Parachute Design Examples

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Parachute Seminar

3rd International Planetary Probe Workshop

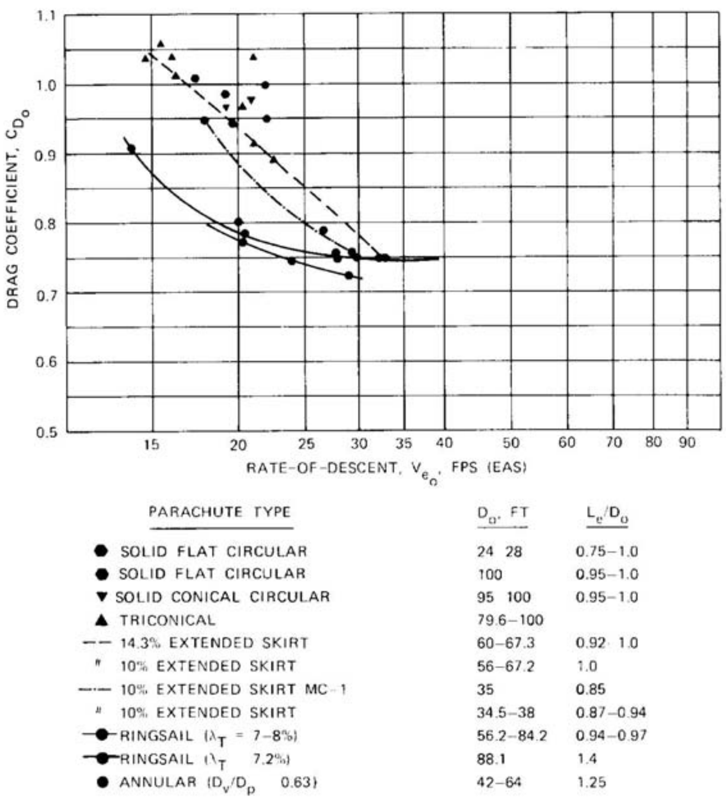
Outline

- **Drag Coefficient vs Velocity**
- **Porosity and Permeability**
- **Wind Tunnel Blockage Correction**
- **Infinite Mass Opening Shock**
- **Vent Design**
- **Skirt Inversion**

Drag Coefficient vs Velocity

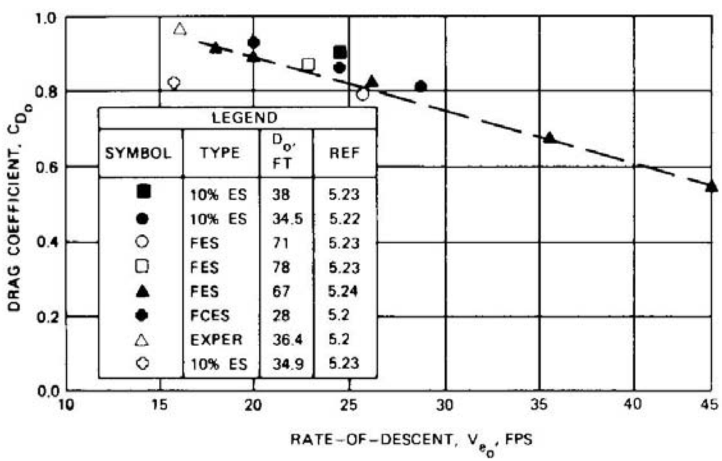
- **It is a widely accepted "truth" in the parachute industry that drag coefficient increases at low descent velocities**
- **Drag coefficient is often plotted versus descent velocity to prove this "truth"**
- **Of course, measured descent velocity was used to calculate drag coefficient so this correlation is somewhat self fulfilling**

C_D vs V for "Solid" Cloth Canopies



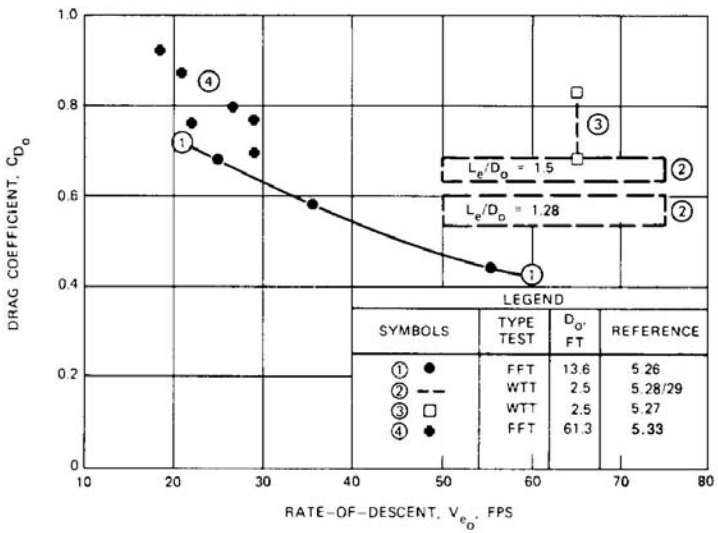
- **Knacke NWC TP 6575 Figure 5-24**
- **Solid Canopies, Ringsails and Annulars**
- **For any one canopy, the data tend to group in one location**
- **Variations in other design parameters are ignored**

C_D vs V for Extended Skirt Canopies



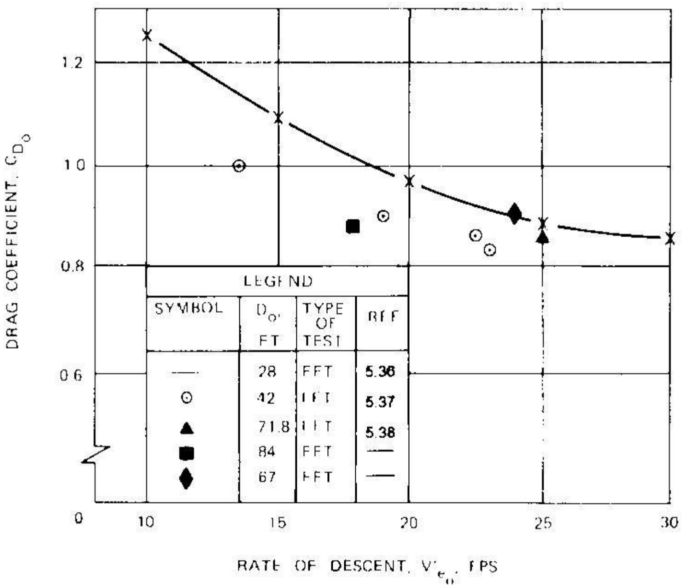
- Knacke NWC TP 6575 Figure 5-25
- Straight and full extended skirt canopies
- Only one canopy has data over a velocity range
- No explanation of how that variation was obtained

C_D vs V for Cross Parachutes



- Knacke NWC TP 6575 Figure 5-27
- Only one canopy has data over a velocity range
- No explanation of how that variation was obtained

C_D vs V for Annular Parachutes



- **Knacke NWC TP 6575 Figure 5-28**

Possible Explanations for Correlation

- **Aerodynamic**
  - Pressure distribution
- **Structural**
  - Elastic
  - Material permeability
- **Stability**
  - Gliding
  - Coning
- **Vertical winds**
- **Data errors**

Drag Coefficient vs Velocity

- **Beware of correlations like this that imply a cause and effect but don't really explain the cause**
- **Note any possible contributors to change in drag coefficient for a series of tests**
- **Measurement errors and data scatter are a real part of any test**

Porosity and Permeability

- For canopies that contain both geometric porosity and fabric permeability, it is necessary to combine both effects
- The handbook method of combining the two effects is given by the equation :

$$\lambda_T = \lambda_g + \lambda_m$$

where λ_T is total porosity, λ_g is geometric porosity and λ_m is the contribution due to cloth permeability

Porosity and Permeability

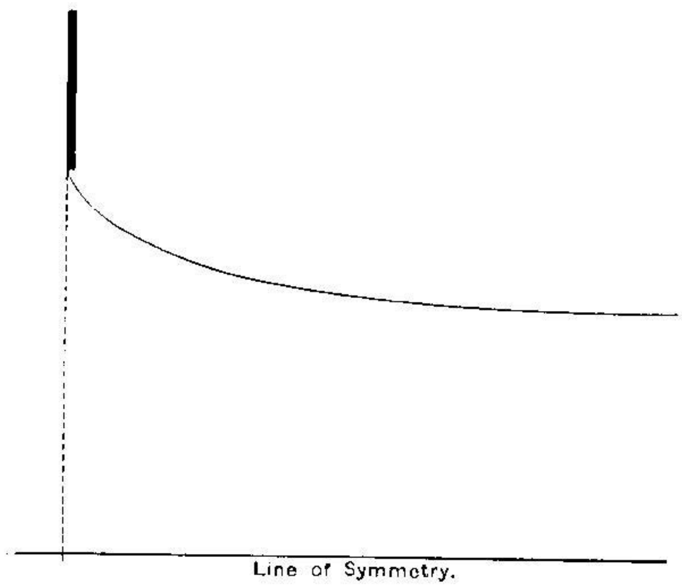
- **The cloth permeability part is given as:**

$$\lambda_m = (C_m/28)(A_m/A_0)$$

where C_m is permeability $(ft^3/min)/ft^2$ at a Δp of ½ inch of H_2O or 2.6 lb/ft^2, A_m is the permeable fabric area and A_0 is the total canopy area

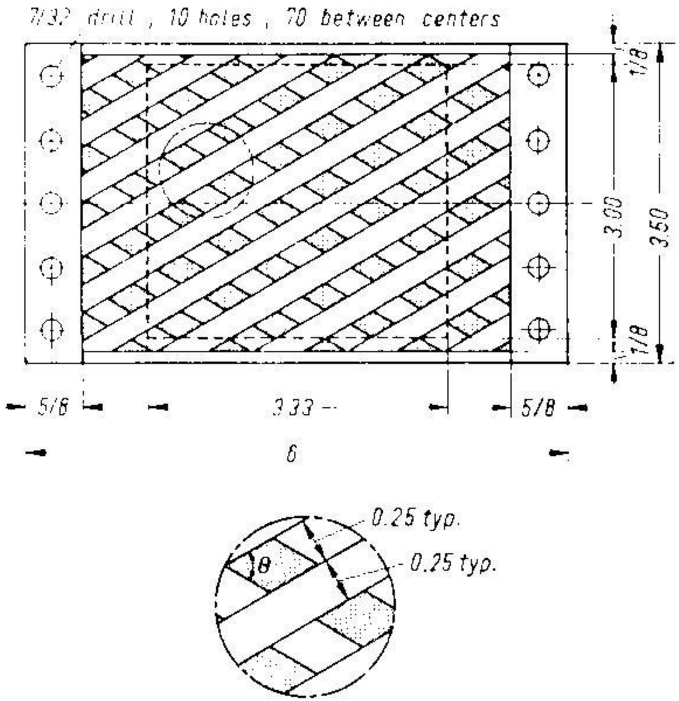
- **The constant 28 is derived assuming flow through the geometric porosity openings has an orifice coefficient of 1.0**
- **This is not a valid assumption for flow through a sharp edged orifice**

Theoretical Orifice Coefficient



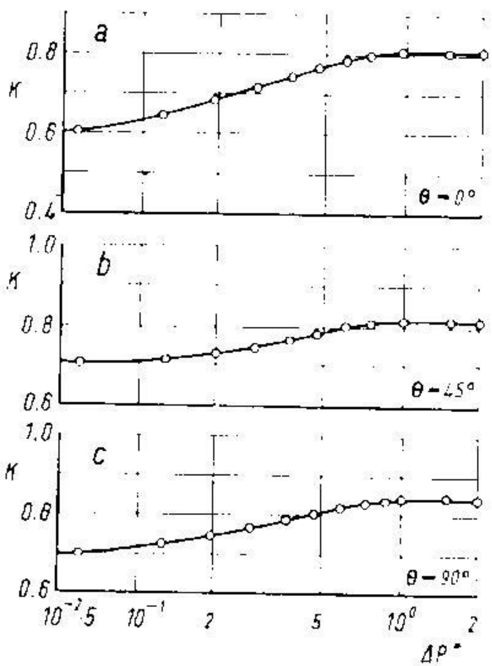
- Lamb Hydrodynamics 6th edition
- 2 dimensional complex analysis
- Free streamline theory
- $C_o = 0.611$

Orifice Coefficient Model



- Heinrich and Greig AFFDRL-TR-65-110
- Grid intersection angle is θ
- Values of θ = 0°, 45° and 90° were tested
- Pressure ratio is "critical" pressure ratio
  - Relative to sonic pressure ratio

Experimental Orifice Coefficients

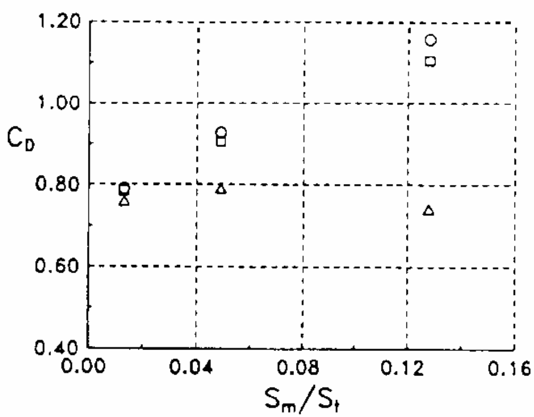


- **Most parachute applications near the Y-axis**
- **Top curve just greater than 0.6**
  - **Lamb was right**
- **Other configurations show orifice coefficient values of about 0.7**

Porosity and Permeability

- For an orifice coefficient of 0.7, the constant in the λ_m equation is 20 instead of 28
  - The permeability effect is greater
- The total porosity calculations in the literature assume an orifice coefficient of 1.0
- Studies of Reynolds number effects on permeability should be expanded

Wind Tunnel Blockage Correction



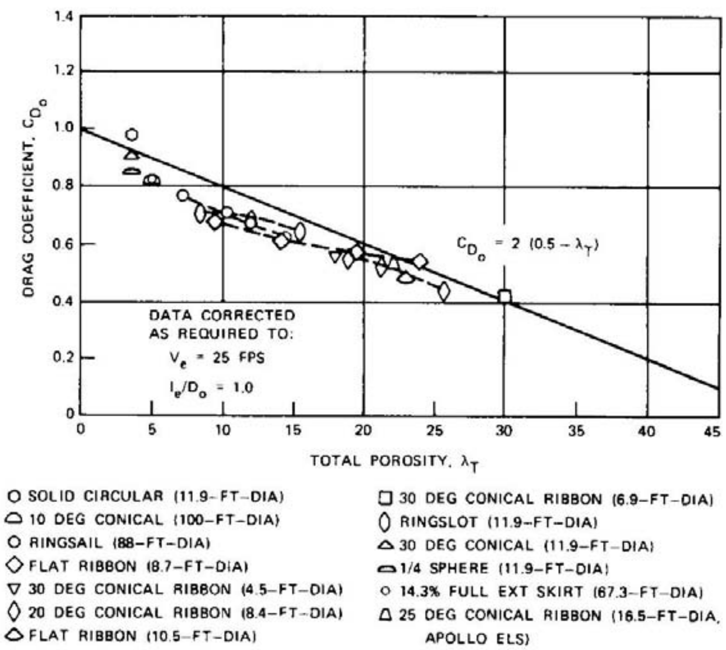
Parachute drag coefficient as a function of geometric blockage ratio.

○ - uncorrected
△ - corrected using Eq. (1)
□ - corrected using Eq. (2)

$$\frac{q}{q_u} = 1 + 1.85 \times \frac{C_D S_u}{S_t} \quad \textbf{(1)} \qquad \frac{q}{q_u} = 1 + 0.5 \times \frac{S_m}{S_t} \quad \textbf{(2)}$$

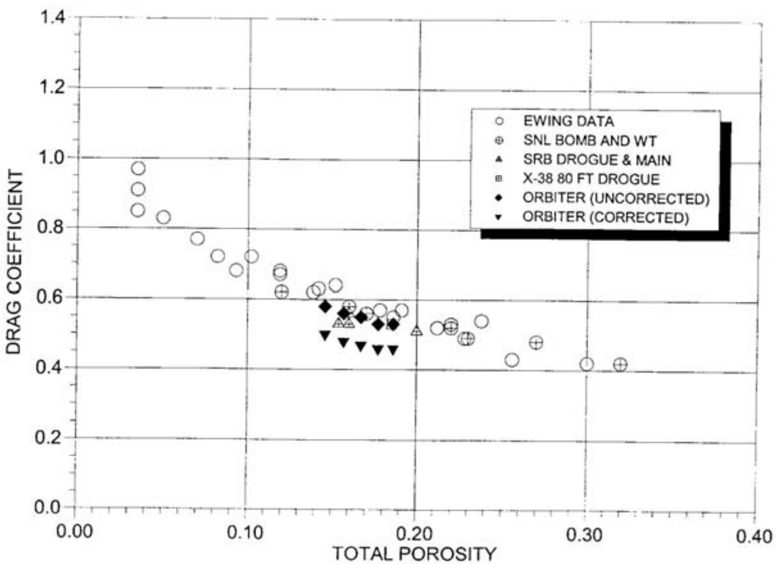
- **Macha AIAA 91-0858**
- **Based on wind tunnel data only**
- **Not validated by comparison with free-flight data**

Drag Coefficient vs Porosity



- Knacke NWC TP 6575 Figure 5-62
- Collection of free flight data
- Corrected to a suspension line L/D = 1.0
- Corrected to velocity of 25 ft/sec
  - How?

Drag Coefficient vs Porosity

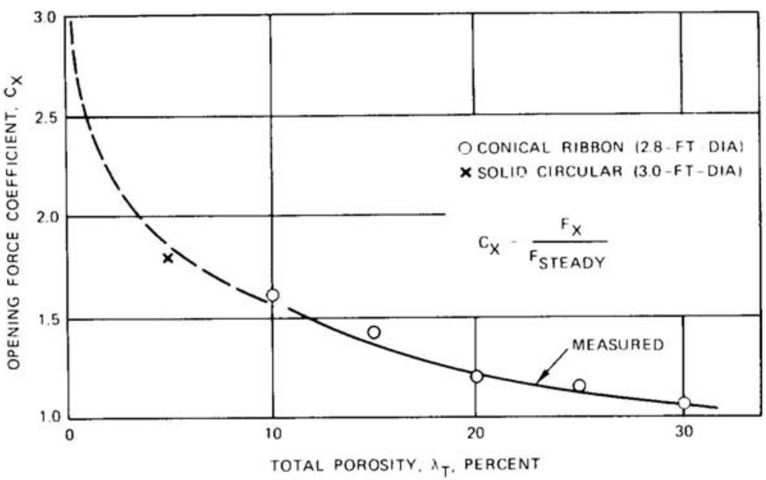


- **Knacke NWC TP 6575 Figure 5-62 is Ewing data**
- **Data from Sandia bomb and wind tunnel, SRB flight test and X-38 drogue flight test data added**
- **Orbiter wind tunnel data without blockage correction agrees better with data set**

Parachute Infinite Mass Opening Shock

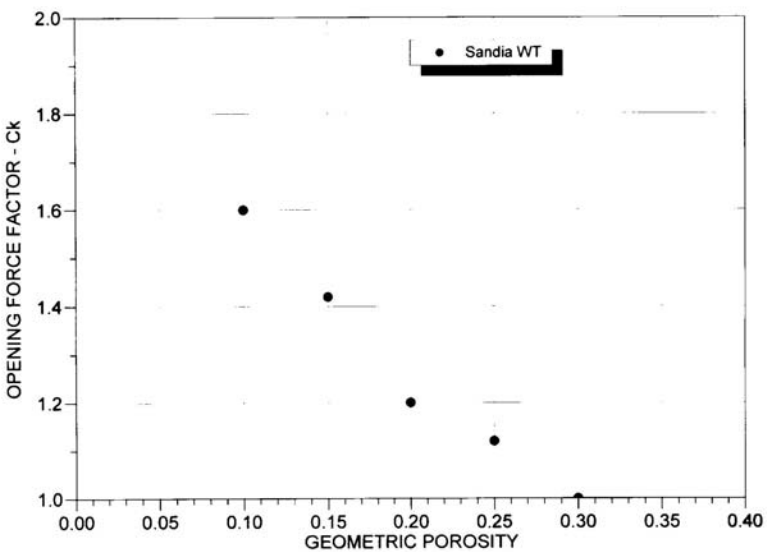
- **Proposed contributors to parachute opening shock**
  - Apparent mass
  - Rate of change of apparent mass
  - Overinflation
  - Reefing
  - Elasticity
  - Nylon/Kevlar lines
  - Canopy porosity
  - Mass ratio
  - Froude number

Infinite Mass C_k vs Porosity



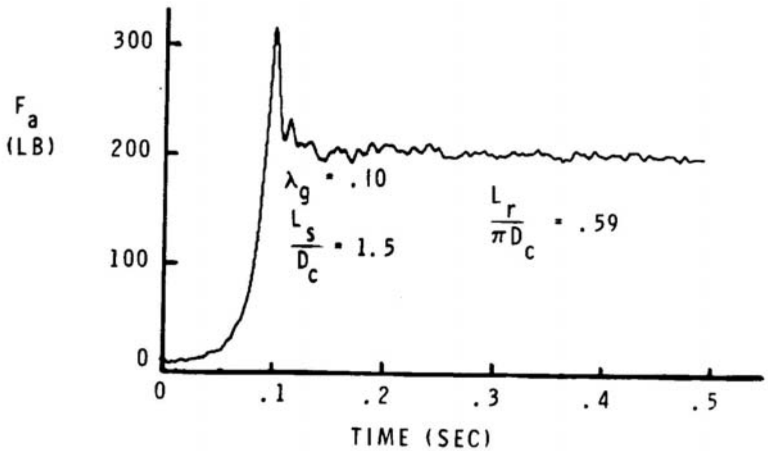
- **Knacke NWC TP 6575 Figure 5-64**
- **Low porosity parachutes inflate faster and generate higher opening shock**

Infinite Mass C_k From Wind Tunnel Data



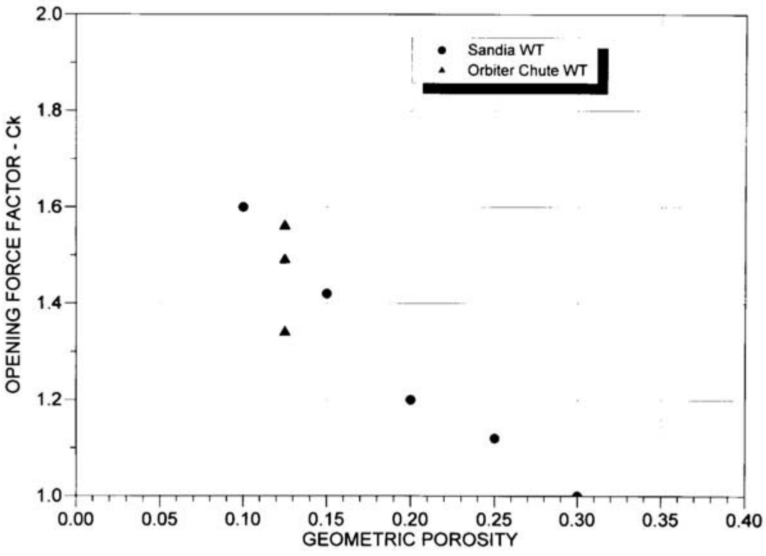
- Low speed wind tunnel
- 3 ft diameter models
- All Nylon parachute construction
- Data questioned because of small models and wind tunnel origin

Infinite Mass C_k From Wind Tunnel Data



- Low speed wind tunnel
- 3 ft diameter models
- All Nylon parachute construction
- C_k is maximum force divided by steady force

Infinite Mass C_k From Wind Tunnel Data

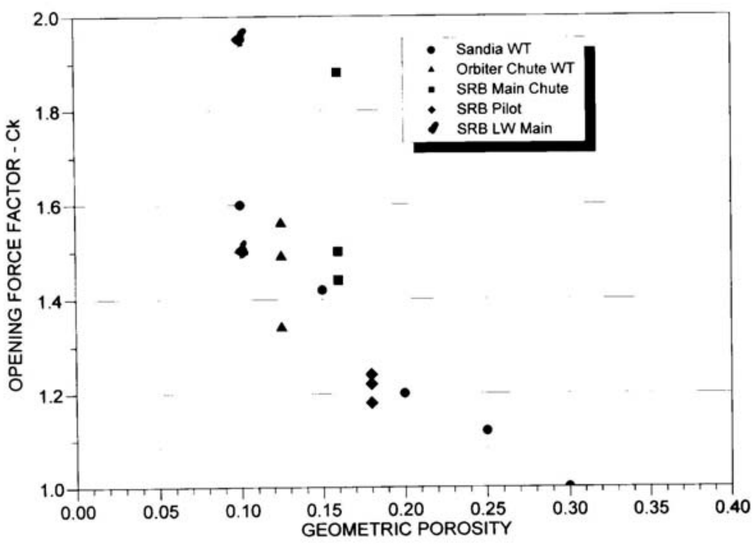


- Orbiter drag chute data added
- 40 ft diameter parachute
- Nylon/Kevlar parachute construction
- 120 x 80 ft wind tunnel

Quasi - Infinite Mass C_k from Free Flight Data

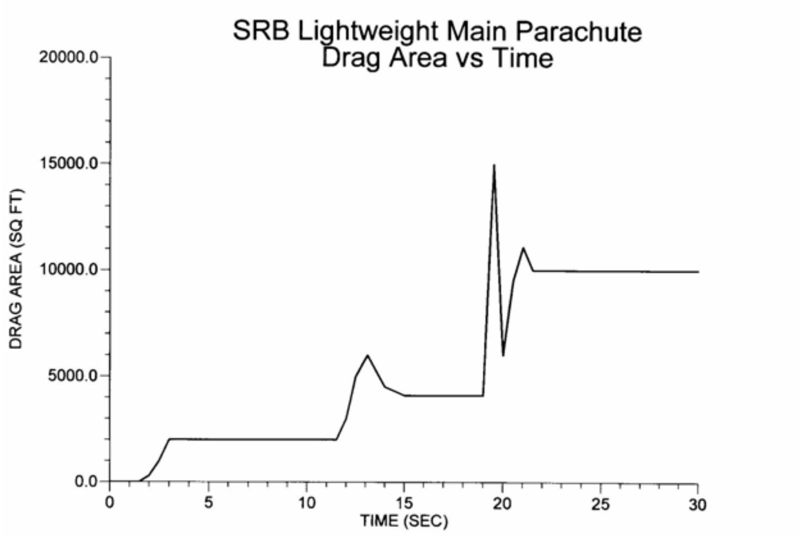
- **An approximation of infinite mass opening shock can be obtained from free flight data by dividing instantaneous parachute force by instantaneous dynamic pressure**
- **Some errors are inherent in this process because of the difficulties in the measurement of loads, the calculation of dynamic pressure and the synchronization of the two**

Quasi - Infinite Mass C_k from Free Flight Data



- **Free flight data added**
- **Some wild points due to synchronization problems**
- **The data indicate that infinite mass C_k values are not wind tunnel specific**
- **Geometric porosity appears to be the primary influence**

Quasi - Infinite Mass C_k from Free Flight Data



- **C_k is maximum drag area divided by steady drag area for any stage**

Vent Entanglement

- During the Space Shuttle SRB parachute flights, several main parachute failures occurred
  - No SRBs were lost due to parachute failures
- All of the major main parachute damage was eventually attributed to entanglement in the canopy vent region

SRB Main Chute Cluster

- SRB main chute cluster with 1 parachute deflated
- SRB lands on 2 main parachutes
- Damaged parachute is repaired

Damaged SRB Main Chute

- SRB main chute with split gore
- View looking from skirt to vent
- Gore split from vent to skirt
- Localized burning near the vent
- Entire split tension failures

Vent Hoop Design Origin

- **Vent line management band and improved stacking sequence minimized entanglement once the mechanism was understood**
- **A search for a new design that eliminated the entanglement problem entirely was initiated**

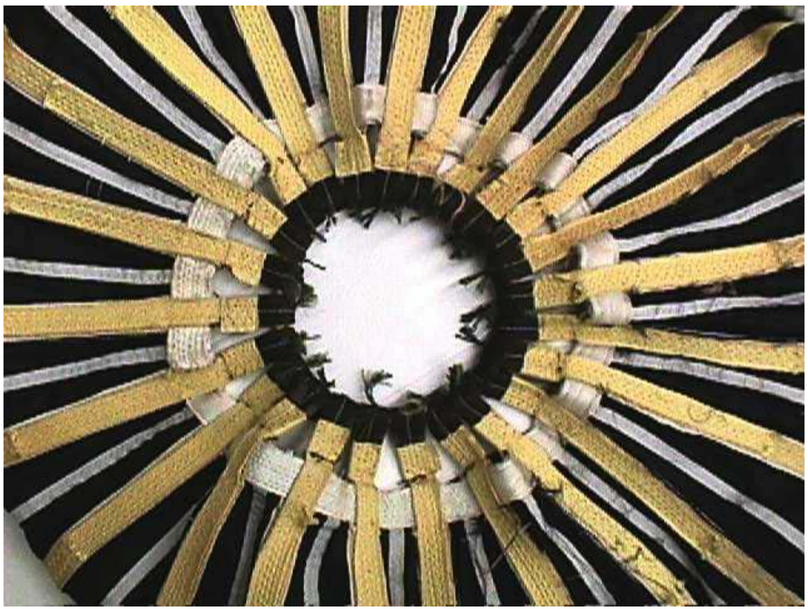
Vent Hoop Design Concept

- Radials are terminated at a structural hoop at the vent opening
- The hoop is made of high strength braided material (Kevlar, Spectra, Zylon) to minimize weight
- Free vent lines are completely eliminated, so there is no vent entanglement mechanism remaining
- Vent line abrasion also eliminated

SDW Drogue Vent Hoop

- AIAA-2001-2041
- Semi-Deployable Wing (SDW) drogue and mains were first vent hoop chutes
- Drogue 41-ft ringslot
- Tested 15 times
- Hoop 6500 lb Kevlar

Prototype Drogue Vent Hoop



- Drogue 26-ft ringslot
- Prototype drogue used to test lightweight fabric at Q = 400 lb/ft^2
- Tested several times
- Hoop 6500 lb Kevlar

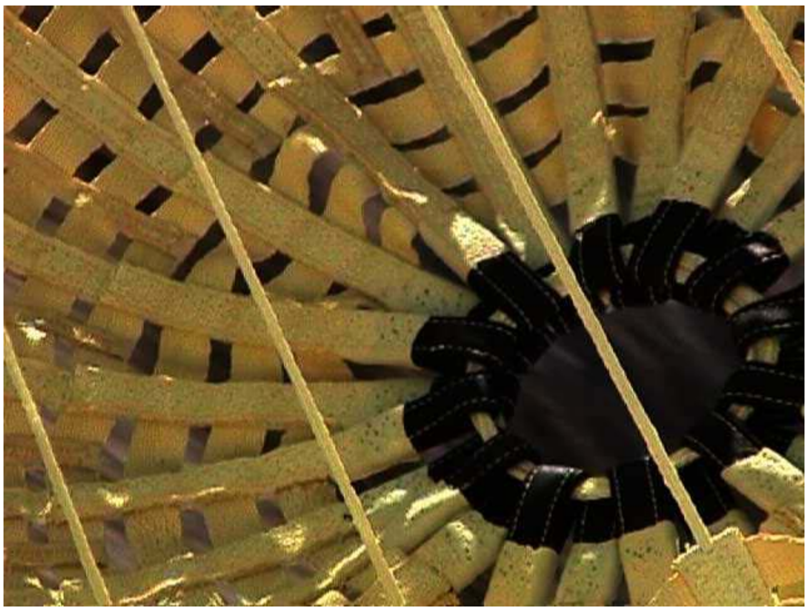
X-38 Drogue Vent Hoop

- AIAA-2001-2041
- Double vent hoops used to reduce vent diameter
- Drogue 80-ft ribbon
- Tested 20 times
- Hoop 6500 lb Kevlar
  - Each hoop 4 plies for redundancy

X-38 Supersonic Drogue Vent Hoop

- AIAA-2001-2041
- Double vent hoops used to reduce vent diameter
- Supersonic drogue 16-ft Zylon/Kevlar ribbon
- Tested at high Q subsonic
- Hoop 12000 lb Zylon
  - Each hoop 2 plies

X-38 Supersonic Pilot Vent Hoop

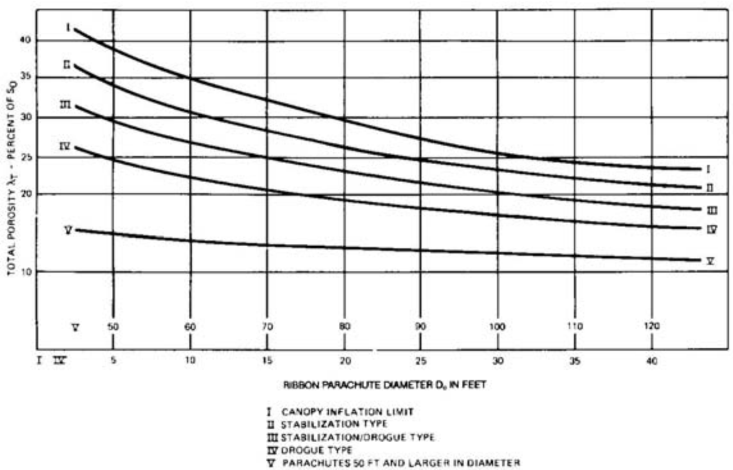


- AIAA-2001-2041
- Double vent hoops used to reduce vent diameter
- Supersonic drogue 2.2-ft Kevlar ribbon
- Tested at high Q subsonic
- Hoop 1500 lb Kevlar
  - Each hoop 2 plies

Experience with Vent Hoops

- **No problems encountered with vent hoops during many tests of several different designs**

Parachute Porosity vs Diameter



- Knacke NWC TP 6575 Figure 6-23
- Large parachutes require lower porosity
- Universal truth or just reflection of most common applications for different sized parachutes?
  - Why?

NASA/JSC and Natick Joint Program

- JSC was designing large round parachute for use as X-38 backup parachute in cluster of 3
  - 105-ft ringslot with ribbon vent area
- Natick provided some test support if the parachutes were tested in the 500-ft LVAD mode
  - Low altitude extraction from airdrop aircraft

NASA/JSC and Natick Joint Program

- 3 parachutes were fabricated by USA at the KSC PRF
- Three single parachute tests were planned to evaluate the deployment, inflation and load characteristics of the first parachute
- No reefing was planned because the LVAD delivery required rapid inflation

Test Results for First 3 Tests

- Test 1: Parachute skirt damage
  - Parachute did not inflate
- Test 2: Skirt inversion (Mae West)
  - Structural failures allowed parachute to inflate with major damage
- Test 3: Skirt inversion
  - Parachute did not inflate

Angle of Attack at Bag Strip

- **Test 2 – no change for all tests**
- **Large angle of attack at line stretch**

Skirt Inversion Formation

- **Windward canopy fabric blown under skirt band and inflates outside main canopy**

Inverted Skirt

- **Parachute in steady descent with large inverted skirt (Mae West)**

Analysis of Test Results for First 3 Tests

- **Large angle of attack at bag strip causes skirt inversion before parachute can inflate**
- **Skirt inversion observed on all 3 tests**
- **Skirt inversion prevents inflation and causes canopy damage as parachute inflates**

Cause of Skirt Inversion

- **Large amount of canopy skirt material is uncontrolled at line stretch**
- **Uncontrolled fabric must be controlled to prevent skirt inversion**
- **Angle of attack cross flow blows uncontrolled fabric under skirt band**

How to Prevent Skirt Inversion

- One way to control the canopy skirt material would be to install a short reefing line with a short time delay cutter
- Reefing would control canopy skirt but would not delay inflation
  - G-11 has a similar system
  - Reason for G-11 reefing was not clear
- Install short reefing line and short time delay cutter and test again

Results for Test 4

- Reefing line prevented skirt inversion
- Angle of attack at line stretch caused severe canopy infolding and skirt collapse that prevented inflation
- Parachute did not inflate

Redesign of Canopies

- **Skirt collapse could not be prevented because of test conditions**
- **Reduce porosity of canopy vent to cause more positive inflation**
- **Canopy vent areas were lined to reduce porosity**
  - Extent of lining limited by construction of canopies and time available

Results for Tests 5 an 6

- Test 5 was a single chute test that repeated tests 1 through 4 with a short reefing line
  - No skirt inversion
  - Full inflation somewhat sluggish
- Test 6 was a 3 chute cluster with a scaled up weight tub
  - Good inflation on all 3 chutes

Conclusions from LVAD Tests

- **LVAD parachute deployment conditions (large angle of attack) cause severe inflation and skirt inversion problems for large parachutes**
- **Short reefing line is effective in preventing the skirt inversion problem**
- **Reducing canopy porosity near the vent is effective in improving inflation**

Conclusions from LVAD Tests

- **The test peculiar conditions of an LVAD deployment for large parachutes cause a requirement for a much lower canopy porosity than normal**
- **Most large parachutes would have to be tested using similar methods regardless of their actual application**
- **The LVAD test environment could explain why “large parachutes must be less porous than small parachutes”**