Appendix 2

Group Chairman's Factual Report

Human Performance

DCA06MA009

Southwest Airlines
Autobrake System Training Handout
Dated February 07, 2005

Autobrake System Training Handout

The purpose of this training handout is to explain the autobrake system and the proposed autobrake policy and procedures. This handout should answer any significant questions on how to operate this system. You will be asked to evaluate this handout, and your suggestions will be considered for inclusion in the final training product.

Autobrake Philosophy

Just Another Tool

The basic landing and rollout procedures have not changed with the authorization to use autobrakes for landing. Autobrakes are provided only as a tool to stop the aircraft, just as manual braking, thrust reversers and spoilers are tools.

Pilot Responsibility

Pilots are expected to touchdown within the first 1500 feet of the usable runway, on speed.

The autobrake system is not a panacea against "runway excursions." The autobrake system cannot compensate for a poorly executed landing. The OPC Landing Output page data is predicated on a touchdown point of 1500 feet from the approach end of the runway (or DT), on speed. If the landing is long or fast, the stopping margin calculated by the OPC is no longer valid. At some point, even using the MAX setting or maximum manual braking, the runway remaining will be insufficient to stop the aircraft. In reality, the MAX setting will rarely be the required autobrake setting.

Expanded System Description

Plumbing

The manual braking system and the autobrake system have individual hydraulic pressure inputs. The hydraulic pressure outputs from each system meet at the autobrake shuttle valve. The valve senses hydraulic pressure from both the manual system and the autobrake system. The system with the higher pressure is selected and ported to the antiskid control unit through a common hydraulic line. The antiskid control may release hydraulic pressure to the brakes in response to a skid condition. The antiskid control unit doesn't know if the input pressure is from manual or automatic braking. (See Figure 1.)

Initial Brake Application

As detailed in the FRM, the autobrake system is designed to automatically apply brakes at touchdown. To prevent nose gear "slam down," the autobrake controller applies the brakes in a two stage process. First, after the thrust levers are retarded to idle and the main wheels spin up, the autobrake controller commands a hydraulic pressure of 200 psi to the brakes, with pressure increasing at a rate of 100 psi/second. Then, at approximately 2 seconds after main wheel spinup, the controller commands the hydraulic pressure required to achieve the selected deceleration rate. Manual override of the autobrake system is inhibited for the first 3 seconds after landing to prevent disengagement due to inadvertent brake inputs while manipulating the rudder pedals.

Autobrake Deceleration Levels

The autobrake system is designed to achieve a certain deceleration rate. This rate is selected by setting the AUTO BRAKE select switch to one of four positions, 1-3 and MAX. The settings equate to the following deceleration rates:

- Level 1 – 4 feet per second, per second
- Level 2 – 5 feet per second, per second
- Level 3 – 7.2 feet per second, per second
- MAX – 14 feet per second, per second to 80 knots, then 12 feet per second, per second

Note: The autobrake controller commands hydraulic pressure (up to a limit value for each setting) to achieve the desired deceleration rate. The limit value to achieve the MAX rate is less than full hydraulic system pressure. Manually applying maximum pedal pressure to achieve maximum hydraulic pressure to the brakes, will result in a higher deceleration rate than MAX, and a shorter stopping distance.

The autobrake controller senses total aircraft deceleration and modulates brake pressure to maintain the desired deceleration level. At higher speeds the deceleration forces produced by the thrust reversers and spoilers peak, and the autobrake controller reduces brake pressure accordingly. As the aircraft slows, these deceleration forces decrease, and the autobrake controller will increase brake pressure to maintain the desired deceleration level. (See Figures 2 and 3)

Autobrake Disarm

The autobrake controller will command braking to achieve a complete stop, and at 30 knots, the amount of hydraulic pressure to the brakes is held constant. This results in a lurch as the aircraft stops. The severity of the lurch increases as a function of deceleration rate, with the most uncomfortable lurch at the MAX position. For this reason, it is desirable to disengage the autobrake system prior to coming to a complete stop. There are four ways to disengage the system:

- Override the autobrakes with manual braking
- Stow the SPEEDBRAKE lever
- Rotate the AUTO BRAKE select switch to OFF
- Advance the thrust levers (in case of a go-around after touchdown)

Note: **(-700)** The brake system has two ratios of pedal pressure/brake pressure. The first ratio is 4 to 1 for the first 750 psi of brake pressure, the second ratio is 1 to 1 for brake pressure in excess of 750 psi. This means that it takes four times the pedal pressure to achieve the first 750 psi of brake pressure as it does to achieve the second (and subsequent) 750 psi increments of brake pressure. When overriding the autobrake system, it will take more pedal pressure than in the -300/-500 aircraft, which use a 1 to 1 ratio for all braking.

Southwest Airlines’ Autobrake Policy

From The FOM

Autobrakes, if operational, will be used when the reported or anticipated runway condition is not DRY and the Min (2) stopping margin is less than 500 feet. Autobrake use in all other situations is at the Pilot’s discretion. When autobrakes are used, comply with the following:

- Use the ***lowest*** autobrake setting resulting in a stopping margin of **500 feet or more**.
- If a stopping margin of at least 500 feet cannot be achieved with any autobrake setting, landing is still authorized using an autobrake setting which results in a positive stopping margin.

Required Use

Use of the autobrake system is required only when the runway is not DRY and the OPC computed Min stopping margin is less than 500 feet. If the autobrake system is not operational, landings are still authorized under these conditions using the appropriate manual braking techniques.

The distinction between DRY and not DRY was made because of the friction characteristics of the runway in these conditions. With a dry runway, the friction (and thus stopping capability) is generally good on all portions of the runway, so braking at later stages should be effective. On a runway that is not DRY, stopping capability at the departure end of the runway may be significantly reduced by rubber deposits and runway markings (painted areas). Autobrake use will ensure that a significant amount of braking is accomplished immediately after touchdown, on a relatively clean runway surface. Although manual brakes may be applied immediately upon touchdown, most pilots typically delay brake application for a few seconds. The typical touchdown speed is approximately 200 feet per second, so a short delay in manual brake application can result in wasting several hundred feet of "clean" runway.

The minimum margin of 500 feet was chosen based on the results of a landing distance survey. Approximately 40% of the landings in this survey resulted in a touchdown beyond 1500 feet. The average of these "long" landings was approximately 500 feet. The 500 foot margin affords a measure of protection for long landings, but is not unduly restrictive in requiring autobrake use. It remains the Pilot's responsibility to land within the first 1500 feet of the effective runway length.

Discretionary Use

Autobrake use in all other situations is at the Pilot's discretion. The Crew is expected to remain proficient at both manual braking and the use of autobrakes.

Some suggested conditions for the evaluation are:

- Landing in strong/gusty crosswinds or landing with a condition (such as one engine inoperative or a thrust reverser inoperative) where uniform or timely brake application due to rudder inputs may be affected.
- Landing from a Cat IIIA approach.
- Non-normal landing configurations resulting in higher than normal approach speeds.

Selecting An Autobrake Level

Use the ***lowest*** autobrake setting resulting in a stopping margin of **500 feet or more**.

The 500 foot stopping margin was chosen to allow for the variability that will be introduced in the actual stopping margin during the transition to manual braking. If the same or greater deceleration rate is maintained during this transition, the original OPC stopping margin will be valid. If a lesser deceleration is used after the transition to manual braking, due to differences in pilot braking technique, the 500 foot margin will provide an adequate margin for the transition.

When autobrake use is required by policy, autobrake level 3 will be the most prevalent setting. Level 2 in these situations will not provide a 500 foot stopping margin, so it cannot be used. In certain circumstances, such as WET-POOR combined with heavy gross weights, MAX may be the level required to achieve a 500 foot stopping margin.

When the autobrake system is used at the Pilot's discretion, there may often be situations where the Min stopping margin is in excess of 500 feet. In these cases, autobrake level 2 would be appropriate. The OPC does not compute stopping margins for autobrake level 1, so this level will not be used.

If A 500 Foot Margin Cannot Be Achieved

If a stopping margin of at least 500 feet cannot be achieved with any autobrake setting, landing is still authorized using an autobrake setting which results in a positive stopping margin.

An Autobrake Landing

Autobrake application is extremely smooth. The braking action is very mild at level 1 and becomes increasingly aggressive as the level is increased. Even at MAX braking on a dry runway, the braking action is very smooth. The uncomfortable part of an autobrake landing occurs if the pilot allows the autobrakes to bring the aircraft to a complete stop. The brake pressure is "frozen" at 30 knots and below, and the brakes will remain engaged even after a complete stop. This results in a significant "lurch" at the completion of the stop. This "lurch" is more pronounced and uncomfortable as the autobrake level is increased. With MAX selected, a complete stop by the autobrake system would probably cause alarm in the passenger cabin. For this reason, the autobrake system should be disengaged prior to the aircraft coming to a complete stop. This allows the Pilot to make a smooth manual stop when required.

Autobrake System Disengagement

The autobrake system will be disengaged by a manual braking override accomplished by the PF at approximately 80 knots (or closer to a safe taxi speed in extremely slippery conditions). The intent of manual braking is to ***override*** the autobrake system and **maintain the same or greater deceleration rate until reaching a safe taxi speed**, at which time manual brakes may be used as required. The disengagement will be indicated by the illumination of the AUTO BRAKE DISARM light.

The FRM lists three alternate methods of disengaging the autobrake system: advancing the thrust levers; stowing the SPEEDBRAKE lever; and turning the AUTO BRAKE select switch to OFF. The first of these methods allows for disengagement in the event a rejected landing after touchdown. The remaining two methods are contrary to current SWA procedures and **will not** be used.

Southwest Airlines' Autobrake Procedures

Determining The Requirement For Autobrakes

This step is performed prior to the Top of Descent, during evaluation of the OPC Landing Output page. If WET-GOOD/FAIR/POOR is selected, and the runway selection yields a Min stopping margin of less than 500 feet, autobrakes, if operational, are required.

At this point, the Crew may elect to alter the conditions by selecting a greater flap setting or selecting a different runway. If these options are not desired or available, then autobrakes are required.

During this evaluation period, the Crew must carefully analyze the stopping margin and runway condition to determine autobrake requirements. An upcoming OPC revision will place a note at the bottom of the landing output page stating that autobrake use is required. (See Figure 4.)

Select Autobrakes, If Required

If an autobrake landing is required, select the lowest setting resulting in a stopping margin of 500 feet or more. The OPC currently displays stopping margins for three levels of braking, Min, Med, and Max. These levels equate to autobrake levels 2, 3, and MAX. If autobrake use is required and the Med Brk stopping margin is 500 feet or more, then the Crew would select autobrake level 3. An upcoming OPC revision will modify the braking labels by adding the autobrake level. The levels will become: Min(2), Med(3), and Max(M). (See Figure 4.)

If an autobrake landing is to be made at the Pilot's discretion, the autobrake level should be set in a similar manner.

The Descent Checklist

A new step has been added to the Descent Checklist, to confirm the position of the AUTO BRAKE select switch. An example response is in the FOM section 3.11.

The Landing Rollout

After touchdown, the current procedures remain basically unchanged. Autospoilers and thrust reverser use is unchanged. Manual braking will be initiated at approximately 80 knots when autobrakes are used for landing.

The only significant change is the addition of a callout in the event of an autobrake system malfunction. From touchdown until the “80 knots” call, the PM will monitor the AUTO BRAKE DISARM light. If the light illuminates, a system malfunction may be indicated, and the PM will call “Autobrake disarm.” Since the PF is relying on the autobrake system to slow the aircraft and the system may have malfunctioned, there is a potential for a period of time where brakes are not being applied. Since this situation may become critical with minimal stopping margins, a timely callout is required so that the PF may immediately commence manual braking.

After the “80 knot” call, the PF is most likely performing manual braking, and if not, the aircraft speed will be relatively low. A system malfunction at this point is not as critical, so a callout is not required.

When using autobrakes and performing a HGS Cat 3 approach, the FO must monitor both the ground roll steering and the AUTO BRAKE DISARM light, with the ground roll steering taking precedence.

After Landing Flow

A step has been added to the After Landing Flow for the FO to turn off the autobrake system.

Brake Wear

There is a significant concern that the use of the autobrake system will result in an increase in brake wear. As a result, a discussion on brake wear is in order.

Steel Brakes

All B-737 aircraft use steel brakes. There is not enough weight savings on the brake assemblies or gain in ATOG to offset the expense of carbon brakes. The brake systems on SWA aircraft are Honeywell steel brakes with a proprietary Ceramatalix brake lining.

Factors Affecting Brake Wear On Steel Brakes

The primary factor in steel brake wear is the amount of kinetic energy absorbed during a stop. Several factors influence the amount of kinetic energy absorbed. They are: kinetic energy dissipated by aerodynamic drag, kinetic energy dissipated by reverse thrust, brakes on speed, and severity of brake application. Changing any one of these factors will have an impact on the amount of kinetic energy absorbed by the brakes. (See Figure 5).

With the authorization for autobrake use for landing, it is imperative that current procedures concerning use of auto-spoilers and reverse thrust be followed. The autobrake controller will command brakes as required to meet the selected deceleration level. If we become procedurally sloppy (with reverser application in particular) the autobrake controller will compensate and we will introduce unnecessary kinetic energy into our brakes. For example, a 5 second delay in selecting reverse thrust on a -700 will result in an increase of approximately 9 million foot pounds of energy into the brakes. (See Figure 6.)

The other factors such as brakes-on speed and the severity of brake application also have a significant influence in kinetic energy absorption. If the brakes are applied earlier and harder, the aircraft will stop in a shorter time span. This means that the spoilers and reversers have less time to aid in kinetic energy dissipation, and more energy will be absorbed by the brakes. If this increase in braking is required due to stopping margin issues, then it is an acceptable tradeoff to the alternative of running out of runway. (See Figure 7).

In most cases, the energy differences between an autobrake stop at the appropriate level and a manual stop will be minimal. If the Crew selects level 3 when level 2 is sufficient, we will have an energy penalty.

Analysis of landing data regarding brakes-on speeds and deceleration rates (severity of brake application) have shown a wide variation in both. In some cases, the pilots probably overuse the brakes compared to a very predictable autobrake application and we again have an energy penalty. On the other hand, if a runway and stopping margin permit a rollout to 80 knots followed by mild manual braking to a safe taxi speed, we enjoy an energy advantage over autobrakes. (See Figure 8.)

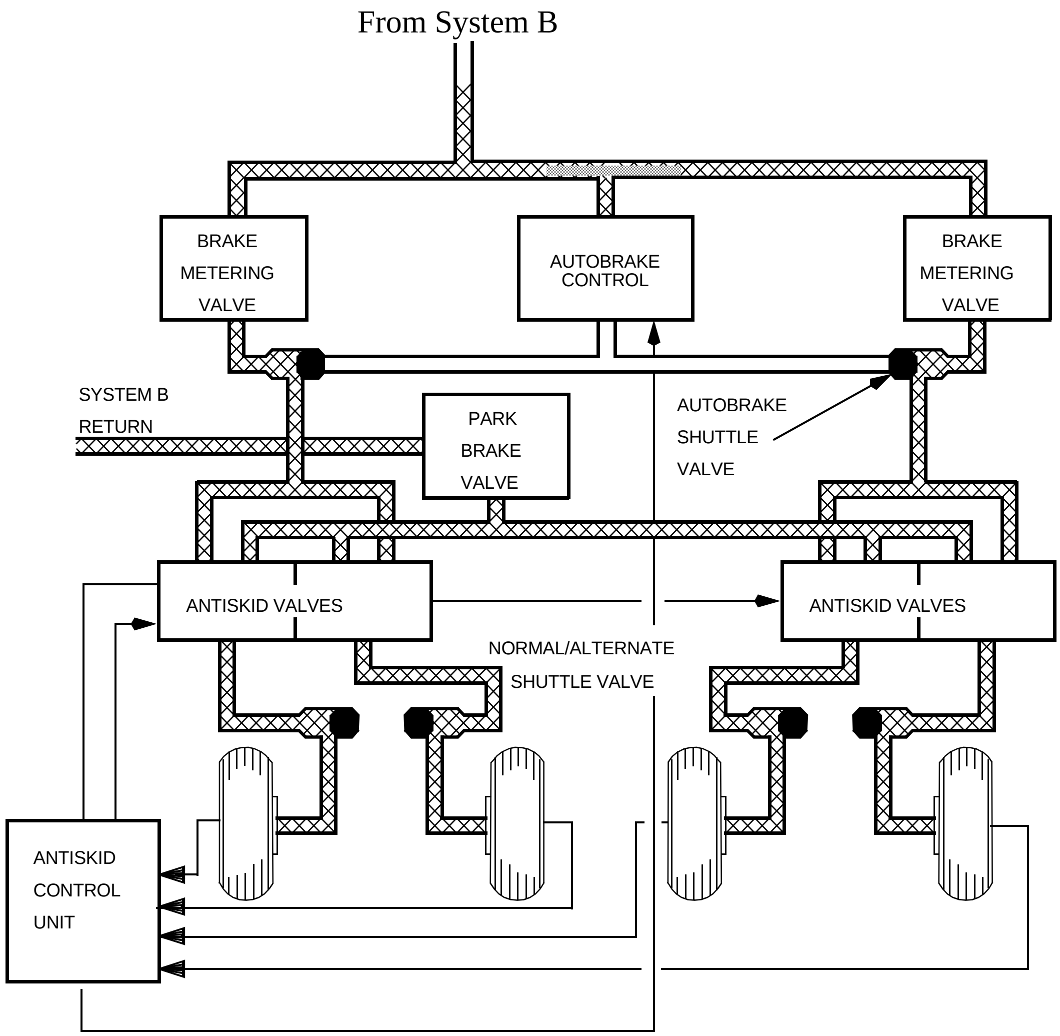
From System B
BRAKE METERING VALVE
AUTOBRAKE CONTROL
BRAKE METERING VALVE
SYSTEM B RETURN
PARK BRAKE VALVE
AUTOBRAKE SHUTTLE VALVE
ANTISKID VALVES
ANTISKID VALVES
NORMAL/ALTERNATE SHUTTLE VALVE
ANTISKID CONTROL UNIT

Figure 1.

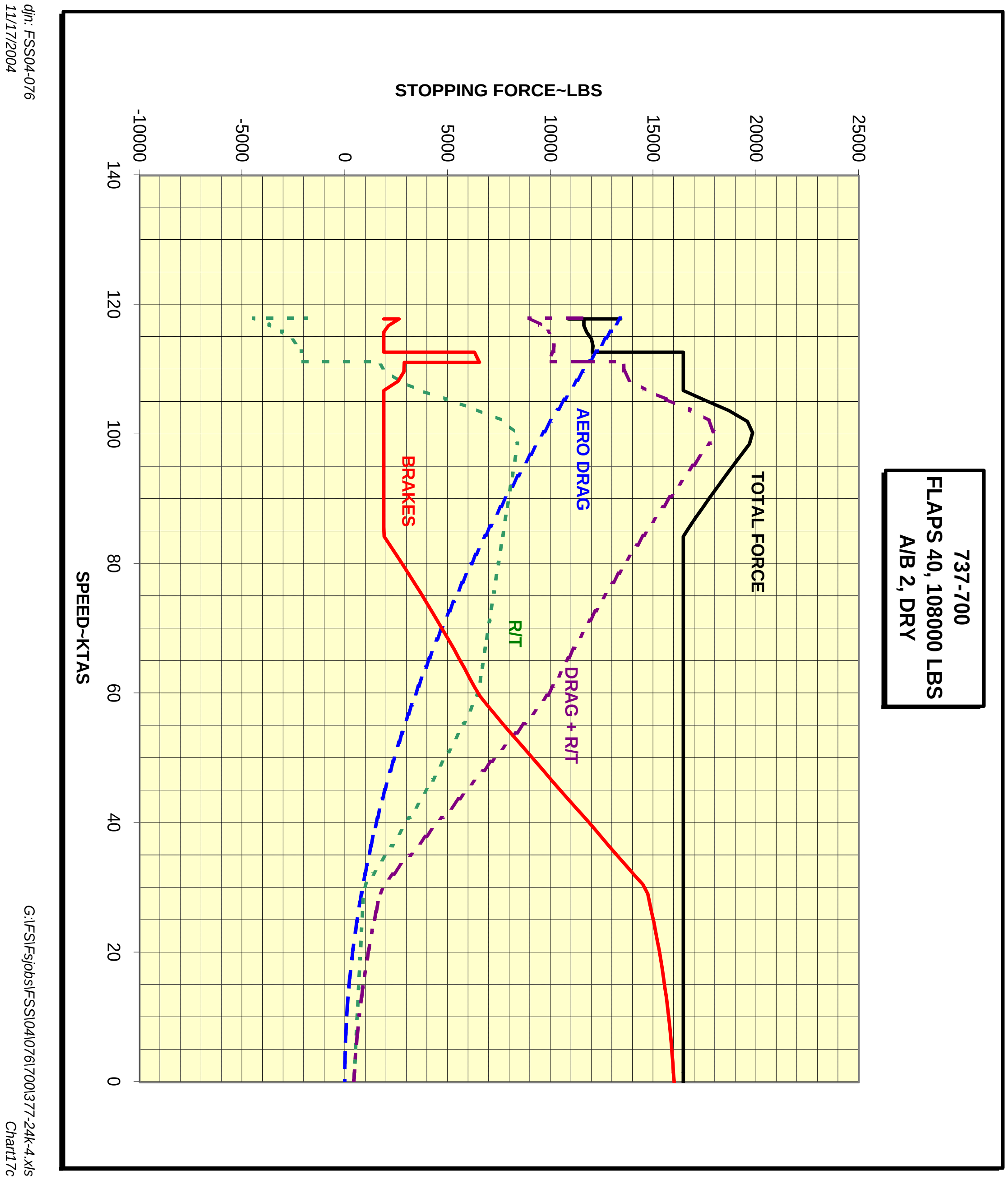

Figure 2.

This plot shows how the autobrake controller modulates the brakes to maintain the braking force for the selected deceleration rate. In the case of level 2, the reverse + drag actually produces more stopping force than required, so for a period of time, there is virtually no brake application. This corresponds closely to our manual braking technique.

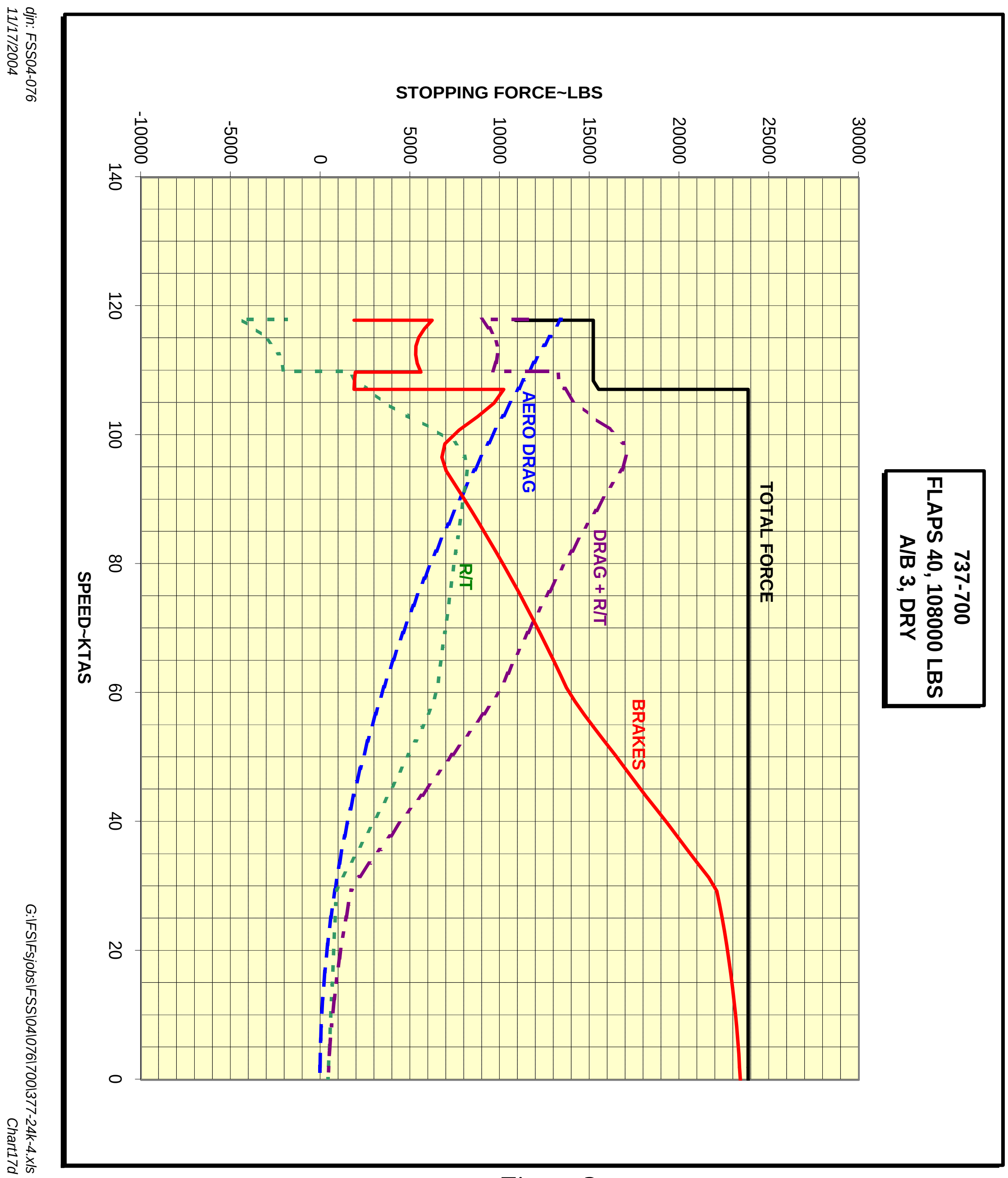

Figure 3.

This plot shows how the autobrake controller modulates the brakes to maintain the braking force for the selected deceleration rate. In the case of level 3 (and Max), the reverse + drag never produces the stopping force required, so significant brake application is apparent throughout the landing roll.

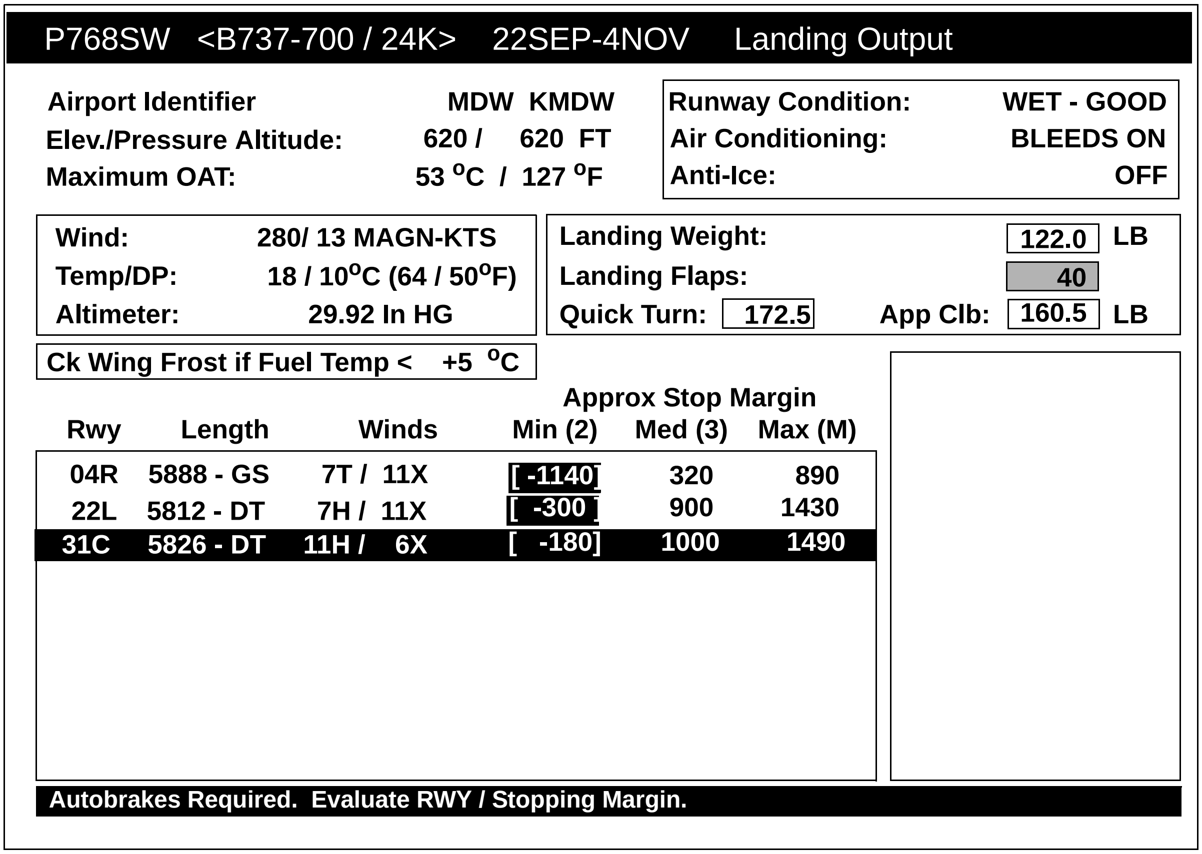

Figure 4.

This graphic shows the proposed label changes to the Min, Med, and Max brake columns and the proposed "Autobrakes Required" message.

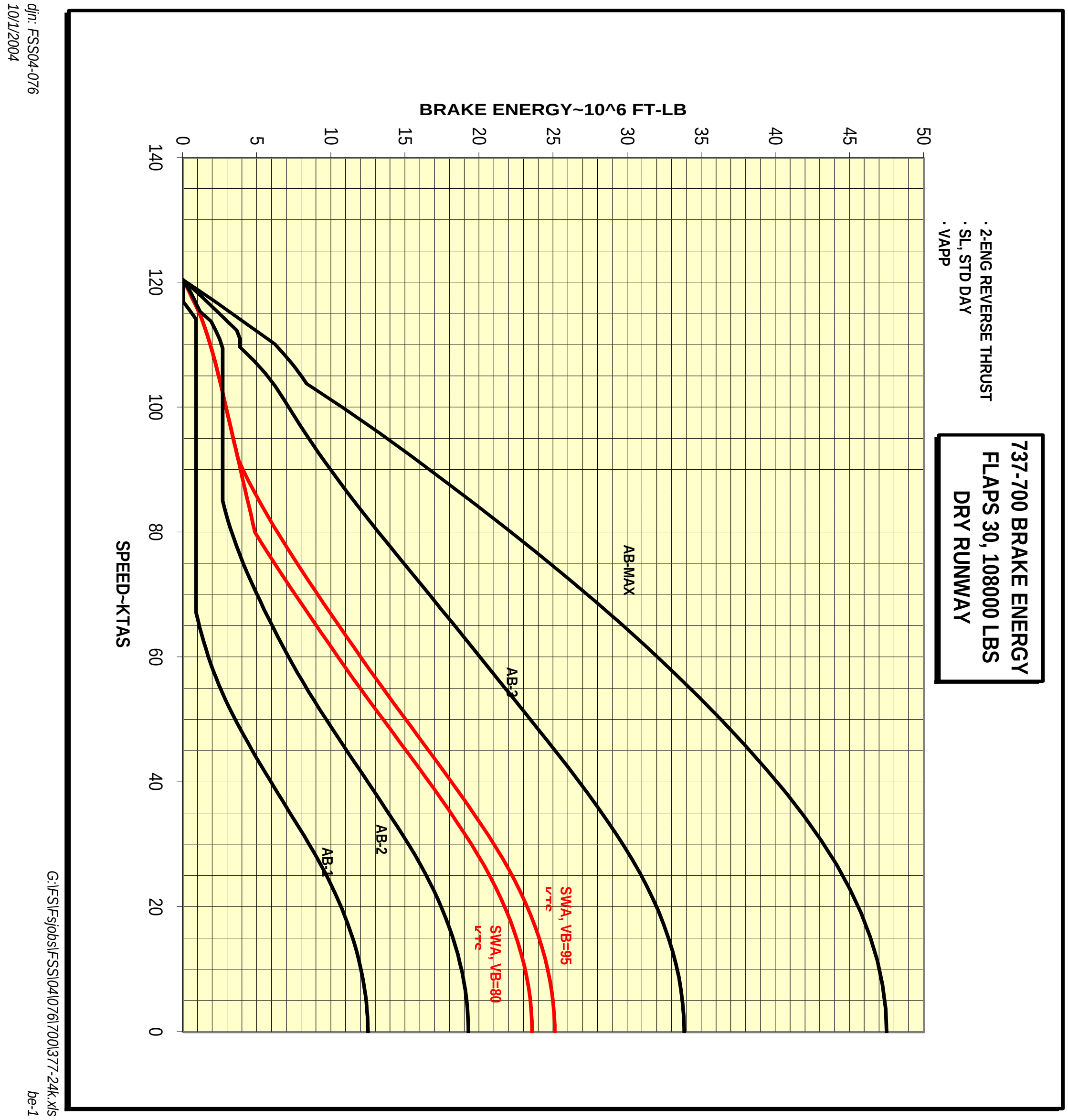

Figure 5.

The red plots show the energy absorbed by inreasing the brakes on speed from 80 to 95 knots. The severity of brake application has been set artificially high, so an energy absorbed comparison between the red plots and the black autobrake plots cannot necessarily be made with this information.

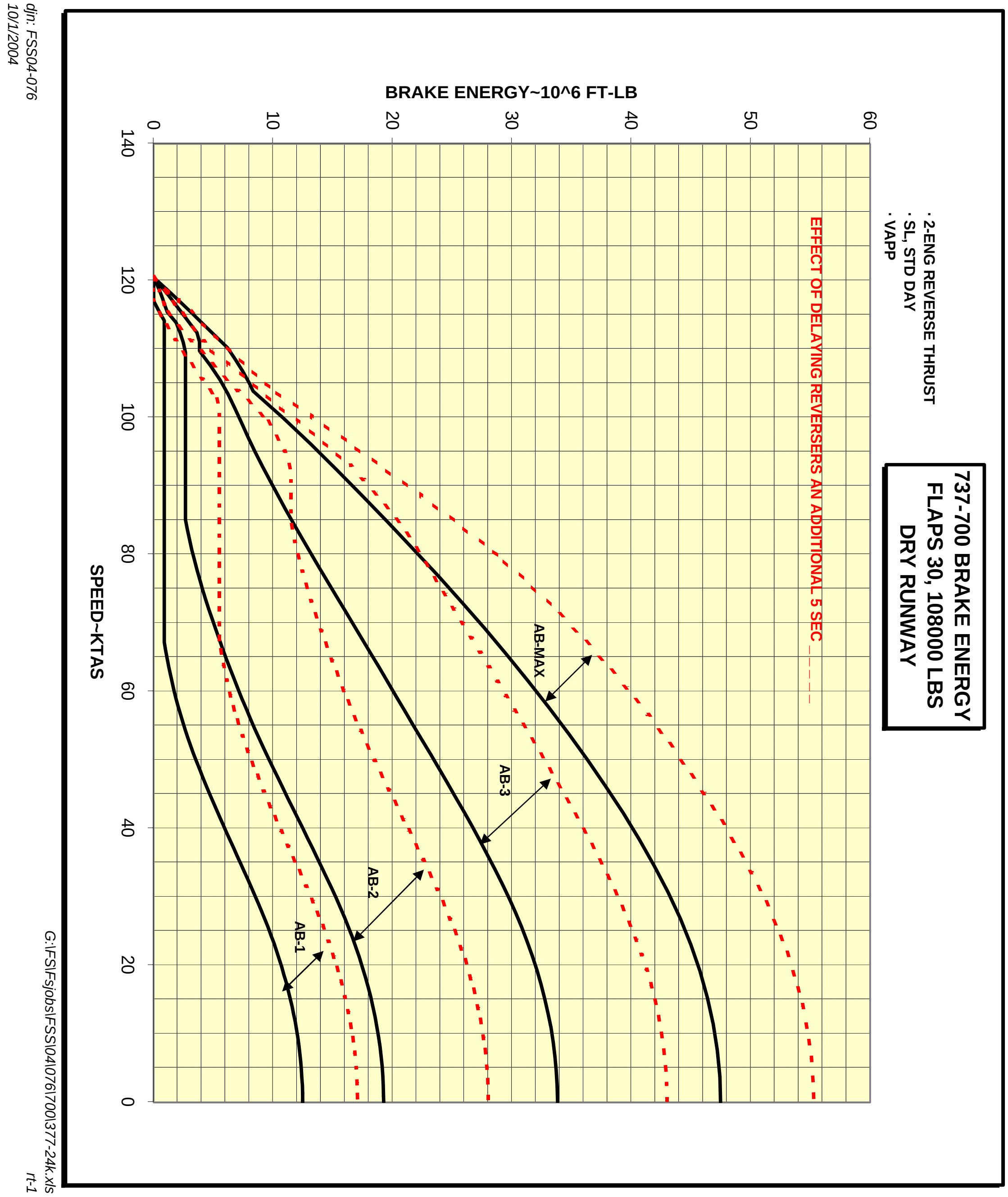

Figure 6.

This plot shows the effect of delaying thrust reverser application by 5 seconds. The dashed lines represent the energy absorption with the delay. The approximate increase is 9 million foot-pounds of energy.

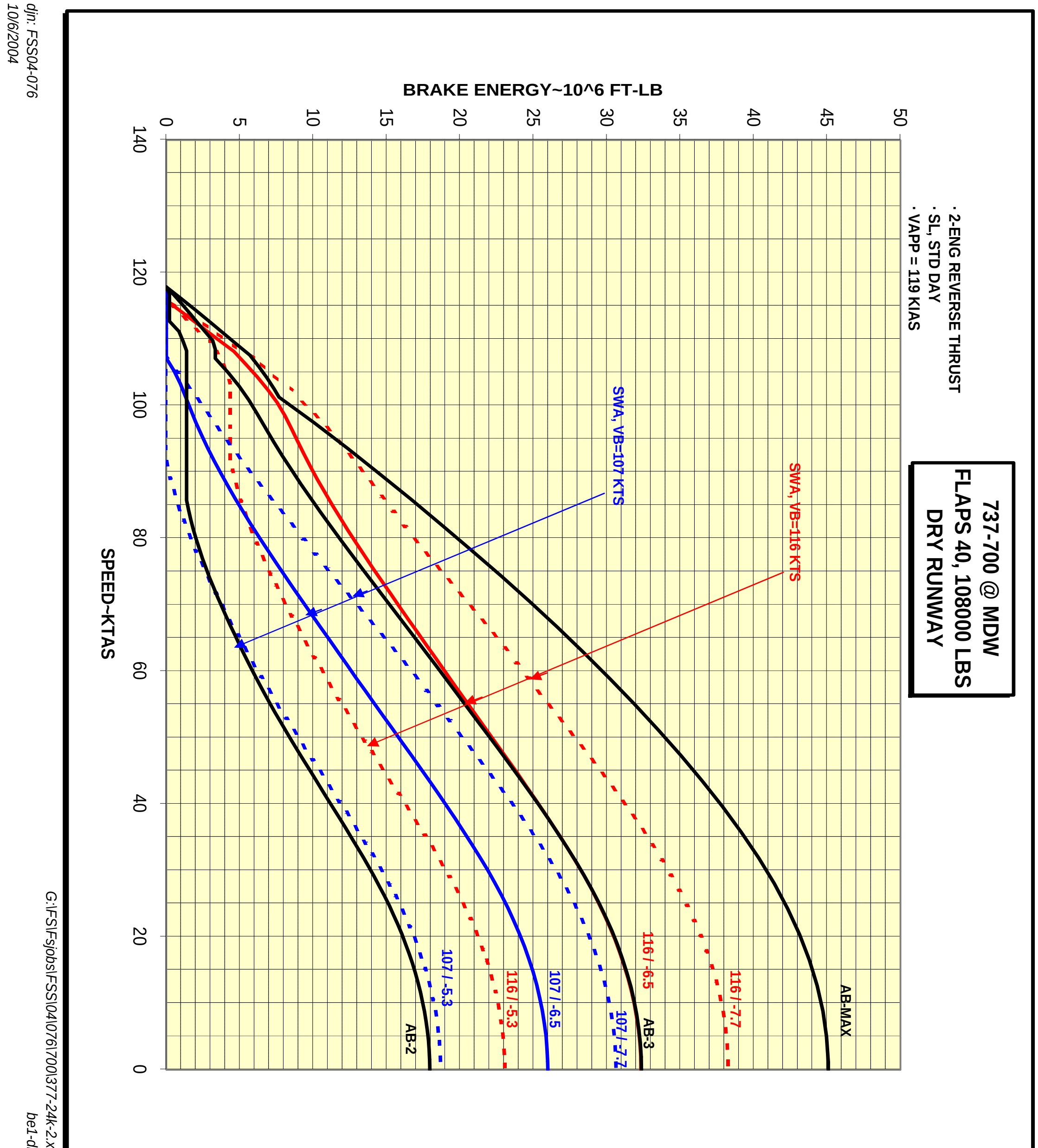

Figure 7.

This plot shows the effect of varying the brakes-on speed and the deceleration rate (severity of brake application). The solid blue plot represents a brakes-on speed of 107 knots and 6.3 fps deceleration rate. The dashed blue plots represent 107 knots and 7.7/5.1 fps. There is a significant variance in the amount of kinetic energy absorbed.

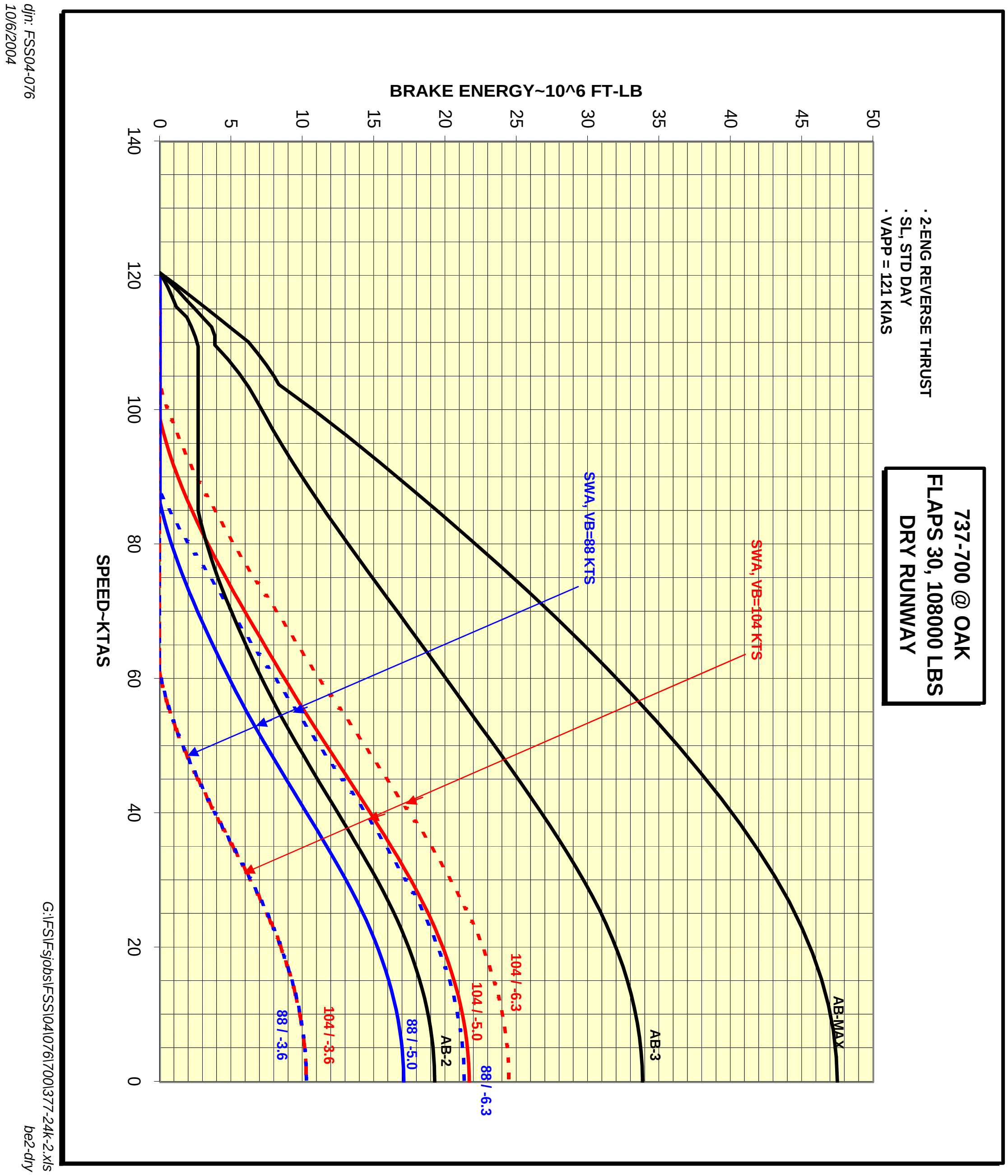

Figure 8.

The solid blue plot shows the energy absorbed with a brakes-on speed of 88 knots and a deceleration rate of 5.0 fps. This condition was derived from data for OAK landings and represents the mean brakes-on speed and mean deceleration rate. Comparing with AB2, there is an energy savings (less brake wear).