.35 braking friction coefficient. The results from the most conservative "design case" are used to determine recommended EMAS bed length. However, it is useful to see performances under both cases for certain aircraft types.

In ESCO's planning and design efforts, we also consider which EMAS block material strengths are likely to provide better performance. In general, EMAS beds constructed of the lower strength ("60") EMAS blocks tend to provide better predicted overall performance for the smaller commercial aviation fleet, and EMAS beds using the higher strength ("80") blocks result in better predicted overall performance for larger air carrier aircraft. Recently, FAA has approved the utilization of a new 50-strength block in EMAS system design considerations. These ("50") blocks provide modeling accuracy to aircraft weighing less than 25,000 lbs. that is similar to that for the 60 and 80 strength for larger aircraft. This range is limited to approximately 12,500 lbs. minimum weight. Because of the size of the aircraft in the fleet mix, it became apparent in preliminary modeling that the 60-strength blocks were best-suited for Songshan.

Another critical variable dictating EMAS performance is the weight of the aircraft. In looking at a specific aircraft model, its weight and center of gravity may vary quite a bit depending on how the aircraft is loaded, flown and balanced. It is not possible to model all of these different scenarios. At the time of final design, we will look at both Maximum Take-Off Weight (MTOW) and 80% of Maximum Landing Weight (80%MLW). Because aircraft performance may not necessarily follow a general expectation that heavier aircraft are harder to stop, both weights are used for modeling purposes. The weight figures representing 80% of Maximum Landing Weight are informative and are a factor in EMAS bed length discussions when there is this much RSA available and the fleet includes smaller aircraft. Current policy guidance favors the use of site-adjusted MTOW (maximum take-off weight) for modeling efforts. Site adjustment is simply the reduction of absolute maximum Take-Off Weights for an unlimited runway length at sea level to the specifics of this site (Elevation of 18 meters - 59 feet and runway length of 2605 meters - 8547 feet).

The Advisory Circular also requires "to the extent practicable, the EMAS shall be designed for the range of aircraft expected to use the runway." From information provided by the CAA, the projected primary aircraft using Runway 10/28 are the B757-200, A330-200F, B737-800, A320/321, MD-90, MD-82, FK-100, ATR72-500 and DHC-8-200, with occasional usage by the B777-200 and B747-400F (less than 500 operations annually). In summary, a focused study was undertaken to determine the EMAS stopping capability for the 7 Category C aircraft (plus the DHC-8-200 and ATR72-500) within the available runway safety area, with performance for the B777-200 and B747-400F predicted for informational purposes but not used to develop the final EMAS design. To determine the stopping distances for this EMAS installation, ESCO used multiple iterations of a computerized performance modeling capability that has been validated by FAA following actual aircraft testing. The design modeling results for poor braking and no reverse thrust are charted.

Under FAA's policy, the standard safety area lengths range from 240 to 1,000 feet long, which has been determined to be sufficient to stop most aircraft exiting a runway at 70 knots or less. For the Category C and higher aircraft served by this runway, this RSA should be 1,000 feet long. In order to reflect this guideline and this site in our modeling, ESCO has developed a braking friction coefficient based on this 70-knot performance for 1,000 feet. It is the 0.25 braking friction coefficient that we now use in our design case, whereas the 0.35 braking friction coefficient used in the typical case is an industry standard representative of aircraft stopping performance on wet pavement with full brakes and reverse thrust or pitch.

TSA RUNWAY 10 DEPARTURE END SITE SPECIFICS

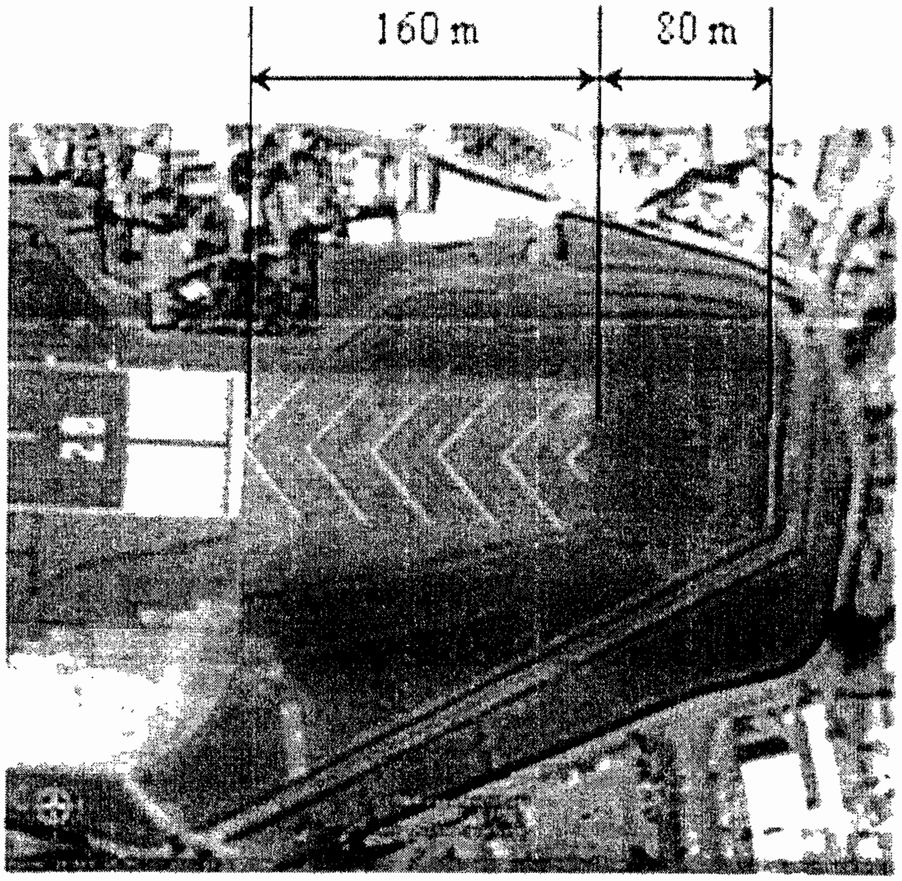
- Runway Length: 2605 m (8547 ft)
- Runway Width: 60 m (197 ft)

Elevation: 18 ft AMSL

- Slope: RESA -0.14% for 120 m (364 ft), then -0.566% (existing w/ minor re-grading)
- Aircraft Mix: for design: A330-200F, B757-200, A320/321, B737-800, MD-90, MD-82, FK-100, ATR72-500, DHC-8-200 for info only: B777-200, B747-400F
- Obstructions: Drainage swales (to be removed/replaced with underground pipe), dual commercial/military localizers at rear of Runway End Safety Area – 241 m (790 ft)

TSA RUNWAY 10 DEPARTURE END AERIAL VIEW

(SITE OF PROPOSED EMAS BED)



PREDICTED RESULTS

Results from our computer modeling are presented below.

RESULTS FOR RUNWAY 10 DEPARTURE END

EMAS Design for Taipei Songshan Airport RW10 Dep End WINEMAS 2000 V3.0
(RW length 8547', Elevation 13.4' MSL) 2/18/2010

60-strength 765.00' EMAS with 364.08' setback + 400.92' arrestor starts at 6" high, goes to 20" with 113.37' ramp, then starts the second 24.30' ramp at 586.80' away from RW end up to 26"
Centerline Profile: RW -0.14% and RSA -0.14% for 364.00' and then -0.566% to the end

EMAS Performance Simulation Results on Exit Speed (kt)

Aircraft	MTOW (lb)	MTOW (kg)	Design Case	Notes
DHC-8-200	36,500	16,560	>70	Using Dash 8-300
ATR72-500	49,000	22,230	>70	Estimated using Dash 8
FK-100	101,000	45,810	>70	Estimated using DC 9
MD-82	149,000	67,590	>75	
MD-90	168,000	76,204	>75	Using MD-82
A320/321	162,000	73,480	>70	Estimated w/ B737-400
B737-800	175,000	79,380	>75	Using B737-400
B757-200	255,000	115,670	>75	
A330-200F	460,000	208,660	70	Estimated using B767
B777-200	*765,000*	*347,000*	*65*	*Estimated AC data*
B747-400F	*875,000*	*396,900*	*66*	

EMAS Performance Simulation Results on Exit Speed (kt)

Aircraft	80% MLW (lb)	80% MLW (kg)	Design Case	Notes
DHC-8-200	25,400	11,520	>70	Using Dash 8-300
ATR72-500	38,530	17,480	>70	Estimated using Dash 8
FK-100	73,460	33,320	>70	Estimated using DC 9
MD-82	104,000	47,170	>75	
MD-90	113,600	51,530	>75	Using MD-82
A320/321	113,760	51,600	>70	Estimated w/ B737-400
B737-800	117,040	53,090	>75	Using B737-400
B757-200	168,000	76,200	>75	
A330-200F	306,000	138,800	>70	Estimated using B767
B777-200	*368,000*	*166,920*	*>70*	*Estimated AC data*
B747-400F	*524,000*	*237,690*	*>75*	

Notes:
Design Case: using poor braking (.25 braking friction coefficient) and no reverse thrust
Typical Case: full brakes, wet pavement (.35 braking friction coefficient) and full reverse thrust
() reduced performance for NLG safety
* NLG load exceeds limits
x: no R/T data available

The design above represents a 400.92 foot (122.23 m) EMAS bed set back 364.08 feet (111.00 m) from end of runway for a system length of 765.00 feet (233.23 m). From the back of the proposed EMAS bed, there would be a clear space of about 24 feet (7.32 m) to the localizer. The design above shows a 99 row bed which would result in predicted stopping performance of 70 knots for the A330-200F at MTOW, and greater than 70 knots predicted performance for all other fleet mix aircraft at MTOW and 80% MLW. Note the shading and italics used to report predicted results for the B777-200 and B747-400F. These data are provided for informational purposes only, since neither aircraft is a frequent user of the Airport.

For this proposed design, a recommended layout plan and illustrative performance charts have been produced and incorporated into attachments A & B of this design report. The purpose of this report is to document the modeling and design efforts which were undertaken to support the proposed EMAS bed for Taipei Songshan Airport.

EMAS PROFILE, LENGTH AND WIDTH

Design of the EMAS support pavement is the responsibility of Calvin Consulting Engineers, but is conducted concurrently with modeling efforts. For maximum EMAS block longevity, ESCO recommends and FAA has supported the use of moisture mitigation measures within the pavement design, including the use of underdrains where appropriate, a geotextile fabric under the pavement base, heavy prime coats and heavy tack coats. Together, Calvin Consulting Engineers and ESCO have also assessed several longitudinal slope options for the site with the goal of minimizing the construction cost and matching the elevations of the runway end. For the existing site constraints at the departure end, performance was confirmed with setting the design centerline at the specified grade from the end of the runway to the back of the EMAS anchor beam, dropping 3 inches (7.62 mm) and then maintaining the specified grade to the back of the RSA. Due to the precise EMAS block measurements, the specific dimensions of the proposed RW 10 departure end bed are 400.92 feet (122.23 m) long by 226.80 feet (69.15 m) wide.

The typical runway setback used for EMAS is 75 feet (22.87 m) from the end of the runway. Wind tunnel testing of jet blast from air carrier aircraft demonstrates the ability of Jet Blast Resistant (JBR) blocks to withstand 35 foot (10.67 m) setback. The proposed bed's setback distance is 364.08 feet (111.00 m).

The EMAS bed was designed in accordance with the fourteen system design requirements listed in Advisory Circular 150/5220-22A. Civil engineering design of the slopes and grades of the support pavement is conducted concurrently with modeling efforts and mindful of the model's sensitivity to grade breaks at various locations. The use of a centerline ridge with transverse slope grading was accepted, generally matching the existing site slopes to prevent ponding of surface water on the EMAS beds.

Based on performance modeling, the RW 10 departure end EMAS bed would consist of a clear area of grooved asphalt pavement 364.08 feet (111.00 m) long between the end of the runway and the back of the 2.58 foot (0.787 m) wide anchor beam and then into the arrestor bed (99 EMAS block rows long – 400.92 feet (122.23 m)) extending to the back of the safety area (about 24 feet (7.32 m) clear to the localizer).

For the proposed design, the front of the RW 10 departure end EMAS bed would be a row of 6" (0.152 m) nominal blocks treated with a Jet Blast Resistant (JBR) system that makes them about 6-13/16" (0.173 m) high. The block heights would continue to ramp-up until reaching a row of 20" (0.508 m) nominal height blocks in twenty eight rows or 113.37 feet (34.56 m). The arrestor bed would hold this 20" (0.508 m) nominal height from the 29th row to the 56th row*, where a second ramp would begin until reaching a row of 26" (0.660 m) nominal height blocks in 6 rows or 24.30 feet (7.41 m). The arrestor bed would hold this 26" (0.660 m) nominal height from the 62nd row to the 96th row. Then the 97th row would drop to a row of 20" (0.508 m) nominal blocks, the 98th row would drop to a row of 14" (0.356 m) nominal blocks and the bed would end (99th row) with a row of 8" (0.203 m) nominal blocks. The entry ramp is included to minimize the stresses placed upon the landing gear during arrestment. The exit steps, like the side steps on the arrestor bed, are provided for emergency ARFF vehicle access and for passengers to "step-down" after exiting an arrested aircraft. Given the 197 foot (60 m) width of this runway and the maximum nominal block height of 26 inches (0.660 m), the recommended bed width consists of fifty full-height blocks and six side step rows of blocks (three per side) for a net width of 56 blocks.

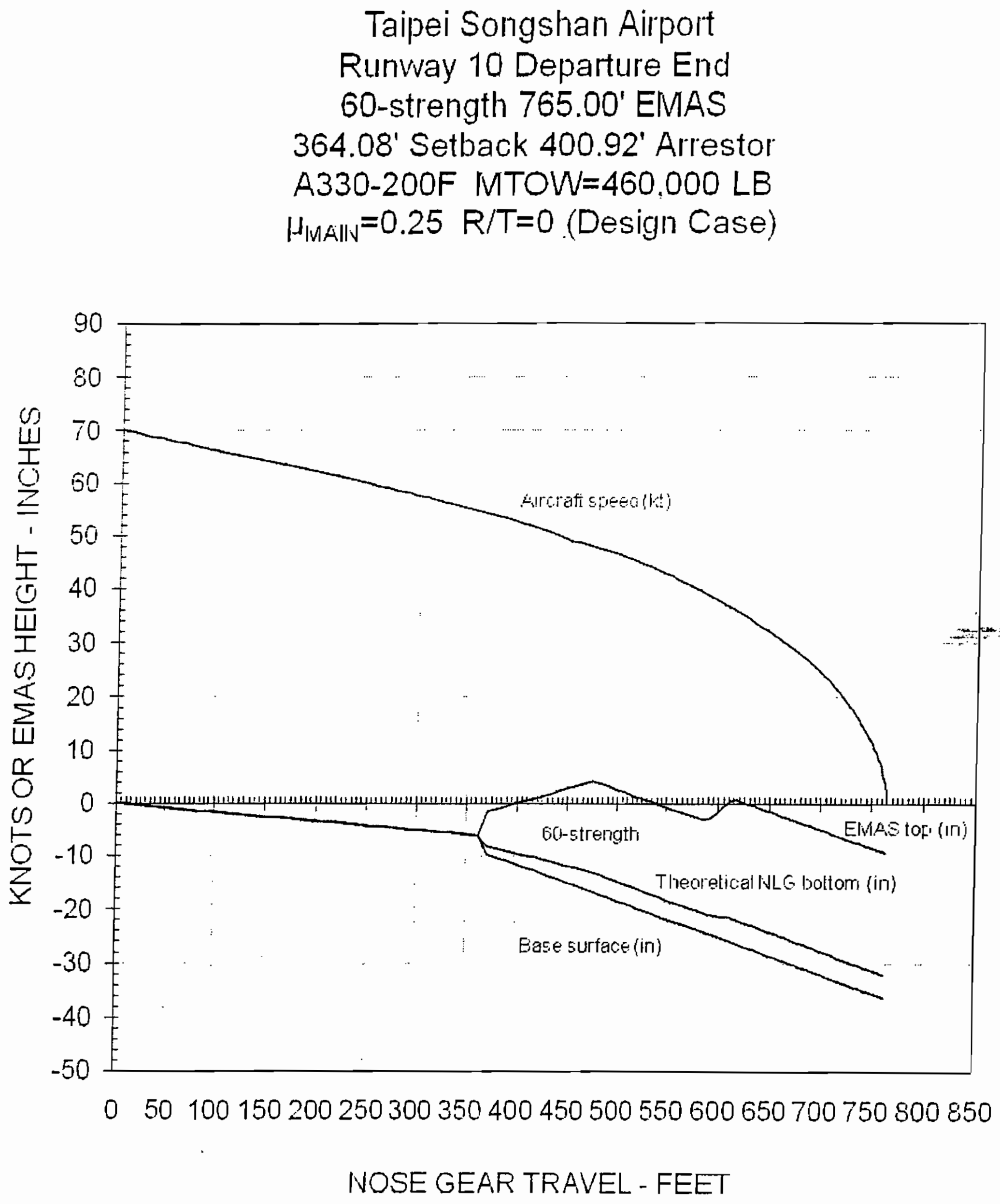
Each and every four foot square EMAS block requires a 4.05 foot (1.235 m) square grid for installation after a snug fit size of 4.02 feet (1.225 m) for the very first row. The proposed EMAS bed for Runway 10 departure end consists of 99 rows and 56 columns for a total of 5,544 blocks.

(*The reason for the "plateau" of 20" blocks is the low-hanging nacelles on the B737. The modeling takes into account this feature by predicting how much of the bed is required to stop the B737. After this point, the 2nd ramp up to 26" blocks can begin.)

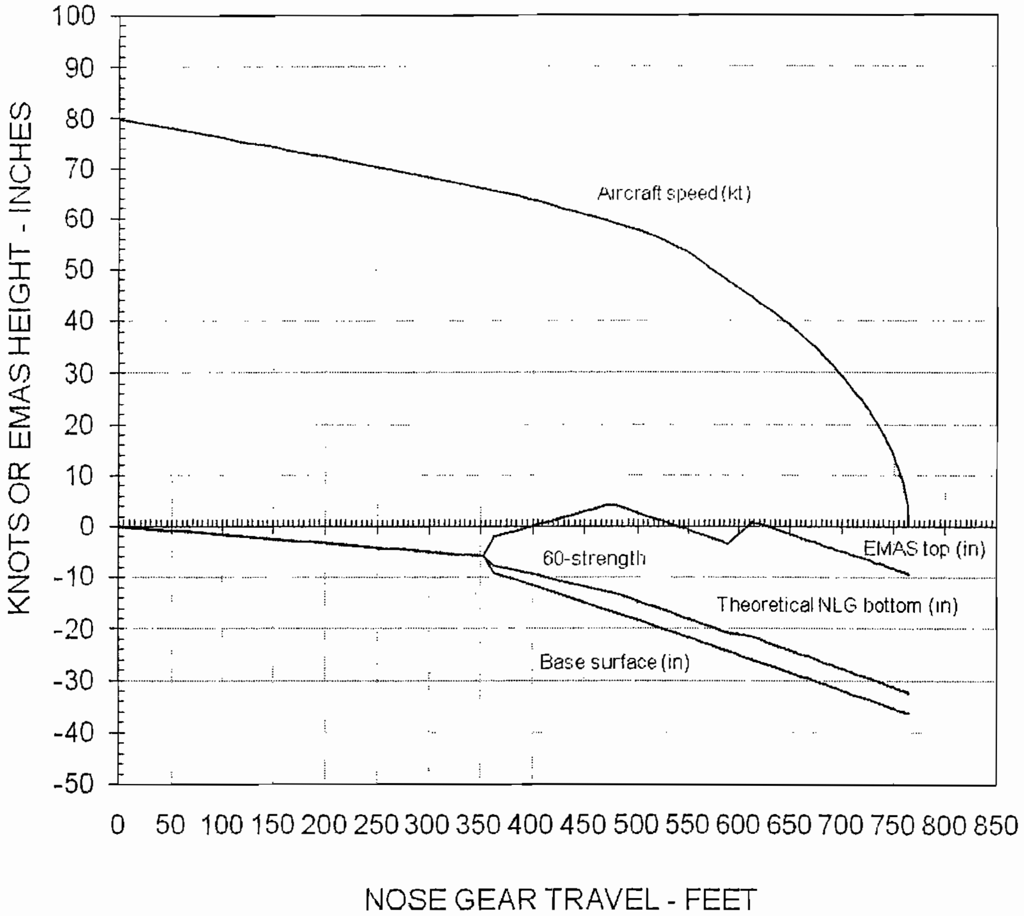
SUMMARY

The EMAS site at the Runway 10 departure end is large enough to support a full performance EMAS with 70 knot predicted stopping power for the critical aircraft operating at the Maximum Take Off Weight and 80% Maximum Landing Weight in accordance with FAA Order 5200.9. The EMAS is designed to meet all of the other requirements found in the United States, such as governing FAA Orders and Advisory Circular and represents a significant EMAS safety contribution for this site. ESCO awaits the review of this EMAS design proposal and stands ready to respond to any questions, comments or further adjustments needed to implement the full site design for this project.

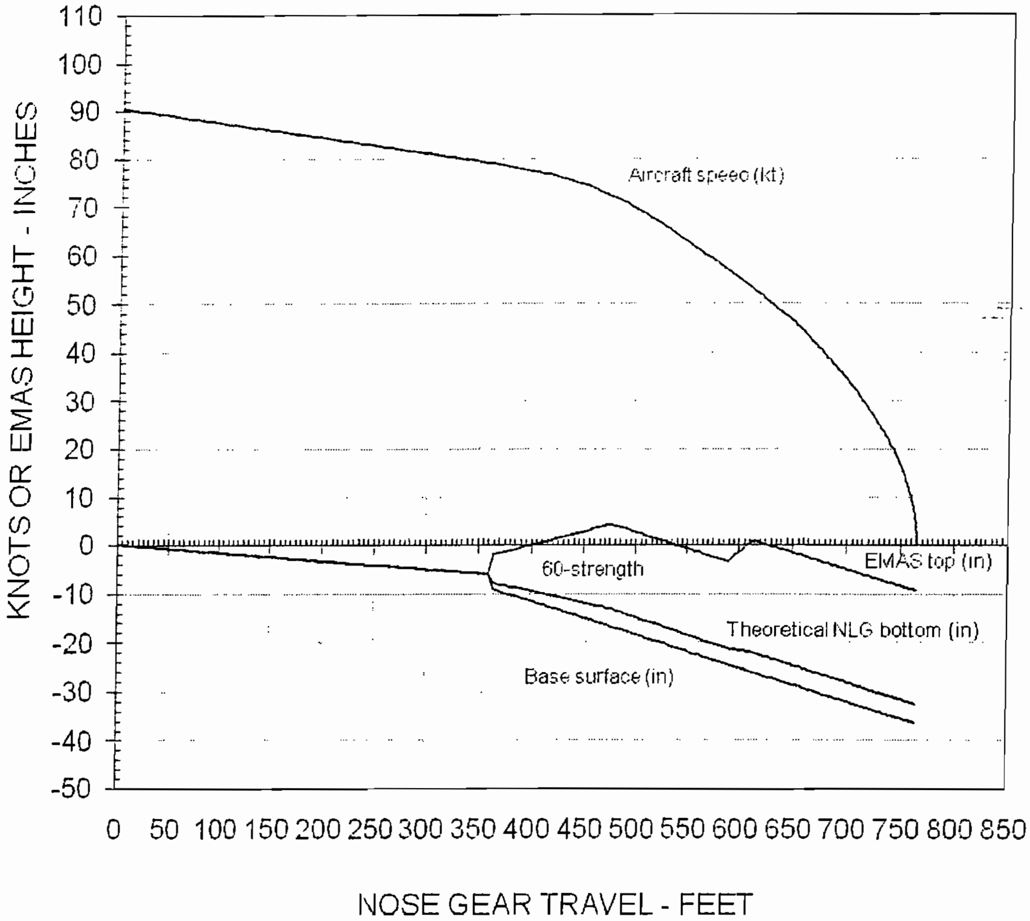
ATTACHMENT A: Performance Curves


Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
A330-200F MTOW=460,000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)
KNOTS OR EMAS HEIGHT - INCHES
Aircraft speed (kt)
60-strength
EMAS top (in)
Theoretical NLG bottom (in)
Base surface (in)
NOSE GEAR TRAVEL - FEET

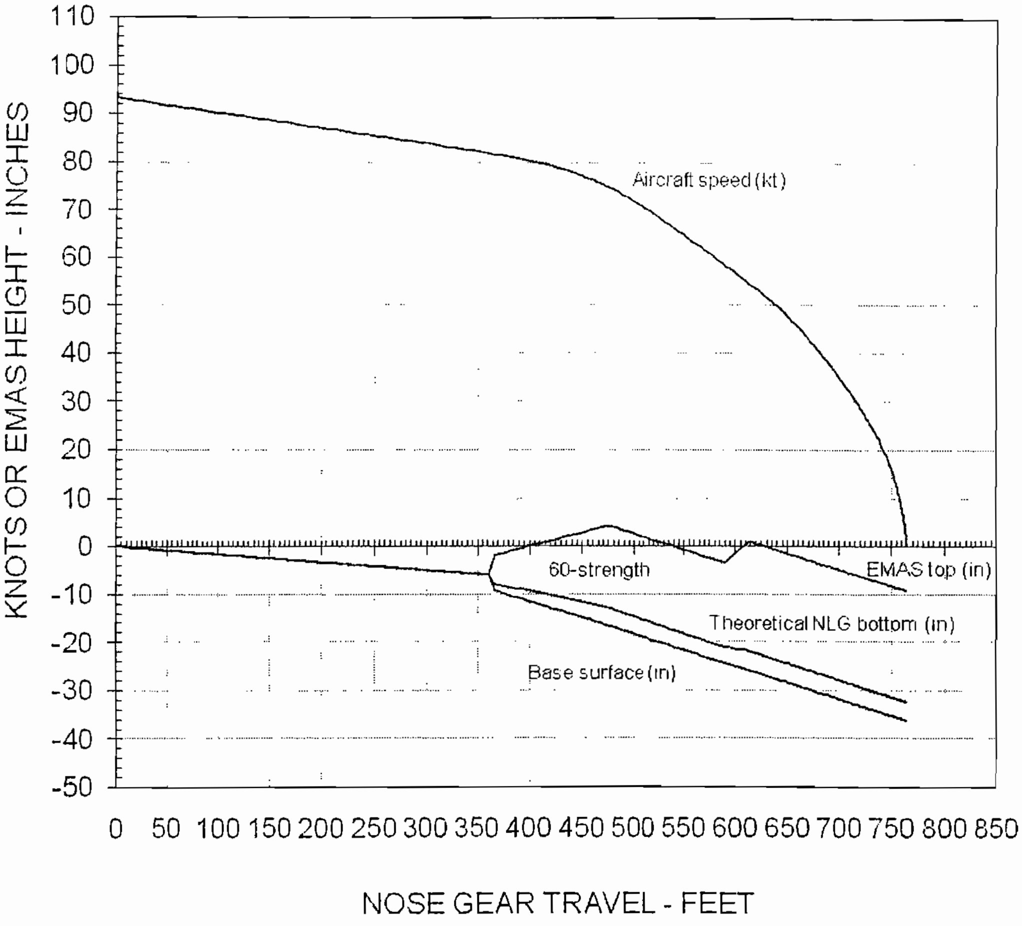
Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
B757-200 MTOW=255.000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)



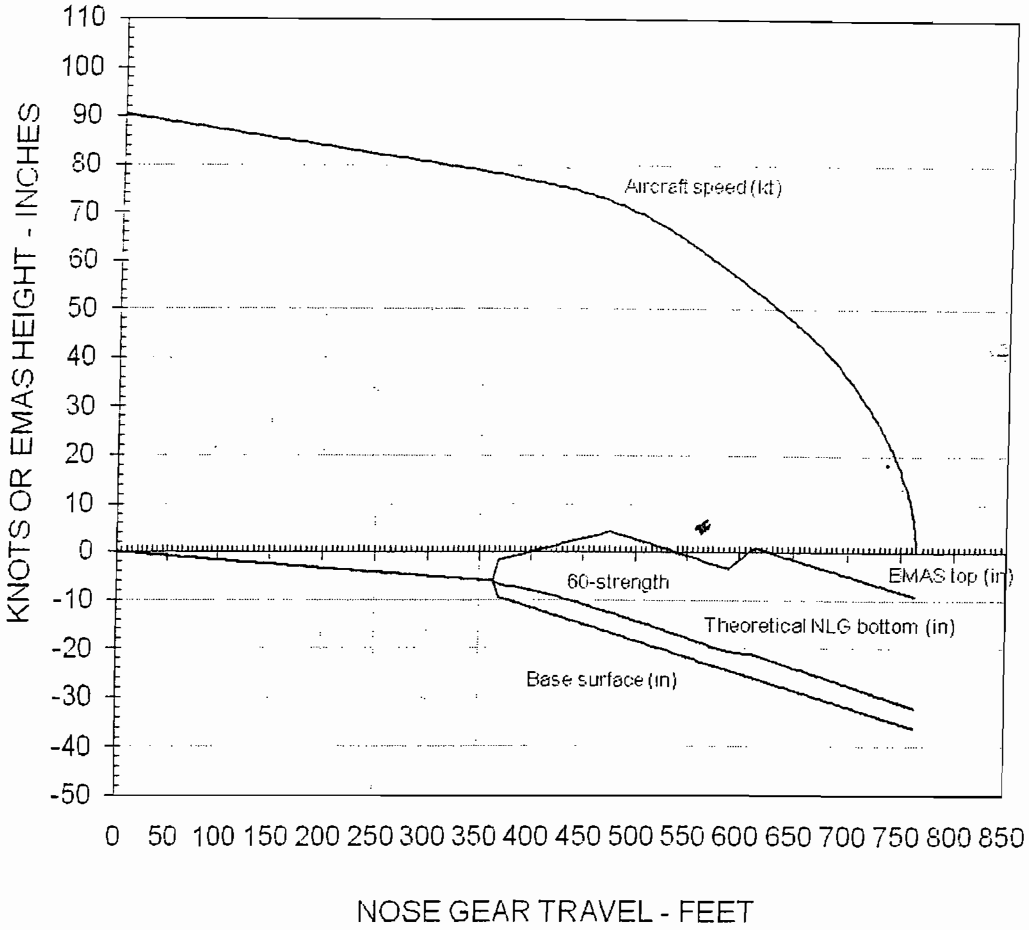
Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
B737-800 MTOW=175.000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)

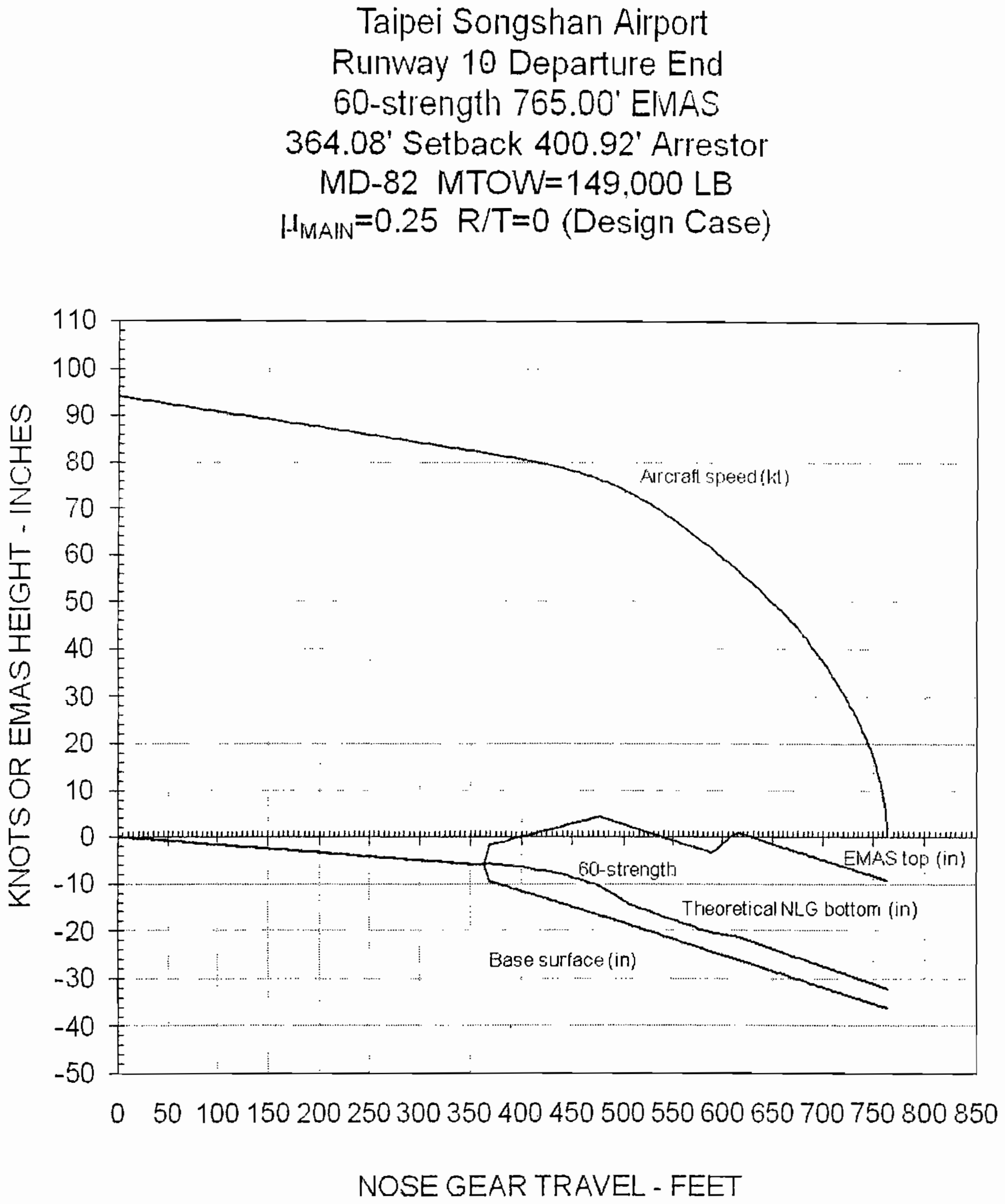


Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
A320/321 MTOW=162,000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)

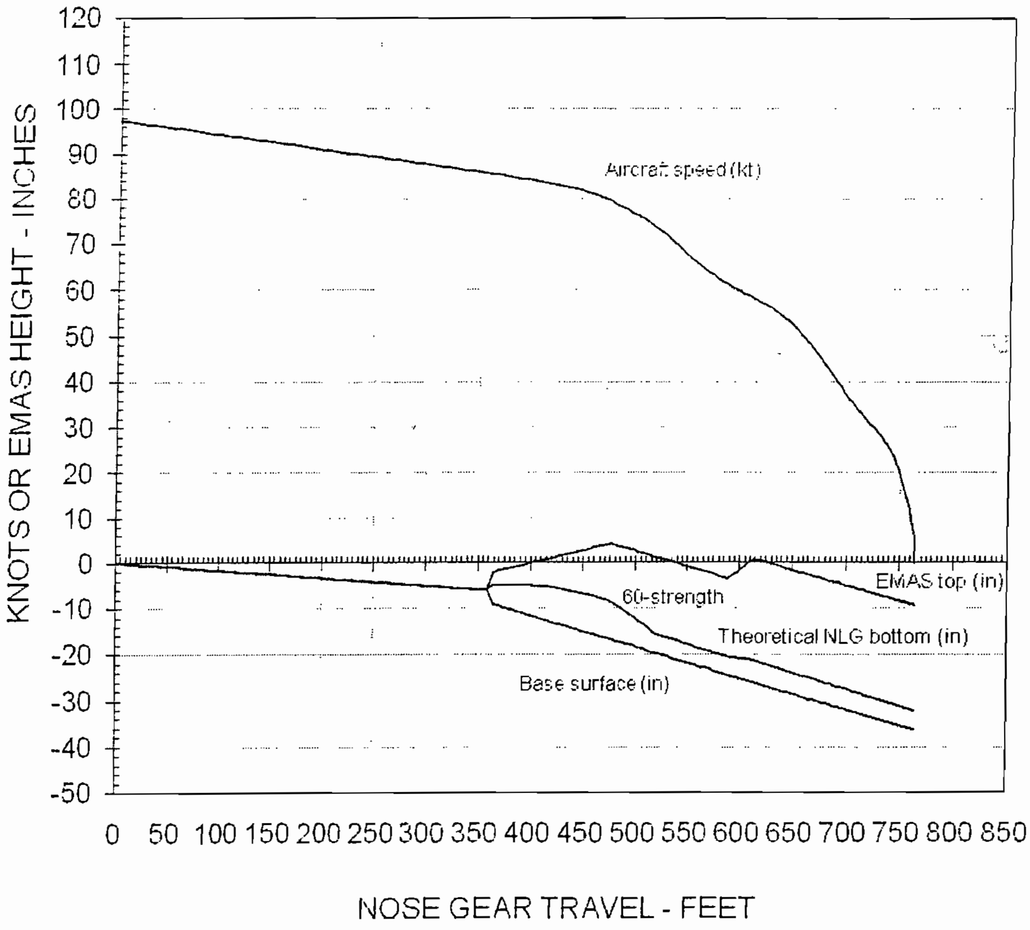


Taipei Songshan Airport
Runway 10 Departure End
50-strength 340.00' EMAS
364.08' Setback 400.92' Arrestor
MD-90 MTOW=168,000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)

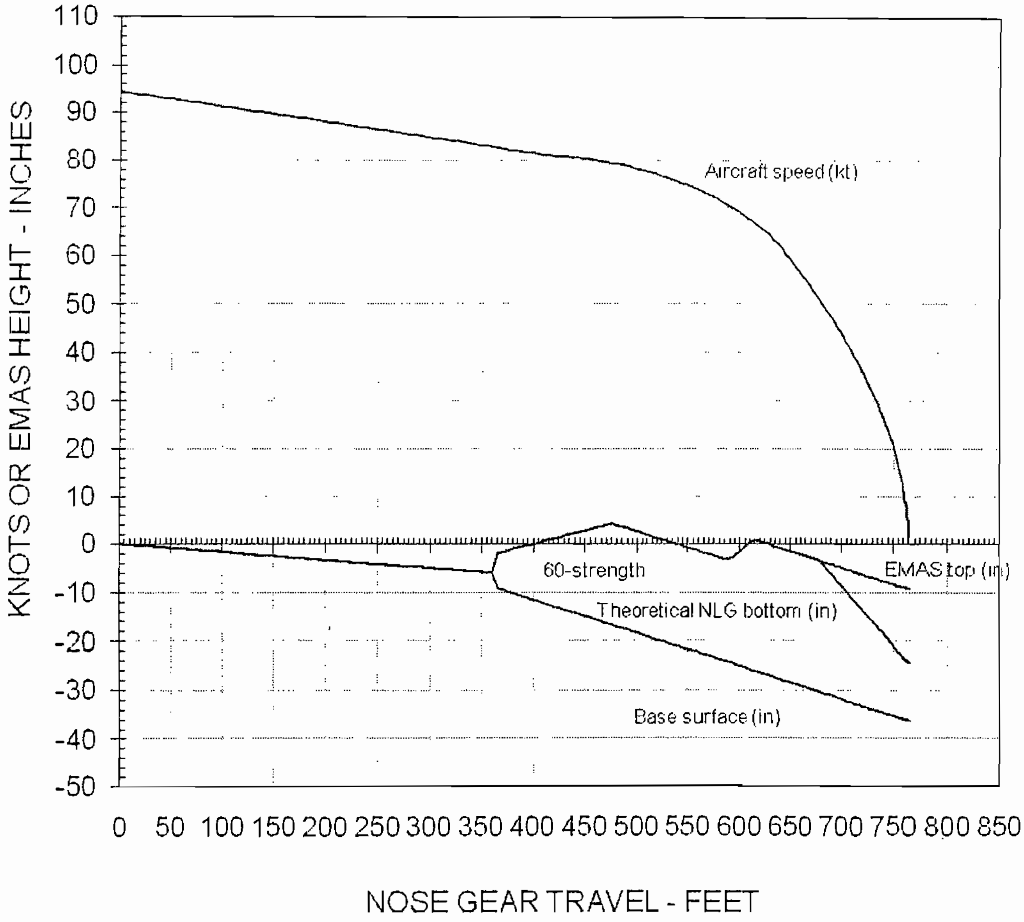



Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
MD-82 MTOW=149,000 LB
μMAIN=0.25 R/T=0 (Design Case)
KNOTS OR EMAS HEIGHT - INCHES
NOSE GEAR TRAVEL - FEET
Aircraft speed (kt)
60-strength
EMAS top (in)
Theoretical NLG bottom (in)
Base surface (in)
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850

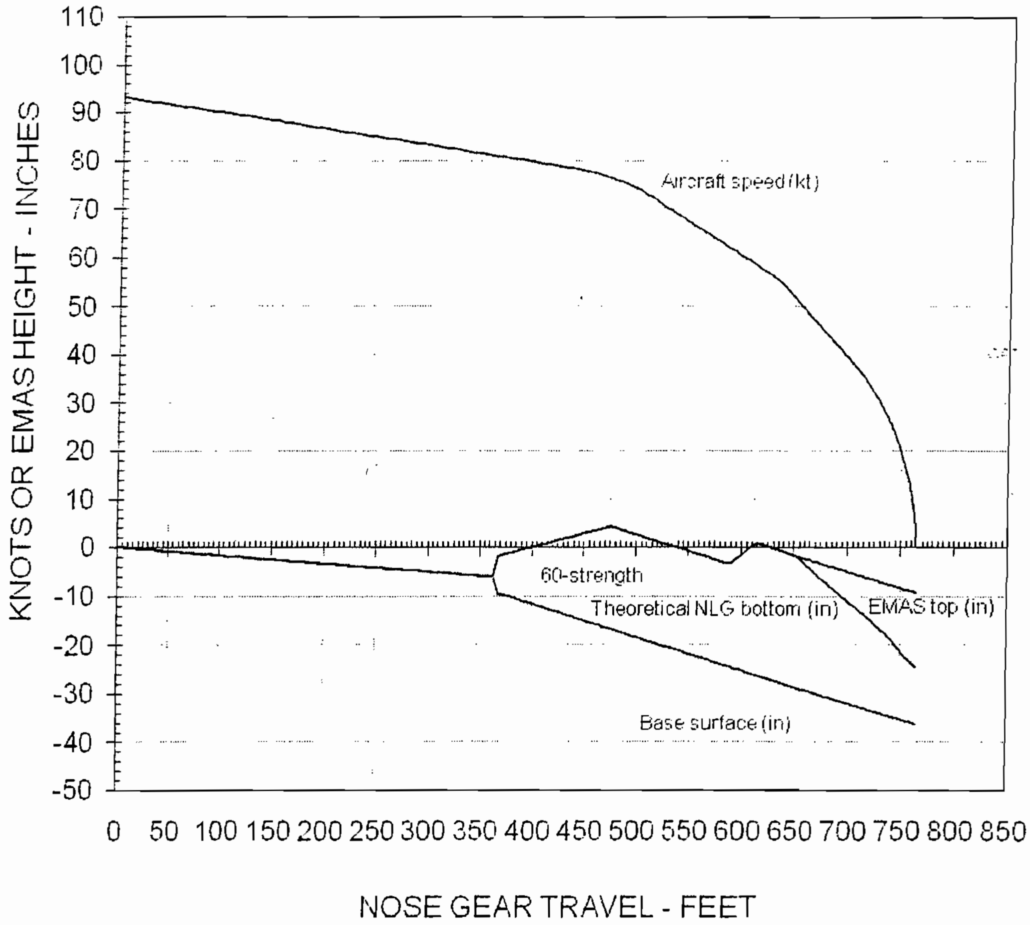
Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
FK-100 MTOW=101,000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)



Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
ATR72-500 MTOW=49,000 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)

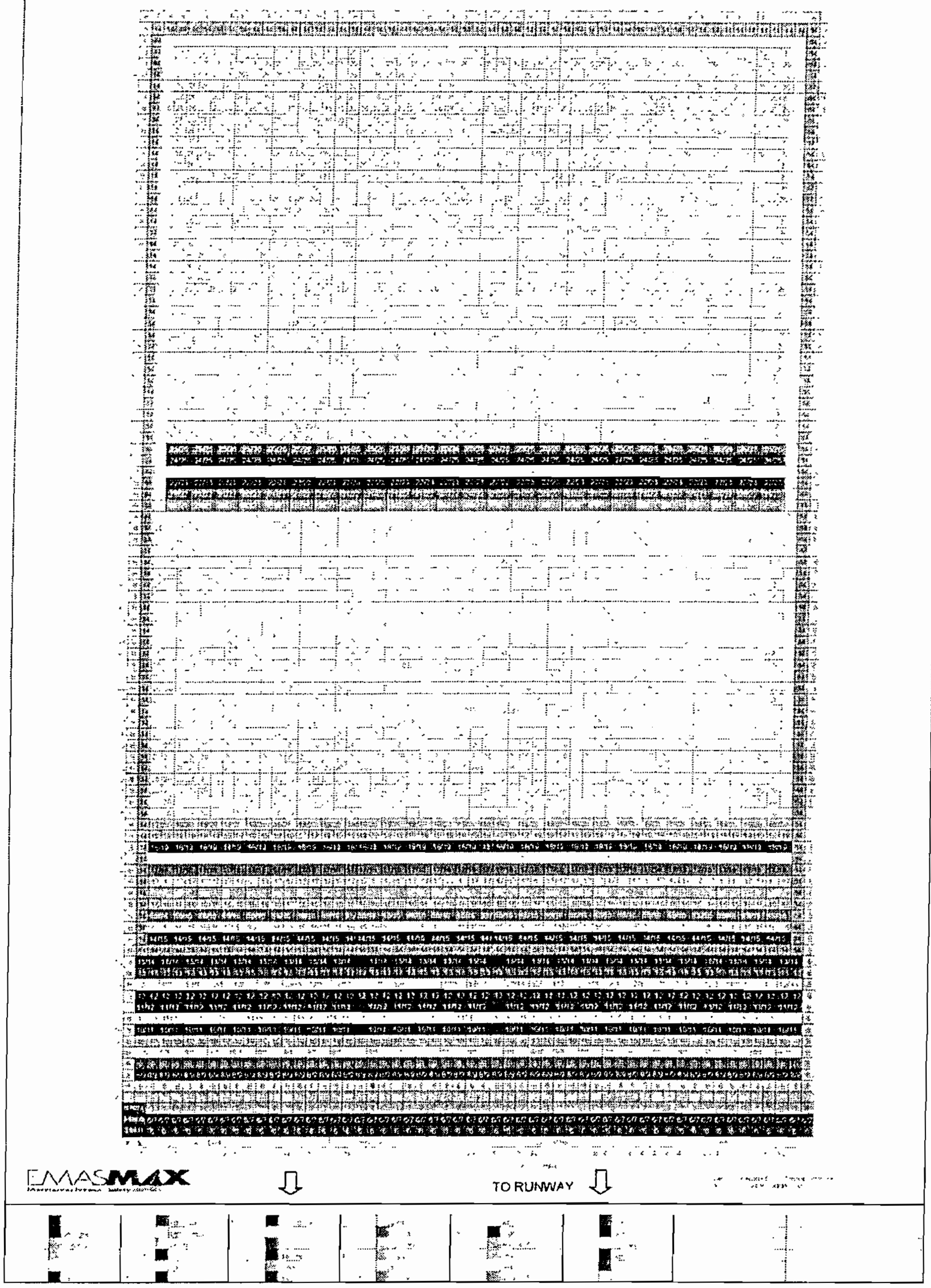


Taipei Songshan Airport
Runway 10 Departure End
60-strength 765.00' EMAS
364.08' Setback 400.92' Arrestor
DHC-8-200 MTOW=36,500 LB
μ_{MAIN}=0.25 R/T=0 (Design Case)

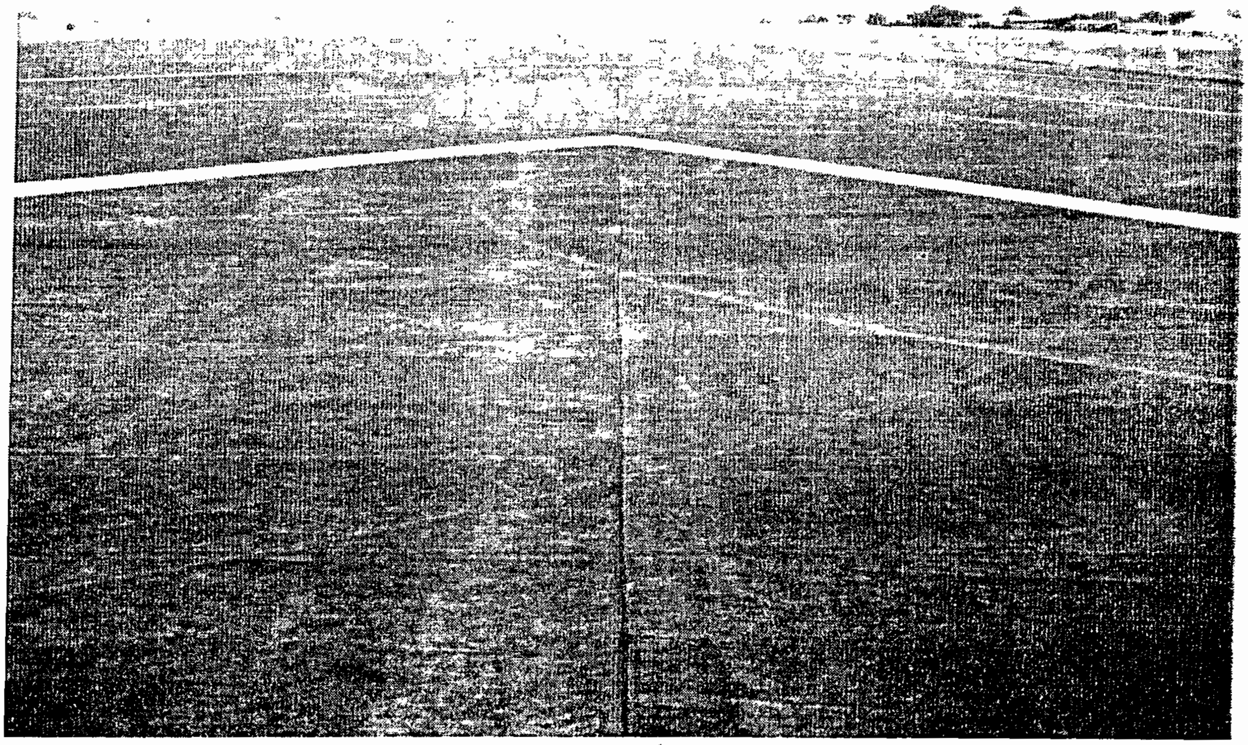


ATTACHMENT B: Bed Layout

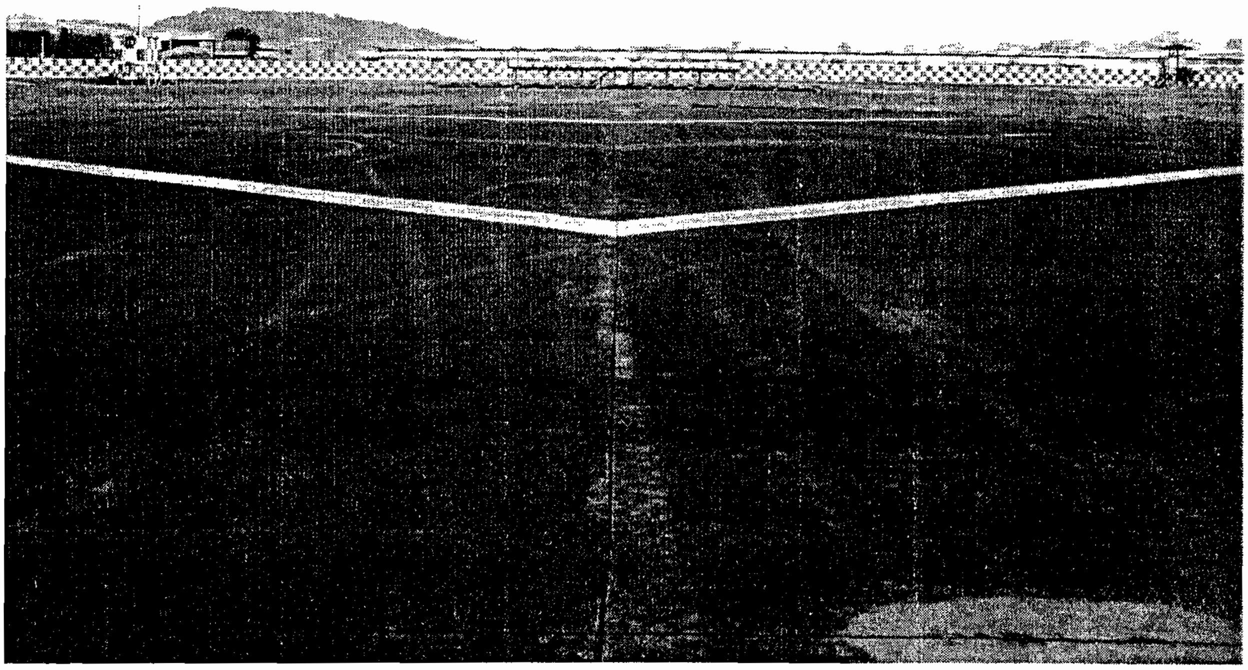
PRELIMINARY EMAS BLOCK LAYOUT PLAN - NOVEMBER, 2009
TAIPEI SONGSHAN AIRPORT RUNWAY 10 DEPARTURE



ATTACHMENT C: Pre-construction Site Photos



VIEW OF RESA LOOKING WEST



VIEW LOOKING EAST AT LOCALIZER

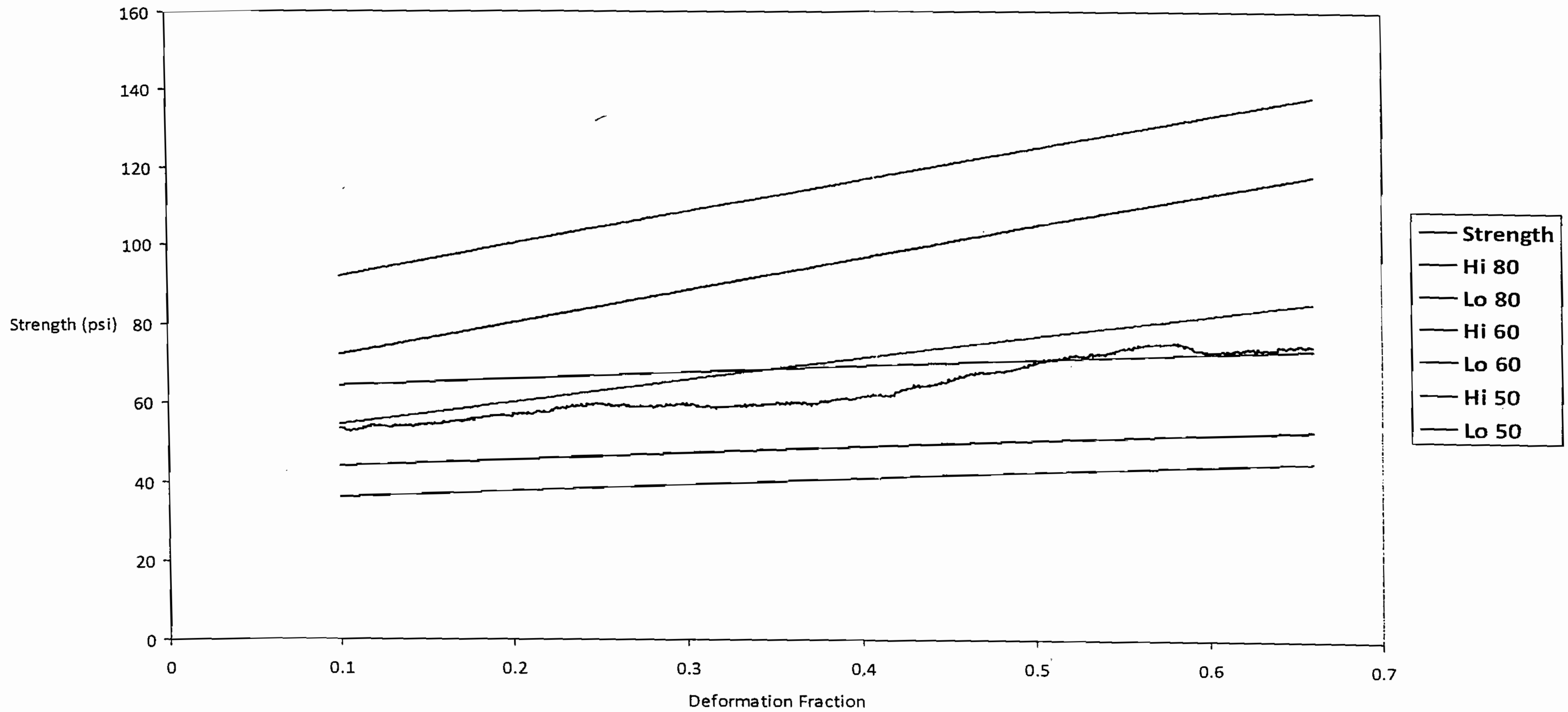
VIEW LOOKING SOUTH AT LOCALIZER
with Taipei 101 beyond

ATTACHMENT D: EMAS Installations

Number of EMAS	Airport	Location	Departure End of Runway(s)	Installation Date
2	JFK International	Jamaica, NY	4R, 22L	1996(1999)/2007
1	Minneapolis St. Paul	Minneapolis, MN	12R	1999(2008)
2	Little Rock	Little Rock, AR	4R, 22R	2000/2003
1	Rochester International	Rochester, NY	28	2001
1	Burbank	Burbank, CA	8	2002
1	Baton Rouge Metropolitan	Baton Rouge, LA	13	2002
2	Greater Binghamton	Binghamton, NY	16, 34	2002
1	Greenville Downtown	Greenville, SC	1	2003
1	Barnstable Municipal	Hyannis, MA	24	2003
1	Roanoke Regional	Roanoke, VA	33	2004
2	Fort Lauderdale Intl.	Fort Lauderdale, FL	27R, 9L	2004
1	Dutchess County	Poughkeepsie, NY	6	2004
2	La Guardia	Flushing, NY	22, 13	2005
2	Boston Logan	Boston, MA	4L, 15R	2005/2006
1	Laredo International	Laredo, TX	17R	2006
2	Jiuzhai-Huanglong (JZH)	Sichuan Province, PRC	2/20	2006
1	San Diego	San Diego, CA	27	2006
1	Teterboro	Teterboro, NJ	6	2006
4	Chicago-Midway	Chicago, IL	31C, 4R, 22L, 13C	2006/2007
1	Charleston Yeager	Charleston, WV	23	2007
1	Cordova	Cordova, AK	27	2007
2	Madrid-Barajas Intl.	Madrid, Spain	33L, 33R	2007
1	Manchester	Manchester, NH	6	2007
2	Wilkes-Barre/Scranton Intl.	Wilkes-Barre, PA	4, 22	2008
2	San Luis Obispo	San Luis Obispo, CA	11, 29	2008
2	Chicago-O'Hare Intl.	Chicago, IL	4R, 22L	2008
1	Newark International	Newark, NJ	29	2008
1	Charlotte Douglas Intl.	Charlotte, NC	36R	2008
2	St. Paul Downtown	St. Paul, MN	14, 32	2008
2	Worcester Regional	Worcester, MA	11, 29	2008/2009
1	Reading Regional	Reading, PA	31	2009
1	Kansas City Downtown	Kansas City, MO	19	2009
48	**Systems Installed**			

附錄三-EMAS材料品管作業書面文件（含本次廠驗現場試驗圖表、抗壓梯度強度試驗品管文件及該試驗專利證明資料）

Project Name: Taiwanese Guests   Project: Inv./Blk.   Pour Date: 6/24/2010   Test Date: 6/24/2010
Batch: 123   21 Day Test   35% Strength: 62.1   ACCEPT 60/50



ZODIAC ESCO ENGINEERED ARRESTING SYSTEMS CORP. EMAS Division	Page No: 1 of 8	Procedure No: EMAS.110.01.P
	Revision Date: November 3, 2008	Revision Letter: R
Subject: EMAS INSPECTION & TESTING PROCEDURE		

1.0 PURPOSE

To ensure that product conforms to all requirements at each stage of production and final inspection, and to identify nonconforming product at the earliest possible stage in order to facilitate corrective action. Finished product shall not be dispatched until all activities documented in this procedure have been satisfactorily completed and the associated data documented and authorized for release.

2.0 RESPONSIBILITIES

2.1 The ESCO Director of Quality Assurance is responsible to ensure the proper verification and acceptance of purchased items for the production of the EMAS JBR Arrestor Bed is accomplished in accordance with the purchase order or contract requirements, and to ensure that all product requirements for the production of the EMAS JBR Arrestor Bed are verified.

2.2 The EMAS Quality Assurance Department is responsible for the verification of product acceptance from incoming receiving inspection. Operations Certified Production Workers (CPW) shall be responsible for the inspection of product through component product production and shipment. CPW personnel are responsible to ensure that all inspections are conducted in accordance with EMAS Quality and Production Work Instructions.

2.3 The EMAS Civil Engineer and ESCO IMRO (Installation, Maintenance, and Repair Organization) Personnel shall ensure that the designated Quality Installation Parameters are followed during installation of the EMAS Arrestor Bed.

2.4 EMAS Civil Engineer is responsible for verifying that the final product (EMAS Jet Blast Resistant (JBR) Arrestor Bed) conforms to all Quality, customer, and FAA Advisory Circular requirements upon completion prior to release to the customer.

Originator: Gary Era	Title: EMAS Quality Assurance Supervisor
Signature: [signature]	Date: 11-3-08
Approved by: Geoffrey H. Fowler	Title: Director, ESCO Quality Assurance & Continuous Improvement
Signature: [signature]	Date: 11/03/08

3.0 APPLICABLE FORMS OR REFERENCES

- EMAS.109.01.01.FM Daily Production Log
- EMAS.113.01.P EMAS Control of Nonconforming Product Procedure
- EMAS.112.01.P EMAS Inspection Status Procedure
- EMAS.110.02.P EMAS Receiving Inspection Procedure
- EMAS PC 002 Process Control Instruction (PC) for the Wet Material Process
- EMAS.110.01.01.FM EMAS Product Accept/Reject Sheet
- EMAS.110.01.05.FM EMAS JBR Block Final Product Release Form
- EMAS.110.01.06.FM EMAS JBR Arrestor Bed Final Product Release Statement
- EMAS.110.01.09.FM EMAS JBR Arrestor Bed Final Inspection Form
- EMAS.115.01.P EMAS Handling, Storage, Packaging, Preservation & Delivery Procedure
- EMAS QCI 004 Quality Control Instruction for Testing Product Samples
- EMAS FSP 001 EMAS Field Service Procedure (FSP) for JBR block Installation
- EMAS PC 001 Process Control Instruction for the Block Saw, Preparation and Packaging Operation
- EMAS PC 004 Process Control Instruction for Wrapping EMAS Blocks with Jet Blast Resistant (JBR) Protection
- QA.116.01.P ESCO Quality Records Maintenance and Retention Procedure
- FAA Advisory Circular
- Movex Database at Saw Cut, JBR Wrap, and Final JBR Block Inspection
- IMRO ESCO Installation, Maintenance, and Repair Organization

4.0 PROCEDURE

4.1 Inspection of all incoming raw materials and product shall follow the procedures designated in the EMAS Receiving Inspection Procedure, EMAS.110.02.P. Verification of the specified requirements for incoming products shall be in accordance with the EMAS Receiving Inspection Procedure.

4.1.2 The criteria for the disposition of all product inspected shall follow the Parameters documented in EMAS.112.01.P (EMAS Inspection Status Procedure) And EMAS.113.01.P, the EMAS Control of Nonconforming Product Procedure.

4.2 In-process Inspection of Component Product
When an EMAS concrete block (the component product) has passed the initial in-Process inspection by the Production Department per the Process Control Instruction for The Wet Material Process (EMAS PC 002), it is tagged with a batch tag and placed for Curing. If in-process material fails, it is discarded and recorded as "trash" on the Daily Production Log EMAS.109.01.01.FM.

4.3 Final EMAS Block Strength Testing
After the product has cured for a minimum of 18 days, a test coupon (a sample from the coinciding batch) is tested per EMAS QCI 004, the Quality Control Instruction for the Testing of Product Samples. If the first coupon is rejected, the second coupon is tested. If the second coupon also fails, the block is rejected and entered as such along with a short comment why the batch was rejected in the "Comments" column on EMAS.110.01.01.FM, the Product Accept/Reject Sheet. If either the first or second test coupon meets the criteria for acceptance, the batch is accepted and the results are recorded on the Product Accept/Reject Sheet by the EMAS Quality Assurance Technician or their designee. The corresponding blocks are then processed in accordance with EMAS.109.01.P, Process Control Procedure.

4.3.1 If during EMAS block sample testing it has been determined that the samples designated for strength testing of a particular batch have been lost or Damaged to the point where testing is not possible, those blocks correlating with The batch samples in question shall be tested as designated by the EMAS Quality Assurance Manager and QCI 004 and the test results recorded on the Product Accept /Reject Sheet.

4.4 EMAS Block Height Verification (Saw Room)
After the EMAS block has been cut in the Saw Room, the block is measured to insure that the proper block height tolerances have been met per EMAS PC 001 (Process Control Procedure for Block Saw, Preparation and Packaging Operation) prior to further processing. The inspection results are entered in the Saw Cut MOVEX Database by the designated or Saw Room Certified Production Workers (CPW), and maintained electronically by Inventory Control.

4.5 JBR Block Wrap Verification
The JBR (Jet Blast Resistant) protection for the EMAS blocks is applied on the JBR Wrapping Line after the EMAS block has been cut to the desired height. The wrapped JBR block is then inspected by the Operations CPW to ensure final tolerances are met per EMAS PC 004. Once Final inspection has been complete the batch tag on each block shall be stamped with the CPW's assigned stamp number by the CPW to verify JBR block final inspection acceptance.

4.6 JBR Block Final Processing Inspection
The EMAS JBR blocks that have been inspected and stamped with the CPW's assigned stamp number they are then palletized and entered into the MOVEX Data base per EMAS 109.01.P by the Production Administrator.

NOTE: *Blocks inspected for shipment prior to the release of Revision K of this Procedure may not have the final inspection stamp included on the JBR block batch tag.*

4.7 Verification of Acceptance of EMAS JBR Blocks Prior to Shipping
The EMAS JBR blocks to be shipped will be brought to the shipping staging area and Prepared in accordance with EMAS.115.01.P. Verification of final product Quality Acceptance of the JBR blocks for shipment shall be documented on the EMAS JBR Block Final Product Release Form (EMAS.110.01.05.FM) which shall be signed by the EMAS Quality Assurance Manager and kept on file in the Quality Assurance department.

4.8 Final Product Inspection (EMAS Arrestor Bed)
ESCO IMRO Personnel shall perform the required inspections at the designated points of installation as required by the appropriate EMAS Quality Assurance Arrestor Bed Installation parameters cited in EMAS FSP 001 (EMAS Field Service Procedure (FSP) for JBR Block Installation)

4.8.1 The final product shall not be released for use by the customer until the Designated EMAS personnel have inspected the EMAS JBR Arrestor bed To insure that all Quality, Customer, and FAA Advisory Circular requirements have been met and EMAS.110.01.09.FM (EMAS JBR Arrestor Bed Final Inspection Form) has been completed and released by the EMAS Civil Engineer. This form shall be maintained in the EMAS Engineering and Quality Assurance Departments.

4.8.2 Verification of final product release shall be documented on the EMAS JBR Arrestor Bed Final Product Release Statement (EMAS.110.01.06.FM) signed by the EMAS Civil Engineer and/or the EMAS Quality Assurance Manager. A copy of this Statement shall be filed in the EMAS Quality Assurance and Engineering Departments.

4.9 Inspection of Outsourced Processes

Product produced by means of outsourcing shall be required to meet the appropriate EMAS inspection criteria. The product shall be inspected by designated EMAS Quality Assurance personnel at the site of production and the appropriate inspection report for that particular project shall be completed and the product released by the designated Quality Assurance personnel on the inspection form.

4.9.1 When the product is packaged for shipment back to EMAS or to the designated location, a " DOCK TO STOCK" label shall be attached to each shipment properly filled out to verify release of the product. All inspection records for outsourced product shall be maintained in the EMAS Quality Assurance Department.

5.0 RECORDS / OBJECTIVE EVIDENCE

5.1 Records shall be maintained in accordance with Quality and Environmental Records Maintenance and Retention Procedure, QA.116.01.P.

6.0 REVISION HISTORY

REVISION	REVISION DATE	SUMMARY
A	July 7, 1997	Initial release
B	August 7, 1997	Added Verification of Acceptance Prior to Shipping
C	September 17, 1997	Added form control numbers. Revised para. 4.1.2 to provide provisions for handling/processing of unacceptable product that cannot be immediately returned.
D	October 8, 1997	Changed Material Controller to EMAS QA Representative. Changed para. 2.0 to more clearly define individual responsibilities; reformatted footer.
E	April 8, 1998	Changed EMAS QA Representative to QA Engineer. Revised Section 4.2 and 4.3 to enable more consistent traceability of product.
F	December 28, 1999	Revised header & footer. Clarified the purpose of the procedure in paragraph 1.0 to reflect standard requirements. Changed paragraph 2.0 to more clearly define individual responsibilities. Changed 4.1 heading to Incoming Product; referred to EMAS.110.02.P in paragraph 4.1.1. Cited EMAS.110.02.P and QA.114.01.02.FM in paragraph 4.1.2. Revised paragraph 4.2 to link initial inspection of blocks to EMAS.109.01.P and records to EMAS.109.01.01.FM; Combined all subparagraphs in 4.3 into one paragraph headed Final Product Inspection. Eliminated the second sentence in paragraph 4.4; Added EMAS.115.01.02.FM to paragraph 4.4; Eliminated paragraph 4.5.
G	August 14, 2000	Made appropriate revisions to Paragraph 3.0; cited Production personnel for incoming product inspection in section 4.1.1; Cited the Quality Assurance Department for curing inspection in section 4.2.2; Added reference to QCI 004 in section 4.3; Added section 4.3.1 to reflect the disposition of blocks when samples are lost or damaged.

H	December 21, 2000	Revised section 2.1 to include EMAS Field Service personnel for in-process installation inspection; added section 2.3 to verify final product conformance to Quality and customer requirements; included appropriate forms and references to para. 3.0; Revised title of section and body 4.2 to reflect the status of the concrete blocks as component products; Revised the title and body of section 4.3 to reflect final inspection of component product; added section 4.5 to include responsibilities of in process and final product inspection and release of the EMAS Arrestor Bed to the customer.
I	N/A	Revision level not utilized in ESCO documentation.
J	September 18, 2001	Revised Paragraph 3.0 to reflect changes in the body of the procedure; added new section 4.4 to cite block measurement in Saw Room per EMAS PC 001; added new section 4.5 to reflect final JBR block inspection per EMAS PC 004; added reference to QCI 016 in section 4.7.
K	November 27, 2001	Eliminated reference to incoming and raw material product inspection in this procedure, citing procedure EMAS.110.02.P Receiving Inspection Procedure for clarification referenced all new applicable procedures/ forms documented in this procedure in Paragraph 3.0; added reference to EMAS.110.01.07.FM in section 4.2.1; added reference to EMAS.110.01.02.FM in section 4.4; added reference to EMAS.110.01.03.FM to section 4.5; added new section 4.6 to include final paint inspection per EMAS PC 005 and utilization of EMAS.10.01.03.FM for final processing inspection including the use of a final inspection stamp on batch tags; changed old section 4.6 to section 4.7; section 4.7 is now section 4.8 including reference to the EMAS JBR Arrestor Bed Final Product Release Statement (EMAS.110.01.06.FM).
L	May 10, 2002	Revised section 2.1 to clarify EMAS Quality Assurance Specialist responsibility for product release; included responsibility of QA Inspectors to ensure product inspected to EMAS Quality and Process Control procedures; added applicable documents to Paragraph 3.0 per revisions in the procedure dictate; included designation for verification of inspection and release of product sections 4.2.1, 4.3, 4.4, 4.5, 4.6, 4.7, and 4.8; revised section 5.2 to better define Archive retention; included appropriate documents to Records table in Paragraph 5.0.

M	August 1, 2002	Revised the footer and body of the procedure to reflect title change from EMAS Quality Assurance (QA) Specialist to EMAS QA Engineer; added EMAS QCI 017 to section 4.2.1; added section 4.9 to include the inspection of product produced by outsourcing; revised Paragraphs 3.0 and 5.0 to reflect changes in the body of the procedure.
N	April1, 2003	Revised header and footer to include Zodiac emblem and applicable approvals; eliminated "polyurethane" in section 4.6 and clarified inspection requirements; revised Active Retention in Paragraph 5.0 to three (3) years minimum.
O	N/A	Revision level not utilized in ESCO documentation.
P	April 4, 2006	Revised the footer and body of the procedure to reflect title change from EMAS Quality Assurance (QA) Engineer to EMAS QA Manager; Eliminated Block Curing Inspection, section 4.2 1; Implemented the Access Database to encompass Inspection data and eliminated inspection forms for Saw, JBR Wrap, and Final; Eliminated the Paint process cited in 4.6; Eliminated Retention History section 5.3.
Q	N/A	Revision level not utilized in ESCO documentation.
R	November 3, 2008	Revised header and footer. Revised Para 2.2 Deleted QA inspection Personnel added Operations CPW responsible for component product production and shipment. Revised Para 4.4 added Movex Data Base and Saw Room CPW or designate. Revised Para 4.5 added Operations CPW and removed Red Final Inspection stamp. Revised Para 4.6 Deleted Final Inspection Screen on Access Data Base and added Movex Data Base and inventory Control Clerk. 3.0 Deleted Access Data Base and Replace with Movex Data Base.

US005789681A

United States Patent [19]

Angley et al.

[11] Patent Number: 5,789,681

[45] Date of Patent: Aug. 4, 1998

[54] ARRESTING MATERIAL TEST APPARATUS AND METHODS

[75] Inventors: Richard D. Angley, Aston; Michael S. Ciesielski, Broomall; Christopher T. Dial, Lansdowne; Peter T. Mahal, Ardmore, all of Pa.; Robert F. Cook, Chipley, Fla.

[73] Assignee: Datron Inc., Garland, Tex.

[21] Appl. No.: 796,968

[22] Filed: Feb. 7, 1997

[51] Int. Cl.[6] G01N 3/00

[52] U.S. Cl. 73/803; 73/82

[58] Field of Search 73/12.13, 12.01, 73/12.08, 786, 803, 844, 862.541, 866, 81, 82, 85

[56] References Cited

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Primary Examiner—Elizabeth L. Dougherty
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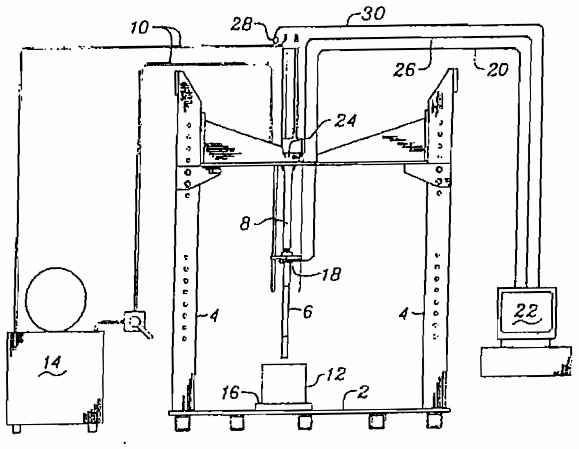
[57] ABSTRACT

Arresting material test apparatus, test probes and test methods enable testing of compressive gradient strength of cellular concrete, and materials having similar characteristics, on a continuous basis from the surface of a section to a typical internal penetration depth of at least 60 percent of thickness. Previous testing of cellular concrete typically focused on testing to confirm a minimum structural strength prior to structural failure or shattering of a test sample. For an aircraft arresting bed, for example, cellular concrete must exhibit a compressive gradient strength in a relatively narrow precalculated range continuously from the surface to penetration depth equal to 60 to 80 percent of sample thickness. Precalculated and controlled compressive gradient strength is critical to enabling an aircraft to be safely stopped within a set distance, without giving rise to drag forces exceeding main landing gear structural limits. New test apparatus, test probes with post-compression build-up relief and test methods are described to enable such testing and recordation of data showing the gradient of compressive strength as it increases from the surface of a test sample to a predetermined depth of penetration. Resulting compressive gradient strength data is representative of performance of cellular concrete sections in decelerating an aircraft.

34 Claims, 5 Drawing Sheets



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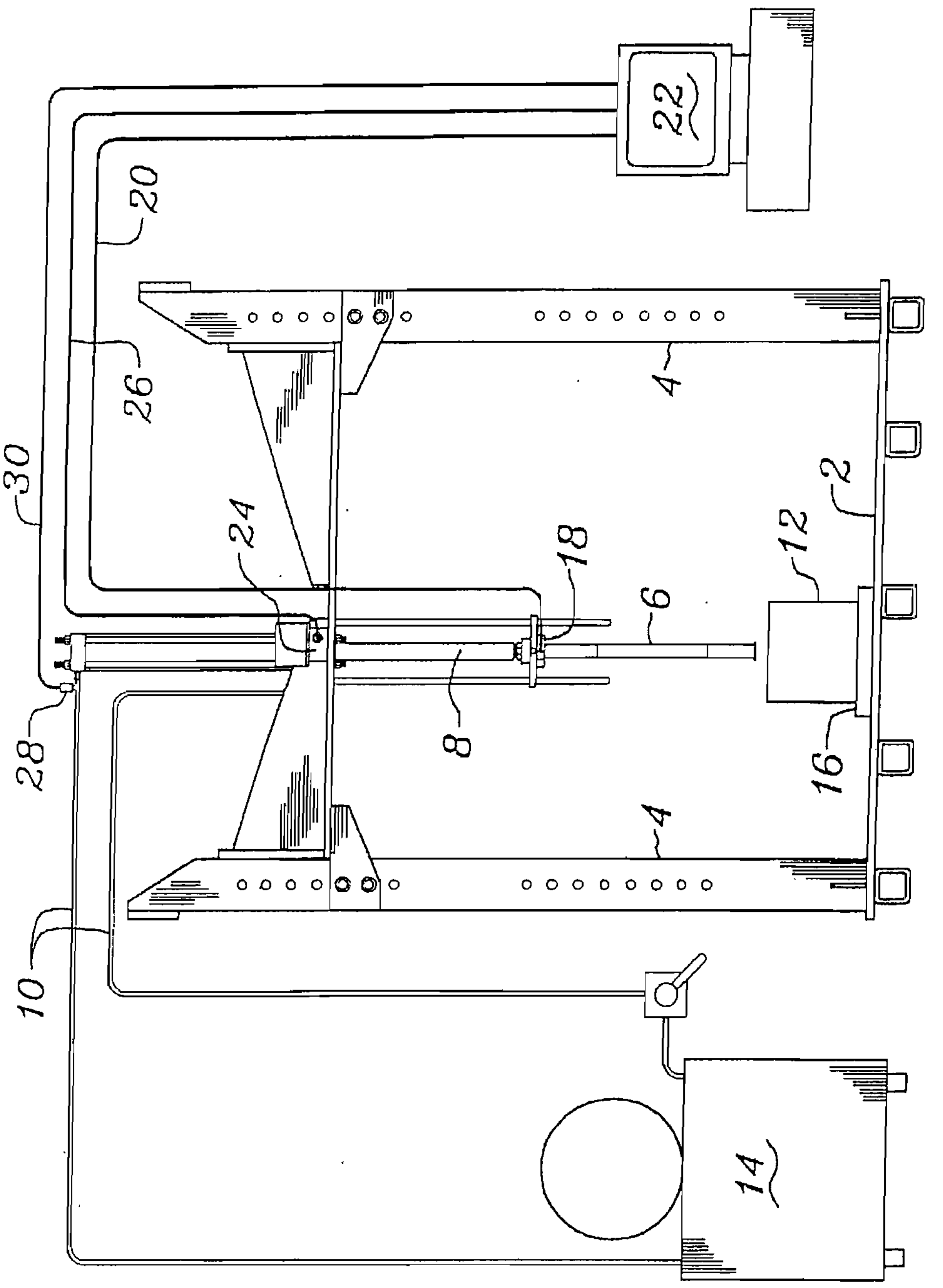

Fig. 1

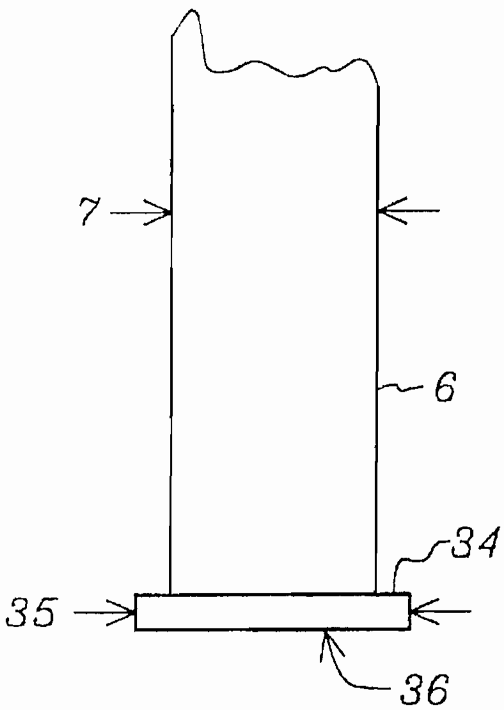

Fig. 2

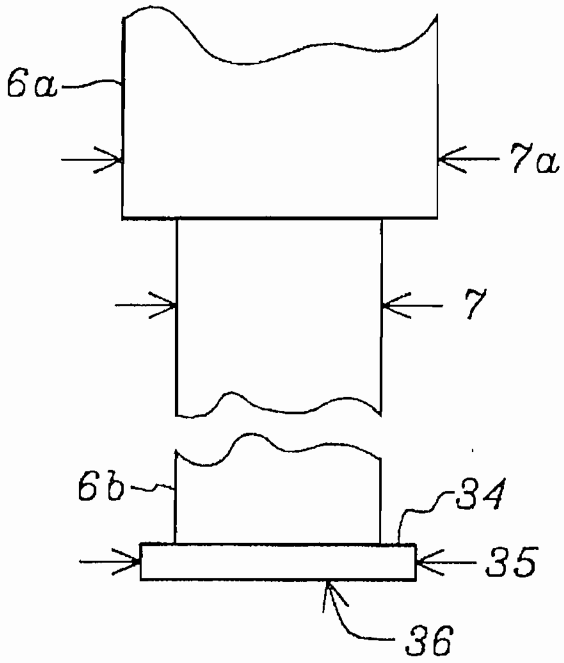

Fig. 3

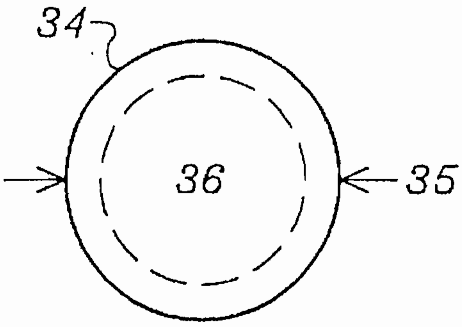

Fig. 4

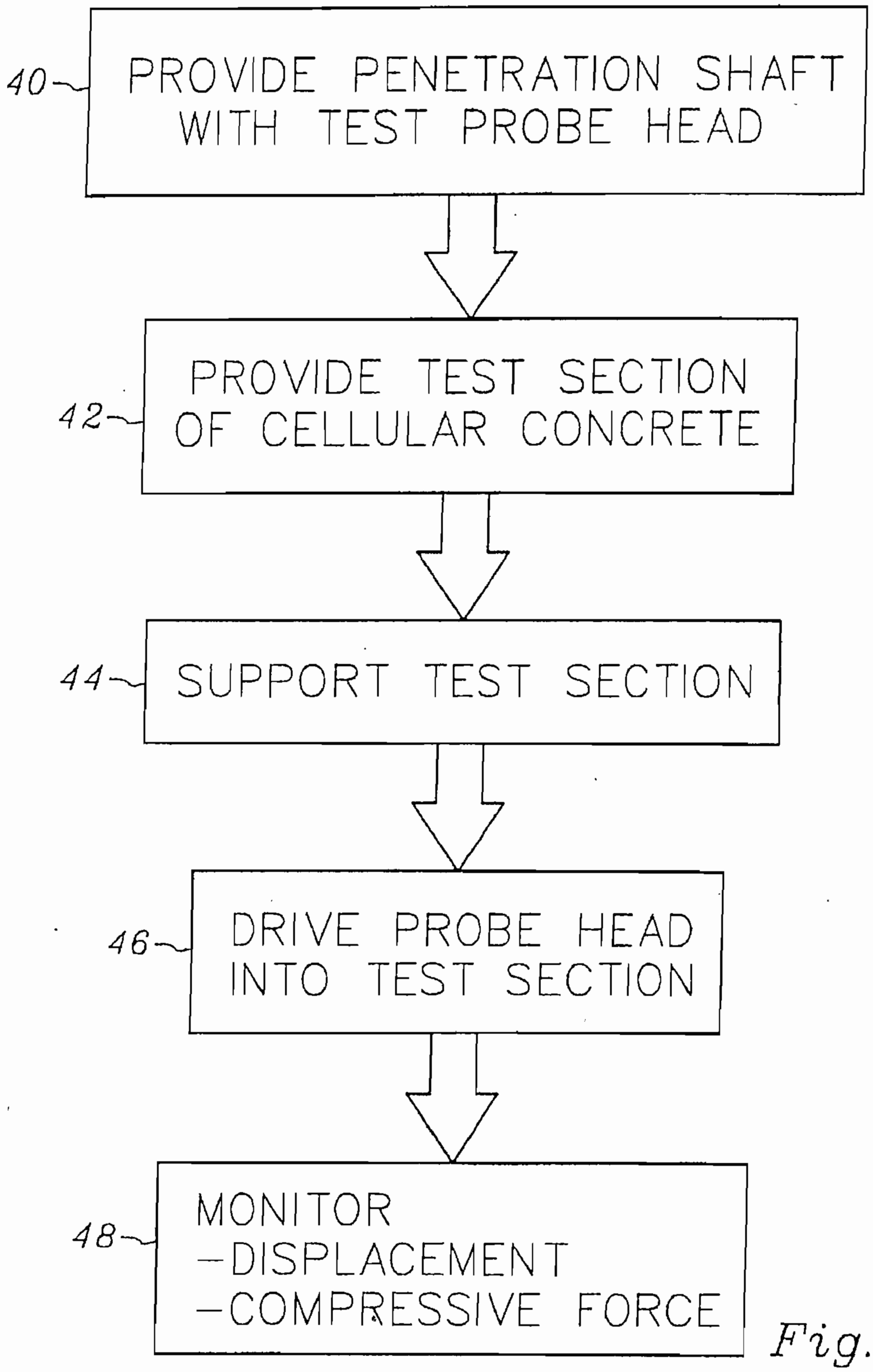
40
PROVIDE PENETRATION SHAFT WITH TEST PROBE HEAD
42
PROVIDE TEST SECTION OF CELLULAR CONCRETE
44
SUPPORT TEST SECTION
46
DRIVE PROBE HEAD INTO TEST SECTION
48
MONITOR
-DISPLACEMENT
-COMPRESSIVE FORCE

Fig. 5

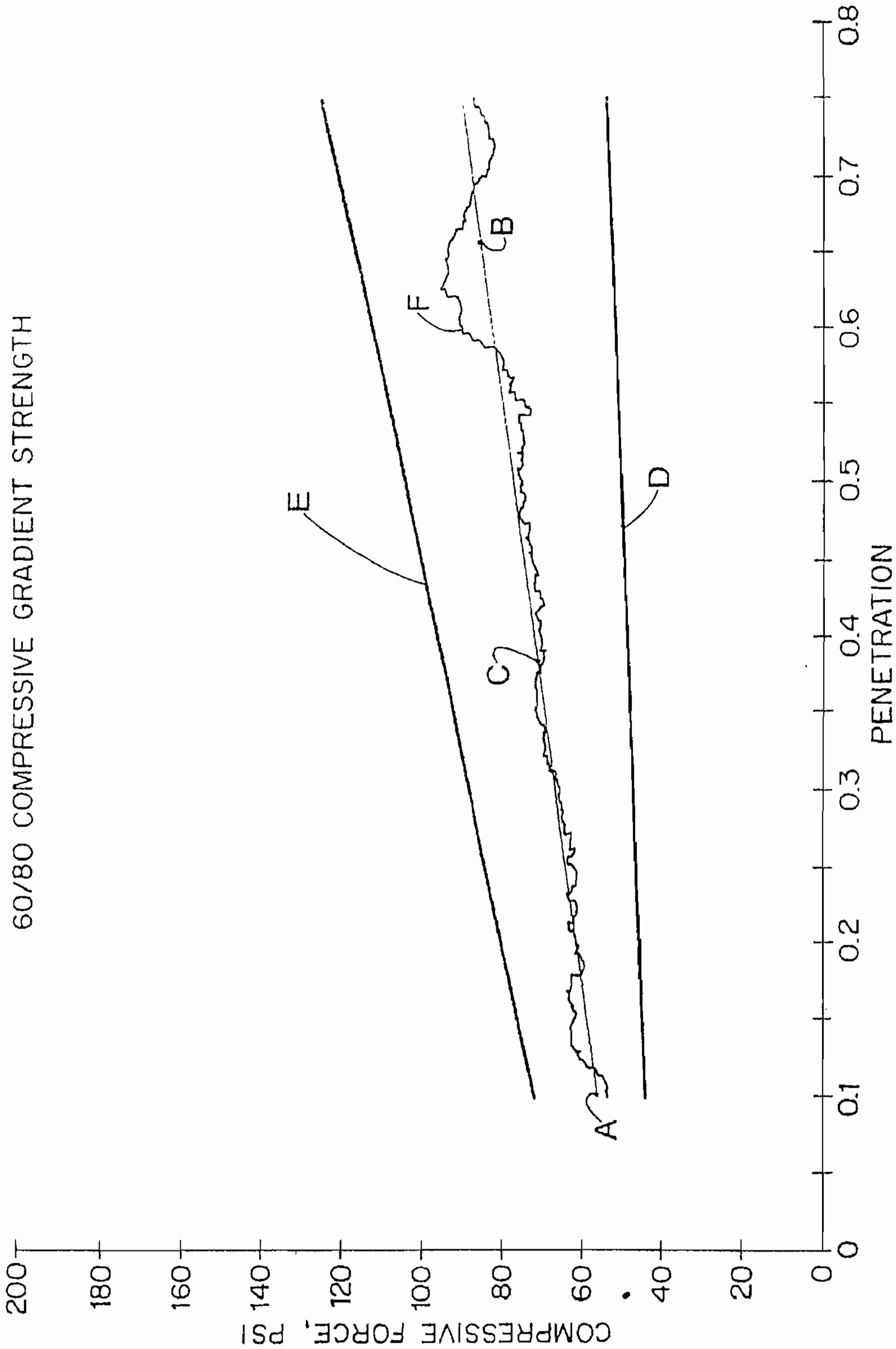
60/80 COMPRESSIVE GRADIENT STRENGTH
COMPRESSIVE FORCE, PSI
PENETRATION
0
20
40
60
80
100
120
140
160
180
200
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
A
B
C
D
E
F

FIG. 6

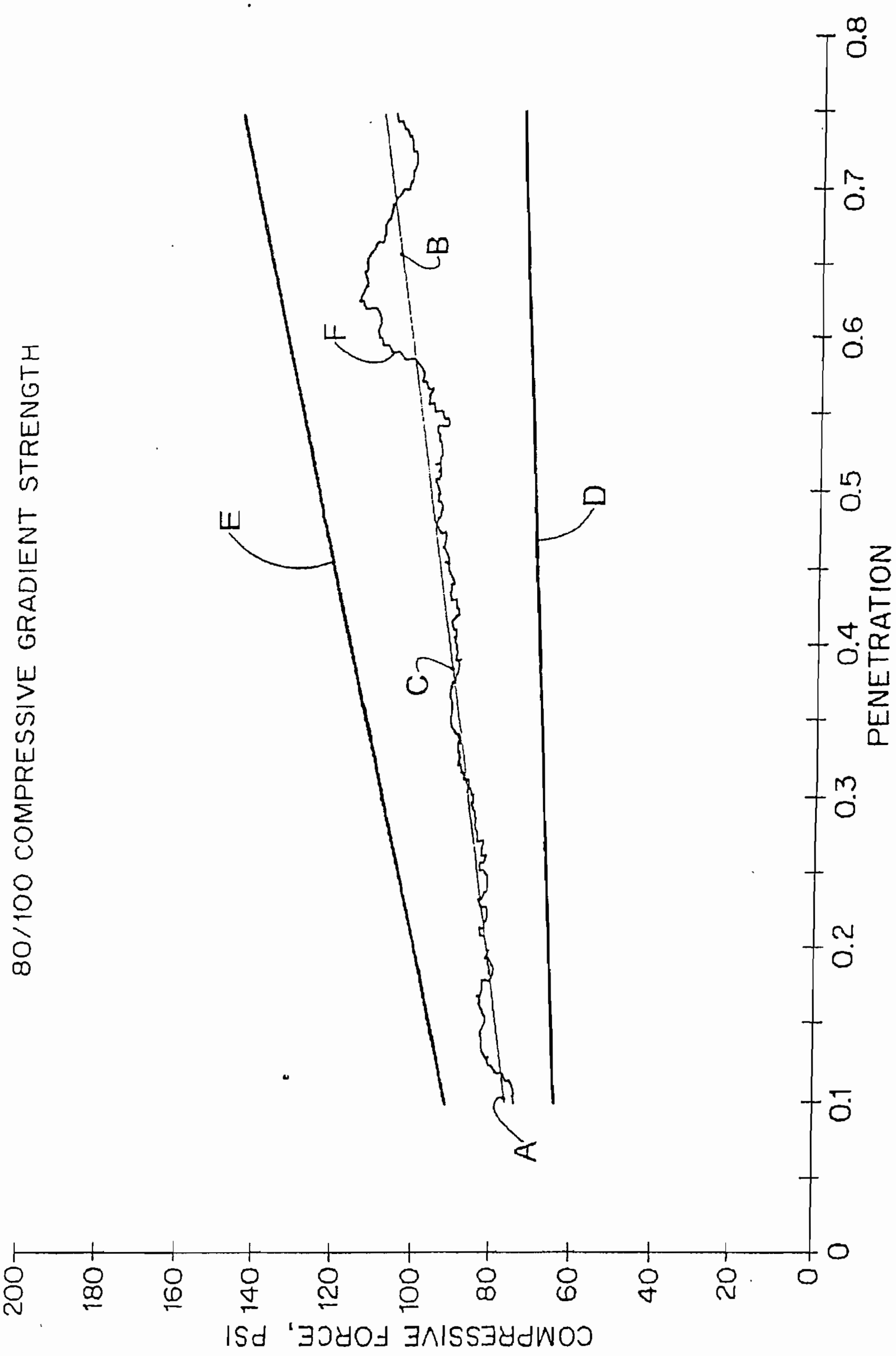
80/100 COMPRESSIVE GRADIENT STRENGTH
COMPRESSIVE FORCE, PSI
200
180
160
140
120
100
80
60
40
20
0
PENETRATION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
A
B
C
D
E
F

FIG. 7

ARRESTING MATERIAL TEST APPARATUS AND METHODS

BACKGROUND OF THE INVENTION

This invention relates to systems for slowing travel of vehicles and, more particularly, to test apparatus and methods to test cellular concrete intended for use in arresting bed systems to safely decelerate an aircraft which runs off the end of a runway.

Aircraft can and do overrun the ends of runways raising the possibility of injury to passengers and destruction of or severe damage to the aircraft. Such overruns have occurred during aborted take-offs or while landing, with the aircraft traveling at speeds to 80 knots. In order to minimize the hazards of overruns, the Federal Aviation Administration (FAA) generally requires a safety area of 1,000 feet in length beyond the end of the runway. Although this safety area is now an FAA standard, many runways across the country were constructed prior to its adoption and are situated such that water, roadways or other obstacles prevent economical compliance with the one thousand foot overrun requirement.

Several materials, including existing soil surfaces beyond the runway have been assessed for their ability to decelerate aircraft. Soil surfaces are very unpredictable in their arresting capability because their properties are unpredictable. For example, very dry clay can be hard and nearly impenetrable, but wet clay can cause aircraft to mire down quickly, cause the landing gear to collapse, and provide a potential for passenger and crew injury as well as greater aircraft damage.

A 1988 report addresses an investigation by the Port Authority of New York and New Jersey on the feasibility of developing a plastic foam arrestor for a runway at JFK International Airport. In the report, it is stated that analyses indicated that such an arrestor design is feasible and could safely stop a 100,000 pound aircraft overrunning the runway at an exit velocity up to 80 knots and a 820,000 pound aircraft overrunning at an exit velocity up to 60 knots. The report states that performance of an appropriate plastic foam arrestor configuration was shown to be potentially "superior to a paved 1,000 foot overrun area, particularly when braking is not effective and reverse thrust is not available." As is well known, effectiveness of braking may be limited under wet or icy surface conditions. (University of Dayton report UDR-TR-88-07, January 1988.)

More recently, an aircraft arresting system has been described in U.S. Pat. No. 5,193,764 to Larrett et al. In accordance with the disclosure of that patent, an aircraft arresting area is formed by adhering a plurality of stacked thin layers of rigid, friable, fire resistant phenolic foam to each other, with the lower-most layer of foam being adhered to a support surface. The stacked layers are designed so that the compressive resistance of the combined layers of rigid plastic foam is less than the force exerted by the landing gear of any aircraft of the type intended to be arrested when moving into the arresting area from a runway so that the foam is crushed when contacted by the aircraft. The preferred material is phenolic foam used with a compatible adhesive, such as a latex adhesive.

Tests of phenolic foam based arrestor systems indicate that while such systems can function to bring aircraft to a stop, the use of the foam material has disadvantages. Major among the disadvantages is the fact that foam, depending upon its properties, can typically exhibit a rebound property. Thus, it was noted in phenolic foam arresting bed testing that some forward thrust was delivered to the wheels of the aircraft as it moved through the foamed material as a result of the rebound of the foam material itself.

Foamed or cellular concrete as a material for use in arresting bed systems has been suggested and undergone limited field testing in the prior art. Such testing has indicated that cellular concrete has good potential for use in arresting bed systems, based on providing many of the same advantages as phenolic foam while avoiding some of phenolic foam's disadvantages. However, the requirements for an accurately controlled crushing strength and material uniformity throughout the arresting bed are critical and, so far as is known, the production of cellular concrete of appropriate characteristics and uniformity has not previously been achieved or described. Production of structural concrete for building purposes is an old art involving relatively simple process steps. Production of cellular concrete, while generally involving simple ingredients, is complicated by the nature and effect of aeration, mixing and hydration aspects, which must be closely specified and accurately controlled if a uniform end product, which is neither too weak nor too strong, is to be provided for present purposes. Discontinuities, including areas of weaker and stronger cellular concrete, may actually cause damage to the vehicle that is being decelerated if, for example, deceleration forces exceed wheel support structure strength. Such non-uniformity also results in an inability to accurately predict deceleration performance and total stopping distance. In one recent feasibility test utilizing commercial grade cellular concrete, an aircraft instrumented for recording of test data taxied through a bed section and load data was acquired. Even though steps had been taken to try to provide production uniformity, samples taken and aircraft load data from the test arresting bed showed significant variations between areas where the crush strength was excessively high and areas where it was excessively low obviously, the potential benefit of an arresting system is compromised, if the aircraft is exposed to forces that could damage or collapse the main landing gear.

Thus, while arresting bed systems have been considered and some actual testing of various materials therefor has been explored, practical production and implementation of either an arresting bed system which within specified distances will safely stop aircraft of known size and weight moving at a projected rate of speed off of a runway, or of materials suitable for use therein, have not been achieved. The amount of material, and the geometry in which it is formed to provide an effective arresting bed for vehicles of a predetermined size, weight, and speed, is directly dependent upon the physical properties of the material and, in particular, the amount of drag which will be applied to the vehicle as it moves through the bed crushing or otherwise deforming the material. Computer programming models or other techniques may be employed to develop drag or deceleration objectives for arresting beds, based upon the calculated forces and energy absorption for aircraft of particular size and weight, in view of corresponding landing gear strength specifications for such aircraft. However, the models must assume that the arresting bed is constructed of a material having a section to section and batch to batch uniformity of characteristics, such as strength, durability, etc., to produce uniform results with a predictable amount of energy absorption (drag) when contacted by the portions of the aircraft (or other vehicle) which are bearing the load of the vehicle through the bed (e.g., the wheels of an aircraft as it moves through the bed after having overrun the runway).

One of the potential benefits of the use of foamed or cellular concrete in arresting bed systems is that the material itself is capable of being produced in a variety of different ways using numerous different starting materials. For prior types of applications not relating to vehicle deceleration the concrete has been produced by using a particular type of cement (usually Portland) which is combined with water, a foaming agent, and air to produce a cellular concrete. However, a significant distinguishing requirement separates such prior applications of cellular concrete from production of a product suitable for use in an arresting bed. In prior applications, the objectives are typically reduced weight or cost, or both, while providing a predetermined minimum strength with the more strength the better. Prior applications have typically not required that cellular concrete be produced to strict standards of both maximum strength and minimum strength. Also, prior applications have not required a high degree of uniformity of material, provided basic strength objectives are met. Even for prior applications of cellular concrete, it is known that the amount and type of cement, the water/cement ratio, the amount and type of foaming agent, the manner in which the materials are combined, processing conditions and curing conditions can all have critical effects on the resulting properties of the cellular concrete. No necessity to refine production to the levels required to produce cellular concrete suitable for vehicle arresting beds has been presented by prior applications.

Thus, it is one thing to specify objectives as to mechanical properties of materials appropriate to obtain the desired deceleration on entry of an airplane or other vehicle into the arresting bed. However, the capability of consistently producing cellular concrete material which will actually have the required properties of predetermined strength and uniformity is not known to have been previously achieved.

One substantial problem in the art is the lack of established techniques for production of cellular concrete in the low strength range, in a uniform fashion to very tight tolerances, to enable construction of an entire arresting bed consistently having the desired mechanical properties throughout its geometry. While poured in place cellular concrete has been suggested, no practical design for successfully implementing a cellular concrete arresting bed has previously been provided.

Another problem is determining in advance what mechanical forces the vehicle will actually experience as it moves through foamed concrete of a particular grade of manufacture. The mechanical properties of interest are not the strength, per se, of the material, but rather the decelerating force experienced by an object moving through the material as the material is deformed. Most conventional testing of concrete samples measures the fracture strength of the material, in order to establish that at least a specified load will be supported. By contrast, in arresting bed technology it is the energy absorbed on a continuing basis during compressive failure of the material which is the important characteristic (i.e., actual strength during continuing compressive failure). Without an appropriate test methodology which can be used to determine on a continuing basis the compressive strength that will be supplied by foamed concrete of a particular formula, production technique, curing, and design, the art would be left with the requirement of building very costly arresting bed structures with a variety of different cellular concrete samples in an effort to determine which of these, when used as an actual arresting bed, functions in a manner that could be predicted. More particularly, since, in the past, applications for structural cellular concrete could be supported by minimum strength testing, neither suitable test methods nor apparatus have been provided to enable reliable testing of compressive strength continuously over a depth of penetration from the surface of a section of cellular concrete and continuing to an internal penetration depth up to eighty percent of section thickness.

Objects of the invention are to provide new and improved test apparatus and methods for testing cellular concrete arresting material, and such test apparatus and methods which provide one or more of the following advantages and capabilities:

- reliable determination of compressive gradient strength which will be experienced when decelerating a moving object;
- compressive strength testing without structural collapse of a test sample;
- determination of compressive gradient strength from the surface of a sample continuously to an internal depth of penetration of the order of 70 percent of sample thickness;
- recording of compressive failure test pressure and penetration depth on a continuous basis;
- use of an improved test probe head continuously driven by a penetration shaft; and
- use of a penetration shaft having a shaft portion of restricted cross section to reduce post-compression material build-up effects which can distort accuracy of data obtained.

SUMMARY OF THE INVENTION

In accordance with the invention, arresting material test apparatus, to test compressive gradient strength continuously from the surface to an internal depth of penetration within compressible arresting material, includes a penetration shaft having a length not less than the internal depth of penetration and a cross-sectional size. A test probe head is connected to the penetration shaft and has a compressive contact surface. The penetration shaft includes a constricted shaft portion, beginning behind the test probe head and continuing for at least a part of the length of the penetration shaft. This constricted shaft portion typically has a cross-sectional area at least ten percent smaller than the area of the contact surface of the test probe, in order to reduce post-compression material build-up behind the test probe head and data distortion resulting from such build-up.

A drive mechanism is coupled to the penetration shaft to displace the shaft to drive the test probe head to the internal depth of penetration within arresting material. A displacement sensing device coupled to the penetration shaft is provided to sense displacement thereof. A load sensing device coupled to the penetration shaft senses the pressure exerted against the test probe contact surface as it compresses arresting material to the internal depth of penetration. The apparatus also includes a data acquisition device responsive to pressure sensed by the load sensing device and responsive to the depth of penetration of the test probe contact surface to provide data representative of continuous measurement of compressive gradient strength of compressible arresting material subject to test.

Also in accordance with the invention, an arresting material test probe, suitable to test compressive gradient strength continuously from the surface to an internal depth of penetration within compressible arresting material, includes a penetration shaft, test probe head and constricted shaft portion as described above. The cross-sectional area and length of the constricted shaft portion are selected as appropriate to reduce post-compression build-up effects behind the contact surface as it travels from the surface to an internal depth of penetration within arresting material under test. Such depth of penetration may typically be at least 60 percent of the thickness of a section of arresting material to be tested.

Further in accordance with the invention, a method for continuous compressive failure testing of a cellular concrete section suitable for vehicle arresting use, includes the steps of:

(a) providing a penetration shaft bearing a test probe head with a contact surface having a contact surface area;

(b) providing a test section of cellular concrete having a thickness and having a cross-sectional area at least twenty times larger than the contact surface area;

(c) supporting the test section longitudinally;

(d) driving the contact surface of the test probe head longitudinally into the test section from a surface to an internal depth of penetration within the test section;

(e) monitoring on a continuous basis the displacement of the test probe head; and

(f) monitoring the compressive force on said contact surface at a plurality of intermediate depths of penetration within the test section.

For a better understanding of the invention, together with other and further objects, reference is made to the accompanying drawings and the scope of the invention will be pointed out in the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an embodiment of arresting material test apparatus in accordance with the invention.

FIGS. 2 and 4 are respectively side and bottom views of a test probe head and portion of an associated penetration shaft utilizing the invention.

FIG. 3 is a side view showing a test probe head mounted to a penetration shaft of an alternative construction in accordance with the invention.

FIG. 5 is a flow chart useful in describing a test method in accordance with the invention.

FIGS. 6 and 7 show test data obtained using the FIG. 1 apparatus and FIG. 5 method, in terms of compressive force indicated along the ordinate versus percentage of penetration indicated along the abscissa for samples of cellular concrete of two different strengths.

DETAILED DESCRIPTION OF THE INVENTION

The use of cellular concrete in arresting bed applications requires the material to be generally uniform in its resistance to deformation since it is the predictability of forces acting on the surface of contacting members of the vehicle which is being decelerated that allows the bed to be designed, sized and constructed in a manner which will ensure acceptable performance. In order to obtain such uniformity, there must be careful selection and control of the ingredients used to prepare the cellular concrete, the conditions under which it is processed, and its curing regime.

The ingredients of cellular concrete are generally a cement, preferably Portland cement, a foaming agent, and water. Relatively fine sand or other materials can also find application in some circumstances, but are not used in presently preferred embodiments. For present purposes, the term "cellular concrete" is used as a generic term covering concrete with relatively small internal cells or bubbles of a fluid, such as air, and which may include sand or other material, as well as formulations not including such sand or other material.

There are many known methods for producing cellular concrete. In general the process includes the steps of mixing the foam concentrate with water, generating foam by inducing air, adding the resulting foam to the cement slurry or cement/aggregate slurry mix, and thoroughly blending the foam and cement slurry in a controlled manner that results in a homogeneous mixture with a significant amount of voids or "cells" which keep the density of the material relatively low as compared to other types of concrete. Because the application of cellular concrete to arresting bed applications requires a general uniformity of material properties, uniform foaming, mixing, and setting of the materials is of extreme importance.

Construction of the arresting bed system can be accomplished by producing the cellular concrete at a central production facility or at the site of the bed and pouring the concrete into forms of appropriate dimensions to achieve the desired geometry for the system. However, in the interests of uniformity of material characteristics and overall quality control, it has been found preferable to cast sections of the overall bed using forms of appropriate size and then transport the sections to the site and install them to form the overall configuration of the bed. In the latter case, such units or sections, in the form of blocks of predetermined sizes, can be produced and held until completion of quality control testing. The blocks can then be transported to the site, placed in position and adhered to the runway safety area using asphalt, cement grout, or other suitable adhesive material, depending on the construction materials of the safety area itself.

DEFINITION OF "COMPRESSIVE GRADIENT STRENGTH" OR "CGS"

The term "compressive strength" (not CGS) is normally understood to mean the amount of force (conventionally measured in pounds per square inch) which, when applied at a vector normal to the surface of a standardized sample, will cause the sample to fail. Most conventional test methods specify test apparatus, sampling procedures, test specimen requirements (including size, molding, and curing requirements) rates of loading and record keeping requirements. An example is ASTM C 495-86 "Standard Method for Compressive Strength of Lightweight Insulating Concrete." While such conventional test methods are useful when designing structures that are required to maintain structural integrity under predicted load conditions (i.e., have at least a minimum strength), the object of arresting bed systems is to fail in predictable specified manner, thereby providing controlled, predictable resistive force as the vehicle deforms the cellular concrete (i.e., a specific compressive gradient strength). Thus, such conventional testing focuses on determining strength up to a point of failure, not strength during compressive failure. Stated more simply, knowing what amount of force will shatter a specimen of cellular concrete material does not answer the critical question of what amount of drag or deceleration will be experienced by a vehicle moving through an arresting bed system. In contrast to a "one time" fracture strength as in the prior art, for present purposes testing must evaluate a continuous compressive failure mode as a portion of a specimen is continuously compressed to about twenty percent of its original thickness. Equipment and methods suitable for such continuous testing as appropriate for present purposes have generally not been previously available.

Because of the wide range of variables available in materials and processing of cellular concretes, and the size and cost of constructing arresting beds for testing, it is imperative that accurate test information be available to predict the amount of resistive force a particular variety of cellular concrete, processed and cured in a certain way, will provide when used in an arresting bed system. By developing new test methodology to focus the resulting data on measurement of the resistive force occurring during continuous compressive failure of a sample, instead of simple one-time "compressive strength", new test methods and apparatus have been developed to enable reliable testing and confirmation of appropriate cellular concrete materials and process variables. As a result, it has been determined that the compressive force needed to crush cellular concrete to 20 percent of its original thickness varies with the depth of penetration. This characteristic, which the present inventors term "compressive gradient strength" or "CGS" must be accurately specified in order to construct a cellular concrete vehicle arresting bed having known deceleration characteristics to safely slow an aircraft.

The test method and equipment of the present invention provide load and deformation data for test samples of cellular concrete, or materials with similar characteristics, that can be used to accurately predict how an arresting bed constructed from the same material will perform. Thus, a penetration type test method where the compressive strength of a sample of cellular concrete is gauged not by applying a force that will fracture a sample, but rather will continuously report information on resistive forces generated as a test probe head having a specified compressive contact surface is moved through a volume of cellular concrete, is key to obtaining the data necessary to formulate and use cellular concrete in arresting bed applications. As thus measured, CGS will vary over a range with penetration depth, resulting in a gradient value (such as 60/80 CGS) rather than a simple singular fracture value as in prior tests.

For present purposes, the term "compressive gradient strength" (or "CGS") is used to refer to the compressive strength of a section of cellular concrete from a surface and continuing to an internal depth of penetration which may typically be 66 percent of the thickness of the section. As thus defined, CGS does not correspond to compressive strength as determined by standard ASTM test methods.

FIG. 1 TEST APPARATUS

Referring now to FIG. 1, there is illustrated an embodiment of arresting material test apparatus in accordance with the invention. As will be described further, the FIG. 1 apparatus is arranged to test compressive gradient strength continuously from the surface to an internal depth of penetration within a sample section of compressible arresting material. As shown, there is included a structural platform base 2 suitable to support the bottom of a test section and form a test support structure in combination with side frame members 4.

A piston, in the form of penetration shaft 6 is slidably engaged in cylinder 8 and arranged for activation via fluid coupled through hydraulic lines 10. The configuration is such that a shaft 6 can be driven down toward a test section 12 of cellular concrete or other suitable material in reaction to activation of hydraulic pressure source 14. Test section 12 is supported during test by a bottom bearing block 16 resting on base 2. A test probe head mounted at the bottom of penetration shaft 6 will be described with reference to FIGS. 2–4. It will thus be appreciated that hydraulic cylinder 8, fed by lines 10 from hydraulic pressure source 14, comprise one form of drive mechanism coupled to penetration shaft 6 and provide the capability of continuously displacing shaft 6 to drive a test probe head to an internal depth of penetration within an arresting material test section 12.

As illustrated, the test apparatus further includes a load sensing device, shown as load cell 18. In known manner, load cell 18 is arranged to measure the force exerted upon penetration shaft 6 and the contact surface of the test probe head as it is displaced into, and causes compressive failure of, the cellular concrete of test section 12. Alternatively, the measured force may be considered to be a measure of the resistance provided by the cellular concrete against the contact surface of the test probe head during compressive failure of test section 12. Forces measured by the load cell comprising load sensing device 18 are continuously monitored and can be recorded in terms of force or pressure during test via data line 20 coupled to a data acquisition device 22. In FIG. 1, the test apparatus also includes a displacement sensing device, shown as a linear potentiometer 24, arranged so that its impedance varies with changes in the position of penetration shaft 6. Displacement sensing device 24 is coupled to data acquisition device 22 via data line 26 to enable displacement of shaft 6 to be continuously monitored and recorded during test. In the illustrated test apparatus, hydraulic pressure as sensed by a pressure sensing device, shown as pressure transducer 28, is also monitored and recorded via data line 30.

With reference now to FIGS. 2–4, there are shown in greater detail two exemplary configurations of an arresting material test probe in accordance with the invention, which is suitable to test compressive gradient strength continuously from the surface to an internal depth of penetration within arresting material. The test probe comprises a penetration shaft and a test probe head mounted at the lower end thereof. FIG. 2 shows the lower portion of a penetration shaft 6 having an overall length not less than the depth of internal penetration during testing, and a cross-sectional size represented by diameter 7. Penetration shaft 6 may typically be formed of steel and have a circular cylindrical form. Test probe head 34 is suitably connected to the lower end of shaft 6 (e.g., fixed thereto by welding, screwed into the end, etc.) so as to remain in position when exposed to longitudinal pressure. Test probe head 34 has a compressive contact surface 36, which may be hardened or otherwise suitable for compression of cellular concrete or other material without excessive deformation of surface 36. The size of contact surface 36, represented by diameter 35 indicated in the bottom view of FIG. 4, is larger than the cross-sectional size of a constricted shaft portion of penetration shaft 6. In FIG. 2 it will be seen that contact surface diameter 35 is larger than diameter 7 of shaft 6, which in this example is of a uniform diameter over its length. FIG. 3 shows an alternative configuration. In FIG. 3 penetration shaft *6a* has a basic diameter *7a* which mates with hydraulic cylinder 8 of FIG. 1. Penetration shaft *6a* includes a restricted shaft portion *6b* of smaller cross-sectional area, which begins behind test probe head 34 and continues for at least a portion of the length of the penetration shaft. Thus, with reference to FIG. 2, it will be seen that in the first configuration the restricted shaft portion having a reduced cross-sectional area, relative to contact surface 36, effectively extends for the full length of the penetration shaft, as also illustrated in FIG. 1. In FIG. 3, the restricted shaft portion represents only part of the length of shaft *6a*. Pursuant to the invention it has been found that providing a restricted shaft portion extending behind the test probe head is effective to reduce potentially error-producing effects of post-compression build-up of particles of cellular concrete behind the contact surface as it travels into the arresting material under test. Preferably, the restricted shaft portion will have a length at least equal to the intended penetration depth. This feature has been found to enhance the accuracy and reliability of test results as an indication of actual compressive gradient strength to be experienced in use of arresting material.

A presently preferred configuration of test probe head 34 includes a flat circular contact surface 36 approximately 2 inches in diameter, with the restricted shaft portion (6 or 6b) behind head 34 having a cross-sectional area 10 to 50 percent smaller than the contact surface and continuing behind the test probe head 34 for a distance at least equal to the depth of penetration. The construction should have a basic structural integrity and contact surface hardness adequate to survive compressive pressures of at least 100 and preferably 500 pounds per square inch (psi) without failure or significant surface distortion. In other embodiments, the contact surface 36 may have a hexagonal or other suitable shape and be of any appropriate size. However, in this regard it is presently considered preferable that the size of contact surface 36, relative to the cross-sectional size of test portion 12, be such that testing may be completed without general structural failure or shattering of the test sample such as fall-away of side portions of test portion 12 prior to about 70 percent penetration. Pursuant to the invention, in order to obtain accurate results indicative of compressive gradient strength in arresting bed use, it is presently preferred that test portion 12 be supported only from the bottom, without lateral support, banding or enclosure, and should remain intact during testing except for internal compressive failure along the path of test probe head 34. General structural failure or shattering of the test sample after 70 or 80 percent penetration is typically not a matter of concern as to validity of test results. By using a test method where the sample is unconstrained as the piston penetrates and exerts resulting stresses, a closer approximation to arresting test bed performance is achieved since there will not be a constraint or reflection of stress forces caused by the cellular concrete or other material under test being forced up against an artificially strong container wall.

FIG. 5 TEST METHOD

The test methodology includes the ability to measure the load dynamically as the test probe head moves through the sample. In a preferred method, the load is applied at a relatively fast constant speed with force measurements occurring continuously or at small increments of displacement as the test probe head moves through the sample. A currently preferred test probe head displacement rate is approximately 60 inches per minute, which is relatively fast in comparison to the 0.05 inches per minute specified for the different form of testing specified in the ASTM C39-86 standard test procedure. Cellular concrete samples which are deformed in this manner will reach a point of deformation where essentially all the void spaces or cells have been crushed and the amount of compressive force needed for further deformation will rapidly increase or the test sample will experience general structural failure. That point typically occurs at a penetration depth of the order of 80 percent of sample thickness. It is the forces that are necessary to deform the sample from an initial point to the point where this rapid rise in compression force occurs (e.g., to at least 60 percent of sample thickness) that are of interest and which the test methodology and apparatus should seek to capture. Thus, it will be appreciated that an objective of the present invention is to provide test results indicative of deceleration which will be experienced by a vehicle or other object moving through a volume of compressible arresting material. This objective differs from the objective of prior known test approaches which are inadequate for present purposes.

In accordance with the invention and with reference to FIG. 5, a method for continuous compressive gradient testing of a cellular concrete section suitable for vehicle arresting use, comprises the following steps:

(a) providing, at step 40 in FIG. 5, a penetration shaft bearing a test probe head with a compressive contact surface having a contact surface area;

(b) providing, at step 42, a test section of cellular concrete having a cross-sectional area at least twenty times larger than the contact surface area and having a thickness;

(c) supporting the test section longitudinally, at step 44;

(d) driving the contact surface of the test probe head, at step 46, longitudinally into the test section from the top surface to an internal depth of penetration within the test section;

(e) monitoring, at step 48, displacement of the test probe head; and

(f) monitoring, at step 48, compressive force on said contact surface at a plurality of intermediate depths of penetration within said test section.

The method may additionally include the step of making available a presentation of a gradient representing values of compressive force at the plurality of intermediate depths, as will be described with reference to FIGS. 6 and 7. The presentation may take the form of a computer printout as in FIGS. 6 and 7, a comparable display on a computer monitor, or other suitable form.

In application of the test method, step (c) preferably comprises supporting the bottom of the test section, with an absence of lateral restriction of the sides of the test section. Also, step (d) preferably comprises driving the contact surface continuously to an internal depth of penetration equal to at least 60 percent (and typically to about 70 percent) of the thickness of the test section, and in step (e) force on the contact surface of the test probe head is preferably recorded at short intervals (e.g., 10 to 30 times per second) until the contact surface reaches such internal depth of penetration.

The apparatus is arranged to apply the load to the sample continuously rather than intermittently, and without shock. The rate of loading should be adjustable, preferably controllable through software run by the data acquisition means which can, for example, be a general purpose personal computer with appropriate data acquisition software. Preferably, the apparatus provides a prescribed rate of loading for the full stroke during penetration of the test section. Stroke length will vary depending on test section thickness with a longer loaded stroke length for a deeper penetration depth as appropriate for thicker test sections. The load information, distance information, and pressure information is acquired by the data acquisition means during penetration and may be sampled and recorded at a rate of 30 times per second for each individual test. In other applications the sampling rate may be different. While tolerances should be specified as appropriate in particular embodiments, a test specification may provide that the maximum error allowable at any point for load is 3 in 1,000 pounds, for distance is 0.0625 inches in 24 inches, and for pressure 1 in 1,000 psig. Verification of the accuracy of operation and data acquisition should include testing through the full loading range.

The data acquisition software used on the data acquisition computer can be arranged and configured by skilled persons so that it is effective in monitoring all of the information received from each sensing device of the apparatus. Preferably, the software should enable use of a display to permit the operator to continuously display and observe data as the testing occurs. Data to be recorded includes readings representative of load (pounds), displacement (inches) time (seconds), and preferably also hydraulic pressure (psig). Data should typically be sampled at short intervals (e.g., 30 readings per second). This should occur for the full stroke of the test probe head as it penetrates the sample. In certain configurations, hydraulic pressure may not be monitored, or may be utilized as backup or substitute data for loading data. To provide for maximum accuracy, zeroing and adjustment of the test apparatus should be monitored and recorded by the data acquisition software. It may be desirable to record raw incoming data directly and also to automatically make available data in converted form. Thus, for example, load data regarding contact surface force may typically be recorded in pounds and can be converted to psi by factoring in contact surface area. Similarly, a resistance representative voltage output from displacement sensor **24** can be converted to inches of displacement.

Preparation of uniform samples and careful recording with regard to their characteristics is an important part of the testing process. Certain specific observations can be made regarding the testing process. Sampling of cellular concrete may, for example, utilize appropriate provisions of method C-172 of the ASTM with the following exceptions: when sampling from pump equipment, a bucket of approximately 5 gallon capacity should be filled by passing it through the discharge stream of the concrete pump hose being used to place the concrete at the point of placement of the concrete. Care should be exercised to insure that the sample is representative of the pour, avoiding the beginning or ending of the discharge of the equipment. The test specimens should then be prepared, as described below, by pouring lightweight concrete from the bucket. Furthermore, no remixing of samples should be allowed in this test procedure. Typically, test specimens may be 12 inch cubes or have other suitable three-dimensional shapes. Specimens are molded by placing the concrete in a continuous and forceful pouring manner. The molds should be gently shaken as the material is added. The concrete should not be rodded. The specimens should be struck off immediately after filling the molds. They should be covered in a manner to prevent evaporation without marring the surface. The specimens should not be removed from the mold until such time as they are to be tested. Curing of the specimens should desirably occur at about the same curing temperature as used for the arresting bed section of which the specimens are representative. The specimens should remain covered, to restrict evaporation, for at least about 21 days or until tested for compressive strength, in a manner consistent with curing of the corresponding arresting bed sections.

In preparation for testing, the specimen should be removed from the mold and placed beneath the test probe head. The top surface should have a smooth face to accommodate the face of the probe head contact surface. The surface of the specimen in contact with the lower bearing block of the test machine should be flat enough to be stable and prevent skewing of the piston during the test. Prior to the test, the specimen should be weighed and measured along three axes (height, length, width). These dimensions are then used in computing the density as of the time of testing. At the time of the test, the contact surface of the test probe head and the surfaces of the bottom bearing block should be clean and the sample should be carefully aligned so that the test probe head will pass through the approximate center of the specimen. As the contact surface is initially brought to bear on the specimen, the specimen positioning may be gently adjusted by hand. Then continuous load should be applied without shock at a constant rate, typically about 1 inch per second. Data points are preferably recorded to the full depth of penetration. The type of any failure and the appearance of the concrete at completion of testing are preferably recorded and included with the test data.

Compressive gradient strength data is calculated by dividing the load at the data point by the surface area of the piston. Data points during initial displacement up to about 10 percent of test section thickness and data that is captured after the specimen reaches a fully compressed state are typically discarded as less reliable than the remaining test data. The depth of penetration should be calculated by subtracting the piston displacement at initial contact from the last data point of piston displacement.

Referring to FIGS. 6 and 7, examples of test data recorded during testing of cellular concrete samples are shown. In this case the test samples were of a size and shape approximating 12 inch cubes. Test data was derived using a test probe head having a flat circular contact surface, with a load cell used to measure loads through 75 percent of the total sample thickness. FIG. 6 illustrates the CGS characteristics of a cellular concrete sample representative of an arresting block as determined by test. In FIG. 6, the bottom scale represents percentage of test probe penetration expressed in tenths of sample thickness or height. The vertical scale represents test probe compressive force expressed in pounds per square inch (psi). The test data of interest is typically within the range of penetration from 10 to 60 percent of sample thickness. Data outside this range may be less reliable, with total compression effects occurring beyond about 70 percent penetration.

As illustrated in FIG. 6, the failure strength of cellular concrete exhibits a gradient with resistance to compression increasing with depth of penetration. The line through points A and B in FIG. 6 represents a generalized 60/80 CGS, i.e., a CGS characterized by a compression strength changing linearly from approximately 60 psi to approximately 80 psi over a 10 to 66 percent penetration range. The average, over this range is thus approximately 70 psi at mid-point C. Lines D and E represent quality control limits and line F represents actual test data as recorded for a specific test sample of cellular concrete. In this example, a test sample for which test data over a 10 to 66 percent penetration range remains within quality control limit lines D and E, represents an arresting block fabricated within acceptable tolerances. FIG. 7 is a similar illustration of CGS characteristics of a test sample of an 80/100 CGS arresting block.

While there have been described the currently preferred embodiments of the invention, those skilled in the art will recognize that other and further modifications may be made without departing from the invention and it is intended to claim all modifications and variations as fall within the scope of the invention.

What is claimed is:

1. Arresting material test apparatus, to test compressive gradient strength on a continuous basis from the surface to an internal depth of penetration within compressible arresting material, comprising:

a penetration shaft having a length greater than said internal depth of penetration and a cross-sectional size;

a test probe head connected to said penetration shaft and having a compressive contact surface;

said penetration shaft including a constricted shaft portion beginning behind said test probe head and continuing for at least a part of said length, said constricted shaft portion having a cross-sectional area smaller than the area of said contact surface of said test probe;

a drive mechanism coupled to said penetration shaft to displace said shaft to drive said test probe head to said internal depth of penetration within arresting material;

a displacement sensing device coupled to said penetration shaft to sense displacement thereof;

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a load sensing device coupled to said penetration shaft to sense the force exerted against said test probe contact surface as it compresses arresting material to said internal depth of penetration; and

a data acquisition device responsive to force sensed by said load sensing device and to the depth of penetration of said test probe contact surface to provide data representative of compressive gradient strength of said compressible arresting material to said depth of penetration.

2. Arresting material test apparatus as in claim 1, wherein said cross-sectional area of the constricted shaft portion is smaller than the area of said test probe contact surface by an amount effective to reduce distortive effects of post-compression build-up of particles of cellular concrete during testing of cellular concrete arresting material.

3. Arresting material test apparatus as in claim 1, wherein said test apparatus is arranged to drive said test probe head to an internal depth of penetration of at least 60 percent of the thickness of cellular concrete arresting material while exerting a force of up to at least 100 psi against said test probe head.

4. Arresting material test apparatus as in claim 1, wherein said data acquisition device has a capability to provide data representative of compressive gradient strength, at increments of penetration from the surface of a section of compressible arresting material to an internal depth of penetration within said section.

5. Arresting material test apparatus as in claim 1, wherein said test probe head has a flat contact surface and said constricted shaft portion has a cross-sectional area at least ten percent smaller than the area of said contact surface.

6. Arresting material test apparatus as in claim 1, wherein said test probe head has a flat circular contact surface with an area in a range from 1 to 4 square inches.

7. Arresting material test apparatus as in claim 1, wherein said constricted shaft portion of said penetration shaft continues behind said test probe head for at least the intended depth of penetration and has a cross-sectional area in a range of 10 to 50 percent smaller than said contact surface.

8. Arresting material test apparatus as in claim 1, wherein said drive mechanism includes a hydraulic cylinder mated to said cross-sectional size of said penetration shaft and providing a capability of exerting test probe head pressure in a range to at least 150 psi over a displacement from the surface of a section of compressible arresting material to a penetration depth equal to at least 60 percent of the thickness of said section.

9. Arresting material test apparatus as in claim 1, wherein said load continuously sensing device has a capability to sense force on said test probe head in a range to at least 100 psi as said test probe head is displaced from the surface of a section of compressible arresting material to a penetration depth equal to at least 60 percent of the thickness of said section.

10. An arresting material test probe, suitable to test compressive gradient strength continuously from the surface to an internal depth of penetration within compressible arresting material, comprising:

a penetration shaft having a length not less than said internal depth of penetration and a cross-sectional size; and

a test probe head connected to said penetration shaft and having a compressive contact surface;

said penetration shaft including a constricted shaft portion, beginning behind said test probe head and continuing for at least a part of said length, said constricted shaft portion having a smaller cross-sectional area than the area of said contact surface of said test probe;

the smaller cross-sectional area of said constricted shaft portion being effective to reduce distortive effects of post-compression build-up of material behind said contact surface as it travels from the surface to said internal depth of penetration within compressible arresting material under test, and the combination of said compressive contact surface and smaller cross-sectional area of said constricted shaft portion being effective to enable determination of compressive gradient strength over said depth of penetration within a section of compressible arresting material to be tested.

11. An arresting material test probe as in claim 10, wherein said test probe head has a flat circular contact surface.

12. An arresting material test probe as in claim 10, wherein said test probe head has a flat contact surface with an area in a range from 1 to 4 square inches.

13. An arresting material test probe as in claim 12, wherein said contact surface is circular.

14. An arresting material test probe as in claim 10, wherein said constricted shaft portion of said penetration shaft continues behind said test probe head for at least the intended depth of penetration and has a cross-sectional area in a range of 10 to 50 percent smaller than said contact surface.

15. An arresting material test probe as in claim 10, wherein said penetration shaft and test probe head are constructed to withstand compressive forces associated with a test probe head pressure in a range to at least 150 psi.

16. An arresting material test probe as in claim 10, wherein said contact surface of said test probe head has a surface hardness adequate to survive compression testing of cellular concrete to pressures of at least 150 psi, without significant surface distortion.

17. A method for continuous compressive testing of a cellular concrete section suitable for arresting motion of an object, comprising the steps of:

(a) providing a penetration shaft bearing a test probe head with a compressive contact surface having a contact surface area;

(b) providing a test section of cellular concrete having a thickness and having a cross-sectional area larger than said contact surface area;

(c) supporting said test section longitudinally;

(d) driving said contact surface of said test probe head longitudinally into said test section from a surface to an internal depth of penetration within said test section;

(e) monitoring displacement of said test probe head; and

(f) monitoring compressive force on said contact surface at a plurality of intermediate depths of penetration within said test section.

18. A method as in claim 17, wherein step (a) comprises providing said penetration shaft with a constricted shaft portion beginning behind said test probe head, said constricted shaft portion having a smaller cross-sectional area than said contact surface area, said smaller cross-sectional area being effective to reduce distortive effects of post-compression build-up of material behind said test probe head during penetration of said cellular concrete section.

19. A method as in claim 18, wherein said penetration shaft is provided with a shaft portion having a cross-sectional area in a range of 10 to 50 percent smaller than contact surface area.

20. A method as in claim 17, wherein step (a) comprises providing said test probe head with a flat circular contact surface.

21. A method as in claim 17, wherein step (a) comprises providing said test probe head with a flat contact surface having a contact surface area in a range from 1 to 4 square inches.

22. A method as in claim 21, wherein said test probe head is provided with a circular contact surface.

23. A method as in claim 17, wherein step (b) comprises providing said test section having a cross-sectional area at least twenty times larger than said contact surface area.

24. A method as in claim 17, wherein step (c) comprises supporting the bottom of said test section, with an absence of lateral restriction of the sides of said test section.

25. A method as in claim 17, wherein step (d) comprises driving said contact surface continuously to an internal depth of penetration equal to at least 60 percent of the thickness of said test section.

26. A method as in claim 17, wherein step (f) comprises recording pressure on the contact surface of said test probe head on a continuous basis until said contact surface reaches an internal depth of penetration of at least 60 percent of the thickness of said test section.

27. A method for determining compressive gradient strength over a depth of penetration of a test section, comprising the steps of:

(a) driving a contact surface into said test section to an internal depth of penetration within said test section equal to at least 60 percent of the thickness of said test section;

(b) during step (a), recording a measure of compressive force on said contact surface for a plurality of intermediate depths of penetration within said test section; and

(c) making available a presentation of a gradient representing values of compressive force at said plurality of intermediate depths of penetration.

28. A method as in claim 27, wherein step (a) comprises driving a contact surface into a test section of cellular concrete.

29. A method as in claim 27, wherein step (a) includes using a contact surface having an area not greater than 5 percent of the cross-sectional area of said test section.

30. A method for determining compressive gradient strength over a depth of penetration of a test section of compressible material, comprising the steps of:

(a) driving a flat contact surface into said test section to compress said compressible material from a surface to an internal depth of penetration within said test section;

(b) during compression in step (a), recording a measure of compressive force on said contact surface for a plurality of intermediate depths of penetration within said test section; and

(c) making available a presentation of compressive gradient strength representing values of compressive force at said plurality of intermediate depths of penetration during compression of said compressible material.

31. A method as in claim 30, wherein step (a) comprises driving a contact surface into a test section of cellular concrete.

32. A method as in claim 30, wherein step (b) comprises recording compressive force in pounds at least ten times per second while step (a) is implemented.

33. A method as in claim 30, wherein step (c) comprises making available a gradient in the form of a line joining points each representing a value of compressive force at an intermediate depth of penetration within said test section.

34. A method as in claim 33, wherein said gradient is made available as a computer printout.

* * * * *

附錄四-EMAS 基塊數量統計表（摘錄部分表單）

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
0000411827	TAIPEI B00510	BFB-060-06	A-296	56433C	WW01	1
				56467C	WW01	1
				56668C	WW01	1
				56729B	WW01	1
				56749A	WW01	1
				56752B	WW01	1
				56753B	WW01	1
				57156D	WW01	1
			A-297	56257A	WW01	1
				56640A	WW01	1
				56643A	WW01	1
				56665C	WW01	1
				56666C	WW01	1
				56667C	WW01	1
				56729A	WW01	1
				56752A	WW01	1
			A-298	56424C	WW01	1
				56583B	WW01	1
				56588B	WW01	1
				56590B	WW01	1
				56643B	WW01	1
				56682C	WW01	1
				56749B	WW01	1
				56750A	WW01	1
			A-299	56433B	WW01	1
				56442A	WW01	1
				56568C	WW01	1
				56583A	WW01	1
				56588A	WW01	1
				56600B	WW01	1
				56663C	WW01	1
				56669C	WW01	1
			A-300	56462C	WW01	1
				56499B	WW01	1
				56500A	WW01	1

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
				56566C	WW01	1
				56600A	WW01	1
				56607B	WW01	1
				56640B	WW01	1
				56672C	WW01	1
			A-302	56439B	WW01	1
				56607A	WW01	1
				56641B	WW01	1
			A-304	58410C	WW01	1
				58412C	WW01	1
				58413C	WW01	1
				58425C	WW01	1
				58441C	WW01	1
				58479C	WW01	1
				58496C	WW01	1
				58548C	WW01	1
			A-305	56468C	WW01	1
				56498B	WW01	1
				56582B	WW01	1
				56584B	WW01	1
				58416C	WW01	1
				58495C	WW01	1
				58539C	WW01	1
				58547C	WW01	1
			Total			59
		BFB-060-06/07	AA-358	47192C	WW01	1
				47193C	WW01	1
				47194C	WW01	1
				47195C	WW01	1
				47437C	WW01	1
				47442C	WW01	1
				47445C	WW01	1
				47446C	WW01	1
			AA-389	52658C	WW01	1
				52662C	WW01	1

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
				52666C	WW01	1
				52668C	WW01	1
				52683C	WW01	1
				52684C	WW01	1
				52690C	WW01	1
				52691C	WW01	1
			AA-390	52677C	WW01	1
				52678C	WW01	1
				52679C	WW01	1
			AA-392	51185C	WW01	1
				52675C	WW01	1
				52701C	WW01	1
				52706C	WW01	1
				52708C	WW01	1
				52949B	WW01	1
				53770C	WW01	1
				53776C	WW01	1
			AA-416	56416B	WW01	1
				56441B	WW01	1
				56442B	WW01	1
				56445B	WW01	1
				56462A	WW01	1
				56478B	WW01	1
				56830A	WW01	1
				56831B	WW01	1
			AA-417	56414A	WW01	1
				56414B	WW01	1
				56416A	WW01	1
				56426B	WW01	1
				56441A	WW01	1
				56445A	WW01	1
				56487B	WW01	1
				56843A	WW01	1
			AA-418	56440A	WW01	1
				56440B	WW01	1

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
				56450A	WW01	1
				56450B	WW01	1
				56453A	WW01	1
				56454A	WW01	1
				56462B	WW01	1
				56489B	WW01	1
			AA-420	56453B	WW01	1
				56454B	WW01	1
				57069C	WW01	1
				58413A	WW01	1
				58416A	WW01	1
				58416B	WW01	1
				58455B	WW01	1
				58458A	WW01	1
			Total			59
		BFB-060-07	B-321	52795C	WW01	1
				52799C	WW01	1
				52800C	WW01	1
			B-322	51085C	WW02	1
				51104C	WW02	1
				56476A	WW02	1
				56476B	WW02	1
				56479A	WW02	1
				56489A	WW02	1
				56920B	WW02	1
				56920C	WW02	1
			B-323	56475B	WW02	1
				56477A	WW02	1
				56477B	WW02	1
				56488A	WW02	1
				56491B	WW02	1
				56828B	WW02	1
				56830B	WW02	1
				56831A	WW02	1
			B-324	56490A	WW02	1

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
			U-4966	58662B	WW58	1
			U-4967	58567B	WW57	1
			U-4968	58792B	WW58	1
			U-4969	58794B	WW58	1
			U-4970	58801A	WW58	1
			U-4971	58801B	WW57	1
			U-4972	58792A	WW58	1
			U-4973	58800B	WW57	1
			U-4974	58384B	WW57	1
			U-4975	58799A	WW57	1
			U-4976	58800A	WW	1
			U-4977	58798A	WW	1
			U-4978	58799B	WW	1
			U-4979	58794A	WW	1
			U-4980	58798B	WW	1
			U-4981	58802A	WW	1
			U-4982	58307B	WW	1
			U-4983	58305A	WW	1
			U-4984	58796B	WW	1
			U-4985	58797A	WW	1
			U-4986	58807A	WW	1
			U-4991	58333B	WW	1
			U-5011	58593B	WW67	1
			U-5014	58797B	RR49	1
			U-5015	57300B	WW49	1
			Total			1,774
		BFB-060-413/57 6	SR-162	16216B	RR49	1
				57347A	RR49	1
				57347B	RR49	1
				58933B	RR49	1
				58934B	RR49	1
			Total			5
		BFB-060-576/7.5	SR-163	26689C	RR49	1
				57066C	RR49	1
				57067C	RR49	1

Order Number	Reference Text	Item Number	Container2	Lot Number	Location	On-Hand Balance
				57344A	RR49	1
				57344B	RR49	1
			Total			5
	Job Total					5,739

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附錄五-FAA 諮詢公告 AC150/5220-22A 規定

U.S. Department of Transportation

Federal Aviation Administration

Advisory Circular

Subject: Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns

Date: 9/30/2005
Initiated by: AAS-100

AC No: 150/5220-22A
Change:

1. **PURPOSE.** This advisory circular (AC) contains standards for the planning, design, installation, and maintenance of Engineered Materials Arresting Systems (EMAS) in runway safety areas (RSA). Engineered Materials means high energy absorbing materials of selected strength, which will reliably and predictably crush under the weight of an aircraft.

2. **CANCELLATION.** This AC cancels AC 150/5220-22, *Engineered Materials Arresting Systems (EMAS) for Aircraft Overruns*, dated August 28, 1998.

3. **BACKGROUND.** Aircraft can and do overrun the ends of runways, sometimes with devastating results. An overrun occurs when an aircraft passes beyond the end of a runway during an aborted takeoff or while landing. Data on aircraft overruns over a 12-year period (1975 to 1987) indicate that approximately 90% of all overruns occur at exit speeds of 70 knots or less (Reference 7, Appendix 4) and most come to rest between the extended runway edges within 1000 feet of the runway end (Reference 6, Appendix 4).

To minimize the hazards of overruns, the Federal Aviation Administration (FAA) incorporated the concept of a safety area beyond the runway end into airport design standards. To meet the standards, the safety area must be capable, under normal (dry) conditions, of supporting the occasional passage of aircraft that overrun the runway without causing structural damage to the aircraft or injury to its occupants. The safety area also provides greater accessibility for emergency equipment after an overrun incident. There are many runways, particularly those constructed prior to the adoption of the safety area standards, where natural obstacles, local development, and/or environmental constraints, make the construction of a standard safety area impracticable. There have been accidents at some of these airports where the ability to stop an overrunning aircraft within the runway safety area would have prevented major damage to aircraft and/or injuries to passengers.

Recognizing the difficulties associated with achieving a standard safety area at all airports, the FAA undertook research programs on the use of various materials for arresting systems. These research programs, as well as, evaluation of actual aircraft overruns into an EMAS have demonstrated its effectiveness in arresting aircraft overruns.

4. **APPLICATION.** Runway safety area standards cannot be modified or waived. The standards remain in effect regardless of the presence of natural or man-made objects or surface conditions that might create a hazard to aircraft that overrun the end of a runway. A continuous evaluation of all practicable alternatives for improving each sub-standard RSA is required. FAA Order 5200.8, *Runway Safety Area Program*, explains the evaluation process.

FAA Order 5200.9, *Financial Feasibility and Equivalency of Runway Safety Area Improvements and Engineered Material Arresting Systems*, is used in connection with FAA Order 5200.8 to determine the best practicable and financially feasible alternative for an RSA improvement.

The FAA does not require an airport sponsor to reduce the length of a runway or declare its length to be less than the actual pavement length to meet runway safety area standards if there is an operational impact to the airport. An example of an operational impact would be an airport's inability to accommodate its current or planned aircraft fleet. Under these circumstances, installing an EMAS is another way of enhancing safety.

A standard EMAS provides a level of safety that is generally equivalent to a full RSA built to the dimensional standards in AC 150/5300-13, *Airport Design*. It also provides an acceptable level of safety for undershoots.

The FAA recommends the guidelines and standards in this AC for the design of EMAS. In general, this AC is not mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline a method of compliance. However, use of these guidelines is mandatory for an airport sponsor installing an EMAS funded under Federal grant assistance programs or on an airport certificated under Title 14 Code of Federal Regulations (CFR) Part 139, *Certification of Airports*. Mandatory terms such as "shall" or "must" used herein apply only to those who seek to demonstrate compliance by use of the specific method described by this AC.

If an airport sponsor elects to follow an alternate method, the alternate method must have been determined by the FAA to be an acceptable means of complying with this AC, the runway safety area standards in AC 150/5300-13, and 14 CFR Part 139.

5. RELATED READING MATERIAL. Appendix 4, Related Reading Material, contains a list of documents with supplemental material relating to EMAS. These documents contain information on materials evaluated, as well as design, construction, and testing procedures utilized. Testing and data generated under these FAA studies may be used as input to an EMAS design without additional justification.

6. PLANNING CHARTS. The figures included in Appendix 2, Planning Charts, are for planning purposes only. They are intended as a preliminary screening tool and are not sufficient for final design. Final design must be customized for each installation. The figures illustrate estimated EMAS stopping distance capabilities for various aircraft types. The design used in each chart is optimized specifically for the aircraft noted on the chart. Charts are based on standard design conditions, i.e. 75-foot set-back, no reverse thrust, and poor braking (0.25 braking friction coefficient).

a. Example 1. Assume a runway with a DC-9 (or similar) as the design aircraft. Figure A2-1 shows that an EMAS 400 feet in length (including a 75-foot set-back) is capable of stopping a DC-9 within the confines of the system at runway exit speeds of up to 75 knots.

b. Example 2. Assume the same runway, but assume the design aircraft is a DC-10 (or similar). Figure A2-2 shows an EMAS of the same length, but designed for larger aircraft, can stop the DC-10 within the confines of the system at runway exit speeds of up to 62 knots.

7. PRELIMINARY PLANNING. Follow the guidance in FAA Orders 5200.8 and 5200.9 to determine practicable, financially feasible alternatives for RSA improvements. Additional cost and performance information for EMAS options to consider in the analysis can be obtained from the EMAS manufacturer.

8. SYSTEM DESIGN REQUIREMENTS. For purposes of design, the EMAS can be considered fixed by its function and frangible since it is designed to fail at a specified impact load. An aircraft arresting system such as EMAS is exempt from the requirements of 14 CFR Part 77, *Objects Affecting Navigable Airspace*. When EMAS is the selected option to upgrade a runway safety area, it is considered to meet the safety area requirements of 14 CFR Part 139. The following system design requirements must prevail for all EMAS installations:

a. Concept. An EMAS is designed to stop an overrunning aircraft by exerting predictable deceleration forces on its landing gear as the EMAS material crushes. It must be designed to minimize the potential for structural damage to aircraft, since such damage could result in injuries to passengers and/or affect the predictability of deceleration forces. An EMAS should be design for a 20-year service life.

b. Location. An EMAS is located beyond the end of the runway and centered on the extended runway centerline. It will usually begin at some setback distance from the end of the runway to avoid damage due to jet blast and undershoots (Figure A1-2, Appendix 1). This distance will vary depending on the available area and the EMAS materials. Where the area available is longer than required for installation of a standard EMAS designed to stop the design aircraft at an exit speed of 70 knots, the EMAS should be placed as far from the runway end as practicable. Such placement decreases the possibility of damage to the system from short overruns or undershoots and results in a more economical system by considering the deceleration capabilities of the existing runway safety area.

The resulting runway safety area must provide adequate protection for aircraft that touch down prior to the runway threshold (undershoot). Adequate protection is provided by either: (1) providing at least 600 feet (or the length of the standard runway safety area, whichever is less) between the runway threshold and the far end of the EMAS bed if the approach end of the runway has vertical guidance or (2) providing the full length standard runway safety area when no vertical guidance is provided.

An EMAS is not intended to meet the definition of a stopway as provided in AC 150/5300-13. The runway safety area and runway object free area lengths begin at a runway end when a stopway is not provided. When a stopway is provided, these lengths begin at the stopway end (AC 150/5300-13).

The airport sponsor, EMAS manufacturer, and the appropriate FAA Regional Airports Division/Airport District Office (ADO) should consult regarding the EMAS location to determine the appropriate location beyond the end of the runway for the EMAS installation for a specific runway.

c. Design Method. An EMAS design must be supported by a validated design method that can predict the performance of the system. The design (or critical) aircraft is defined as that aircraft using the associated runway that imposes the greatest demand upon the EMAS. This is usually, but not always, the heaviest/largest aircraft that regularly uses the runway. EMAS performance is dependent not only on aircraft weight, but landing gear configuration and tire pressure. In general, use the maximum take-off weight (MTOW) for the design aircraft. However, there may be instances where less than the MTOW will require a longer EMAS. All configurations should be considered in optimizing the EMAS design. To the extent practicable, however, the EMAS design should consider both the aircraft that imposes the greatest demand upon the EMAS and the range of aircraft expected to operate on the runway. In some instances, this composite design aircraft may be preferable to optimizing the EMAS for a single design aircraft. Other factors unique to a particular airport, such as available RSA and air cargo operations, should also be considered in the final design. The airport sponsor, EMAS manufacturer, and the appropriate FAA Regional Airports Division/ADO should consult regarding the selection of the design aircraft that will optimize the EMAS for a specific airport.

The design method must be derived from field or laboratory tests. Testing may be based either on passage of an actual aircraft or an equivalent single wheel load through a test bed. The design must consider multiple aircraft parameters, including but not limited to allowable aircraft gear loads, gear configuration, tire contact pressure, aircraft center of gravity, and aircraft speed. The model must calculate imposed aircraft gear loads, g-forces on aircraft occupants, deceleration rates, and stopping distances within the arresting system. Any rebound of the crushed material that may lessen its effectiveness must also be considered.

d. Operation. The EMAS must be a passive system.

e. Width. The minimum width of the EMAS must be the width of the runway (plus any sloped area as necessary—see 8 (h) below).

f. Base. The EMAS must be constructed on a paved surface capable of supporting the occasional passage of the critical design aircraft using the runway and fully loaded Aircraft Rescue and Fire Fighting (ARFF) vehicles without deformation of the base surface or structural damage to the aircraft or vehicles. It must be designed to perform satisfactorily under all local weather, temperature, and soil conditions. It must provide sufficient support to facilitate removal of the aircraft from the EMAS. Full strength runway pavement is not required. Pavement suitable for shoulders and blast pads is suitable as an EMAS base. AC 150/5300-13 provides recommendations on pavement for shoulders and blast pads. State highway specifications may also be used.

g. Entrance Speed. To the maximum extent possible, the EMAS must be designed to decelerate the design aircraft expected to use the runway at exit speeds of 70 knots (approach category C and D aircraft) without imposing loads that exceed the aircraft's design limits, causing major structural damage to the aircraft or imposing excessive forces on its occupants. Contact the FAA's Airport Engineering Division (AAS-100) at 202-267-7669 for guidance when other than approach category C and D aircraft is proposed for the EMAS design. Standard design conditions are no reverse thrust and poor braking (0.25 braking friction coefficient).

Generally, when there is insufficient RSA available for a standard EMAS, the EMAS must be designed to achieve the maximum deceleration of the design aircraft within the available runway safety area. However, a 40-knot minimum exit speed should be used for the design of a non-standard EMAS. For design purposes, assume the aircraft has all of its landing gear in full contact with the runway and is traveling within the confines of the runway and parallel to the runway centerline upon overrunning the runway end.

The airport sponsor, EMAS manufacturer, and the appropriate FAA Regional Airports Division/ADO should consult regarding the selection of the appropriate design entrance speed for the EMAS installation.

Note that current EMAS models are not as accurate for aircraft with a maximum take-off weight less than 25,000 pounds.

h. Aircraft Evacuation. The EMAS must be designed to enable safe ingress and egress as well as movement of ARFF equipment (not necessarily without damage to the EMAS) operating during an emergency. If the EMAS is to be built above existing grade, sloped areas sufficient to allow the entrance of ARFF vehicles from the front and sides must be provided. Provision for access from the back of the EMAS may be provided if desirable. Maximum slopes must be based on the EMAS material and performance characteristics of the airport's ARFF equipment.

i. Maintenance Access. The EMAS must be capable of supporting regular pedestrian traffic for the purposes of maintenance of the arresting material and co-located navigation aids without damage to the surface of the EMAS bed. An EMAS is not intended to support vehicular traffic for maintenance purposes.

j. Undershoots. The EMAS must not cause control problems for aircraft undershoots which touch down in the EMAS bed. Fulfillment of this requirement may be based exclusively on flight simulator tests. The tests will establish the minimum material strength and density that does not cause aircraft control problems during an undershoot. Materials whose density and strength exceeds these minimums will be deemed acceptable.

k. Navigation Aids. The EMAS must be constructed to accommodate approach lighting structures and other approved facilities within its boundaries. It must not cause visual or electronic interference with any air navigation aids. All navigation aids within the EMAS must be frangible as required by 14 CFR Part 139. To meet the intent of this regulation, approach light standards must be designed to fail at two points. The first point of frangibility must be three inches or less above the top of the EMAS bed. The second point of frangibility must be three inches or less above the expected residual depth of the EMAS bed after passage of the design aircraft. As a part of the EMAS design, the EMAS manufacturer must provide the expected residual depth to allow the determination of this second frangibility point.

l. Drainage. The EMAS must be designed to prevent water from accumulating on the surface of the EMAS bed, the runway or the runway safety area. The removal and disposal of water, which may hinder any activity necessary for the safe and efficient operation of the airport, must be in accordance with AC 150/5320-5, *Airport Drainage.*

The EMAS design must consider ice accumulation and/or snow removal limitations/requirements dictated by the project locale. Requirements/limitations must be addressed in the approved inspection and maintenance program discussed in paragraph 14 and Appendix 3.

m. Jet Blast. The EMAS must be designed and constructed so that it will not be damaged by expected jet blast.

n. Repair. The EMAS must be designed for repair to a usable condition within 45 days of an overrun by the design aircraft at the design entrance speed. Note that this is a design requirement only.

An EMAS bed damaged due to an incident (overrun/undershoot, etc.) must be repaired in a timely manner. The undamaged areas of the EMAS bed must be protected from further damage until the bed is repaired.

9. MATERIAL QUALIFICATION. The material comprising the EMAS must have the following requirements and characteristics:

a. Material Strength and Deformation Requirements. Materials must meet a force vs. deformation profile within limits having been shown to assure uniform crushing characteristics, and therefore, predictable response to an aircraft entering the arresting system.

b. Material Characteristics. The materials comprising the EMAS must:

(1) Be water-resistant to the extent that the presence of water does not affect system performance.

(2) Not attract vermin, birds, wildlife or other creatures.

(3) Be non-sparking.

(4) Be non-flammable.

(5) Not promote combustion.

(6) Not emit toxic or malodorous fumes in a fire environment after installation.

(7) Not support unintended plant growth with proper application of herbicides.

(8) Exhibit constant strength and density characteristics during all climatic conditions within a temperature range appropriate for the locale.

(9) Be resistant to deterioration due to:

(a) Salt.

(b) Approved aircraft and runway deicing fluids.

(c) Aircraft fuels, hydraulic fluids, and lubricating oils.

(d) UV resistant.

(e) Water.

(f) Freeze/thaw.

(g) Blowing sand and snow.

(h) Paint.

10. Material Conformance Requirements. An EMAS manufacturer must establish a material sampling and testing program to verify that all materials are in conformance with the initial approved material force versus deformation profile established under paragraph 9.a. Materials failing to meet these requirements must not be used.

The initial sampling and testing program must be submitted to and approved by the FAA, Office of Airport Safety and Standards for each design method found by the FAA to be an acceptable means of complying with this AC. Once approved, the program may be used for subsequent projects.

11. DESIGN PROPOSAL SUBMITTAL. The EMAS design must be prepared by the design engineer and the EMAS manufacturer for the airport sponsor. The airport sponsor must submit the EMAS design through the responsible FAA Airports Region/District Office, to the FAA, Office of Airport Safety and Standards, for review and approval. The EMAS design must be certified as meeting all the requirements of this AC and the submittal must include all design assumptions and data utilized in its development as well as proposed construction procedures and techniques. The EMAS design must be submitted at least 45 days prior to the bid opening date for the project.

12. QUALITY ASSURANCE (QA) PROGRAM. A construction quality assurance program must be implemented to ensure that installation/construction is in accordance with the approved EMAS design. The construction contractor and EMAS manufacturer prepare the construction QA program for the airport sponsor. The airport sponsor must submit the construction QA program to the responsible FAA Airports Region/District Office for approval 14 days prior to the project notice to proceed.

13. MARKING. An EMAS must be marked with yellow chevrons as an area unusable for landing, takeoff, and taxiing in accordance with AC 150/5340-1, *Standards for Airport Markings*. Paint application should be in accordance with the EMAS manufacturers' recommendations for the EMAS system.

14. INSPECTION AND MAINTENANCE. The EMAS manufacturer must prepare an inspection and maintenance program for the airport sponsor for each EMAS installation. The airport sponsor must submit the program to the responsible FAA Airports Region/District Office for approval prior to final project acceptance. The airport sponsor must implement the approved inspection and maintenance program. The program must include any necessary procedures for inspection, preventive maintenance and unscheduled repairs, particularly to weatherproofing layers. Procedures must be sufficiently detailed to allow maintenance/repair of the EMAS bed with the airport sponsor's staff. The program must include appropriate records to verify that all required inspections and maintenance have been performed by the airport sponsor and/or EMAS manufacturer. These records must be made available to the FAA upon request. Appendix 3, Inspection and Maintenance Program, outlines the basic requirements of an EMAS inspection and maintenance program.

Airport personnel must be notified that the EMAS is designed to fail under load and that precautions should be taken when activities require personnel to be on, or vehicles and personnel to be near, the EMAS.

15. AIRCRAFT RESCUE AND FIRE FIGHTING (ARFF).

a. Access. As required by paragraph 8 (h), an EMAS is designed to allow movement of typical ARFF equipment operating during an emergency. However, as the sides of the system are typically steeply sloped, and the system will be severely rutted after an aircraft arrestment, ARFF vehicles so equipped should be shifted into all-wheel-drive prior to entering and maneuvering upon an EMAS.

b. Tactics. Any fire present after the arrestment of an aircraft will be three-dimensional due to the rutting and breakup of the EMAS material. A dual-agent attack and/or other tactics appropriate to this type of fire should be employed.

16. NOTIFICATION. Upon installation of an EMAS, its length, width, and location must be included as a remark in the Airport/Facility Directory (AFD). To assure timely publication, the airport sponsor must forward the required information to the FAA Aeronautical Information Services (AIS) as soon as possible, but not later than the "cut-off" dates listed in the AFD, for publication on the desired effective date. (The AIS address and cut-off dates are listed on the inside front cover of the AFD.) The airport sponsor must also notify the appropriate FAA Regional Airports Division/ADO.

The following is an example of a typical entry:

- "Engineered Materials Arresting System, 400'L x 150'W, located at departure end of runway 16."

When an EMAS is damaged due to an overrun or determined to be less than fully serviceable, a Notice to Airmen (NOTAM) must be issued to alert airport users of the reduced performance of the EMAS.

DAVID L. BENNETT
Director of Airport Safety and Standards

APPENDIX 1. STANDARD EMAS AND TYPICAL SECTIONS.

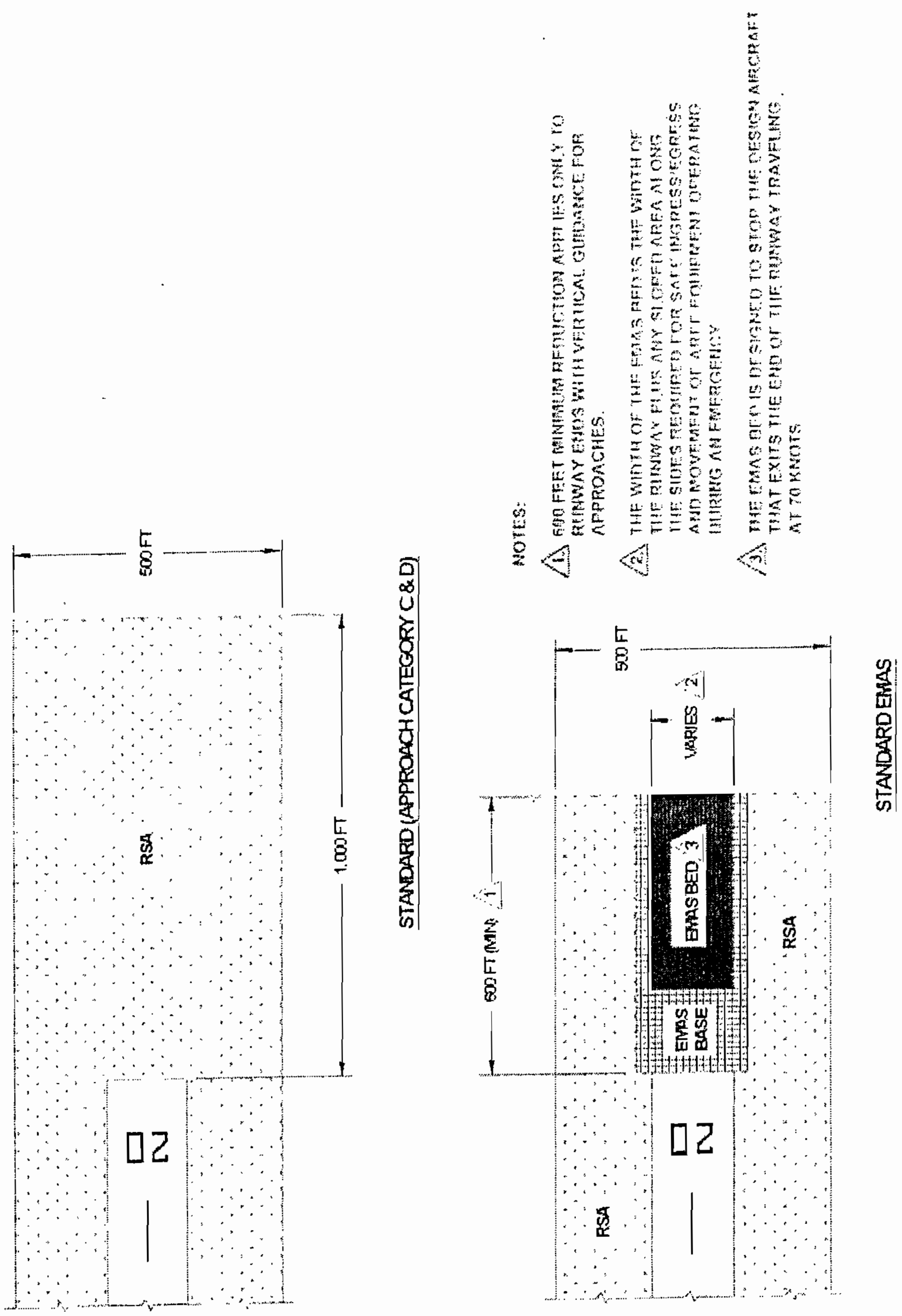


FIGURE A1-1. STANDARD EMAS INSTALLATION PROVIDES A LEVEL OF SAFETY THAT IS GENERALLY EQUIVALENT TO A STANDARD RUNWAY SAFETY AREA (RSA).

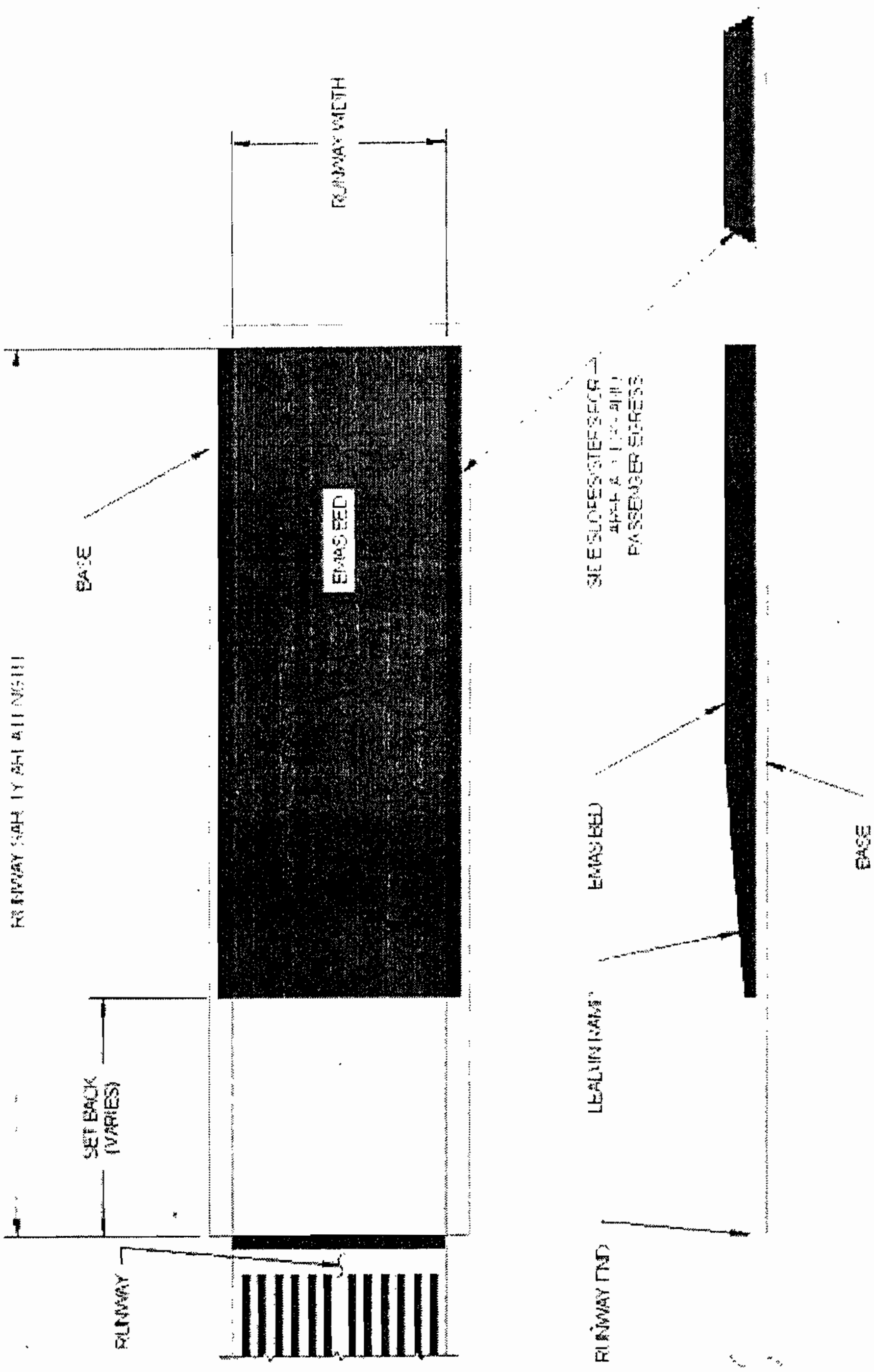
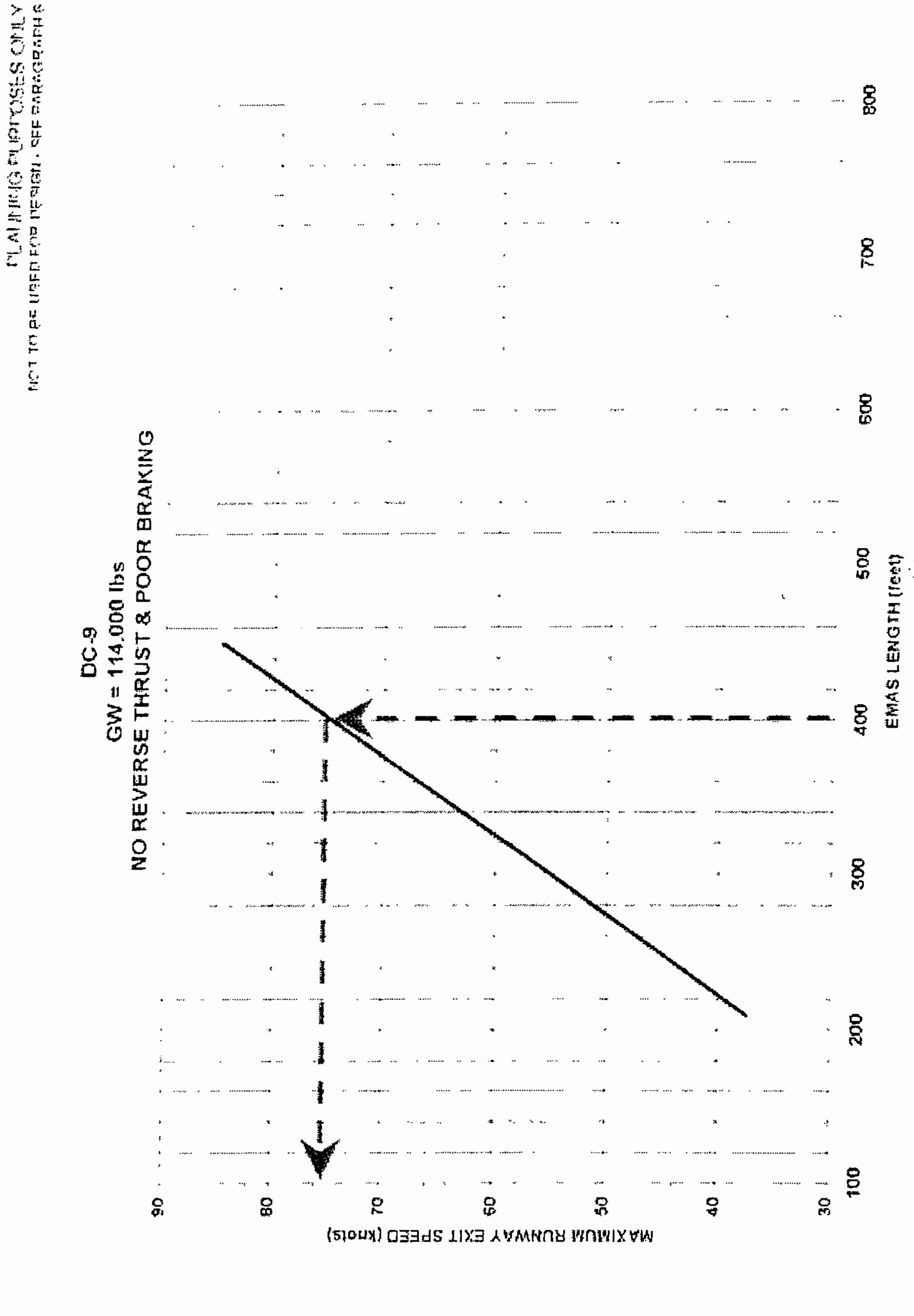


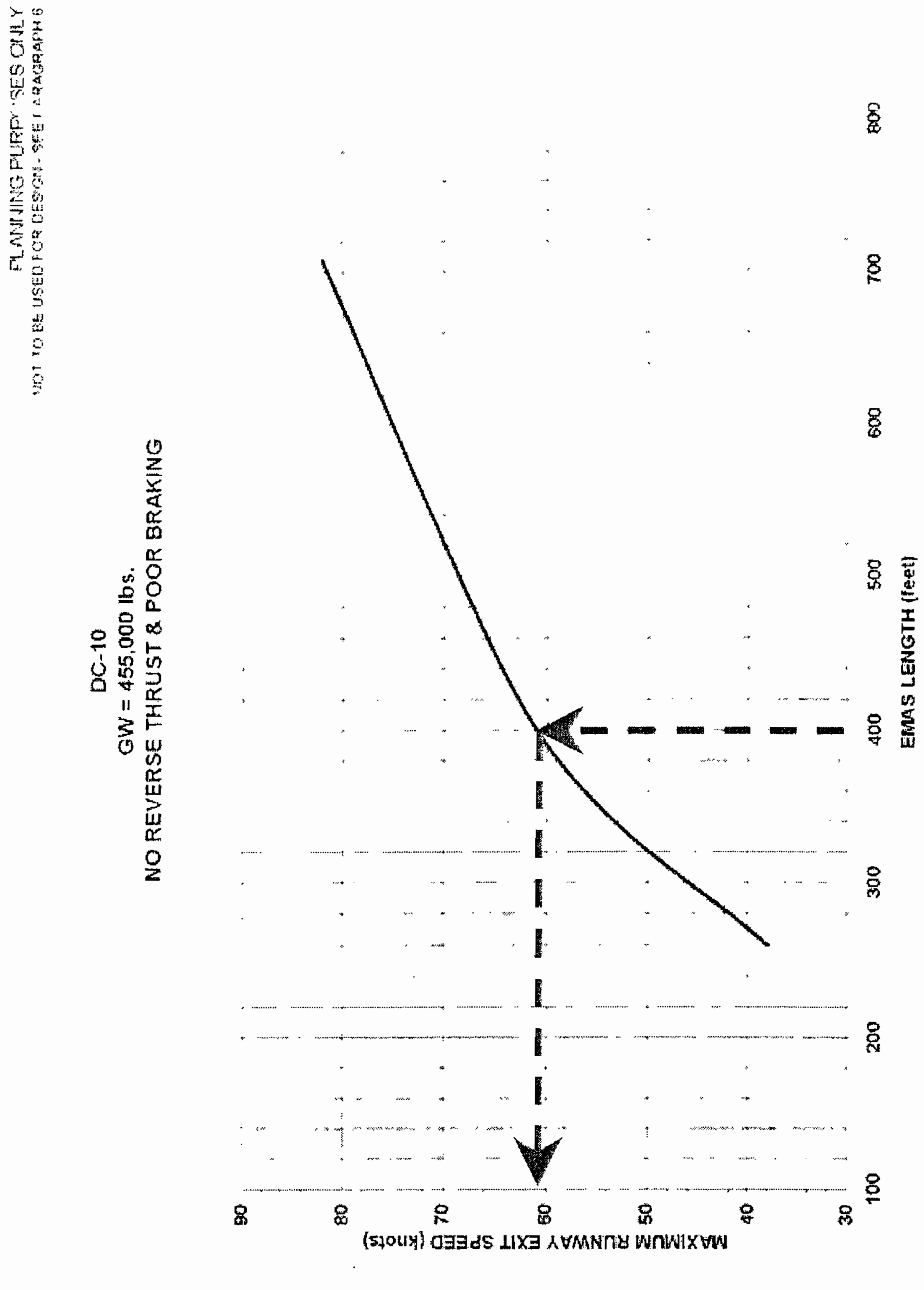
FIGURE A1-2. EMAS TYPICAL SECTION.

APPENDIX 2. PLANNING CHARTS.



Notes
1. Arrestor includes a 25 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using 0.25 braking friction coefficient.

FIGURE A2-1.

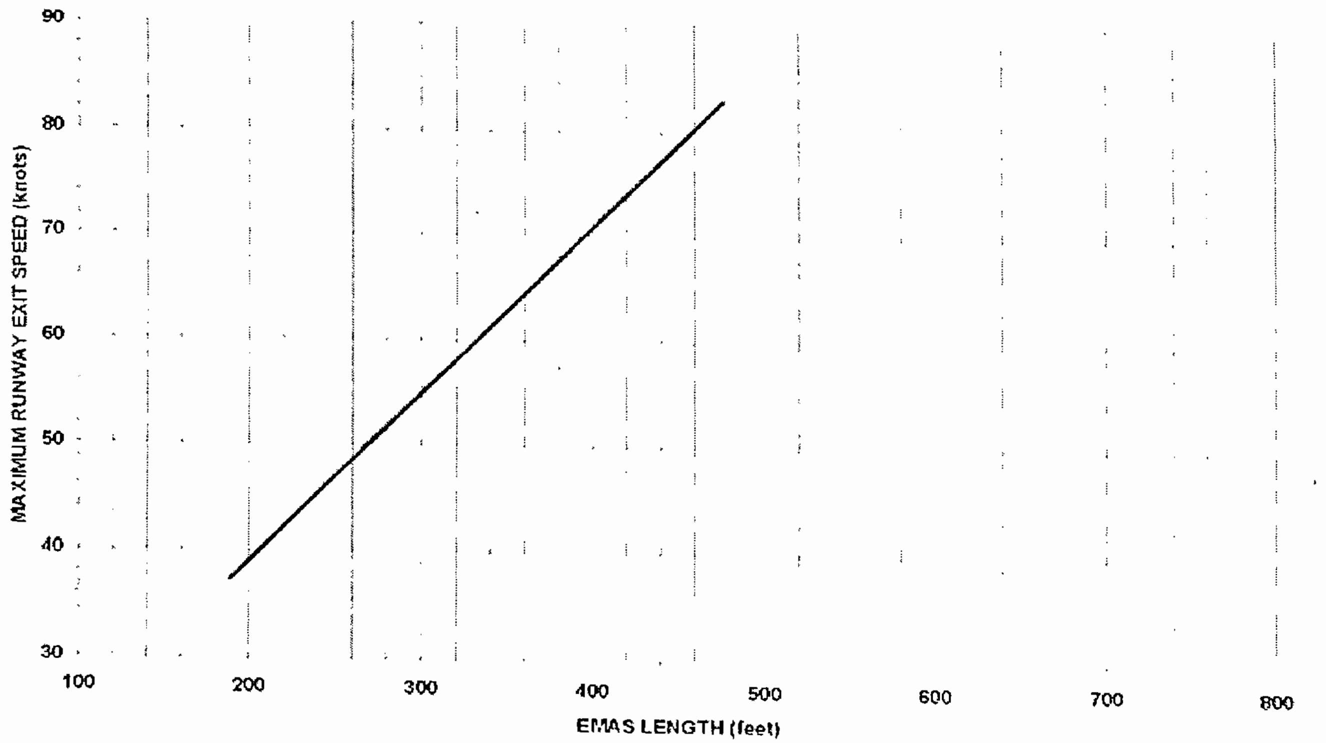


Notes
1 Arrestor includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas
2 Poor braking simulated using 0.25 braking friction coefficient

FIGURE A2-2.

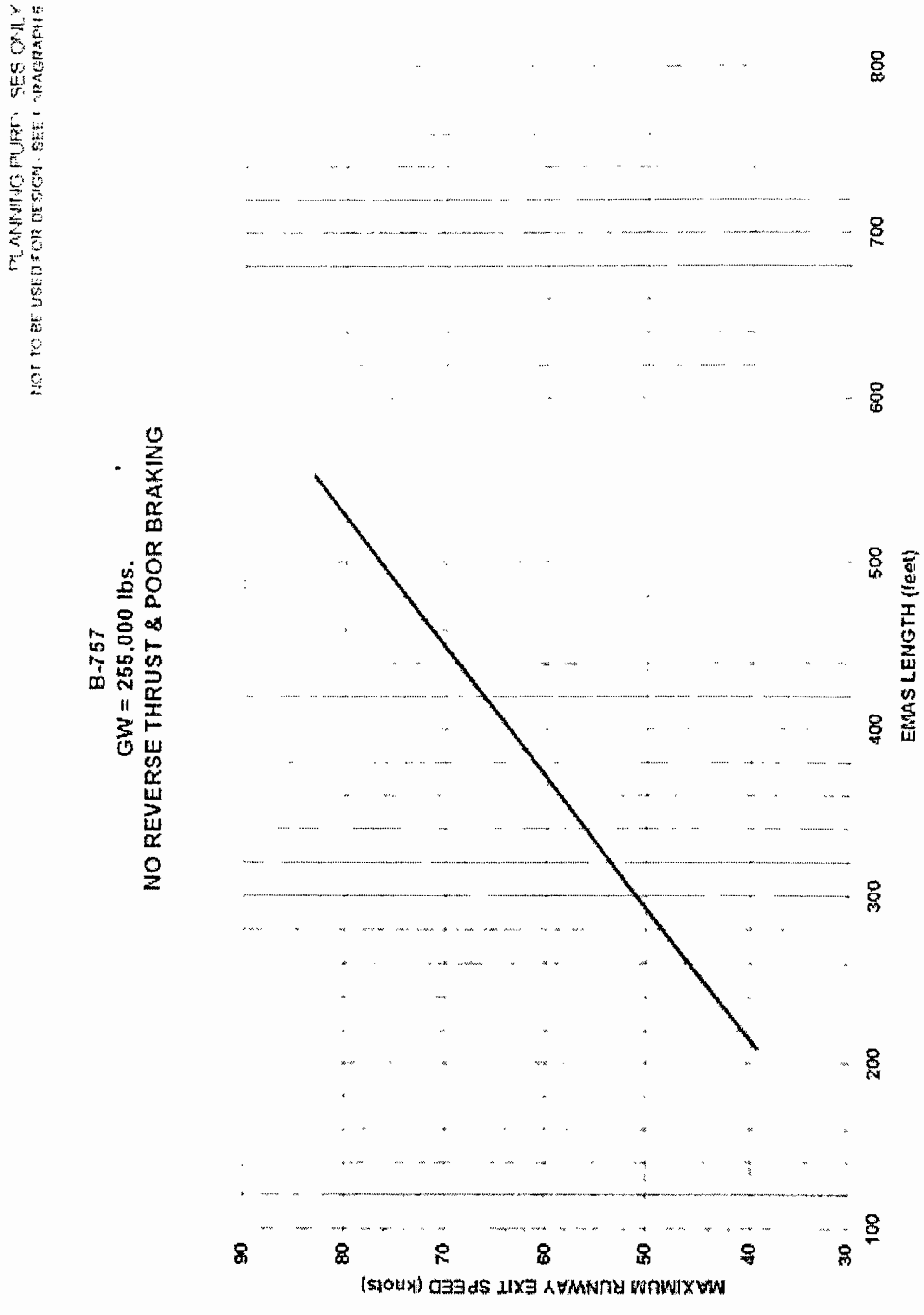
PLANNING PURPOSES ONLY
NOT TO BE USED FOR DESIGN SEE PARAGRAPH 6

B-737-400
GW = 150,000 lbs.
NO REVERSE THRUST & POOR BRAKING



Notes
1 Arrestor includes a 75 ft paved lead-in rigid ramp A 35 ft setback can be used to improve performance for short safety areas
2 Poor braking simulated using 0.25 braking friction coefficient

FIGURE A2-3.



Notes
1 Arrestor includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas
2 Poor braking simulated using 0.25 braking friction coefficient

FIGURE A2-4.

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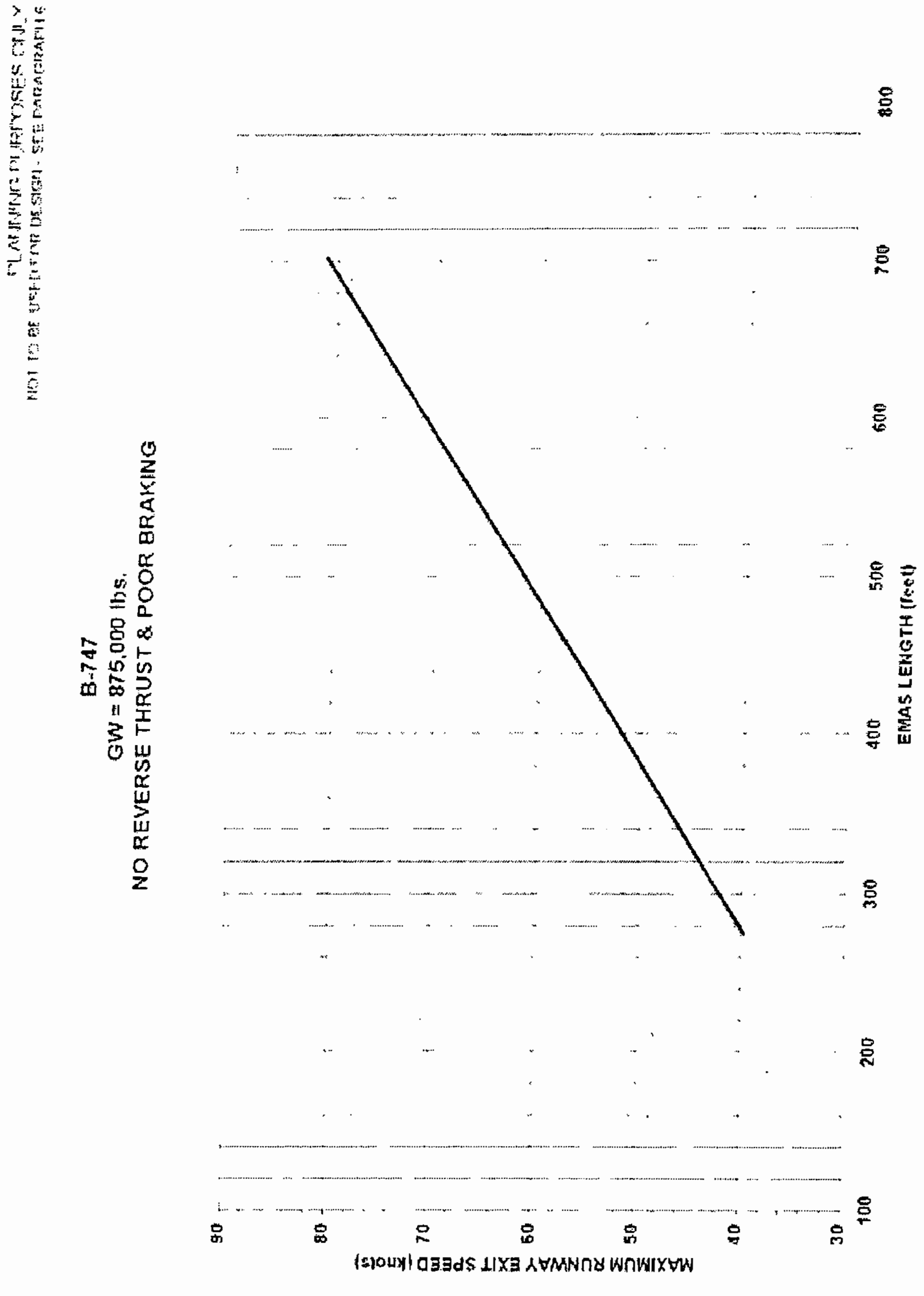


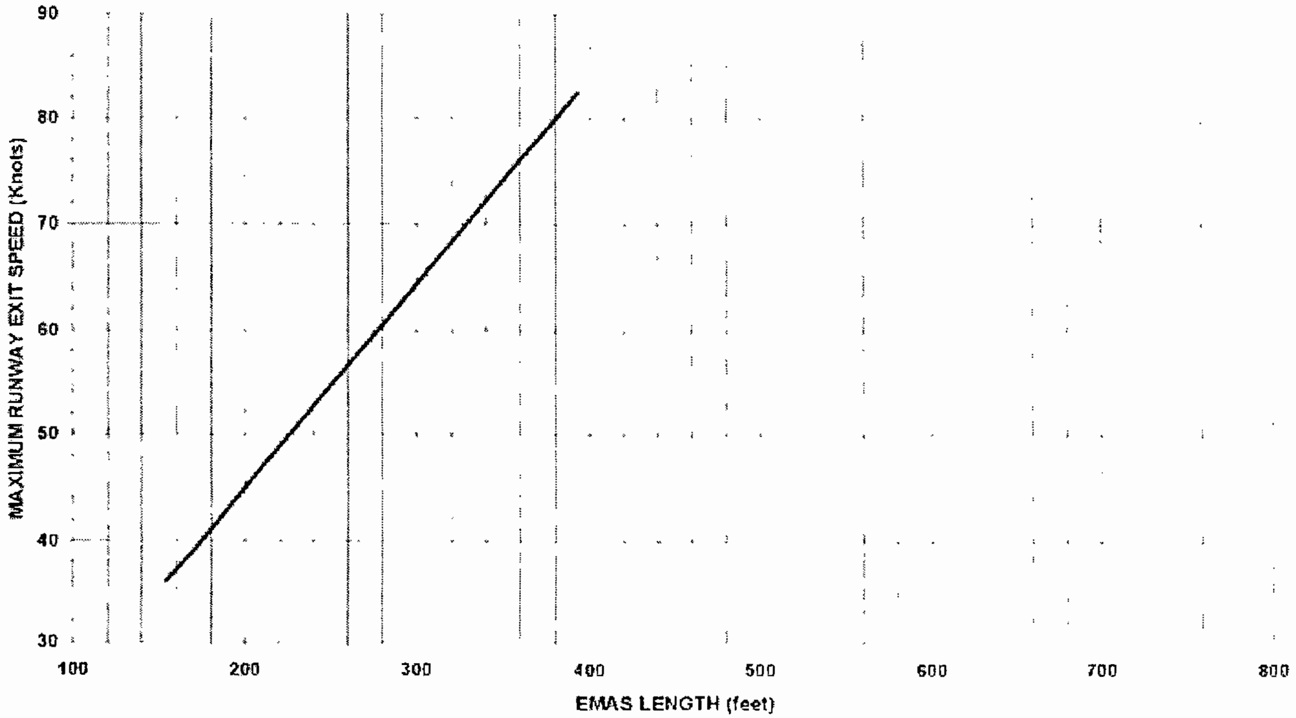
Notes

1. Arrestor includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas
2. Poor braking simulated using 0.25 braking friction coefficient

FIGURE A2-5.

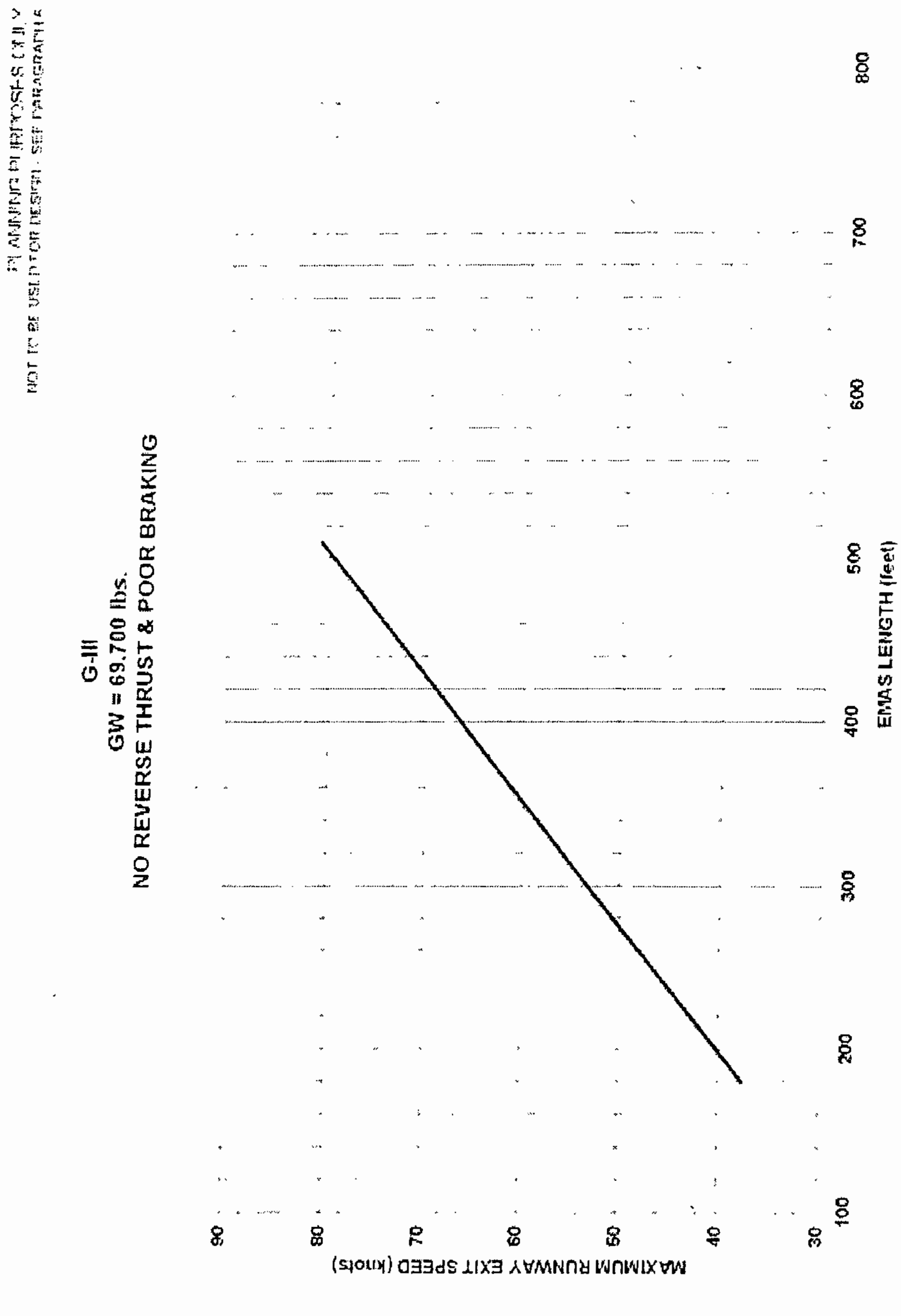
PLANNING PURPOSES ONLY
NOT TO BE USED FOR DESIGN. SEE PARAGRAPH 5

CRJ-200
GW = 53,000 lbs.
NO REVERSE THRUST & POOR BRAKING



Notes
1. Arrestor includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas
2. Poor braking simulated using 0.25 braking friction coefficient

FIGURE A2-6.



Notes:
1. Arrestor includes a 75 ft paved lead-in rigid ramp. A 35 ft setback can be used to improve performance for short safety areas.
2. Poor braking simulated using 0.25 braking friction coefficient.

FIGURE A2-7.

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APPENDIX 3. INSPECTION AND MAINTENACE PROGRAM.

An inspection and maintenance program, prepared by the EMAS manufacturer, will be submitted to and approved by the FAA Regional/Airports District Office. The Airport sponsor must implement the approved inspection and maintenance program. As a minimum, a basic EMAS inspection and maintenance program must address the following areas:

1. General information on the EMAS bed including
   - A description of the EMAS bed
   - Material description
   - Contact information for the EMAS manufacturer
2. Inspection requirements including:
   - Type and frequency of required inspections
   - Training of personnel
   - Instructions on how to conduct each inspection
   - List of typical problems and possible solutions
   - Required documentation for inspections
   - Inspection forms
3. Maintenance and repair procedures including:
   - List of approved materials and tools
   - Description of repair procedures for typical damage to an EMAS bed such as repairing depressions/holes, abrasion damage, replacing a damaged block, repairing coatings, caulking/joint repair, etc.

4. Any unique requirements due to location such as snow removal requirements and methods. Identify compatible deicing agents. Specify snow removal equipment that is compatible with the EMAS bed and recommended clearing procedures and/or limitations.

5. Warranty information

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APPENDIX 4. RELATED READING MATERIAL.

This appendix contains a listing of documents with supplemental material relating to the subject of EMAS. These documents contain certain information on materials evaluated as well as design, construction, and testing procedures utilized to date. These publications may be obtained from the National Technical Information Service (NTIS), Springfield, VA 22151.

1. DOT/FAA/PM-87/27, *Soft Ground Arresting Systems*. Final Report, Sept. 1986–Aug. 1987. published Aug. 1987 by R.F. Cook. Universal Energy Systems. Inc., Dayton, OH.

2. 2. DOT/FAA/CT-93/4, *Soft Ground Arresting Systems for Commercial Aircraft*. Interim Report. Feb. 1993 by Robert Cook.

3. DOT/FAA/CT-93/80, *Soft Ground Arresting Systems for Airports*. Final Report. Dec. 1993 by Jim White, Satish K. Agrawal, and Robert Cook.

4. DOT/FAA/AOV 90-1. *Location of Commercial Aircraft Accidents/Incidents Relative to Runways*. July 1990.

5. UDR-TR-88-07. *Evaluation of a Foam Arrestor Bed for Aircraft Safety Overrun Areas*. 1988 by Cook, R.F., University of Dayton Research Institute, Dayton, OH.

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