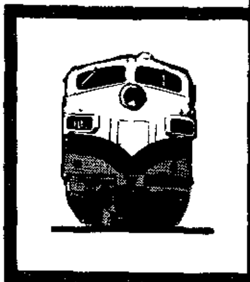
NATIONAL TRANSPORTATION SAFETY BOARD



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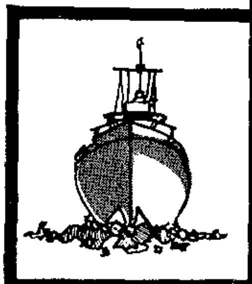
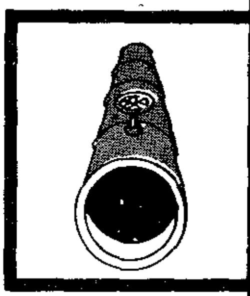


RAILROAD ACCIDENT REPORT

DERAILMENT OF NEW YORK CITY TRANSIT AUTHORITY SUBWAY TRAIN NEW YORK, NEW YORK DECEMBER 12, 1978



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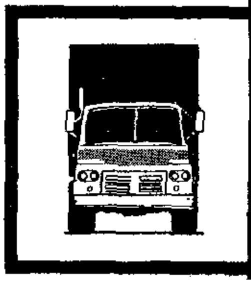

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16 Abstract

About 4:38 p.m., on December 12, 1978, the sixth and seventh cars of a New York City Transit Authority subway train designated "CC" 4:06 p.m. derailed within moments after departing 59th Street station. Twenty-two persons were injured, and property damage was estimated to be $667,500.

While the Safety Board was investigating this accident, three other trains derailed from what appeared to be similar causes. Therefore, the investigation was expanded to include all four accidents.

The National Transportation Safety Board determines that the probable cause of each of the four accidents was a cracked wheel which had resulted from extensive overheating. Contributing to the cause of the overheating of the wheels was the partial application of a handbrake. Because of a lack of adequate inspection procedures, the New York City Transit Authority employees failed to detect the partially applied handbrake and the thermally damaged wheels before they cracked.

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Derailment; subway train; wheels; inspection procedures

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C. 20594

RAILROAD ACCIDENT REPORT

Adopted: August 2, 1979

DERAILMENT OF NEW YORK CITY TRANSIT AUTHORITY SUBWAY TRAIN NEW YORK, NEW YORK DECEMBER 12, 1978

SYNOPSIS

About 4:38 p.m., on December 12, 1978, the sixth and seventh cars of a New York City Transit Authority subway train designated "CC" 4:06 p.m. derailed within moments after departing 59th Street station. Twenty-two persons were injured, and property damage was estimated to be $667,500.

While the Safety Board was investigating this accident, three other trains derailed from what appeared to be similar causes. Therefore, the investigation was expanded to include all four accidents. The other derailments were: (1) At 8:08 a.m. on January 15, 1979, when the fourth car of an "A" train derailed north of Rockaway Avenue; (2) at 7:23 p.m. on February 14, 1979, when the seventh car of an "E" train derailed at 53rd Street; and (3) at 7:04 a.m. on March 21, 1979, when the first car of a "CC" train derailed at 14th Street.

The National Transportation Safety Board determines that the probable cause of each of the four accidents was a cracked wheel which had resulted from extensive overheating. Contributing to the cause of the overheating of the wheels was the partial application of a handbrake. Because of a lack of adequate inspection procedures, the New York City Transit Authority employees failed to detect the partially applied handbrake and the thermally damaged wheels before they cracked.

INVESTIGATION

The Accidents

On December 12, 1978, New York City Transit Authority (NYCTA) subway train designated "CC" 4:06 p.m. departed southbound from Bedford Park on time. The train, consisting of eight cars, continued southward making its scheduled station stops. At 170th Street, 2.7 miles south of Bedford Park, passengers in the sixth car became concerned because of the car's bumping and the presence of smoke inside the car. Because of their concern, they began to move from the sixth car to other cars in the train. One woman who had boarded the eighth car of the train at 145th Street stated that the train was going up and down as if it were riding on a bumpy road. She said she smelled an odor like that of tar or oil. Two passengers who boarded the sixth car of the train at 72d Street said that the train bounced them around. One of these passengers said it felt like a wheel was coming off.

A passenger who boarded the sixth car at 96th Street noticed smoke coming from under the car. Because of the bumpy ride, he moved forward one car at 86th Street, to the car from which the conductor was operating the doors. He did not tell the conductor about the conditions in the sixth car. A passenger who boarded the sixth car of the train at 59th Street said the car was filled with a gray haze, and there was an odor like that created by an electrical short circuit. Furthermore, she said she heard hissing and popping sounds like an electrical short circuit coming from between the cars. She said the ride was rough as the train left the station, and it seemed as though the wheels were flat. She said she saw sparks between the sixth and seventh cars.

Earlier, as the train was leaving the 125th Street station, 6 miles south of Bedford Park, the platform conductor had seen smoke coming from under the sixth car. This conductor notified the dispatcher at 125th Street who, in turn, arranged for a road car inspector to meet the train at the 59th Street station. Both the motorman of the train and the dispatcher had operating radios; however, the dispatcher did not notify the motorman about the smoke issuing from his train. As the train arrived at the 59th Street station,the road car inspector was waiting on the platform. When the train stopped he indicated to the conductor to hold the doors open so that the train would not move. The road car inspector then looked down along the side of the sixth car between the car and the platform. He then stepped onto the end of the car, crossed over, and looked down along the other side of the car and the tunnel wall. He later said that he did not detect any defects on the sixth car. Both the motorman and the train conductor said that they did not talk with the road car inspector and that he did not notify them of the smoke emission report. The road car inspector then gave an "okay" to the conductor, by hand signal, for the train to proceed, and he boarded the sixth car to continue to check for the problem. He said that he did not see any smoke coming from under the sixth car during his inspection while the train was at the 59th Street station, so he did not descend to the track level during his inspection.

At 4:38 p.m., approximately 75 feet south of the station, the sixth and seventh cars derailed to the east. As the train continued south, the two derailed cars moved away from the track structure, and at a point approximately 225 feet beyond the point of derailment, the sixth car struck a concrete and steel curtain wall, which is used to separate two tracks. The car was forced back toward the track structure, permitting the leading end of the seventh car to strike the end of the curtain wall. The side of the car was torn off.

At 8:08 a.m. on January 15, 1979, the emergency train brakes applied on a 10-car subway train designated "A" while it was moving northbound at a point 300 feet south of Ralph Avenue. Inspection by the motorman revealed that the Nos. 3 and 4 wheels in the No. 1 truck of the fourth car had derailed.

On February 14, 1979, at 7:23 p.m., a 10-car subway train designated "E" was southbound on the 53d Street line when the train's emergency brakes applied. An air leak was found between the seventh and eighth cars. The motorman had the air brakes isolated on these two cars; the train's brakes were then released and the train continued southward. About 120 feet into the Lexington Avenue station the train brakes again applied in emergency. The No. 1 truck on the seventh car had derailed.

On March 21, 1979, a northbound eight-car subway train designated "CC" departed from Rockaway Park at 7:04 a.m. The motorman felt that his train was running slow and requested that a road car inspector meet the train. At the Euclid Avenue station a road car inspector boarded the train. The train speed seemed slow to him also. He had the motorman operate the controller on and off several times, and each time the train would pick up speed and then drop back to the slower rate. The road car inspector did not make any additional checks of the train's equipment; he said that the slow speed was caused by the the heavy load of people the train was carrying. He told the motorman that it was all right to proceed, and the road car inspector left the train. The train continued northward making regular station stops. As the train approached the 14th Street station at a speed estimated to be 20 to 25 mph, the motorman saw arcing accompanied by a loud noise, and he immediately stopped the train with the first four cars in the station. Both pairs of wheels of the No. 1 truck of the first car had derailed.

Location of the Derailments

The derailment of December 12, 1978, occurred at a crossover switch 120 feet south of the 59th Street station platform. The train was operating on the track designated as A1, which is the most westward track of six tracks which are numbered from west to east A1, B3, A3, A4, B2 and A2. (See figure 1.) There is also a series of crossovers that connect the six tracks . An opening in the curtain wall between tracks A3 and B3 is provided to permit the tracks to converge. Beyond the crossovers the curtain wall is used to separate tracks and to protect a line of columns that support 8th Avenue and 57th Street. The curtain wall was constructed of fabricated H-beams using 3-inch by 3-inch by 1/4-inch angle iron and 1/4-inch flat plate riveted together and secured to a concrete base at the bottom. Six-inch-thick concrete was used between the H-beams to form the wall.

The derailment of January 15, 1979, occurred north of Rockaway Avenue on track A4, an express track. There are four tracks at this location numbered from east to west A2, A4, A3, and A1. The two outside tracks A2 and A1 are for local trains and tracks A4 and A3 are for express trains.

The derailment of February 14, 1979, occurred in the 53d Street tube on track D3. There are two tracks at this location numbered east to west as D4 and D3. The derailed car traveled a distance of 1,300 feet before the train stopped.

The derailment of March 21, 1979, occurred approximately 3,600 feet south of the 14th Street station on track A2. The train traveled 4,050 feet after it derailed, and came to a stop with the four north cars inside the 14th Street station, next to the island platform. There are four tracks at this location numbered from east to west A2, A4, A3, and A1. Tracks A2 and A4 are separated by an island platform, and tracks A3 and A1 are separated by an island platform.

Injuries to Persons. — Derailment of December 12, 1978

Injuries	Passengers	NYCTA Employees
Fatal	0	0
Nonfatal	22	1
None	78	2

There were no reported injuries in the three subsequent derailments.

Damage

In the December 12, 1978, derailment, the force of the collision with the curtain wall caused extensive damage to the sixth and seventh cars. The body of the sixth car was twisted, both sides of the car were pushed inward around the center area, and the car floor and the interior car body were buckled. The motorman's cab of the seventh car was destroyed; the side of the car opposite the motorman's cab was torn off from the end to the middle of the car; seats and frames were destroyed; and the center and side sills were cut, cracked, and twisted to the center of the car.

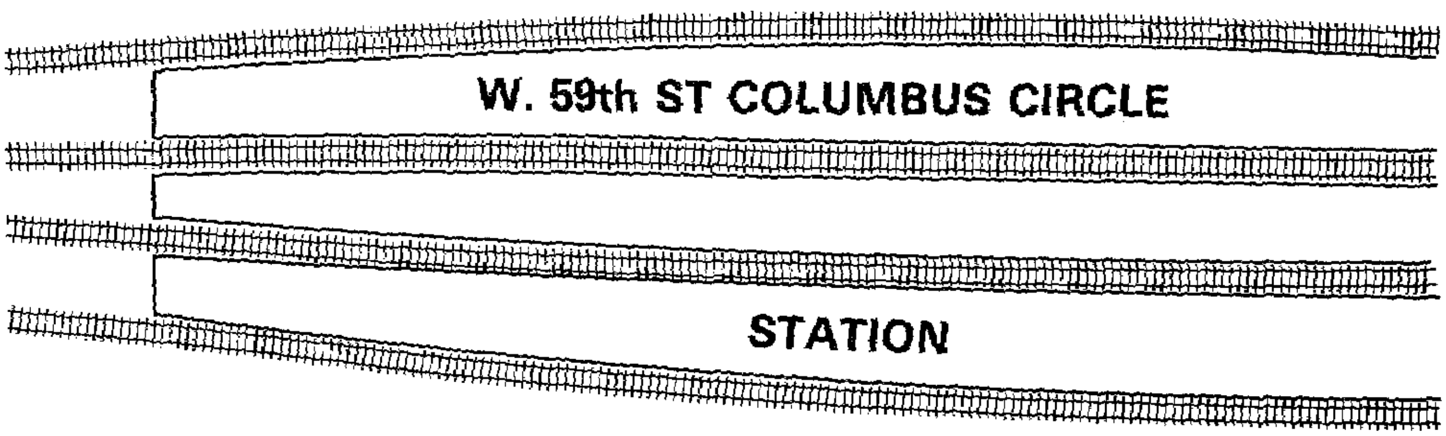
The first three columns of the curtain wall were destroyed, and 12 linear feet of the 6-inch concrete wall was destroyed. Another column approximately 32 feet south of the leading edge of the curtain wall was destroyed. Twenty of the horizontal bracings above the track were deformed and 25 were destroyed; however, there was no structural damage to the roof of the tunnel.

After the December 12, 1978, derailment, two wheels on the same axle of the sixth car were found broken. Metallurgical tests revealed that the wheels broke because of a thermal crack in the flange of each wheel that extended through the rim and plate and into the hub. The cracks expanded and permitted each wheel to become loose on the axle. Both wheels were discolored by heat. (See figure 2.) The wheels had been inspected 1 1/2 days earlier.

After the January 15, 1979, derailment, a wheel that had broken into three pieces was found on the fourth car. Investigators determined that the wheel broke because of a thermal crack which originated in the flange. The crack extended through the rim and into the wheel plate where it went around the circumference of the plate and joined another thermal crack which extended through the rim and flange. The wheel was also discolored by heat. (See figure 3.)

After the February 14, 1979, derailment, a wheel that had broken into five pieces was found on the seventh car. Investigators determined that the wheel broke because of a thermal crack that originated in the flange. The crack extended through the rim and into the plate and went around the full circumference of the plate. It also broke through the rim and flange at three other locations. (See figure 3.) The wheel had been inspected 18 days earlier.

After the March 21, 1979, derailment, a broken wheel was found on the first car. Investigators determined that the wheel broke because of a thermal crack in the flange. The crack extended through the rim and plate and into the hub. The wheel then became loose on the axle. The wheel was also discolored by heat. (See figure 3.) The heat discoloration was a red color which extended from the flange and rim into the plate. The wheel had been inspected 4 days earlier.


W. 59th ST COLUMBUS CIRCLE
STATION

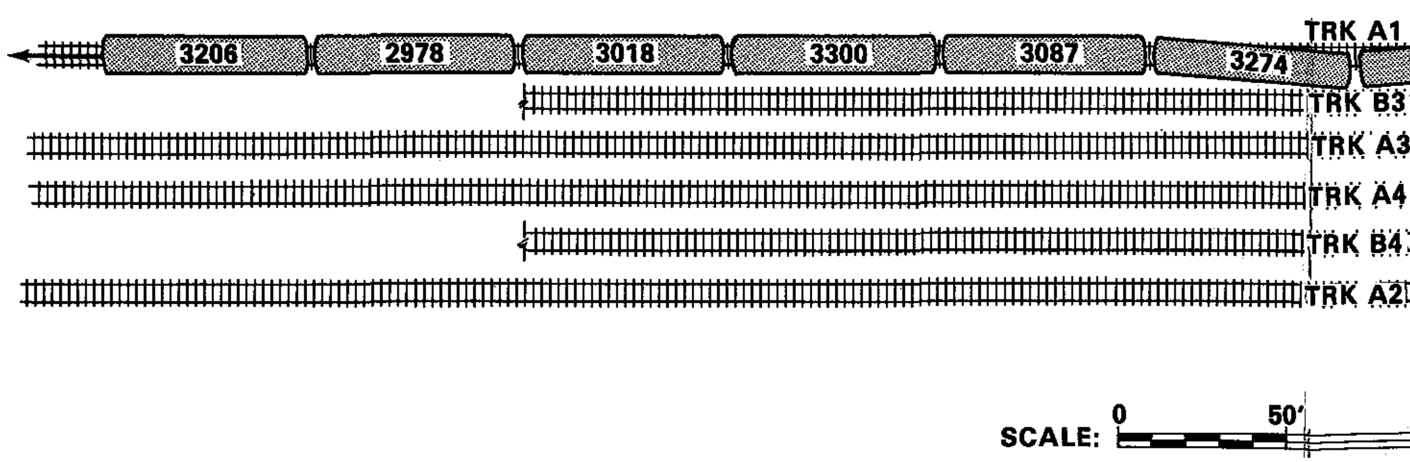


FIGURE 1. PLAN OF DERA

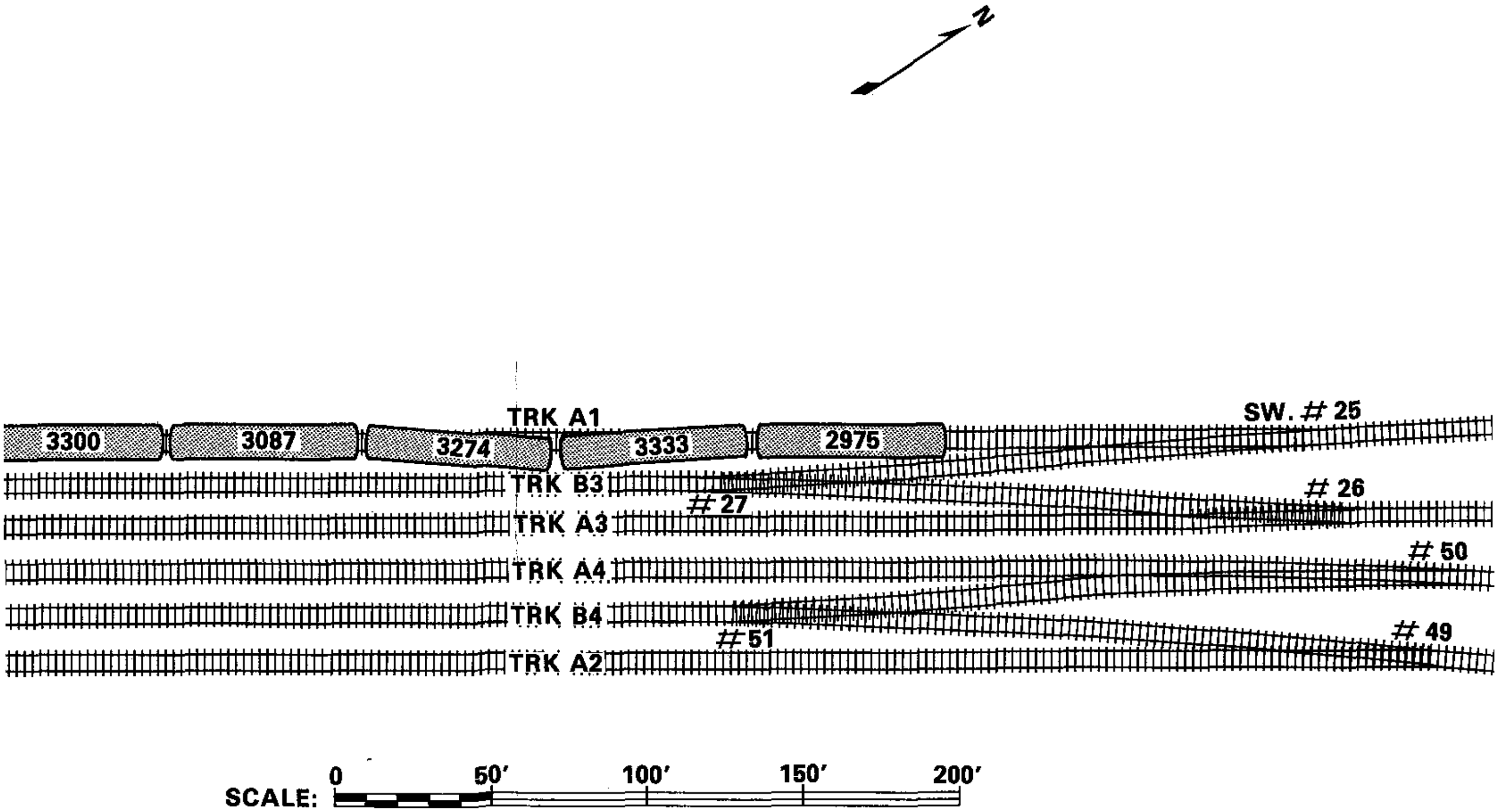
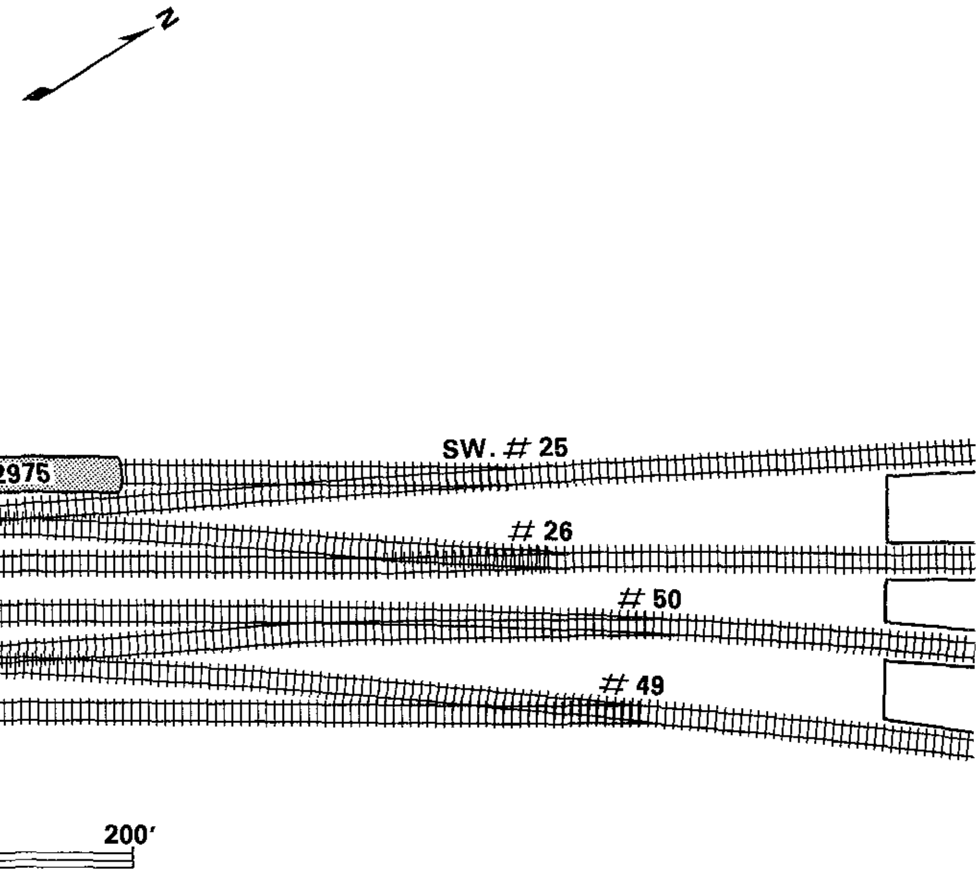


FIGURE 1. PLAN OF DERAILMENT — COLLISION AREA.



— COLLISION AREA.

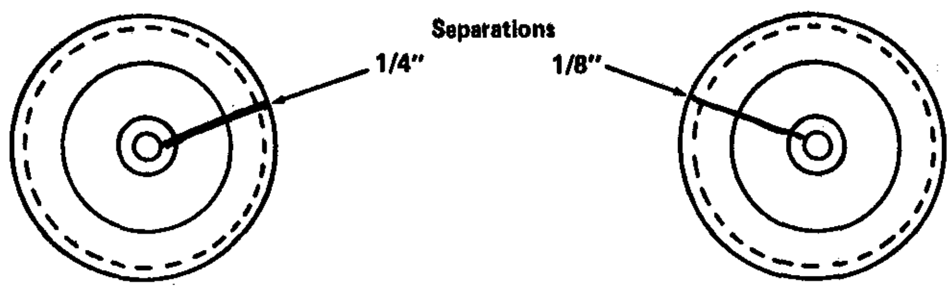


Figure 2. Broken wheels from the December 12, 1978 derailments.

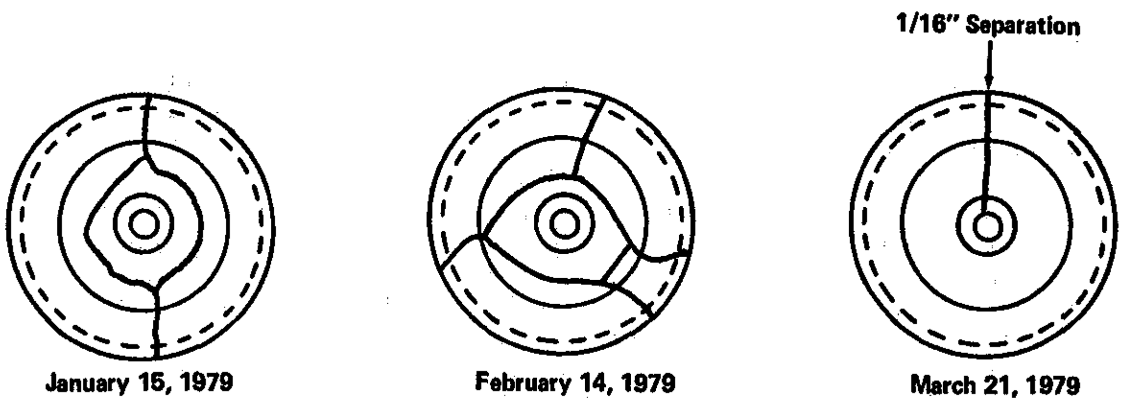


Figure 3. Broken wheels from three subsequent derailments.

Damage costs were estimated as follows:

	12/12/78	1/15/79	2/14/79	3/21/79
Train Equipment	$ 656,000	$ 15,391	$ 9,946	$ 12,195
Signal, Power, Line Equipment	2,188			
Track	7,643	5,228	50,408	13,871
Structure	1,720			
Total	$ 667,551	20,619	60,354	26,066

Grand Total $774,590

Train Information

The four trains in the first three derailments all had R10-type cars. The train that derailed on March 21, 1979 had R32-type cars.

The R10 car is a self-propelled, electrically driven subway car. It is all steel, 60 feet long, and has 4-wheel motor-driven trucks. It is designed to operate as a single unit or in multiple service in a train. Each end of the car contains an operator's compartment. Each car is equipped with a Westinghouse electropneumatic brake system and dynamic braking. The cars were constructed by the American Car Foundry in 1948 and 1949. Each car has end doors which permit passengers to move from one car to another and eight sets of double side doors, four on each side for the passengers to enter and exit.

The R32 subway cars are of the same design and dimensions as the R10. The R32 car was built by the Budd Company in 1965. They are operated in pairs as a unit; the pairs can be operated in multiple.

The motorman controls all cars in the train from the leading end of the train. A radio in each operating compartment allows the motorman to communicate with the motormen of other trains and with dispatchers. Both the R10 and R32 cars are equipped with a peacock handbrake mounted on one end of each car outside of the passenger-carrying section. (See figure 4.) This handbrake applies the brakes on only the No. 1 end. The brake mechanism is contained in a housing but the operating handle and release lever are exposed. The counterweight can only be seen through an opening. The handbrake is not equipped with an indicator to determine if the brake is applied or released. NYCTA instructions require the motorman to observe the position of the counterweight to determine if the brake is released or applied. NYCTA instructions also require that prior to departure, the motorman is to determine if the brake chain is loose, which would indicate that the handbrake is released.

The brakeshoes on these cars are cast iron with a wheel flange recess. The wheels used on these cars are multiple-wear steel with class B heat treatment and are made to ASTM specification A-25. The class B wheel is designed for high-speed service with severe braking conditions and moderate wheel loads. These wheels had also been rim-quenched. The chemical requirements for these wheels was:

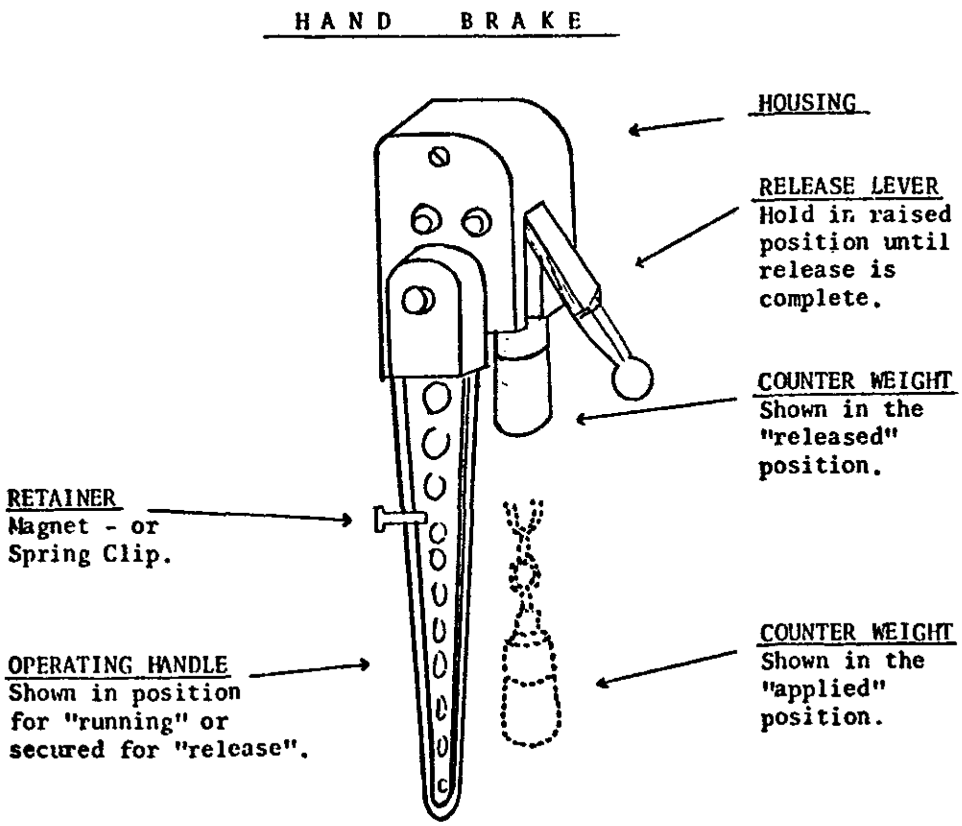


Figure 4. Peacock Handbrake Used on NYCTA Subway Cars.

Carbon — 0.57 to 0.67 percent
Manganese — 0.60 to 0.85 percent
Phosphorus — not over 0.05 percent
Sulfur — not over 0.05 percent
Silicon — not less then 0.15 percent
Brinell hardness — the hardness of the rim for this wheel is a minimum of 377 Bhn and a maximum of 341 Bhn. The wheels involved in these derailments were within these specifications.

The car equipment is inspected every 10,000 miles in one of the car barns. Two types of inspections are performed — a "B" inspection after the first and the second 10,000 miles and a "C" inspection after the third 10,000 miles. The cycle then resumes with a "B" inspection. (See appendix B for the items covered in each of these inspections.) This inspection procedure was established in October 1978. Before then the cars were inspected every 7,500 miles. It takes approximately 7 months for the R10 car to accumulate 10,000 miles. In February 1979, the inspection procedure was changed so that the R10 car must be inspected every 10,000 miles or 120 days, whichever comes first. The R32 car is still inspected only after 10,000 miles.

After the December 12, 1978, and the January 15, 1979, derailments, an inspection of all car wheels for thermal abuse was conducted on February 10 and 11, 1979. Five wheels were found with cracks, and 13 wheels were found to be discolored as a result of heat. The NYCTA decided to continue wheel inspections during the following months and on designated weekends.

The car involved in the derailment on December 12, 1978, had been moved from the repair shop on December 11, 1978, and placed in the yard as the head car of three cars. It remained there until it was coupled to five more cars, making it the sixth car of an eight-car train. The car that derailed on January 15, 1979, had been involved in a switching operation earlier that same morning. The car that derailed on March 21, 1979, had been the head car of an eight-car train; defective cars were switched out of the train on March 18, 1979, but it remained the head car of an eight-car train until it derailed.

Method of Operation

Subway trains are operated by signal indications of an automatic block signal system. The signals are time controlled to govern the speed of the train through a block territory at a predetermined speed. Trains exceeding such speed are automatically stopped.

No mechanical inspection for defects on the cars is conducted on a trip or daily basis. The motorman is required to make an inspection of the cars in his train before departure, but he is not given any instructions about mechanical requirements or limits of wear, nor is he given any instructions to help him recognize defects in the car components. No instruction is given to the motorman for the detection of overheated wheels. (See appendix C.)

Road car inspectors are located at various locations throughout the system. They respond to problems on trains en route. They meet the train and attempt to repair or correct the problem. As troubleshooters, they only attempt to repair or correct the reported problem and do not make any further checks or inspections of the equipment. (See appendix C.)

These inspection procedures were established by the NYCTA. No regulatory agency has established standards to require routine safety inspections of equipment in service. The Urban Mass Transportation Administration (UMTA) has been furnishing funds for operating assistance but has not established minimum safety standards or inspection requirements.

Meteorological Information

Weather was not a factor in any of these accidents.

Medical and Pathological Information

Injuries to passengers in the December 12, 1978, accident included contusions and abrasions of the extremities, upper torso, and head. One person sustained a fractured nose, and one passenger sustained a sprained right ankle. However, the most prevalent injuries were neck and back sprains and strains. Twenty-two passengers were reported to have been treated and released from local hospitals.

Survival Aspects

After the derailment on December 12, 1978, the motorman walked through the cars to assess the situation. There were no lights within the cars, and the passengers remained in their cars and waited for help and instructions. Police, fire, and emergency medical assistance arrived 25 minutes after the derailment occurred. The passengers were instructed to move to the first car. They were led from the car along a 2-foot 1-inch-wide catwalk along the side of the tunnel at the same level as the car door, up a flight of stairs, and through an emergency entrance to the street above. The injured were assisted in the evacuation by the fire and emergency medical personnel.

After the derailment on January 15, 1979, the passengers were all moved into the last six cars; these cars were run back to the ENY station where the passengers detrained. On February 14, 1979, passengers were evacuated after the derailment by moving them through the cars to the first car and then to the platform of the Lexington Avenue station. Passengers were evacuated after the derailment of March 21, 1979, by moving them through the cars to the first four cars and then onto the platform of the 14th Street station.

Tests and Research

During this investigation all cars in the NYCTA's Concourse Yard were inspected. Wheels on the No. 1 truck—the handbrake truck—of three cars were discolored. The wheel industry and the Association of American Railroads (AAR) use discoloration as an indication of thermal damage. No wheels on the other truck of the three cars were discolored.

Applications and release tests of the handbrakes on the R10 and R32 cars revealed that the brake can be partially applied by making a few pumps of the lever to set the brakeshoes against the wheels. This condition of the handbrake could not be determined by looking at the counterweight through the opening in the handbrake housing. This partially applied brake would not release if the release lever was operated.

Investigators observed and interviewed crews on trains before their departure from Concourse Yard for 5 days during the investigation. No crewmember was observed making an outside inspection of train equipment. A check of all trains in the Concourse Yard found that while they remained in the yard unattended, the handbrake on the first car was applied.

Tests were conducted on the fractured wheels from the December 12, 1978, derailment in the National Transportation Safety Board laboratory. Oxidation on the fractured wheel rims and overheated zones on the flanges indicated that the rims of the fractured wheels had been excessively heated. The fracture on one of the wheels stemmed from a fatigue crack in the flange area. Weld material applied subsequent to the fracture had totally obscured the fracture area on the other wheel. A radial microsection prepared near the fracture at a location that was removed from the area of welding disclosed several overheated zones along the flange surface. The largest zone consisted of untempered martensite with varying amounts of fine-grained pearlite, and was located in the filet where the flange blended into the tread. Martensite forms upon cooling from a temperature above approximately 1,350° F. The width of this area on the mounted section was approximately one-half inch. Its total width, however, is unknown, because the area extended beyond the mounted flange portion. The maximum depth of the overheated area was 0.04 inch.

Another major overheated area was found closer to the top of the flange. This area measured 0.09 inch wide and 0.015 inch deep and consisted largely of untempered martensite. An extensive amount of flowed metal accompanied the overheated area suggesting that the overheating condition was produced by contact wear with another surface. Much of the flange surface outside of the two major overheated areas contained a thin layer of flowed metal and/or a very thin overheated layer of untempered martensite indicative of excessive heat.

Westinghouse Air Brake Company (WABCO) and Abex Corporation performed tests and analyses on wheel heating and stresses resulting from a dragging handbrake. Information on schedule speeds and stops of the trains, available adhesion, and car weights were used in making the tests by WABCO and Abex.

WABCO was given a wheel of the same type involved in the December 12, 1978, derailment and was also furnished with two worn-in brakeshoes for the tests which were performed on the dynamometer at Wilmerding, Pennsylvania. A single southbound trip on the CC Line with a dragging handbrake was simulated. Wheel tread temperature, retarding force, distance, and time were monitored. The wheel tread temperature approached 900° F at the end of the simulated run. This wheel was found to have had heat in the affected zones above 1,400° F on the tread. When the wheel was sawed through the rim, the wheel cracked to the hub before the rim was completely sawed through.

Abex performed a computer simulation of the wheel heating under the same conditions as those used by WABCO. Abex used the finite element method of analysis and assumed that heat was applied uniformly across the tread and flange.

The Abex analysis indicated a maximum temperature after one round trip (two runs with a 10-minute interval between runs) of about 1,250° F at the flange tip and an equivalent stress of about 110,000 psi based on elastic strain only at the flange tip. This stress is well above the yield point and will cause permanent damage. (See appendix D.)

Both WABCO and Abex analyses indicated that temperatures and stresses resulting from one trip under these conditions could cause wheel failure of the type seen in these derailments.

ANALYSIS

As the investigation of the derailment that occurred on December 12, 1978, progressed, it became obvious that the wheels fractured due to excessive overheating. Because the wheels were located on the No. 1 truck--the handbrake truck—the Safety Board suspected that a partially or fully applied handbrake was the cause of the overheating. If the handbrake had been fully applied, the wheels would not have turned and would not have been heated. Inspections of other cars disclosed additional evidence of overheating of wheels on the No. 1 truck. Safety Board investigators brought these conditions to the attention of the NYCTA's management, and the Board believed that adequate action would be taken to correct the conditions.

After the derailment on January 15, 1979, indicated that the problem of fractured wheels from overheating on the handbrake truck still existed, the Safety Board recommended that the Metropolitan Transportation Authority (MTA), which has authority over the NYCTA:

> Immediately inspect all NYCTA rapid transit cars to determine if their wheels have been subjected to above normal heat and remove from service any wheel that shows evidence of thermal damage. (Class I, Urgent Action) (R-79-1)
>
> Immediately equip handbrakes on NYCTA rapid transit cars with a positive indicator so that an operator can determine if the brake is applied or fully released. (Class I, Urgent Action) (R-79-2)

Before adequate action was initiated to correct the problem, the third derailment involving broken wheels from overheating occurred on February 14, 1979. Following this accident the Safety Board's staff thoroughly discussed the problem with the MTA's management and were assured that proper corrective action would be taken to comply with the Board's recommendations.

On March 21, 1979, the fourth accident involving broken wheels from overheating, occurred. The Safety Board convened a public hearing following this accident to determine what action would be taken by the NYCTA to correct the wheel conditions before a catastrophic accident occurred.

The tests performed by WABCO and Abex indicated that one trip of a subway train on the CC Line, or a comparative route, with a partially applied handbrake creating a dragging brake condition, would produce temperatures and stresses in a wheel that could cause the wheel to fracture. Each of the wheels that fractured in these four derailments were wheels on the No. 1 truck. The handbrake only applies the brakes on the No. 1 truck. The absence of large flat spots or burn marks on any of the fractured wheels indicated the wheels were turning, not sliding, as they were heated. The extensive amount of flowed metal found in the metallurgical examination of the wheels in the first derailment indicated that the overheating condition was produced by contact wear with the brakeshoe. This would result from a partially applied handbrake. All the fractured wheels in these four derailments broke as a result of thermal fatigue created by overheating.

When the handbrake is applied, the counterweight which is suspended on the free end of the handbrake chain should drop below the cutaway section of the car body. If the brake is released, the counterweight should move to the top of the opening. Some motormen determine the position of the brakes by inserting their hands in the cutaway section. If they feel the brake chain, they assume that the brake is applied; if they feel the counterweight, they assume that the brake is released. A brake can be partially applied by pumping the handbrake lever a few times. Though the brake is partially applied, the counterweight still may be in the cutaway section where it can be felt by the motorman checking the brakes. Therefore, if the only brake check is a manual examination of the counterweight, a partially applied handbrake will not be detected.

Other motormen use a different method to check the train's handbrakes. When preparing a train for service, they raise the handbrake release lever on each car to release the applied handbrake. However, this method also is ineffective for testing the brakes on cars because a partially applied handbrake cannot be released by operating the release lever.

The handbrake is manually applied on the lead car of a train or on a single car when left unattended to prevent the train or car from moving. Several of the cars whose wheels failed were involved in switching operations and consequently were left unattended within a relatively short time period preceding the failures.

Although crewmembers were seen checking handbrakes either manually or by operating the brake release lever during the 5-day observation, no one made a visual inspection by walking around his train; therefore, any slack in the brake chain would not have been detected. Therefore, the Safety Board concludes that the subway cars involved in these accidents were permitted to operate with handbrakes partially applied — a condition which created a brakeshoe drag condition that caused the wheels to overheat and fracture.

No daily or trip inspections are performed on the subway cars that would permit the detection of overheated wheels. Motorman training does not equip the motorman to recognize overheated wheel conditions. The motorman is required by the rules to make a walkaround inspection of his train before taking it from the yard. However, without any instructions in how to detect an overheated wheel, a motorman cannot be expected to recognize this defect.

Although wheels are inspected every 10,000 miles or every 120 days and on a designated weekend each month, the heat-damaged wheels in these accidents escaped detection. The wheels on the sixth car that derailed on December 12, 1978, had been inspected just 1 1/2 days earlier. The wheel that broke on February 14, 1979, had been inspected 18 days before it failed. The wheel that broke on March 21, 1979, had been inspected only 4 days prior to the derailment. The Safety Board concludes that the current inspection procedures on the NYCTA are not adequate to prevent wheel failures.

In the accident on December 12, 1978, the dispatcher at 125th Street did not notify the motorman of the train about the report of smoke coming from the sixth car. The motorman and dispatcher both had operating radios. The dispatcher could have stopped the train for inspection or notified the motorman so that he could have made observations while en route. Instead he permitted this train to travel 3.35 miles, with passengers on board, to the 59th Street station where a road car inspector met the train. However, the road car inspector only conducted a cursory inspection from the platform level. The road car inspector stated that he did not detect anything unusual, and thus did not descend to the track level during his inspection. Moments after his inspection, the train derailed. The Safety Board believes that if the road car inspector had been more thorough in the performance of his duties, this accident might have been prevented.

The hissing and popping sounds resembling an electrical short circuit reported by a passenger boarding the sixth car at 59th Street station probably were due to arcing between the collector shoe and the third rail. The defective wheels probably caused the misalignment of the shoe and third rail.

The road car inspector that boarded the "CC" train on March 21, 1979, responded to the train because of the motorman's report that the train was traveling slow. The only check made while he was on board was to have the motorman operate the controller on and off several times, which did not correct the problem. He felt that the reason for the trains slowness was a heavy load of passengers. This decision was made without any check of the cars, the handbrakes, or any of the car equipment. The additional drag on the train could have resulted from a partially applied handbrake. The Safety Board believes that if the road car inspector had made a more thorough check, this accident might have been prevented also.

Neither the UMTA or the State of New York have established any safety standards for in-service equipment or train operations on the NYCTA. New York State does not have a regulatory agency with accountability for oversight of the NYCTA. Therefore, the NYCTA has established its own safety standards within the system. The Safety Board believes that many factors may have influenced the standards established by the NYCTA, such as convenience to operations, scheduling, and economics. The Board believes that this has resulted in the inadequate inspection procedures, the failure to recognize that car wheels cannot withstand thermal abuse, and the failure to correct the partially applied handbrake conditions on these cars expeditiously.

The Safety Board also believes that if safety standards had been established by the UMTA for transit systems, guidelines for establishing safety standards would have given the NYCTA a minimum level for safety requirements. The U.S. Department of Transportation has designated the UMTA as the rapid transit regulatory agency.

CONCLUSIONS

Findings

1. Inspection procedures for detecting overheated wheels are inadequate as evidenced by wheel failures soon after inspections.

2. Train crewmembers are not trained to detect overheated wheels.

3. Handbrakes on the R10 and R32 cars do not have a positive release indicator. Wheels on the No. 1 truck are exposed to excessive heating from partially applied handbrakes.

4. The dispatcher on December 12, 1978, failed to notify the motorman on the "CC" train that smoke was coming from his train.

5. The road car inspector on December 12, 1978, failed to properly inspect the "CC" train and failed to detect the broken wheels.

6. The Urban Mass Transportation Administration does not have standards for in-service equipment or for operating procedures to provide the desired level of safety.

7. The State of New York does not have established standards to provide the desired level of safety on the New York City Transit Authority.

8. The New York City Transit Authority alone established safety requirements for its system.

Probable Cause

The National Transportation Safety Board determines that the probable cause of each of the four accidents was a cracked wheel which had resulted from extensive overheating. Contributing to the cause of the overheating of the wheels was the partial application of a handbrake. Because of a lack of adequate inspection procedures, the New York City Transit Authority employees failed to detect the partially applied handbrake and the thermally damaged wheels before they cracked.

RECOMMENDATIONS

During its investigation of the first two accidents, the National Transportation Safety Board recommended on January 19, 1979, that the Metropolitan Transportation Authority :

> "Immediately inspect all NYCTA rapid transit cars to determine if their wheels have been subjected to above normal heat and remove from service any wheel that shows evidence of thermal damage. (Class I, Urgent Action) (R-79-1)
>
> "Immediately equip handbrakes on NYCTA rapid transit cars with a positive indicator so that an operator can determine if the brake is applied or fully released. (Class I, Urgent Action) (R-79-2)"

As a result of its complete investigation of this accident, the National Transportation Safety Board recommended that the Metropolitan Transportation Authority:

> "Require the New York City Transit Authority to establish an inspection procedure that will detect overheated wheels before failure. (Class II, Priority Action) (R-79-56)"

The Safety Board also reiterates the following recommendation, which was made to the U.S. Department of Transportation on March 6, 1978, after the Board's investigation of the head-on collision of two Greater Cleveland Regional Transit Authority trains in Cleveland, Ohio, on July 8, 1977:

> "Develop oversight capability to insure that the safety of rail rapid transit systems will be regulated and enforced by a responsible State or Federal Agency. Within the Department of Transportation, accountability for oversight should be assigned to the Administration that controls Federal grants to aid rail rapid transit. (Class II, Priority Action) (R-78-10)" (Issued March 6, 1978).

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ PATRICIA A. GOLDMAN
Member

/s/ G.H. PATRICK BURSLEY
Member

ELWOOD T. DRIVER, Vice Chairman, did not participate.

August 2, 1979

Appendix A

INVESTIGATION AND HEARING

1. Investigation

The National Transportation Safety Board was notified of the accident about 6:00 p.m. on December 12, 1978. The Safety Board immediately dispatched an investigator from the New York Field Office and an investigative team from Washington, D.C., to the scene. Investigative groups were established for operations, equipment, and human factors.

2. Hearing

A 2-day public hearing was held in New York City beginning at 9 a.m. on May 10, 1979. Parties represented at the hearing were the New York City Transit Authority, Urban Mass Transportation Administration, Borough of Manhattan, American Public Transit Association, American Iron and Steel Institute, and the Abex Corporation. Statements were taken from 16 witnesses.

Appendix B

CAR EQUIPMENT INSPECTIONS

ITEMS OPPOSITE MY SIGNATURE WERE INSPECTED BY ME AND LEFT IN GOOD CONDITION FOR SERVICE

A OR B INSPECTION

Air Brake Equipment

1	Air Compressor-oil V-Belts, Brushes, Leads Mounting	
2	Compressor Governor, Safety Valve, After cooler, Reservoir Gauge Auto Drain Valve	
3	Air Hose Drain All Reservoirs, Cutout and Straight Air Angle Cocks — Drain Cocks — Brake Cylinder Cutout Cock, Coupler Hose and Tubing.	
4	A 1 Operating Unit, Feed Valve, Drain J' Filter.	
5	Brake Valve, Air Gauge, Horn and Valve, Conductor's Valve, Emer Magnet Valve	
6	Trip Cock — Gauge — Lube — Paint. Hose Pipes, Clamps, Test.	
7	Brake Test — Electric and Pneumatic. Slack Adjuster. Clearance.	

Car-Body Equipment

8	Pantograph Gates, All Glass, Lights, Signs Seats, Stanchions, Handholds, End Doors Cab Doors, Contact Shoe Slippers W/W, Floor, Body, Fire Extinguisher, Safety Chains, Cords Hand Brake	
9	Side Doors — operation — timing. Drum Switch, Master Door Control Switch, Main Light Switch Conductor's Guard and M/M Signal Light Circuits.	
9a	Door Engines — Arms Levers, Pins, Interlocks, Springs, Tracks, Pockets, Wires, Magnet Valves, Relays, R10-Lube Door Engines.	

Electric Equipment

10	Battery fill check Box — latches.	
11	M G and Trickle Charge Relays and Resistors	
12	M G — brushes	
13	Coupler and Electric Portion. Shutter-lube. Test Slide Advance Test Trigger Release Piston.	
14	Control Group — Switches, Relays, Interlocks, Cams Tips, Fuses, Resistors, Insulators, Emer Contactor. Main Knife Switch lube Main Fuse Auxiliary Fuse Grids.	
15	Main Motors — Brushes, Insulators String Bands, Leads Axle Ground Brush Truck Ground.	
16	Master Controller — clean — fingers — lube D/M Operation Brake Valve — clean — fingers — lube	
17	All Lights, M/M Control Panel, All Panel Switches — Relays — Fuses, Auto Timer	
18	Contact Shoes and Beams — gauge Replace Defective Shoes, Fuse Box — Fuse Leads	
19	Public Address System.	
20	Heating and Fan Equipment	

Truck Equipment

21	Trucks — Frame, Bolster, Spring Plank Hangers, Height Adjuster, Springs, Equalizer Wear Plates, Center Casting, Gear Case, Motor Coupler, Journal Boxes, Carbody Height, Wheels, Gauge and Inspect — Flanges, Treads, Cracks, Draw Bar, Side Bearings.	
22	Brakes — replace defective shoes — Clearance, Slack Adjuster, Lube — Manual Slack Adjuster Brake Rigging Draw Bar and Carrier, Hand Brake Radius Bar	
23	Gear Case - Oil, Check for Leaks Vent Pipe — Clean, Suspension.	
24	Motor Coupler — Spring Action — Leaks — Alignment.	

R10 AND UP

C INSPECTION

Air Brake Equipment

1	Air Compressor oil, V Belts, Brushes, Leads Mounting Clean Exterior, Wipe Commutator Insulating Ring and String Bands.	
2	Compressor Governor — Operation — clean Safety Valve — operation, Aftercooler — clean. Reservoir Gauge Auto Drain Valve — Wipe.	
3	Air Hose Drain ALL Reservoirs, Paint Red — Cutout and Straight Air Angle Cocks — Drain Cocks — Brake Cylinder Cutout Cock and Lube Latches. Coupler Hose and Tubing	
4	A-1 Operating Unit — Apply Lamp and Gauge. Check Variable Load Rheostat and Actuator — Pressures at Light, Heavy, Full Service, Emergency Operation of All Valves and Magnets Feed Valve Setting. On test C — J' Filter V L Rheostat Lockout, Supplementary.	
5	Brake Valve Air Gauge, Horn and Valve Conductor's Valve Emer Magnet Valve Uncoupl Valve.	
6	Trip Cock — Gauge — Lube — Paint Hose Pipes, Clamps Test.	
7	Brake Test — Electric and Pneumatic Slack Adjuster. Clearance.	

Car-Body Equipment

8	Pantograph Gates — Clean and Lube. All Glass Lights, Signs, Seats, Stanchions, Hand holds, End Doors Cab Doors, Contact Shoe Slippers W/W Floor Body, Fire Extinguisher, Safety Chains, Cords, Handbrake. Remove Destination Curtains — clean Lube Gears.	
9	Side Doors — operation — timing Drum Switch — fingers. Master Door Control Switch — remove covers — clean — lube, Main Light Switch Conductor's Guard and M/M Signal Light Circuits.	
9a	Door Relays and Magnet Valves. Door Engines — clean — R10 Lube Brushes Gear case Oil. All Switches.	

Electric Equipment

10	Battery — remove — clean Check Cells Blow, Fill.	
11	M-G and Trickle Charge Relays and Resistors Adjust Pilot Relay Check Voltage Regulator.	
12	M G — brushes — clean	
13	Coupler and Electric Portion, Shutter lube. Test Slide Advance. Drain Trigger Release Chamber — if necessary, Brake Pilot Valve, Brake Closing Valve. Test Trigger Release Piston.	
14	Control Group — Switches, Relays, Interlocks, Cams Tips, Fuses, Resistors, Insulators — clean repair and test Line Switch, 600V Test Emer. Contactor, Main Knife Switch — lube. Main Fuse, Auxiliary Fuse. Grids Adjust Relays, Clean Magnet Valves.	
15	Main Motors — Brushes, Insulators Clean String Bands, Leads, Axle Ground Brush Truck Ground.	
16a	Master Controller — clean — fingers — lube D/M Operation.	
16b	Brake Valve — clean — fingers — lube. Self-Lapping Portion Contacts Brake Applic Valve.	
17	All Lights, M/M Control Panel, All Panel Switches — Relays — Fuses, Auto Timer Contacts On Toggle Switches.	
18	Contact Shoes and Beams — gauge, Replace Defective Shoes, Fuse Box — Fuses, Leads Paint Shoe Beam	
19	Public Address System	
20	Heating and Fan Equipment	

Truck Equipment

21	Trucks — Frame, Bolster, Spring Plank Hangers, Height Adjuster, Springs, Equalizer Wear Plates, Center Casting, Gear Case, Motor Coupler, Journal Boxes, Carbody Height, Wheels Gauge and Inspect — Flanges, Treads, Cracks Draw Bar, Side Bearings.	
22	Brakes — replace defective shoes — Clearance, Slack Adjuster, Lubricate — Manual Slack Adj. — Brake Rigging — Draw Bar and Carrier — Draw Bar Pin — Hand Brake — Radius Bar	
23	Gear Case — Oil. Check for Leaks Vent Pipe — Clean. Suspension.	
24	Motor Coupler — Spring Action — Leaks — Alignment.	

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Appendix C

NYCTA Rules, Regulations, and Instructions

Preparing Train For Service

Motorman, from roadbed at front end of train, will inspect to see:

(a) That coupler electric portion slide is fully retrieved and shutter closed

(b) That brake pipe angle cock (painted black) and straight air pipe angle cock (painted red) are open

NOTE: When angle cocks are open, handles are "in" all the way When closed, handles are "out" all the way

Motorman shall board operating car of train and inspect to see:

(a) That sufficient hand brakes are applied to secure train

(b) That marker lights, tail lights and end signs are properly displayed

(c) That brake valve is in "Handle Off" position

Motorman shall walk through train taking operating handles with him and inspect to see:

(a) That all necessary cab panel switches and circuit breakers are in "ON" position

(b) That door control drum switches are set in proper positions

(c) That all brake valves are in "Handle Off" position

(d) That master controller reverser drums are centered and control cut out switches in "OFF" position

(e) That all conductor's emergency valves are closed

(f) That all cab windows are closed and doors locked in non-operating cabs

(g) That the required number of windows and ventilators are open

(h) That all safety chains are in proper position

Motorman, upon arriving at rear end of train, shall inspect to see:

(a) That marker and tail lights and end signs are properly displayed.

(b) That train is not coupled to other cars

Motorman shall descend to roadbed and inspect to see:

(a) That straight air pipe and brake pipe angle cocks are open

(b) That electric portion of coupler is fully retrieved and shutter closed

Motorman shall walk alongside of train and inspect to see:

(a) That all brakes are applied and shoes against car wheels

NOTE: The piston travel is 2½" to 3" Such action indicates that vent and charging valves are functioning

(b) That all main reservoir gauges read 125 to 140 pounds on R-10 to R-15 cars; 135 to 150 pounds on R-16 and up cars

(c) That all main reservoir and supply reservoir cut-out cocks are open. (Cut-out cock handle perpendicular to pipe)

(d) That the brake pipe and straight air pipe and supply pipe angle cocks between cars are open (These are fully pulled out when closed; fully pushed in when open)

(e) That no equipment is hanging which would drag along roadbed

(f) That there is no air leak in main reservoir or brake cylinder

(g) That the brake cylinder cut-out cock is open (Lever should be fully down)

(h) That there is sufficient slack in hand brake chains

(i) That all cars are properly coupled and electric portions in proper position

Returning to the operating end of the train:

(a) Close control switch and place reverser forward and place brake valve in "Full Service" position to charge brake pipe to 110 pounds and straight air pipe to brake valve setting (72 to 75 lbs on R-10 to R-15, 78 to 80 lbs on R-16 to R-22, 74 to 76 lbs on R-26 and up cars)

(b) Depress master controller handle and check motorman's indication signal light and running lights

(c) Move brake valve to "running release" position to release the air brakes (Indication may be observed on air gauge, straight air pipe hand (red) going to zero)

(d) Check electric brake fuse or circuit breaker B-2: this is done by moving brake valve handle to and from "running release" and "service" positions If circuit is alive, there will be an air exhaust at release magnet valves Move brake valve handle to "release" position, release pressure on master controller handle to check dead man's pilot valve

(e) Move brake valve handle to "full service" position reverser key Release master controller handle

Appendix C

with top side of brake valve handle. Remove Take operating handles with you.

Motorman shall descend to roadbed and inspect other side of train to see:

(a) That brakes are applied noting if there is proper brake cylinder piston travel of 2½" to 3"

(b) That motor generators are operating.

(c) That there are no air leaks.

Motorman shall ascend to cab at rear end of train and:

NOTE: Although brake valve is in "service" position at other end of train, the test out-lined below can be accomplished.

(a) Move master controller reverser drum to "forward" and "reverse" positions to check motorman's indication signal light

(b) Center reverser key and depress master controller handle

(c) Place brake valve in "emergency" position, then "charging" position When brake pipe is "fully" charged move brake valve to "release" position

(d) Release master controller handle to test pilot valve and dead man's application valve.

NOTE: If there is no "emergency" application, or if any other defects in train are found, immediately notify employee in charge

(e) Remove brake valve handle and reverser key Motorman shall return to operating end of train and while walking through cars, make tests of door operation, conductor's buzzer, indication lights and side destination signs, and P A system.

Lay-up Instructions

(a) Motormen when "laying up" trains and arriving at lay-up point will follow instructions covered n Chapter 4, Section 2 (a) to (d)

(b) Apply sufficient hand brakes to secure train

(c) Move heat and fan control momentary switch in motorman's cab to "OFF" position

(d) Close all windows and ventilators and end doors unless other personnel is assigned

NOTE: On R-15 and up cars ventilators are thermostatically controlled

Operation of Hand Brake

To apply hand brake, operate the hand lever upward (Pumping action)

It is not necessary to manipulate the release lever in any way while the brake is being applied

To attain full release of hand brake, it is of utmost importance that the hand brake operating lever be located within the spring clip or against retaining magnet (if so equipped) before lifting the release lever

If counterweight does not return to release position after hand brake release lever is operated, the hand brake must be re-applied and released. If counterweight again fails to return to release position, notify employee in charge

TRAIN DISPATCHERS

Rule 103

(a) Train dispatchers will report to trainmasters and assistant trainmasters

(b) They are responsible for the expeditious and correct dispatch and safe movement of trains within the limits assigned to them and will have supervision of all employees in train and yard service in their respective sections

(c) Whenever extra trains are authorized they must give sufficient advance notice to all concerned of the starting time and destination thereof, the tracks to be operated over and the nature of the work to be performed

(d) They must report to the superintendent of their division any neglect of duty or infraction of rules which comes to their attention

(e) They must report at once to the Desk Trainmaster all unusual intervals between trains with a view to regulating train movements so as to provide intervals in accordance with the current timetable

(f) They must assume charge of any unusual occurrences in train service in their respective sections until the arrival of a ranking supervisory employee of the Rapid Transit Operations Department and must at once notify the Desk Trainmaster of any interruptions to train movements They will be governed by the recommendations of motormen instructors or assistant motormen instructors regarding the safe movement of disabled trains

(g) They must keep records of all absent employees and of other employees who fill their places and of the time worked and must submit such records daily to the Assistant General Superintendent, Rapid Transit Operation, as may be required.

(h) At terminals they must ascertain that motormen and conductors in road service are in fit condition and proper uniform and at their posts on their trains two (2) minutes before their trains are scheduled to depart with all train identification equipment and other fixtures properly displayed and in place When required they must also ascertain that conductors or any other employees assigned to platform duty are in fit condition and proper uniform and that they perform their duties as assigned

(i) They must not permit a train to start with a motorman or a conductor unfit for duty They must remove any unfit employee from service and report such unfitness immediately to the Desk Trainmaster

(j) They are responsible for all Bulletin Boards in their respective sections and must know that all authorized material is properly posted or removed in accordance with the positions designated for each type thereof

(k) They will, when required, conduct and supervise all picks of runs and tours of duty in accordance with the working conditions and be responsible for all assignments of train crews

(l) They must qualify to operate and, upon such qualification, must operate, when directed, interlocking plants and control points within the limits of the section assigned to them

(m) They may be required to hook down stop arms and flag trains in emergencies to expedite train service

(n) They must use or direct the use of the Station Public Address System, where provided, to inform passengers of delays and diversions of service, in emergencies and as otherwise directed

(o) They are responsible for the proper recording of all car trips on the prescribed forms

ROAD CAR INSPECTORS

Rule 139

(a) Road car inspectors will report to the members of the supervisory staff to whom they are assigned They are also subject to the orders of foremen

(b) They will detect trouble on any part of a disabled train and must make such repairs, adjustments or replacements as are necessary to enable such train to continue in service or to enable it to be moved to a siding or terminal They must, when such repairs, adjustments or replacements have been completed, inform the motorman of the train and the ranking supervisory employee of the Rapid Transit Transportation Department present of the condition of the train and the nature and extent of such repairs, adjustments or replacements

(c) They must promptly respond to the whistle or horn signals set forth in Rules 56 (c) and 57 (e), ascertain the reason therefor and make such repairs, adjustments or replacements, when possible, as are necessary to restore car equipment to proper operating condition

(d) They will examine, test, adjust and repair car equipment in accordance with their assignments

(e) They must, when so assigned, assist in making up of trains for service

(f) They must keep records and submit reports when required

(g) They must cooperate with the Assistant General Superintendent (Rapid Transit Transportation), with superintendents (rapid transit transportation), with trainmasters, assistant trainmasters, motormen instructors, assistant motormen instructors, train dispatchers, yardmasters and assistant train dispatchers

Appendix D

Excerpts from Abex Corporation Report of Computer Simulation of NYCTA (line CC) R10 Cars with Dragging Handbrake

Three thermal stress analyses have been conducted in order to help assist in developing a possible failure mode rationalization. Attention should be drawn to the fact that the mechanical loads have not been included.

Exhibit J-1, 2 and 3 show the temperature distributions for the three simulated NYCTA operations. The normal operation, J-1, shows maximum temperatures in the 240°F range. The isotherms are displaced by 20° increments. The medium handbrake dragging simulations, J-2, shows maximum temperature in the flange of 1,250°F and the isotherms have been displaced by 50°F increments. The heavy handbrake dragging run reaches 1,700°F in the flange with isotherms at 50°F increments.

All three temperature distributions show the rim being heated over the tread and flange uniformly; i.e., the heat is progressing through the rim and flange in a manner such that the isotherms are flat and are not concentrated in tread area.

Exhibits K-1, 2 and 3 represent the displacement of the wheel after the normal, medium and heavy braking simulations respectively. Maximum stresses have been labeled for the three critical stress locations - front hub fillet, back rim fillet and apex of flange. Tabulation of the Energy Absorbed Per Handbraked Wheel, and Energy Absorbed vs. Maximum Equivalent Stress Induced is shown as follows:

Appendix D

ENERGY ABSORBED PER HANDBRAKED WHEEL

*NORMAL OPERATION

$$92 \text{ Stops} \times \frac{81{,}200 \text{ Lb. Car} \times (32 \text{ MPH})^2}{8 \text{ Whls./Car} \times 30} = 31.8 \text{ Million Ft-Lbs.}$$

MEDIUM HANDBRAKE DRAGGING

90 Stops (1,200 Lb. R.F. x 2,487 Feet) + 2 Stops (1,200 Lb. R.F. x 6,453 Feet) = 284 Million Ft-Lbs.

HEAVY HANDBRAKE DRAGGING

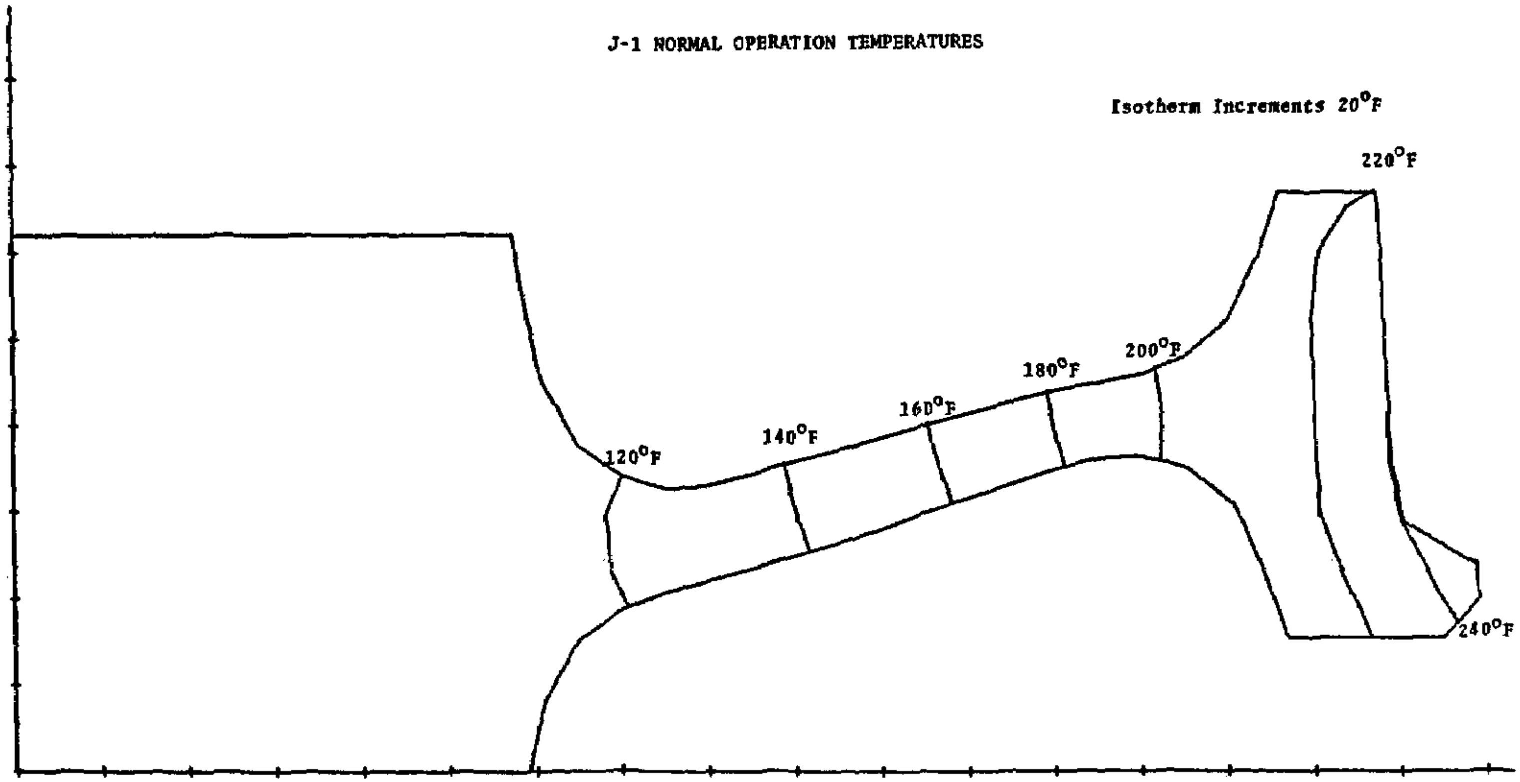
90 Stops (2,200 Lb. R.F. x 2,487 Feet) + 2 Stops (2,200 Lb. R.F. x 6,453 Feet) = 521 Million Ft-Lbs.

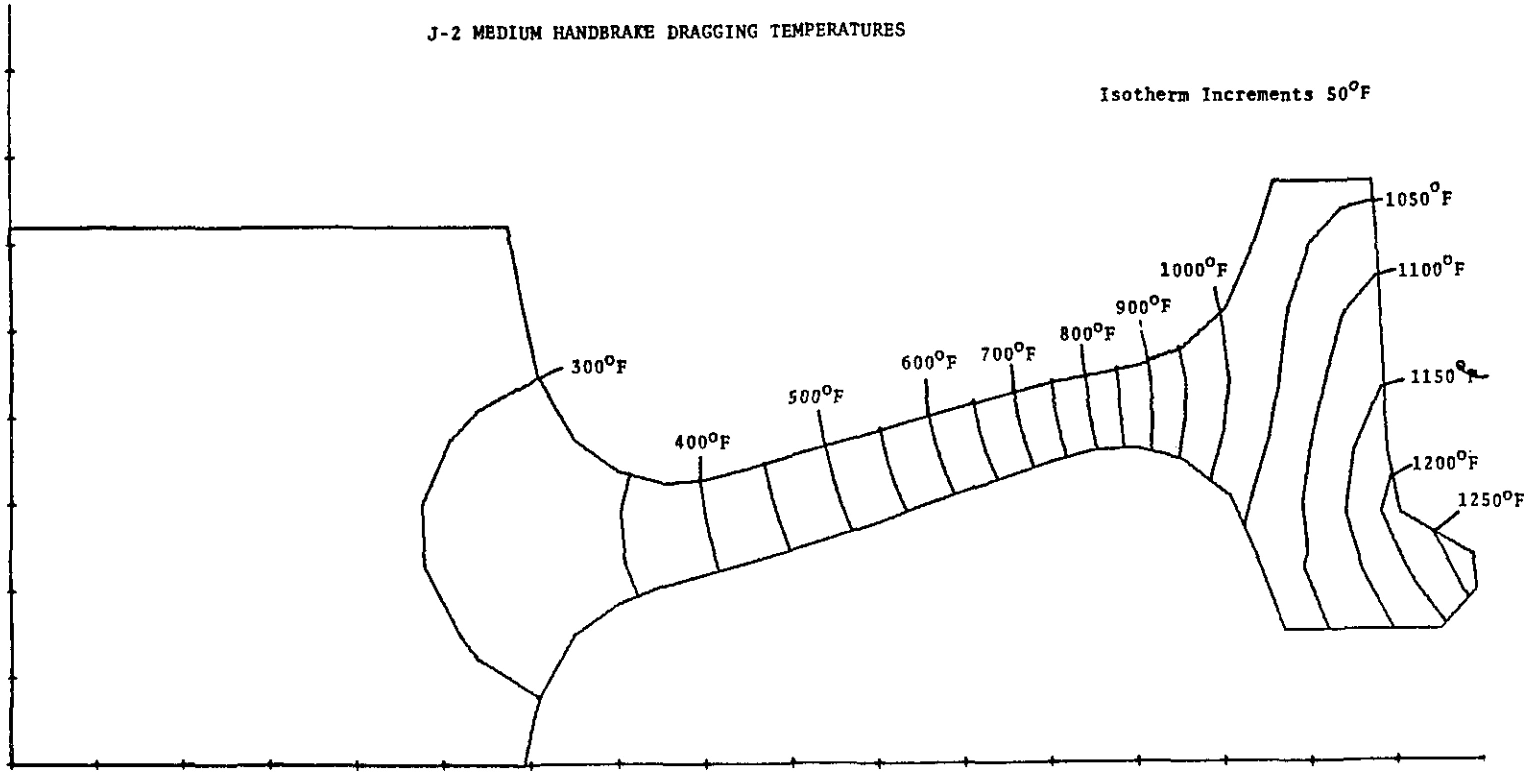
*Normal operation defined as "air brake only used to stop" ....no dragging handbrake

ENERGY ABSORBED VS. MAXIMUM EQUIVALENT STRESS INDUCED

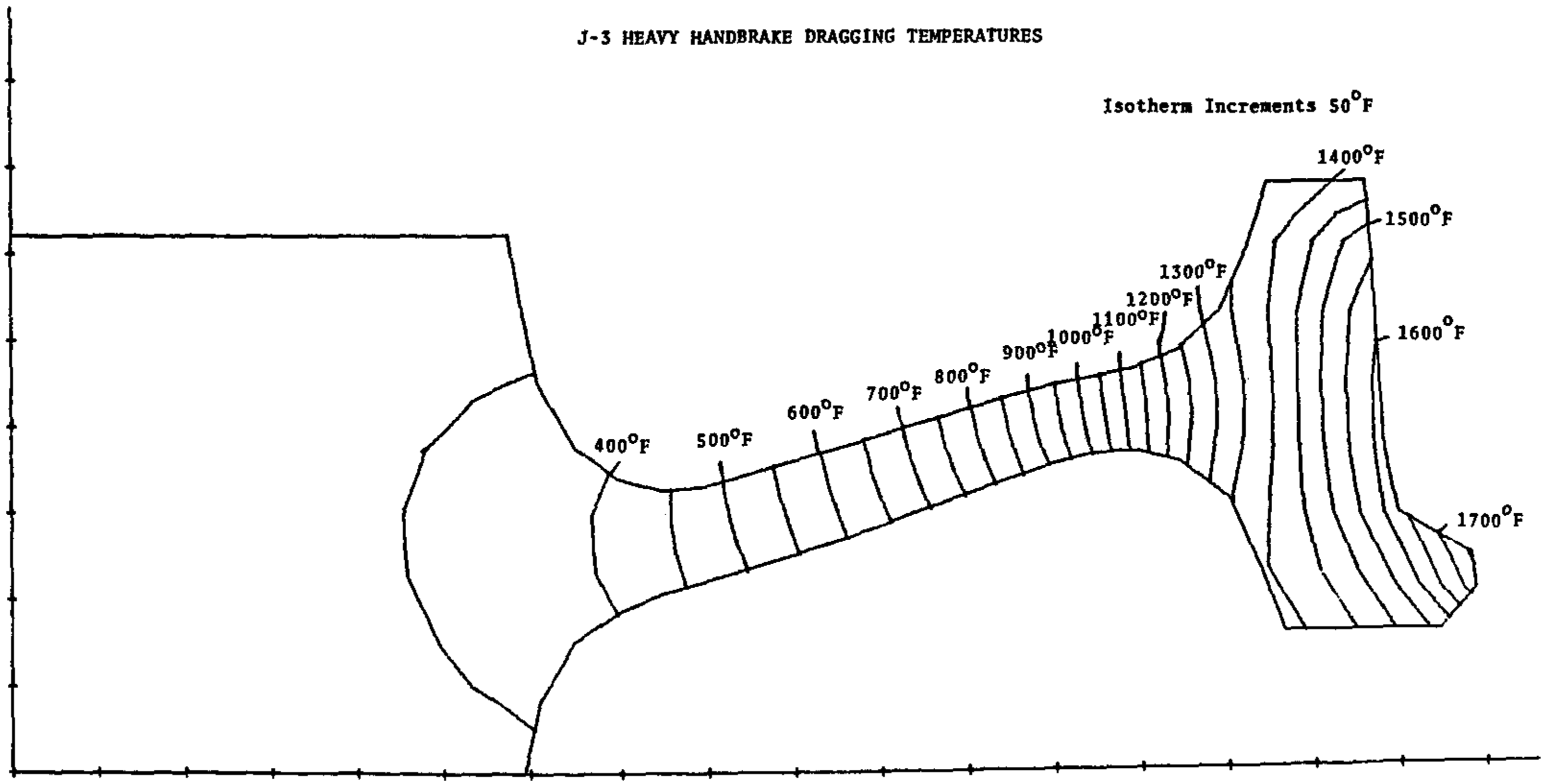
Operation	Energy Absorbed ($Ft\text{-}Lbx10^6$)	Maximum Equivalent Stress Induced: Apex of Flange ($PSIx10^3$)	Back Rim Fillet ($PSIx10^3$)	Front Hub Fillet ($PSIx10^3$)
Normal	31.8	12.6	21.1	25.9
Medium Handbrake	284	107	218	249
Heavy Handbrake	521	247	362	409
	(Ratio)	(Ratio)	(Ratio)	(Ratio)
Normal	1.00	1.00	1.00	1.00
Medium Handbrake	8.93	8.49	10.33	9.61
Heavy Handbrake	16.38	19.60	17.16	15.79

The stresses for the normal operation are well below the yield stress and therefore the analysis has remained in the elastic regime of material properties. The medium and heavy handbrake resulting stresses have been calculated to be well beyond the yield point, due to the approach used, i.e., no account of material yielding and redistribution of stresses have been included.

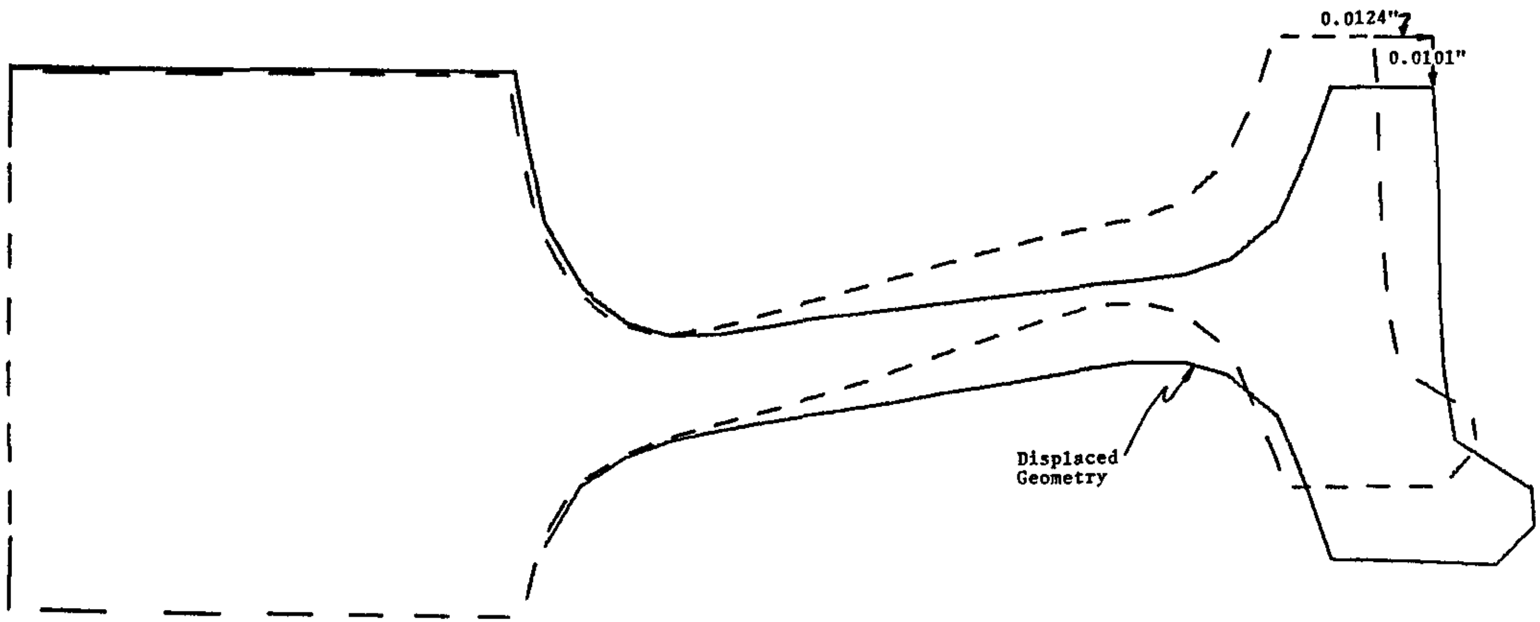

J-1 NORMAL OPERATION TEMPERATURES
Isotherm Increments 20°F
220°F
200°F
180°F
160°F
140°F
120°F
240°F


J-2 MEDIUM HANDBRAKE DRAGGING TEMPERATURES
Isotherm Increments 50°F
300°F
400°F
500°F
600°F
700°F
800°F
900°F
1000°F
1050°F
1100°F
1150°F
1200°F
1250°F

Appendix D

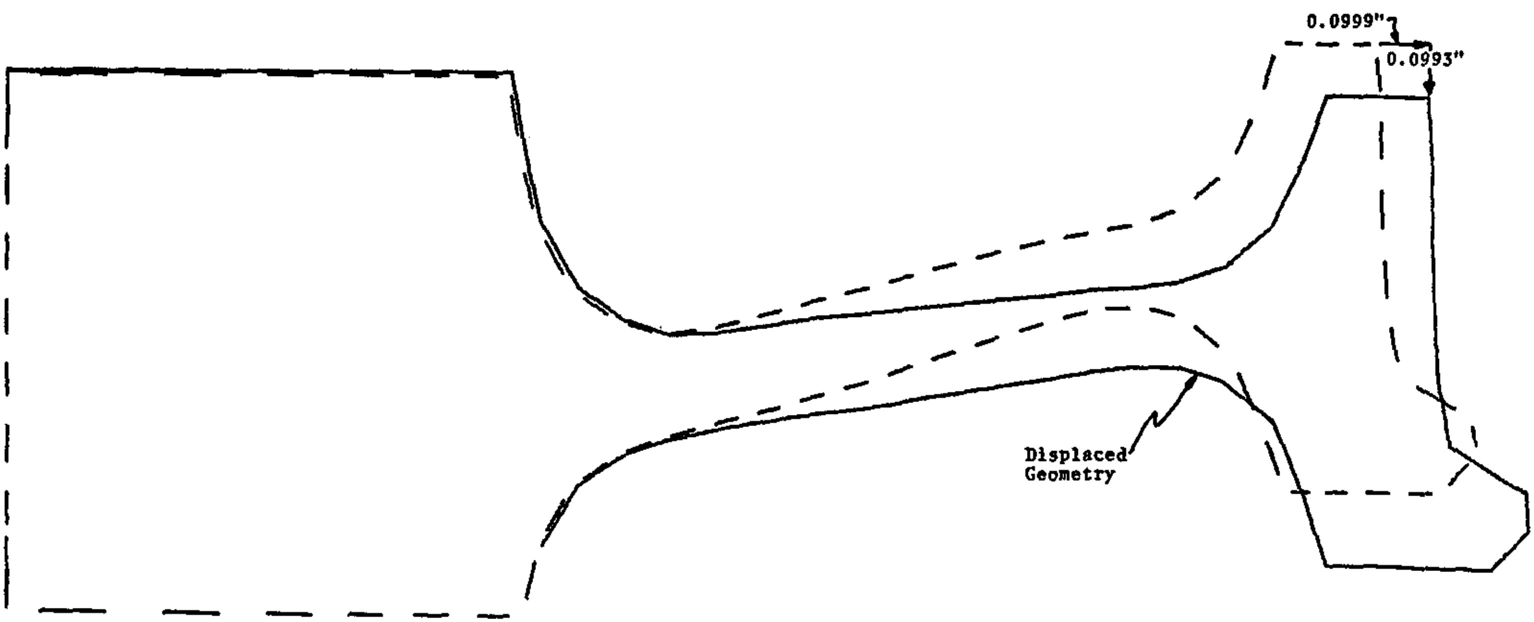

J-3 HEAVY HANDBRAKE DRAGGING TEMPERATURES
Isotherm Increments 50°F
1400°F
1500°F
1300°F
1200°F
1100°F
1000°F
900°F
800°F
700°F
600°F
500°F
400°F
1600°F
1700°F

K-1 NORMAL OPERATION DISPLACEMENTS

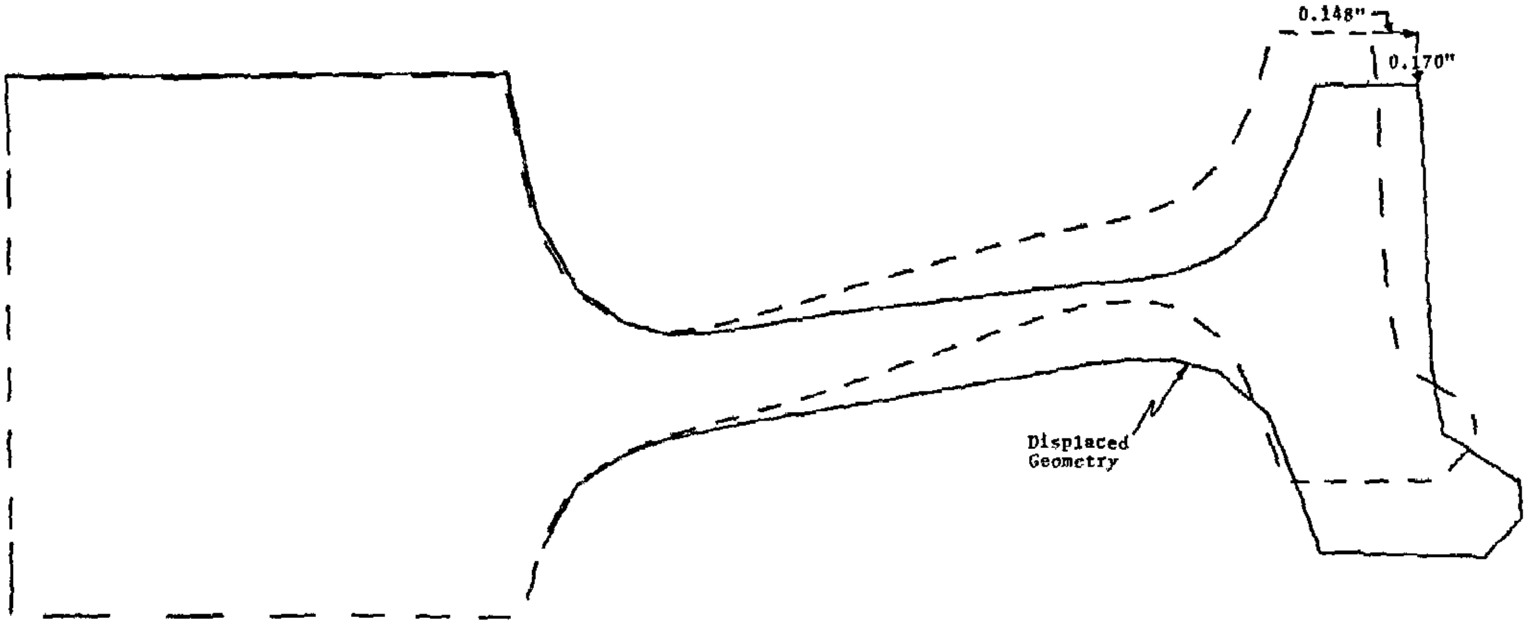


Appendix D

K-2 MEDIUM HANDBRAKE DRAGGING DISPLACEMENTS



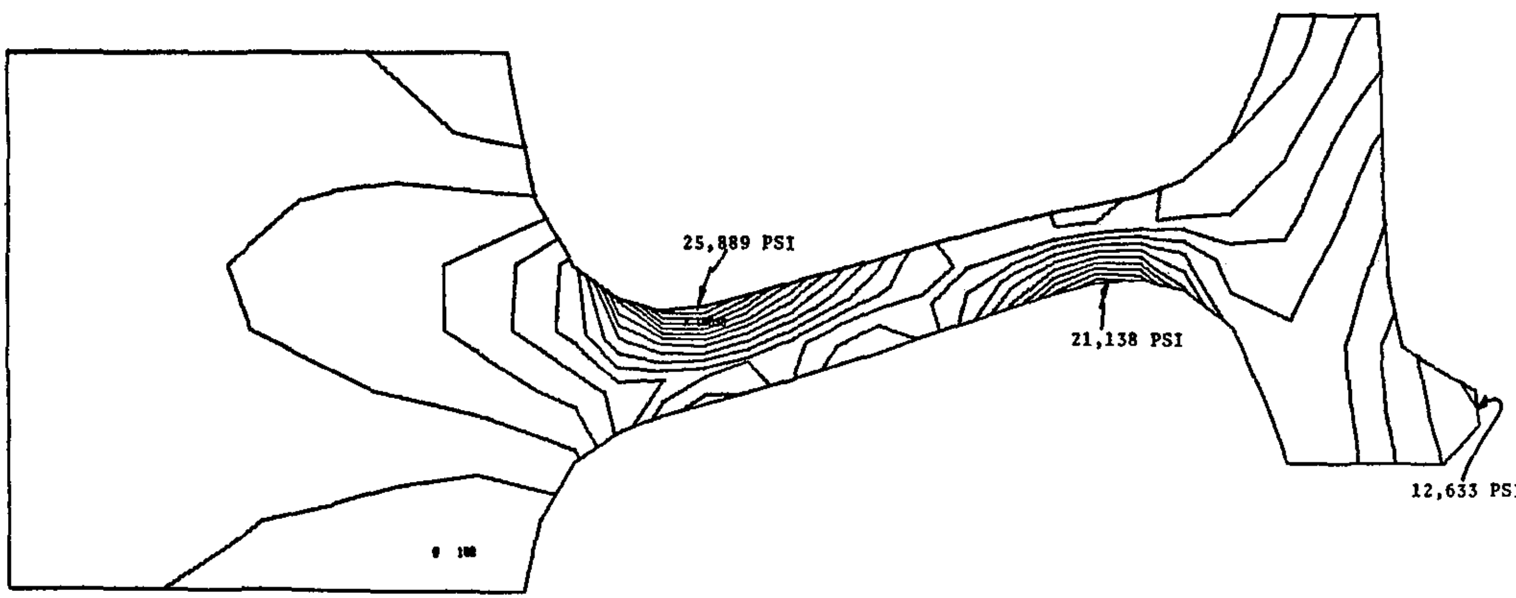
K-3 HEAVY HANDBRAKE DRAGGING DISPLACEMENTS



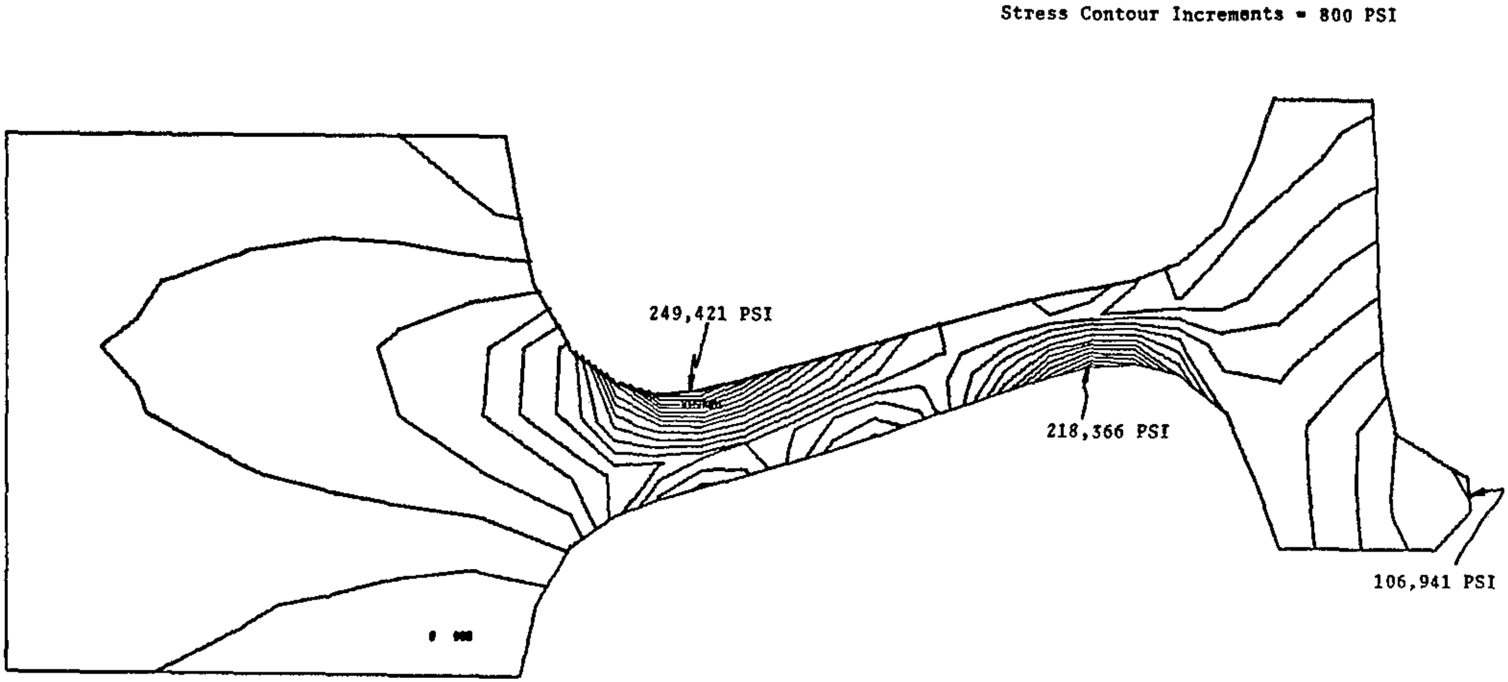
Appendix D

L-1 NORMAL OPERATION EQUIVALENT STRESSES

Stress Contour Increments = 1000 PSI



L-2 MEDIUM HANDBRAKE DRAGGING EQUIVALENT STRESSES



L-3 HEAVY HANDBRAKE DRAGGING EQUIVALENT STRESSES

Stress Contour Increments = 15000 PSI