Tarsier® Overview
Tinker and the Primes

Guy Berry
gberry@moog.com
Moog – When Performance Really Matters™

- Founded in 1951 by Bill Moog
- Headquarters in East Aurora, NY
- Multi-national Company
  - Over 100 locations in 28 Countries
- Over 11,000 Employees Worldwide
- $2.5 Billion in Revenue (FY 2017)
- Aerospace, Defense, Industrial, Medical, Space
- Precision Control System Provider
- Traded on the New York Stock Exchange (MOGA)
- People-oriented environment with emphasis on individual responsibility and solving our customers most difficult challenges
Moog Valve Company Formed

1951

1956
First flight of F-106 with Moog Servovalves

1958
Moog Acquires Allied Signal Actuation Mechanical Systems (Torrance CA)

1970

1972
First flight of F-15 with Moog actuators

1980

1972
First flight of F-15 with Moog actuators

1985
First use of Moog fuel control valves on V2500

1989
First flight of B-2 with Moog Fly-By-Wire Actuation System

1989
First flight of V-22 with Moog Actuation

1990

1995
Moog Acquires Allied Signal Actuation Mechanical Systems (Torrance CA)

1995
First flight of F-18E/F with Moog Actuation for Leading Edge, WingFold, LEX and Servovalves

1994

2000

2003
First flight of G450 with Moog Actuation

2006
First flight of F-35 with Moog EHA Flight Control System

2009
First flight of B-2 with Moog Fly-By-Wire Actuation System

2009
Moog Acquires GE Aviation Systems (Wolverhampton UK)

2009
First flights of B787 with Moog Flight Control Systems

2003
First flight of G450 with Moog Actuation

2006
First flight of F-35 with Moog EHA Flight Control System

2009
First flights of G650, G280 with Moog Flight Control Systems

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2010
First flight of X-47 Moog Primary Flight Control System

2013
First flight of A350 Moog Actuation Control Systems

2015
First flight of KC-46 with Moog Refueling Boom Actuation

2015
First flight of Bell 525 with Moog Flight Control System

2016
First flight of Embraer E2

2017
FOD and Military Aviation

FOD is an old problem for military aviation, but the operating expense of 5th Generation Aircraft and a renewed focus on readiness and combat effectiveness make this old problem more costly than ever.

- Engine production overhaul (F-135, F-402) can not keep up with current demand at any cost. Under resourcing, PBL shortfalls, and throughput issues.

- Readiness cost of taking an engine “off wing”:
  - F-35B: 22 days. Rate .87/1000FH (2018)
  - AV-8B: 27 days. Rate 1.35/1000FH (2018)

- NAVAIR Concerns:
  - Class A Mishaps attributable to FOD:
    - Zero (0) in 2015, One (1) in 2016, and Zero (0) in 2017
  - Cost to the NAE: $117M in 2015, $106M in 2016, and $131M in 2017
  - Seven* (7) class A mishaps since 2002
  - Conservative cost to the NAE $1.5 Billion from 2002 to 2017
  - Significant impact on forward deployed mission readiness
  - Seven (7) clustered events in the past 15 years

Total FOD Cost 2020: $200.5M
Total FOD Cost 2023: $281.3M

*U.S. Tactical fixed wing jet only.
*Does not include Class A Mishaps
FOD and the USAF

“Data collected by the U.S. Air Force reveals that incidents involving FOD cost the service around $240 million between 1995 and 2004. In this time period, Air Force aircraft were involved in nearly 800 FOD events. The average cost of an FOD event was around $300,000. Costs of FOD have only increased in the years after this study was conducted, as the price tag of military aircraft continues to climb.”

- FOD impacts readiness and combat effectiveness...
  - “The US Air Force is studying ways to harden its overseas air bases against attack by “missile swarms” that can scatter debris across runways and ramps, rendering them inoperable.”

- USAF will acquire 1763 F-35A’s.
  - Due to the “global asset management” of F135 engines, it is essential to keep engines “on wing” as long as possible due to spares cost and availability.
  - F-35A is a FOD vulnerable single engine aircraft with a ~$100M replacement cost.
  - F-135 FOD rebuilt approximately 5X most costly than legacy aircraft.
FOD, Costly and Deadly

The monetary cost of FOD is almost inconsequential when compared to the stress on our readiness, maintenance personnel, and loss of aircraft due to engine “off wing” down time and Class A Mishaps... and loss of life.
My Personal FOD Journey

My relationship with FOD has been... let’s say ‘complicated’.
Why is FOD such a difficult challenge?

100% of FOD Incidents are caused by... FOD!

Persistence and Discipline: The “brute force” approach

- FOD is essentially a farm problem; there are things on the airfield and they need to be removed.
- Of course it’s not this simple because of the nature of aircraft interacting with the environment and each other and the operating surface and how its affected by weather, people, climate, aging infrastructure and other ground construction and operations... in all cases persistence and focus are the main challenge.

No “silver bullet” or single solution: The data driven quest for understanding

- Single, federated solutions have been attempted (TREX, FOD Boss, Crack Sweepers, Blowers) and failed; additionally any FOD solution will not be binary, but rather better or worse. There is no 100% solution.
- All these federated acquisitions CAN be used as data collectors and brute force Band-Aids to mitigate FOD damage while required data and analysis are conducted.

FOD as a wicked and an ever-present ineradicable problem: The individualized data-driven strategic approach.

- A flexible, modular, comprehensive data-driven solution has the best chance of driving the curve close to 0.
- True understanding may not happen until after a solution has been achieved... we must learn by doing.
- A versatile, data-driven strategy that combines persistent, targeted brute force FOD removal with FOD detection sensors, FOD inlet detection technology, an operations staff who can quickly respond to weather, construction, runway degradation, aircraft generated FOD incidents, and other factors has the best chance of success.
Case Study: RAF Marham

- Number of FOD rejections considered to be unacceptably high across TGRF: ~ 1.1 / 1000 FH in 2011.

- As part of the ROCET 2 engine availability contract, Rolls-Royce asked to introduce and manage a FOD Service in an attempt to reduce the number of rejections being experienced.

- Historically, the German AF (GR4) had a rejection rate ~ 0.3 / 1000 FH (exclusive of bird strikes). It was considered possible to reduce the TGRF rejection rate to around 0.8 / 1000 FH inclusive of bird strikes.

2011: Year of implementation

- 52 Cat A FOD Rejections across TGRF
- Rejection Rate ~ 1.1 engines per 1000FH (Before ROCET2)

2015: (Only 4 years into the campaign)

- 6 Cat A FOD Rejection so far across TGRF
- 2017 Rejection Rate = 0.43 engines per 1000FH (~ 70% Reduction when compared to 2011)
The Schedule of Success at Marham

No Cat A FOD Rejections in 2014 at Marham; considered impossible in 2011!
The Case for Tarsier®

Tarsier is the most effective, affordable FOD mitigation technology available today; it is already in use at major airports around the world.

- Tarsier was tested alongside other available systems by the FAA.
  - Tarsier the only system to score 100% detection at .6 miles.
  - Tarsier was the ONLY truly all weather system.
  - Tarsier is the only system considered for replacing mandatory runway inspections directed by FAA. There are nearly 1,440 Tarsier inspections per day compared to 4 human inspections per day.

- Tarsier installed at Heathrow and Vancouver International Airports.
  - 10+ years of reliable use at Heathrow and Vancouver.
  - 6+ million FOD free operations, focus on minimizing false alarms.
  - USMC currently installing Tarsier at MCAS Yuma, Az.

“The Tarsier FOD detection radar system was found to detect the necessary objects of various shapes, sizes, and materials on the runway surface and was able to perform satisfactorily in nighttime, daytime, sun, rain, mist, fog, and snow conditions, as required by FAA Advisory Circular 150/5220-24” Airport Foreign Object Debris (FOD) Detection Equipment.
Tarsier®  What is it?

Tarsier is an array of networked, millimeter wave radar systems that continuously scan runway surfaces (once per minute) day or night and in any weather, using advanced signal processing to detect all foreign object and debris down to the size of a AA battery at .6 miles.

- MTBF: Effective 100,000 hours.

After detection, Tarsier transmits position and an image (day/night) via a MIL-SPEC optical system to airfield operations or the control tower where personnel can determine the threat and dispatch to remove debris; the system logs the event (with meta-data) for further analysis.

Runway Module
- Solid State millimeter wave radar with continuous wave emissions.
- Low power 20 dBm (100mW) Transmitter
- 600 MHz/94.5 GHz Center Frequency
- Operational Range 1km/Instrumented Range 2km

Camera Module
- Wide, Zoom, Low-Light Zoom, Eye-Safe Laser Illuminator down to 0 light.

Signal Processor works in all weather for debris and runway damage and has been refined to reduce “false alarm” rate to near 0%.
MADS: More Than Just An Operating System

The Moog Airport Data System (MADS) acts as the operating system for the Tarsier system and the user interface.

- FOD information is relayed to airport operator through a single intuitive graphical “map based” display.
- UHD resolution cameras automatically cue to detected debris to verify the object before dispatch of personnel to remove debris.
- An advanced user toolbox allows operator to store, view and analyze detection data.

MADS is also a powerful airfield integration tool that was designed to be an open architecture hub that will support a modular “whole airfield” approach to airport safety and situational awareness.

- MADS will support and integrate FOD smartphone applications that personnel can use to meta-tag FOD after runway or taxiway identification and removal.
- MADS can be used as the main display for the Moog Counter-Unmanned System (C-UAS) Gauntlet, wildlife mitigation technologies, airfield perimeter surveillance, future autonomous vehicle support, take-off and landing monitoring cameras, or ANY other technology that an airfield integrates into its operations and safety program.
How does Tarsier® fit into a comprehensive solution?

Tarsier and MADS are more than just tools for identifying FOD, they are powerful data collection and analysis tools for crafting a FOD mitigation strategy.

- Tarsier as sensor for big-data analytics.
  - Over time, Tarsier can be used to determine the source, patterns, taxonomy, and ways FOD is introduced moves around the airfield operating surface.
  - Collected data can then be analyzed next to events, weather, and different types of operations (take off, landing, TMS specific and TMS mix) to better understand the FOD risks of operating aircraft in proximity to one another or after weather, seasonal, or other LFE/Airshow events.
  - Over time a data crafted FOD mitigation strategy, tailored to each individual airfield (or portion of an airfield) can be developed to significantly reduce FOD risk; bundled with C-UAS, Birds, Wildlife, Perimeter Security, etc.

- MADS can be configured to present data tailored to need or scope.
  - Squadron Level: Immediate Risk, FOD risk like BASH level.
  - Base Operations: Immediate and Intermediate Risk, data presented annual, monthly, seasonal, event based.
  - NAVAIR: Data from multiple sites can be analyzed to develop a FOD Strategy.
A Comprehensive Approach to FOD

Automated debris remediation informed by Analytics

Ground Radar System (Currently seeking vendors – PMA-257)

Inlet Debris Detection

Debris Characterization (Coinstar™-like concept)

FOD trucks and radar trucks the remove debris, and feed data to the “brain”

Contractor support to manage unique airfield considerations

Enterprise Coordinator empowered with “Big Data” and analytic tools to cater to specific airfield needs.
Gauntlet® and Autonomy

Moog Space and Defense Group offers Gauntlet, a tested C-UAS Solution and vehicle agnostic autonomy which makes FOD removal efforts much more effective.

- Gauntlet Counter-Unmanned Airborne System (C-UAS) solution.
  - Collection of radar and IR sensing technologies arranged in an array to detect and track up to 40 UAS’ out to 10 mi. and locate the user location.
  - Moog offers an array of intervention options from kinetic to EM tracking/disabling; currently after detection action involves an interdiction team dispatched to operator location.
  - FBI contracted with Moog for C-UAS support for Super Bowl LII in Atlanta; extremely challenging urban, high traffic environment: Mission success.

- Autonomy represents the next step in effective FOD mitigation.
  - Manpower is at a premium in the DoD, autonomy takes the man out of the loop and provides a persistent effort for tasks like FOD mitigation.
  - Moog already developing safety protocols, would expand with:
    - Augmented manned technology to ensure full coverage and added safety
    - Full autonomous mode, “ball boy” mode cued by Tarsier, expeditionary ops.
  - Moog already deploying autonomous systems for agricultural use.
Future Expeditionary FOD Mitigation

FOD represents a strategic challenge to future F-35 B/C expeditionary operations.

- Moog is currently working with PMA-251 Engineers and NAVAIR 4.4 on adapting Tarsier for Expeditionary Ops.
  - Tarsier for shipboard operations and using MADS as a comprehensive Naval Aviation Situational Awareness display.
  - Tarsier for AM-2 and mobile Tarsier for expeditionary operations and at all FCLP sites, can integrate C-UAS and perimeter security to drive down the requirement for multiple systems and additional personnel.
  - Distributed STOVL Operations does not take into account FOD vulnerability for F135 engine and there is no plan for engine replacement and/or aircraft salvage on site.

  - Source: MAGTF F-35B Distributed Short Take-Off Vertical Landing (STOVL) Operations - DSO Concept of Operations, 1 Feb 2015
Moog 365 Support

Moog has extensive experience providing life-cycle support in the aerospace industry with more than 1000 systems in operation across 100 countries.

Moog products have been install and are used by civil and military customers across the globe. Moog will provide global logistics support and technical assistance to include:

- Global Support Network
- 24/7 Call Center
- Comprehensive support program including life-time on call technical and logistical support

Moog will also support:

- System Installation and Training
- Site survey and system commissioning
- Safety cases, spares and repairs

Moog’s global reach also makes it idea for deployed and expeditionary technical and logistics support.
Conclusion

**FOD is expensive in every measureable way:**
- Combat Effectiveness
- Engine Availability
- Maintenance Manpower
- Procurement and Sustainment Funding
- Human Life

**FOD mishaps can be SIGNIFICANTLY reduced using a comprehensive approach:**
- FOD radar detection.
- Autonomy
- Data collection and analytics to understand FOD and develop a mitigation strategy
- Physically removing FOD without wasting manpower for time-consuming and ineffective FOD walks
- Representatives to provide education and lead the FOD mitigation efforts at all bases