The 1.5 & 1.4 Ultimate Factors of Safety for Aircraft & Spacecraft – History, Definition and Applications

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Background – Development of the Factor of Safety for Aircraft

Ref: AGAARD REPORT No. 661 : "Factors of Safety – Historical Development, State of the Art and Future Outlook" (Factor of Safety – USAF Design Practice by Muller and Schmid)

- Design of Early Aircraft (1920's to Early 1930's)

    - Aircraft were designed to ultimate conditions using specific load factors for three flight attitudes:
        - Dive recovery initiation
        - Final recovery from a pull-up
        - Inverted flight

    - Loads were distributed on the wing and empennage without consideration of aerodynamics.

    - No constraint or recognition of permanent airframe deformation at the design load factor.

Background – Development of the Factor of Safety for Aircraft

- Concept of Factor of Safety and Limit Flight Envelope

    - Evolved during the Mid-1920's thru Mid-1930's.

    - The formal establishment of an Ultimate Factor of Safety of 1.5 into U.S. Air Corps (Army & Navy) requirements occurred in 1930.

        - Initially, the Ultimate Factor of Safety only applied to tail design loads.

        - Prior to this, all loads were ultimate loads and airplanes were designed to load factors which varied for each type of airplane.

- An Ultimate Factor of Safety of 1.5 could not be substantiated statistically at the time.

    - It was observed that airplanes currently flying that were designed to an inferred Ultimate Factor of Safety of 1.5 were flying safely.
    - Faster airplanes and the availability of flight data evolved the Ultimate Factor of Safety into a design criterion.

Establishment of the Factor of Safety of 1.5 as an Aircraft Design Criterion

- In March 1934, Revision G of The Handbook of Instructions for Airplane Design (HIAD) established the 1.5 Ultimate Factor of Safety as a formal Air Corps design requirement.

- Aircraft could continue operation if within limit load conditions.

  - Criteria for no detrimental, permanent deformation was first established.

- If loads beyond limit are experienced and detrimental deformation is suspected to have occurred:

  - Inspect and repair, if necessary, before continued flight.

- In service, loads above limit may be part of the statistical distribution (e.g. Turbulence), may exceed a selected criteria (e.g. a 3-sigma distribution and prescribed confidence interval), or may be a unique, stand-alone event.

- **Federal Airworthiness Regulation Part 25.303 Factor of Safety**
  - **Unless otherwise specified, a factor of safety of 1.5 must be applied to the prescribed limit loads which are considered external loads on the structure.**

What does the factor of safety cover?

- The 1.5 Ultimate Factor of Safety covers:
    - *Inadvertent In-Service Loads greater than the design limit.*
    - *Structural deflections above limit load that could compromise vehicle structural integrity.*
    - *As-built part thickness within tolerance but less than that assumed in the stress analysis.*

- **NSTS 07700, Volume X, Book 1 Space Shuttle Flight and Ground Specification**
    - **3.2.2.1.5.3 Design Thickness**
        Stress calculations of structural members, critical for stability, shall use the mean drawing thickness or 1.05 times the minimum drawing thickness, whichever is less. Structural members, critical for strength, shall use the mean drawing thickness or 1.10 times the minimum drawing thickness, whichever is less. (DAC internal standard)

- **MPCV 70135, MPCV Structural Design and Verification Requirements**
    - **SDVR0094   Material Thickness for Strength and Stability Margins**
        Flight vehicle structures shall use the lesser of the mean drawing thickness or X times the minimum drawing thickness for structural design and analysis, where X=1.1 for strength critical hardware and X = 1.05 for stability critical hardware.
    - **SDVR0049   Material Thickness for Critical Structures**
        Flight vehicle structures shall use the drawing minimum thickness for structural design an analysis of pressure vessels.

- **SSP 30559 ISS Structural Design and Verification Requirements**
    - **3.5.3 MATERIAL DESIGN AND ANALYSIS THICKNESS**
        The drawing minimum thickness shall be used in stress calculations of pressure vessels, stability critical structure, and single load path structure. The drawing mean/average thickness may be used for stress calculations of all other structure. Actual as–built dimensions may be used in stress calculations when available.

What the factor of safety DOES NOT cover

- The 1.5 Ultimate Factor of Safety DOES NOT cover
  - Analysis or modeling errors
    - Competent structural analysis is assumed and always required.
    - The Factor of Safety concept was developed long before finite element analysis was invented.
  - Poor design practice
    - A Factor of Safety cannot be expected to compensate for a bad design.
  - Material property variations
    - Mechanical properties for structural materials are developed to their own rigorous statistical criteria.
  - Process escapes (e.g. different material used than specified, holes drilled improperly)
    - These should be flagged by Quality Assurance and dispositioned appropriately.

- The 1.5 Ultimate Factor of Safety applies to **_external_** ground and flight loads.
  - Other supplemental safety factors apply to other components:
    - For example (pressurized lines, fittings, pressurized cabins, castings)

- The intent of the 1.5 Ultimate Factor of Safety is for each vehicle and each copy of each vehicle to have a single, fixed Factor of Safety requirement.

Basis of Structural Strength Calculations

- The load-carrying capability of a structure or component is determined by a number of factors:

  - The Definition of Limit Load
  - The Ultimate Factor of Safety
  - Material Properties ("A-basis", "B-Basis", "Premium")
  - Specified part thickness
  - Process controls (e.g., Quality Inspections, heat treatment, bolting, bonding riveting)
  - Eccentricities in applied load to do design or elastic deformation

- Exceedances of limit load conditions occur in commercial aircraft, Apollo, Shuttle and ISS.

  - The Ultimate Factor of Safety provides a certain level of additional capability to maintain structural integrity for limit load exceedances.

    - As the Ultimate Factor of Safety is reduced (lower than 1.5) there will be an increasing number of beyond limit load cases that will not be covered.

Commercial Air Transport – Exceedance of Limit Conditions

- In flight break-ups:

  - 2/12/63 - Northwest Orient Airlines Flight 705, a Boeing 720, breaks up in turbulence associated with a severe thunderstorm and crashes into the Everglades.

  - 3/5/66 – BOAC Flight 911, a Boeing 707, "The aircraft suddenly encountered abnormally severe turbulence over Gotemba City which imposed a gust load considerably in excess of the design limit."

  - 8/6/66– All 42 on board are killed when **Braniff Flight 250**, a BAC One-Eleven, flies into an active squall line and breaks apart in mid-air near Falls City, Nebraska.

  - 3/5/68 - Braniff Flight 352 , a Lockheed L-188A Super Electra en route from Houston, Texas to Dallas, breaks up in mid-air in a thunderstorm and crashes near Dawson, Texas.

  - 5/7/81 – Austral Líneas Aéreas Flight 901, a BAC One-Eleven, crashes near Aeroparque Jorge Newbery after losing control in a thunderstorm, killing all 31 on board.

  - 11/6/81 - October 6 – NLM CityHopper Flight 431, a Fokker F28 Fellowship, is destroyed in flight by a tornado near Rotterdam, killing all 17 people on board.

  - 5/26/91 – **Lauda Air Flight 004**, a Boeing 767, disintegrates in mid-air over Uthai Thani Province and Suphan Buri Province, Thailand, killing all 223 people on board. A thrust reverser had accidentally deployed in flight, causing the disaster. It is the first fatal crash of a Boeing 767.

Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions:

  - On November 9, 1963, a DC-8 (tail number N840TW) operating for Eastern Airlines took off from Houston, TX.

  - At around 3:02 p.m. local time, while the plane was climbing through 19,000 feet, it encountered turbulence and hail associated with a thunderstorm.

  - Airspeed reportedly dropped to zero momentarily, prompting the crew to push the nose down.

  - This turbulence caused the aircraft to dive, resulting in the separation of the #3 engine and damage to the wing. (Anomalies in the Pitch Trim Compensator contributed to the loss of control.)

  - The crew recovered from the dive at 5,000 feet by using reverse thrust in-flight.

  - The airplane performed an emergency landing at Barksdale Air Force Base in Louisiana.

  - Note: A similar issue caused the total loss of a DC-8 on 11/29/1963.

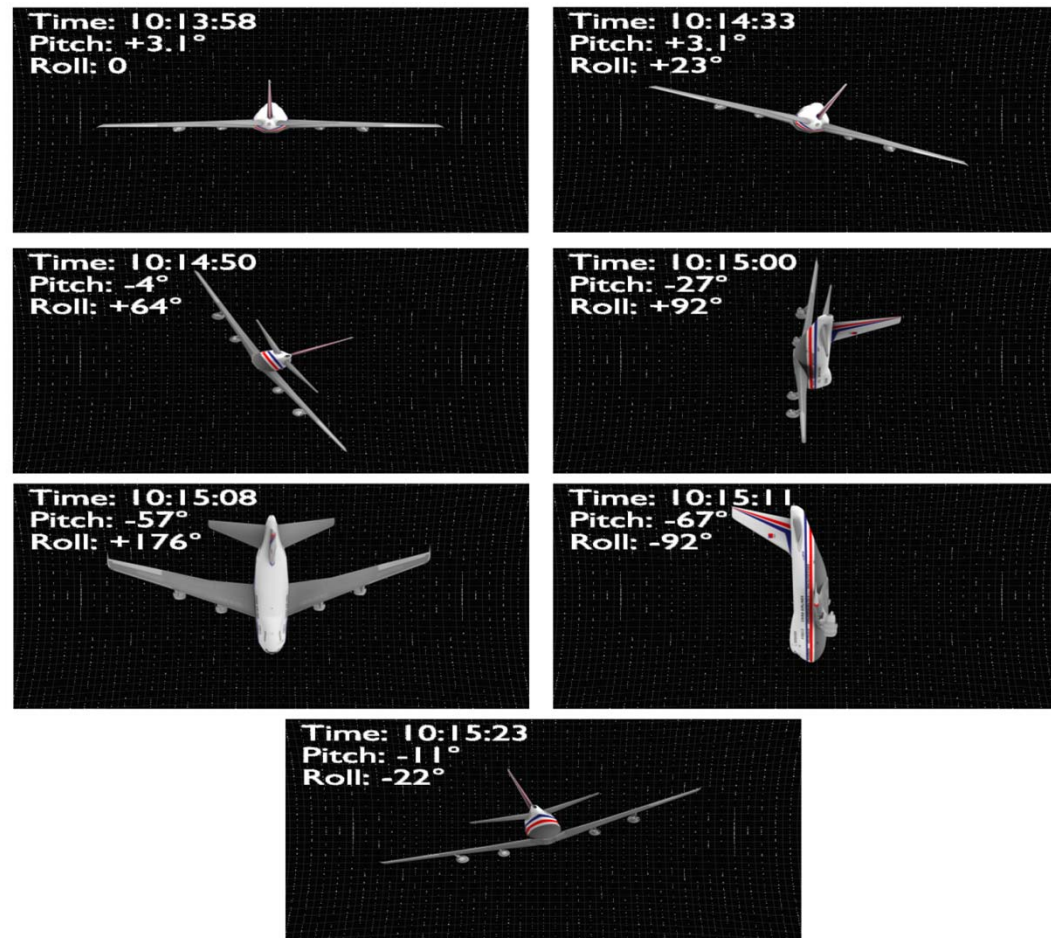# Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions:

  - On April 4, 1979, a Boeing 727-31 (tail number N840TW) operating as **TWA Flight 841** took off from John F. Kennedy International Airport, New York City, en route to Minneapolis-Saint Paul International Airport in Minneapolis, Minnesota.

  - At around 9:48 p. m. local time, over Saginaw, Michigan, while the plane was cruising at 39,000 feet (11,887 m) and Mach 0.816, it began a sharp roll to the right. The roll continued despite the corrective measures taken by the autopilot & the human pilot.

  - The aircraft went into a spiral dive, losing about 34,000 feet (10,363 m) in 63 seconds. During the course of the dive, the plane rolled through 360 degrees twice, and crossed the Mach limit for the 727 airframe.

  - Control was regained at about 5,000 feet (1,524 m) after the first officer, with the captain in agreement, extended the landing gear in an attempt to slow the aircraft, and following the loss of the #7 slat from right wing.

  - The plane suffered substantial structural damage, but made an emergency landing at Detroit Metropolitan Airport, Michigan, at 10:31 p. m.

  - No fatalities occurred among the 82 passengers and seven crew members. Eight passengers reported minor injuries relating to high G forces.

Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions:

  - On 2/19/85, **China Airlines Flight 006**, a Boeing 747SP-09 was 350 miles northwest of San Francisco, cruising at an altitude of 41,000 ft. when the No. 4 engine stalled at a low thrust setting and flamed out. After the flameout, the captain instructed the flight engineer to attempt to restart the engine, with the autopilot still engaged and the Bleed air on. that was contrary to the flight manual procedure, which required the plane to be below 30,000 feet, before attempting to restart a flamed out engine.

  - The attempt failed. The airspeed continued to decrease, while the autopilot rolled the control wheel to the maximum left limit of 23 degrees. By the time the captain disconnected the autopilot, the plane had rolled over 60 degrees to the right and the nose had begun to drop. To counteract the asymmetrical forces created by the loss of thrust from the No. 4 engine, it was essential for the pilot to manually push on the left rudder. However, the captain failed to use any rudder inputs at all, before or after disconnecting the autopilot.

  - As the plane descended through clouds, the captain's attention was drawn to the artificial horizon which displayed excessive bank and pitch. Because such an attitude is highly irregular, the crew incorrectly assumed the indicators to be faulty. Without any visual references (due to the clouds) and having rejected the information from the ADIs, the crew became spatially disoriented. The plane entered a steep dive at a high bank angle. Altitude decreased 10,000 ft within only 20 seconds, a vertical descent averaging 30,000 feet per minute The crew and passengers experienced g-forces reaching as much as 5g.[1]

Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions:

  - Only after breaking through the bottom of the clouds at 11,000 feet (3,400 m) did the captain orient himself and bring the plane under control, leveling out at 9,600 feet (2,900 m). They had descended 30,000 ft in under two and a half minutes. A restart attempt brought No. 4 back into use.

Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions

    - 2/24/89 – **United Airlines Flight 811** experienced a cargo door failure in flight after its stopover at Honolulu International Airport, Hawaii. The resulting decompression blew out several rows of seats, resulting in the deaths of 9 passengers.

    - After the plane had been flying for approximately 16 minutes, and was passing between 22,000 and 23,000 feet a grinding noise was suddenly heard in the business-class section, followed by a loud thud which rattled the whole aircraft.

    - One and a half seconds later, the forward cargo door blew out abruptly. The door swung out with such force that it was forced past its normal stop and slammed the side of the fuselage, busting it open. Pressure differentials and aerodynamic forces caved in the cabin floor, causing ten seats (G and H of rows 8 through 12), as well as an individual seated in 9F whose armrest failed, to be ejected from the cabin. All 9 passengers seated in these locations were killed (seats 8G and 12G were unoccupied).

    - A gaping hole was left in the aircraft. To reach an altitude where the air was breathable, they began an emergency descent, while also performing a 180-degree left turn to fly back to Honolulu. The debris ejected from the airplane during the explosive decompression caused severe damage to the Number 3 and 4 engines, causing visible fires in both. Engine 3 was experiencing heavy vibration, so the crew shut both engines down. Some of the explosively ejected debris damaged the right wing's Leading Edge Devices, dented the horizontal stabilizer on that side, and even struck the tailfin. The aircraft's skin was peeled off in some areas on the upper deck, revealing the frames and stringers and a massive hole in the side of the cabin. 13

Commercial Air Transport – Exceedance of Limit Conditions

- Incidents exposing airliners to over-limit design conditions

  - As the airplane neared the airport, the landing gear were extended. The flaps could only be partially deployed as a result of damage sustained following the decompression. This resulted in a high landing speed of around 190–200 knots (350–370 km/h). Regardless, Captain Cronin was able to bring the airplane to a halt without overrunning the runway. Fourteen minutes had elapsed since the emergency was declared. Evacuation was carried out and all passengers and flight attendants exited the plane in less than 45 seconds. Every flight attendant suffered some injury during the evacuation, however, ranging from scratches to a dislocated shoulder

Apollo, Space Shuttle and ISS Limit Load Exceedances

- Apollo 6 (Vehicle 502) and Apollo 13 POGO instabilities. For the unmanned test flight of Vehicle 502, Engines #2 and #3 shut down on the S-II stage prematurely and portions of the Spacecraft Lunar Module Adapter (SLA) failed. During Apollo 13, the center engine of the second S-II stage shut down prematurely due to POGO.

- Apollo 15 loss of one parachute during landed exposed the structure to higher than anticipated impact loads due to the heavier Command Module weight. (10 m/s vs. 8.5 m/s)

- STS-1: SRB ignition overpressure signature was at a higher frequency than expected. This frequency tuned with the Orbiter first bending mode. One Forward RCS strut was found to be buckled during post-flight inspection. Sound suppression water was used for subsequent missions and the strut was replaced.

- STS-3: I-load designed into ascent trajectory for higher sideslip angle. Between the last balloon wind data and flight, the wind changed direction resulting in a slight overload on one spot of the wing. Inspection revealed no damage.

- 1/14/09 – Excessive vibrations are input into the ISS Structure due to an anomalous reboost firing of the Service Module Thrusters.

http://www.youtube.com/watch?v=ENNq69499tA

The 1.4 Ultimate Factor of Safety for Spacecraft

- The 1.4 Ultimate Factor of Safety originated within The Aircraft Laboratory, Wright Air Development Center (now Wright-Patterson Air Force Base).

    - A study related to the X-20 Dyna-Soar program evaluated the applicability of the 1.5 Ultimate Factor of Safety for large separable boosters for manned space vehicles.

    - To maximize structural efficiency, design working stresses were brought closer to yield stresses.

    - Because of the uncertainty related to the design of large integral pressure vessels subjected to flight loads and temperatures, a 1.1 Factor of Safety on yield was chosen in combination with a 1.4 Factor of Safety on ultimate.

    - The 1.4 Ultimate Factor of Safety was intended specifically for the X-20 booster. It was not intended to be used without the 1.1 Factor of Safety on yield. However, the 1.4 Ultimate Factor of Safety with a 1.0 yield factor of safety has been accepted throughout NASA spaceflight programs.

The 1.4 Ultimate Factor of Safety for Spacecraft

- In the Early 1990's, the NASA Engineering Management Council empowered a group of structural engineers from across the Agency to develop the minimum factor of safety criterion for launch vehicles and spacecraft.
  - The group included representatives from both the manned and unmanned programs.

- The result was the baseline version of NASA-STD-5001, **Structural Design and Test Factors of Safety for Spaceflight Hardware.**
  - The material covered in this standard is based on the consensus judgment of a working group of structural engineers from all the NASA Centers.
  - This activity was prompted by concerns expressed by industry and NASA program management that practices and requirements in this area vary widely between Centers, making the verification of structural adequacy difficult in cases involving multiple Centers, and increasing costs to verify identical hardware under different criteria.

  - Table 1 provides the minimum structural factors of safety for metallic structures
    - 1.4 Ultimate Factor of Safety, 1.0 on Yield for prototype structure (structural certification testing on a dedicated test article).
    - 1.4 Ultimate Factor of Safety, 1.25 on Yield for protoflight structure (structural certification testing performed on a flight vehicle).

- Subsequent revisions of NASA-STD-5001 have added factors for preloaded joints, softgoods, windows, pressure vessels and other pressurized components.

Misconceptions Regarding the Factor of Safety

- ## *2.0 "No-test" Factor of Safety on Ultimate Loads*

  - Skylab used a Yield Factor of Safety of 2.0 and an Ultimate Factor of Safety of 3.0 for its untested launch shroud structure.

  - A Factor of Safety of 1.25 on Yield and 2.0 on Ultimate was used for the untested structures of the Long Duration Exposure Facility (LDEF) experiments, the Shuttle Solid Rocket Booster (SRB) Systems Tunnel, the SRB heater cover and cable channel, the Tethered Satellite System and the metallic components of the Hubble Space Telescope,

  - Very early in the Space Shuttle Program, Air Force Payloads that had already been tested to ultimate loads required certain modifications to fly as a payload in the Orbiter.

  - It was agreed that a 2.0 Ultimate Factor of Safety by analysis could be used to certify these modifications to the *already test-verified structures*.

  - NASA/Goddard Space Flight Center recommends a Yield Factor of Safety of 2.0 and an Ultimate Factor of Safety of 2.6 for untested structures.

  - SSP 30559 permitted the use of a 1.25 Factor of Safety on Yield and a 2.0 Factor of Safety on ultimate for untested ISS Structures that were designed primarily to withstand on-orbit loads.

Misconceptions Regarding the Factor of Safety

- ***2.0 "No-test" Factor of Safety on Ultimate Loads***

  - The Factor of Safety of 2.0 on Ultimate propagated through the Shuttle and ISS payload design community and subsequently other spacecraft structures communities and often became a *de-facto* rule for analyzing untested structures.

    - Shuttle Payload Verification Requirements NSTS 14046 did not have a factor of safety defined for verification of untested payload structures.

  - CXP 70135 included a section which stated that there is no such thing as an "analysis-only" Factor of Safety for spacecraft structures.

    - The determination of whether to certify a structure by analysis and what Factor of Safety to use must be performed on a case-by-case basis. (ref.: NASA-STD-5001 and FAR Part 23 and Part 25 criteria)

High Safety factors do not guarantee no failures. A high Factor of Safety cannot overcome inadequate design practice, ineffective quality control, incorrect structural analysis or brittle material failures.

Misconceptions Regarding the Factor of Safety

- *The 1.5 ultimate Factor of Safety was derived in the early days of aviation by ratioing the ultimate and yield strengths of aluminum.*

    - The 1.5 Ultimate Factor of Safety for tail design loads had already been adopted when the Air Corps began using 2024 Aluminum (designated 24ST at the time).

    - In the early 1930's, 4130 steel had a ratio of ultimate strength-to-yield strength of 1.2 and was widely used in aircraft at the time. Through the 1920's and into the 1930's 1025 steel was used.

    - Other materials used at the time in airframes did not have a 1.5 ratio of ultimate strength-to-yield strength. The 1.5 Ultimate Factor of Safety was supported by, but was not the result of, the 24ST aluminum alloy that was coming into use.

Material	Ultimate Strength (psi)	Yield Strength (psi)	Ratio
Spruce – Bending	9400	6200	1.52
Spruce – Compression	5000	4000	1.25
1025 Steel	55000	36000	1.53
X-4130 Steel	95000	75000	1.27 (For Plate & Tube -0.188)
X-4130 Steel	90000	70000	1.29 (For Plate & Tube +0.188)
17ST Sheet & Plate	55000	32000	1.72
17ST Clad Sheet & Plate	50000	27000	1.85
17SRT Sheet & Plate	55000	42000	1.31
17SRT Clad Sheet & Plate	50000	37000	1.35
24ST Sheet	62000	40000	1.55
24ST Clad Sheet	56000	37000	1.51
24SRT Sheet	65000	50000	1.30
24SRT Clad Sheet	58000	46000	1.26

Ref: ANC-5, Strength of Aircraft Elements – October, 1940.

Misconceptions Regarding the Factor of Safety

- *Lowering the Ultimate Factor of Safety below 1.5 will save a lot of weight.*

  - Comparison studies of aircraft structures show that using an Ultimate Factor of Safety of 1.4 instead of 1.5 saved 4% on the aircraft structural weight.

    - Using an Ultimate Factor of Safety of 1.25 instead of 1.5 would save 10.5% on the aircraft structural weight.

    - Formula: $(1.4/1.5)^{.604}$ and $(1.25/1.5)^{.604}$
      - Based on a study of aluminum airplanes built between 1930 and 1950.
      - Relationship applies if the ratio of the material yield to ultimate strength is less than 1.5 (chart provided on the next slide).

  - The impacts to lowering the Ultimate Factor of Safety are significant:

    - The load cases beyond limit that the structure cannot withstand will increase.

    - Re-use of the structure after a limit load exceedance is problematic if detrimental deformation occurs. Repair is required before returning the structure to service.

    - The structural reliability of the airframe when subjected to limit loads is reduced.

    - The structural life of the airframe is affected since it will be subjected to higher nominal operating stresses.
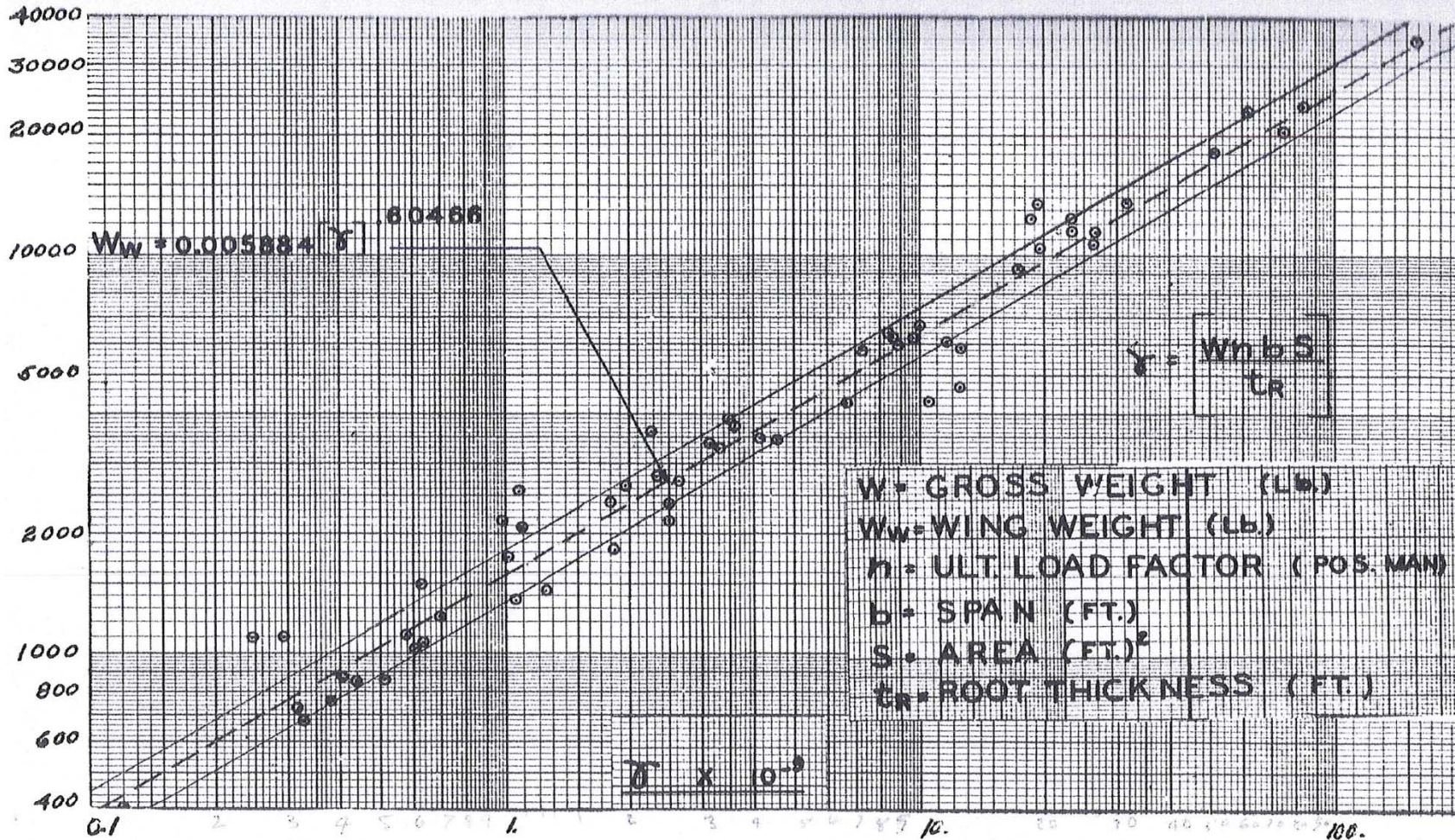
AIRPLANE DESIGN
K.D. WOOD

$$W_w = 0.005884\, \gamma^{.60466}$$

$$\gamma = \frac{W\,n\,b\,S}{t_R}$$

W = GROSS WEIGHT (Lb.)
Ww = WING WEIGHT (Lb.)
n = ULT. LOAD FACTOR (POS. MAN)
b = SPAN (FT.)
S = AREA (FT.)²
t_R = ROOT THICKNESS (FT.)

$\gamma \times 10^{-9}$

Reference: Kelley, Joseph Jr. Wing Weight Estimation. AAF Technical Report 5161.

If above equation is approximated by a line of slope 0.50 (instead of 0.60466) through $\gamma/10^9 = 10$ and $W_w = 6300$ (with some sacrifice in accuracy) resulting equation is $W_w/S = 2.0 \sqrt{\dfrac{n'W}{t_R}} \sqrt{\dfrac{n'W}{1000 c_m}}$ which agrees with Drigg's equation (p. A5:2) for $t_R = 4.2$ ft. Since mean thickness for wings plotted by Kelley was more nearly 2 ft., Drigg's equation (based chiefly on airplanes prior to 1930) is judged to need correction by a factor of approximately $\sqrt{2}$ to be applicable to newer airplanes, as shown in Fig. A5:7.

What do you say when a Program Manager asks you to lower the factor of safety?

- *No, because there are other more effective strategies to reduce weight.*

    - For missions beyond Low Earth Orbit, the weight of the spacecraft will be the overall driving consideration that will determine the feasibility of the mission.

    - If a 1.4 Ultimate Factor of Safety is already being used, what other strategies can be employed when we are challenged to reducing the structural weight?

        - Review loads and structural criteria for unnecessary conservatism.

        - Tighten the manufacturing tolerances on parts.

        - Hand-select materials for better properties than provided in handbooks.

        - Look at the driving load cases to determine if functional redundancy or operational controls can be used to eliminate or reduce the loads.

        - Overweight design might be due to built-in Uncertainty Factors
            - Recommend against the use of load or model uncertainty factors as a general practice. This puts weight in the structure upfront. It is always easier to add weight to a structure later than reduce the weight once it is in the design.

What do you say when a Program Manager asks you to lower the factor of safety?

- Suggest that a Weights Group that tracks and challenges weight growth be included in the Program Plan.

- Don't be afraid of component failures during testing in the effort to reduce weight.
  - As long as the entire structure doesn't collapse you are learning which components are critical and which are not.

- Take advantage of structural optimization routines available in finite element packages.
  - But don't let this substitute for a full understanding of load paths through the structure.

- Loads engineers, stress analysts, structural and mechanical designers, TPS engineers and materials engineers must share the responsibility for developing a lightweight structural design.

  - These different groups must cooperate and from the beginning of the design process and all feel accountable for the weight of the structure.

    - Weight scrub activities on the Lunar Module cost $10,000 / lb.
    - Weight scrub activities on Shuttle cost $50,000 / lb.

Recent Developments

- This discussion was motivated by the need to develop a consistent interpretation of the factor of safety throughout the structural engineering community.

- Also, an NESC White Paper on Factor of Safety, published as a NASA TM in 2012, contained some errors and misinterpretations of the history and implementation of the factor of safety.

- In discussions with both the Loads and Dynamics and the Structures TDT leads at the NESC, a TIM will be held which includes representatives from different NASA Centers, Air Force, Navy, Government and Academia to discuss the contents of the TM.

    - The TM will be reviewed and updated, if needed.
    - If there is a difference in how the Factor of Safety is viewed within NASA vs. outside of NASA, this TIM should help in resolving any varying interpretations.

Conclusions

- This briefing is intended to guide discussions on the meaning and proper use of the factor of safety as we move into future deep-space vehicle development programs.

- This briefing could not have been assembled without the encyclopedic knowledge of C. Thomas Modlin – Chief Engineer and ES2 Branch Chief Emeritus

- Its content is based on:

  - Ref: AGAARD REPORT No. 661 : "Factors of Safety – Historical Development, State of the Art and Future Outlook" (Factor of Safety – USAF Design Practice by Muller and Schmid)

  - The authors' experiences throughout Apollo, Shuttle and ISS.

  - The results of extensive research into aircraft incidents where the factor of safety most likely prevented complete loss of structural integrity.

  - Other scholarly research on airframe reliability.

It is hoped that this briefing can be used as source material in the future when the origin, purpose and proper application of the ultimate factor of safety on spacecraft are discussed.